

**ASSESSMENT OF PLANT DIVERSITY AND CARBON
SEQUESTRATION POTENTIAL OF URBAN AND
FOREST VEGETATION IN SIRSA, HARYANA**

Thesis Submitted for the Award of the Degree of
DOCTOR OF PHILOSOPHY

**in
Botany**

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2026

DECLARATION

I, hereby declared that the presented work in the thesis entitled “**ASSESSMENT OF PLANT DIVERSITY AND CARBON SEQUESTRATION POTENTIAL OF URBAN AND FOREST VEGETATION IN SIRSA, HARYANA**” in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision **Dr. Ridhi Sudhir**, working as **Assistant Professor** in the **School of Allied Sciences** of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled “**ASSESSMENT OF PLANT DIVERSITY AND CARBON SEQUESTRATION POTENTIAL OF URBAN AND FOREST VEGETATION IN SIRSA, HARYANA**” submitted in fulfillment of the requirement for the reward of degree of **Doctor of Philosophy (Ph.D.)** in the **Department of Botany of School of Bioengineering and Biosciences**, is a research work carried out by **Akshay Kumar Chaudhary, 41800797**, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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ABSTRACT

Deforestation and Urbanization have revolutionarily altered natural ecosystems, affecting plant diversity as well as the carbon sequestration ability of these ecosystems. This research investigates the plant diversity and carbon sequestration capacity in urban and forest ecosystems of Sirsa, Haryana. Through stratified random sampling, chief ecological parameters like species composition, density, frequency, Importance Value Index (IVI) and Supremacy Diversity were examined. Further, biodiversity indices such as Shannon-Wiener, Simpson's Index, Margalef index and Pielou's index were utilized to quantify species richness and evenness. This research seeks to present a comparative perspective of the way urban and forest ecosystems support biodiversity and carbon sequestration. In an effort to quantify carbon sequestration, aboveground biomass (AGB), belowground biomass (BGB), and soil organic carbon (SOC) were quantified. Further, species-specific allometric equations and biomass expansion factors (BEF) were used for quantifying total carbon stock. This study was carried out in eight urban and eight forest locations in Sirsa District, where data were gathered through the use of stratified random sampling and quadrant-based techniques. Ecological parameters such as density, dominance, frequency, and diversity indices were used to assess the plant communities existing in each of the locations. The results of the study revealed that Fabaceae was the largest plant family contributing to the biodiversity in both urban and forest ecosystem. Urban ecosystem showed a high level of variation in species diversity, with Site A accounting for the high number of species (35 species) and Site F for the lower number of species (12 species). On the contrary, forest sites showed varying levels of species diversity, with Site K accounting for higher number of species, i.e., 27 and Site M accounting for lower number of species, i.e., 16. Among dominant species, *Cannabis sativa* and *Tagetes erecta* were dominant in almost all the urban locations that signifies their ability to thrive in urban ecosystem. On contrary, *Eucalyptus globulus* was determined to be dominant in forest ecosystem. Further, ecological diversity determined by Shannon-Wiener Index (H') revealed Site A to be highly diverse ($H' = 3.22$), whereas Site F was determined to be least diverse ($H' = 2.39$) in urban ecosystem. For forest ecosystem, the Site K was determined to be highly diverse ($H' = 3.09$) and Site J was determined to have low diversity ($H' = 2.74$). Additionally, according to Simpson's

Index (D) revealed that Site E ($D = 0.05$) showed high species diversity and has the even distribution. Carbon sequestration has also been determined in this study and, based on which, major species responsible for sequestering carbon in both systems were determined. In urban setting, *Delonix regia*, *Ficus religiosa* and *Terminalia arjuna* were determined to be key player in sequestrating carbon. In forest, *Eucalyptus globulus*, *Dalbergia sissoo* and *Ficus benghalensis* were determined to be key player in sequestering carbons in higher amounts. Furthermore, these plant species have important role in mitigating climate change absorbing and sequestering CO₂ from the atmosphere. Major portion of our study involved Soil organic carbon (SOC) estimation, this analysis unveiled that forest soil of Sirsa contains more carbon in comparison to urban soils. This in agreement with worldwide trends that indicate the ecosystems of forests accumulate more carbon because of increased organic inputs and lower soil disturbance than urban ecosystems. These findings highlight the profound effect of deforestation and urbanization on carbon stocks, as urbanization has the tendency to decrease the levels of soil organic carbon (SOC) due to soil sealing and decreased organic matter input. On the other hand, forest ecosystems with more diverse vegetation and less disturbed soils are critical for carbon sequestration. Thus, there is dire need to value forest conservation and land use practices that promote sustainability and contribute to an improved quality of urban living.

ABBREVIATIONS

1. %	– Percent
2. °C	– Degree Celsius
3. DBH	– Diameter at Breast Height
4. AGB	– Above Ground Biomass
5. BGB	– Below Ground Biomass
6. BEF	– Biomass Expansion Factor
7. SOC	– Soil Organic Carbon
8. IPCC	– Intergovernmental Panel on Climate Change
9. FAO	– Food and Agriculture Organization
10. EPA	– Environmental Protection Agency
11. CO₂	– Carbon Dioxide
12. NO₂	-- Nitrogen Dioxide
13. IVI	– Importance Value Index
14. SDGs	– Sustainable Development Goals
15. TLS	– Total Link Strength
16. UN	– United Nations
17. USEPA	– United States Environmental Protection Agency
18. RH	– Relative Humidity
19. RD	– Relative Density
20. RF	– Relative Frequency
21. RA	– Relative Abundance
22. GPR	- Ground-penetrating radar
23. BECCS	- Bioenergy with Carbon Capture and Storage
24. Ab	- Abundance
25. Fr	- Frequency
26. Den	- Density

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I bow humbly to the Almighty, who has been my guiding light and source of strength throughout this journey. I take inspiration from the Bhagavad Gita, which says, “Karmanye vadhikaraste ma phaleshu kadachana”—you have a right to perform your duties, but not to the fruits of your actions. These words have guided me to persevere with dedication and unwavering focus, regardless of the challenges I faced.

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CHAPTER 1

INTRODUCTION

1.1. INTRODUCTION

Biodiversity and carbon sequestration have interconnected roles in maintaining ecological balance and supporting sustainable life on Earth (Naeem et al. 2016; Díaz et al. 2019). A crucial role is played by tropical forests in storage of carbon. They sequester nearly 2.4 billion tons of carbon in the form of CO₂ and nearly half of the terrestrial species are being harboured by tropical forests (Pan et al. 2011). Likewise, only 6 percent of Earth's surface is covered by wetlands, yet they significantly contribute to biodiversity and acts as carbon sink (Mitsch et al., 2013). Biodiversity encompasses variety of species, genetic variation and ecological diversity as well as works as foundation for ecosystem resilience and functionality (Hughes et al. 1997). Processes such as pollination, nutrient cycling and purification of water are facilitated by biodiversity. Biodiversity also regulates the climate and act as a source of resources which are vital for human survival (Reid et al. 2005). Carbon sequestration is a natural process which collects and stores atmospheric CO₂ that regulates climate change by decreasing concentration of greenhouse gases (Lal 2004a; Mitsch et al. 2013). All these processes collective tackle crucial global challenges of biodiversity decline and climate change (IPBES-IPCC 2021). The interaction between ecological services, biodiversity and human well-being is depicted in Figure 1.1.

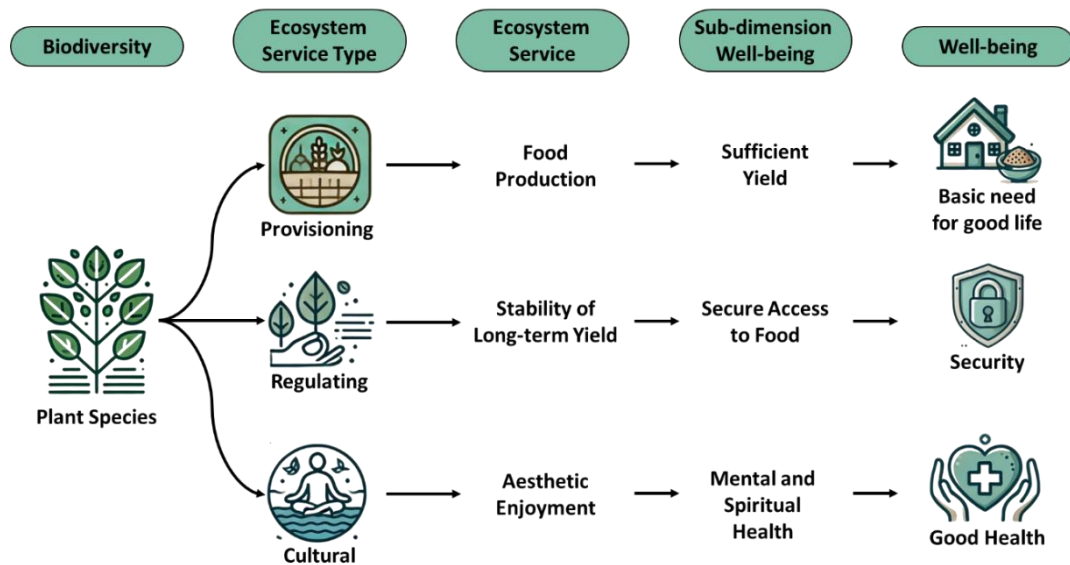


Figure 1.1: Synergistic relationship between biodiversity, ecosystem services, and human well-being

1.2. BIODIVERSITY AND ITS ECOLOGICAL SIGNIFICANCE

The most significant challenges to the ecosystem globally is the speedy recent decline in biodiversity (Wiebe and Wilcove 2025). This crisis is the results of various key factors such as climate change, habitat destruction, pollution and resource overexploitation which has resulted in an unprecedented reduction in species populations (Maxwell et al. 2016). Forest ecosystems, which provide habitat for nearly 80% of terrestrial species, are especially under serious risk (Lindenmayer 2023).

1.3. ROLE OF VEGETATION IN CARBON SEQUESTRATION

These forests play a dynamic role as carbon sinks by sequestering substantial amount of carbon in biomass and soil as well as in regulating the global carbon cycle (Pan et al. 2011). However, land-use changes and deforestation are sternly eroding their ability to function as carbon reservoirs and further exacerbating the issues of biodiversity loss and reducing carbon sequestration (UN 2018). Between 2015 and 2020, global deforestation was determined to be 10 M ha/yr (million hectares per year). However, afforestation and forest management initiatives have reduced net forest loss from 7.8 M ha/yr (in 1990) to 4.7 M ha/yr (between 2010-2020). Currently, planted forest area accounts for 7% of the total forest area, of which Asia holds 62% of this coverage (FAO 2020a). Still, uncertainty persists due to lack of evidence regarding the effectiveness of these forests in conserving biodiversity (Crouzeilles et al. 2020) This raises concerns about their role in mitigating biodiversity loss and carbon sequestration issues (Huston and Marland 2003).

1.4. CONCEPTUAL FRAMEWORK OF PLANT DIVERSITY AND VEGETATION TYPES

Plant diversity refers to variation in species composition, species distribution and structural organization of vegetation in an area. It includes different type of herbs, shrubs and tree and it impacts functioning of an ecosystem (Shannon 1948; Simpson 1949). Urban vegetation unlike forest vegetation is present in fragmented and managed within areas like parks, roadside plantations and home gardens. Urban vegetation is characterised by mix of native and ornamental species which have different ecological importance (Seto et al. 2012; Aronson et al., 2017). On the other

hand, forest vegetation is less disturbed relatively and have multi layered stratification. Forest ecosystem shows dominance of native species, and they significantly contribute to higher biomass accumulation and carbon storage (Pan et al. 2011; Liang et al. 2016).

1.5. SOIL ORGANIC CARBON AND ITS IMPORTANCE

Soil organic carbon (SOC) is a major component of terrestrial carbon pool. It also plays an important role in regulation of global carbon cycling, and it is also linked with climate change mitigation (Lal 2004a). Soil organic carbon is strongly influenced by vegetation type and land-use patterns. Higher SOC stocks are observed generally in forest and natural vegetation in comparison to degraded lands due to more litter input and concentration of biomass (Guo and Gifford 2002). Soil carbon accumulation is further enhanced by vegetation diversity as it increases organic matter input, it improves soil biological activity which leads to strengthening of ecosystem productivity and stability (Shi 2024). Soil organic carbon also supports microbial communities and nutrient cycling processes which is crucial for maintaining soil fertility and long-term functioning of ecosystem (Six et al. 2002). Therefore, SOC represents a key link between plant diversity and carbon sequestration in both urban and forest ecosystems.

1.6. ROLE OF VEGETATION IN CLIMATE CHANGE MITIGATION

Carbon sequestration is a natural process which collects and stores CO₂ from atmosphere and thus regulating climate by decreasing concentration of greenhouse gases (Lal 2004a; Mitsch et al. 2013). A significant role is played by vegetation in regulation of climate change through sequestration of atmospheric carbon into plant biomass and soil. This also reduces greenhouse gas concentrations (Pan et al. 2011; Lal 2004a). Forest ecosystems act as a major sink for carbon and large amounts of carbon is stored in above ground biomass as well as below ground biomass. Long term carbon storage is also achieved by it through the process of litter deposition and soil organic matter formation (Yoon 2022; Bera et al. 2024). Regulation of climate is also affected by vegetation through processes such as moderating climate, improving microclimatic conditions and enhancing evaporation transpiration processes (Murugadoss et al. 2024; Pan et al. 2025). Effectiveness of carbon sequestration

through vegetation is further influenced by composition of species, ecological conditions and stand structure. Which further determines overall biomass production and carbon storage potential (Liang et al. 2016). Consequently, an important role is played by vegetation in maintenance of ecological balance and mitigation of impacts of climate change.

1.7. URBAN VEGETATION AND ITS ECOLOGICAL ROLE

Similarly, the process of urbanization intensifies these ecological issues by fragmenting natural habitats and changing them into inaccessible areas such as buildings, parking lots and highways which disrupts ecological equilibrium and hinders habitat connectivity (Grimm et al. 2008). This change leads to decline in biodiversity, limiting species migration and habitat destruction. Moreover, urban regions substantially contribute to the phenomenon of heat island. It also leads to elevated pollution levels which decreases ecosystem's capacity for carbon sequestration (Seto et al. 2012; Ziter et al. 2019). Studies demonstrates that urban expansion has resulted in 10-20 % reduction of endemic plant species which further curbs local carbon sequestration capability (Seto et al. 2012). Notwithstanding these constraints urban ecosystem still offers potential to enhance biodiversity and sequester carbons through initiatives such as gardens, roadside vegetations and parks (Pataki et al. 2011; Lin et al. 2015). These manmade green spaces functions as carbon sinks which facilitates storage of carbon in plant biomass and soil organic matter which also provides microhabitats for various species (Aronson et al., 2017). Through the execution of well-planned urban greening projects, it is anticipated that they will contribute approximately one-third of the climate mitigation. Which is necessary by 2030 to limit global warming to below 2 °C. Therefore, incorporating carbon sequestration and biodiversity into urban planning is essential for creating ecologically viable cities (Baró et al. 2017).

1.8. FOREST VEGETATION AND CARBON STORAGE

Forests are primary reservoirs of sequestered carbon and are habitat for terrestrial biodiversity (Pan et al. 2011; Liang et al. 2016). Through the disruption of these forests significant amount of stored carbon is released back into atmosphere which destabilizes the ecological balance (Haddad et al. 2015). So along with afforestation and reforestation efforts adoption of sustainable management of forest is also crucial.

It is necessary for mitigation of detrimental impacts of deforestation and to restore the ecological equilibrium (Bastin et al. 2019).

1.9. COMPARATIVE ANALYSIS OF URBAN AND FOREST VEGETATION

There is significant difference in species composition, structural complexity, and carbon sequestration potential in urban and forest vegetation. Forest ecosystems due to dominance of native vegetation and multi layered strata generally shows higher biodiversity and biomass accumulation subsequently resulting in higher storage of carbon (Pan et al. 2011; Liang et al. 2016). Urban vegetation is generally fragmented and contains mix of native and ornamental species, which leads to comparatively lower but significant carbon sequestration potential (Seto et al. 2012; Aronson et al., 2017). Table 1.1 outlines the principal distinctions between urban and forest ecosystems in regards to ecological characteristics for enhanced comprehension of these ecological differences.

Table 1.1: Differential ecological features of urban and forest ecosystems

Ecological Attributes	Forest Ecosystems	Urban Ecosystems	References
Carbon Sequestration Capacity	In this ecosystem, carbon sequestration capacity is high due to substantial biomass accumulation and soil carbon storage.	In this ecosystem, carbon sequestration capacity is moderate as it is limited by landscape fragmentation and reduced biomass accumulation	(Seto et al. 2012; Nayak et al. 2024)
Plant Biodiversity	Plant biodiversity is high in this ecosystem, which is supported by native species and multi-layered vegetation.	Plant biodiversity ranges from moderate to low due to the predominance of ornamental species, which have minimal	(Alam et al. 2023; Nayak et al. 2024)

		ecological benefits	
Soil Composition	The soil in this ecosystem is rich in organic matter, which contributes to the prolonged carbon storage and ecosystem health	The soil in this ecosystem is often degraded because of low organic content and substantial soil compaction	(Yoon 2022; Bera et al. 2024)
Impact on Climate Stability	This ecosystem significantly impacts climate stability as forests serve as pivotal carbon sink by storing carbon in soil and biomass.	This ecosystem has local importance with the potential to reduce urban heat island effects	(Murugadoss et al. 2024; Pan et al. 2025)

1.10. BIODIVERSITY AND CARBON RELATIONSHIP IN VEGETATION

There is interconnection between biodiversity and carbon sequestration, ecosystems with high species diversity also shows enhanced carbon storage capacity due to the ecological synergistic activities of multiple species (Li et al. 2020b). For example, forest ecosystems which are characterized by numerous tree species also optimizes resource usage which includes nutrients, sunlight and water which further enhances efficiency of overall carbon sequestration. Loss of biodiversity leads to undermining ecosystem functionality, diminishes resilience and impairs carbon sequestration efficiency (Liang et al. 2016).

1.11. URBANIZATION AND DEFORESTATION: DUAL CHALLENGES

Anthropogenic activities such as urbanization and deforestation are posing a serious threat to biodiversity and carbon sequestration on a global scale (Seto et al. 2012;

United Nations 2018). Urban area expansion generally leads to fragmentation of habitat and loss of biodiversity. However, urban green spaces within cities which are strategically planned provides an opportunity to counterbalance it (Beninde et al. 2015). In contrast, deforestation caused by infrastructure development, agricultural expansion, and logging remains the leading cause of carbon emissions and the destruction of irreplaceable biodiversity (Pendrill et al. 2019).

1.12. REGIONAL CONTEXT OF BIODIVERSITY AND CARBON SEQUESTRATION DYNAMICS IN SIRSA, HARYANA

Deforestation and urbanization both presents considerable consequences which not only surpasses regional limits but are also having impact on global climate system and biodiversity

(Li et al. 2022). Through the evaluation of significance of regional studies essential insights about carbon sequestration, ecosystem dynamics and species diversity can be gained. These analyses establish the basis for developing customized conservation strategies which are relevant in particular areas (Buotte et al. 2020; Wu et al. 2020). When these policies are aligned with global frameworks such as the SDGs and the Paris Agreement their influence is enhanced considerably (Dzebo et al., 2023). Therefore, by incorporation of biodiversity conservation and carbon sequestration into land-use management as well as urban planning ecological outcomes can be enhanced significantly (Baró et al. 2017; Frantzeskaki et al. 2019). Similarly urban landscape's design which conserves local species and emphasizes on restoration of forest in biodiversity hotspots also guarantees the utilization of resources in a way that helps in achieving global conservation and climate objectives (Ives et al. 2016). Due to difficulties in assessing biodiversity and its carbon sequestration potential in complex ecosystems the examination of the interaction between urban and forest vegetation in these ecosystems are few, particularly in underexplored regions such as Sirsa, Haryana (Singh et al. 2016). Sirsa is comprised of varied terrains encompassing urban gardens as well as forested regions such as Abub Sheher Wildlife Sanctuary. Sirsa also offers a platform for examining biodiversity and carbon sequestration processes. This study seeks to fill the gap by examining the biodiversity and carbon sequestration capacity of urban and forest vegetation in Sirsa.

The current study was designed to analyse plant biodiversity pattern and to evaluate carbon sequestration potential both in urban and forest vegetation of Sirsa, Haryana. This study also explores relationships between plant diversity and carbon storage due to variations in vegetation structure, species composition, and ecological conditions. Through comparison between different vegetation types, this study aimed to provide insight into influence of biodiversity in carbon sequestration potential in different ecosystem. These findings will further contribute to region specific understanding of ecology and sustainable land management.

CHAPTER 2

REVIEW OF LITERATURE

2.1. OVERVIEW OF PLANT BIODIVERSITY AND CARBON SEQUESTRATION

2.1.1. Biodiversity

2.1.1.1. Definitions and types of biodiversity

Biodiversity is the foundation of ecosystem stability and resilience and is known to contain the variety of life forms across three interconnected core levels, i.e., genetic diversity, species diversity and ecosystem diversity (ESA 2000). Genetic diversity refers to the genetic variation at species level that provide ability to populations to adapt to environmental changes, improves disease resistance, and preserve their vitality. Within an ecosystem species diversity is the richness and variety of species that directly affects the stability, functioning, and supply of important ecological services (Cardinale et al. 2012; Jia et al. 2021). Ecosystem diversity is the range of several ecosystems found in a given area, where every one of them offers special functions like habitat for species, control of climate, and nutrient recycling (Cardinale et al. 2012). These linked critical levels of biodiversity used together help to maintain the ecological processes required for human well-being and environmental stability (Bennett et al. 2015).

Biodiversity is divided into three main divisions i.e. Alpha, beta, and gamma diversity. Alpha diversity is the total number of species inside a particular area or ecosystem. It indicates species richness. Beta diversity evaluates the variations in composition of species among various habitats. It provides insightful analysis of the variety of biodiversity and species distribution among many ecosystems. Gamma diversity provides integrated information about the variety from all the habitats within a given area thereby reflecting the general biodiversity across it (Whittaker 1972). Knowledge of these kinds of biodiversity helps in properly grasping the biological patterns and processes which are necessary for establishing efficient conservation strategies (Socolar et al. 2016).

2.1.1.2. Importance of biodiversity for ecosystem functioning and resilience

Biodiversity not only have its aesthetic and cultural value but it also has ecological relevance. Functionally it is the pillar of essential ecosystem services such as nutrient cycling, pest control, climate control and pollination (Naeem et al. 2012). Ecosystems with higher biodiversity generally shows better resilience and survive through natural challenges such as droughts, floods, and invasion of pests (Isbell et al. 2015). A forest with a higher range of plant species shows higher soil stabilisation and nutrient recycling compared to other monoculture plantings (Erskine et al. 2006). Ecosystems with higher biodiversity enhances carbon sequestration substantially and multiple species boost carbon capture efficiency across different ecological strata. As the result, resilient ecosystems are important for mitigating climate change, maintaining soil fertility and conserving water resources (Lal 2004a).

Other than that, biodiversity also confers indirect benefits through ecological redundancy in which different species perform similar functional roles within an ecosystem (Walker 1992). This redundancy ensures the stability of ecosystems to perform critical functions even if certain species become extinct. For example, in the case of pollination including several pollinator species ensures that plant reproduction may go on even in changing surroundings. Therefore, preserving the integrity and stability of an ecosystem depends on this redundancy (Socolar et al. 2016).

2.1.1.3. Threats to biodiversity and conservation strategies

Biodiversity despite of its crucial importance faces unparalleled dangers from the human activity. The primary global reason of biodiversity loss which results from habitat loss is agricultural expansion, deforestation as well as urbanization (IPBES 2019). Climate change intensifies these concerns by disrupting habitats which alters species distribution which further increases the frequency of extreme weather events. Due to the overexploitation of natural resources, the quick spread of alien species and pollution significantly contribute to the reduction of biodiversity (Maxwell et al. 2016). Coastal ecological systems such as mangroves are highly vulnerable due to the coupled threats of climate change, rising sea levels and human encroachment which is jeopardizing their biodiversity which also diminish their carbon storage capacity

(Alongi 2015). These interconnected issues threaten ecosystem stability and their ability to sustain the life on Earth (Steffen et al. 2015).

For redressal of these issues conservation programs have to consider employing a holistic strategy which encompasses the entire ecosystem. A significant approval has been gained by conservation which is ecosystem based and emphasizes the preservation of entire ecosystems rather than individual species (Cohen-Shacham et al. 2019). An important component of this strategy is landscape connectedness. It promotes species migration and genetic exchange specifically in fragmented environments (Fahrig 2003). Examples of practical implementation of this strategy are buffer zones and conservation corridors around protected areas. Community-led conservation initiatives that engage local populations in efforts to protect biodiversity have been proven effective (Martino 2001). These initiatives combine conservation goals with economic opportunities building a shared responsibility for environmental preservation within communities (Gopalakrishna et al. 2024).

Recent technological advancement has increased conservation measures considerably for e.g. remote sensing and satellite photos. These provide real-time evaluation and monitoring of habitat changes. Although genetic technologies increase our understanding of species diversity and point out essential conservation priorities (Hoban et al. 2021; Pettoirelli and Schulte to Bühne 2023). But technological developments along with policy support and worldwide collaboration are also essential to tackle the complex challenges currently affecting the conservation of biodiversity (Ferris et al. 2023).

2.1.2. Carbon Sequestration

2.1.2.1. Definition and Significance

Carbon sequestration refers to the process of capturing CO₂ from the atmosphere and storing it in natural or artificial reservoir. This process reduces atmospheric CO₂ levels and helps in mitigating climate change (Figure 2.1) (Lal 2008). The carbon can be stored in several forms, i.e., in living organisms as organic carbon, in sediments and soils as inorganic carbon, or as mineral carbonates formed by chemical reactions (Figure 2.1) (Batool et al. 2024). The significance of carbon sequestration lies in its dual role, as it is not limited to the mitigation of climate change but is also involved in the strengthening of ecosystem resilience (Hoban 2021). By sequestering CO₂ from

the atmosphere and storing it, ecosystems serve as the natural protective buffer against climate change, especially global warming (Lal 2008). Additionally, it also provides benefits like enhanced biodiversity, increased soil fertility, and improved water regulation. The Table 2.1 provides a detailed overview of state-wise carbon stocks across different pools in India, illustrating the contributions of aboveground and belowground biomass, soil organic carbon, and other components (FSI 2017).

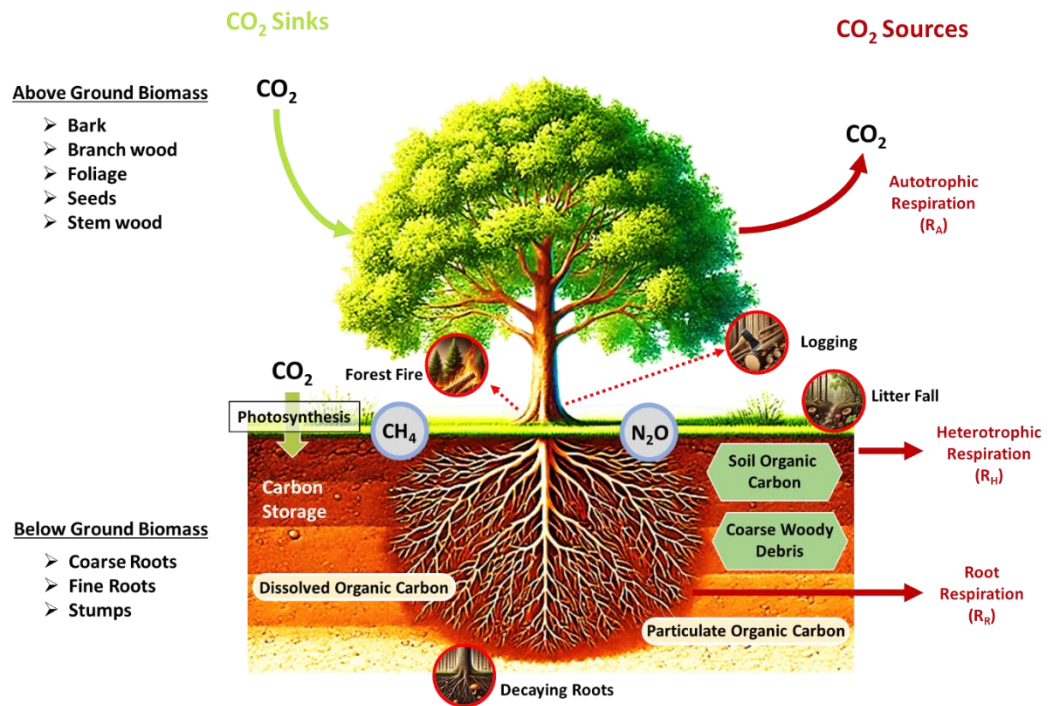


Figure 2.1: Diagrammatic representation of carbon sequestration and storage

Table 2.1: State-wise distribution of carbon stock across different pools (in million tonnes) with per ha stock in parentheses (FSI 2017)

State	Area (sq. km)	AGB	BGB	Deadwood	Litter	SOC	Total Carbon Stock
Andhra Pradesh	28,147	100.54	38.59	0.57	4.53	118.47	262.69
Arunachal Pradesh	66,964	243.46	53.38	4.31	16.23	677.16	994.54
Assam	28,105	47.34	10.82	1.09	5.24	112.35	176.85
Bihar	7,299	19.06	6.71	0.14	0.63	28.86	55.40
Chhattisgarh	55,547	206.68	68.16	2.59	7.63	275.93	560.98
Delhi	192	2.53	0.05	0.00	0.65	6.24	9.48
Goa	2,229	15.51	1.51	0.25	0.48	11.68	29.43
Gujarat	14,757	32.67	3.73	0.02	0.99	64.99	102.40
Haryana	1,588	3.74	1.27	0.02	0.07	7.31	12.41
Himachal Pradesh	15,100	70.66	18.69	0.74	2.51	83.19	175.78
Jammu & Kashmir	23,241	112.92	30.08	1.00	3.53	128.39	275.93
Jharkhand	23,553	86.01	33.17	0.44	1.30	101.97	222.88
Karnataka	37,550	128.10	35.05	2.55	19.75	289.65	475.09
Kerala	20,321	74.17	19.25	1.06	7.35	153.98	255.88

Madhya Pradesh	77,414	266.04	101.52	1.65	7.74	318.71	695.66
Maharashtra	50,682	142.56	48.95	1.99	9.39	290.45	493.33
Manipur	17,346	72.25	8.82	0.53	3.91	102.58	143.09
Meghalaya	17,146	25.17	6.83	0.88	5.18	119.77	155.84
Mizoram	18,186	15.36	3.17	0.63	2.65	73.22	95.04
Nagaland	12,489	16.15	4.15	0.67	2.42	102.16	125.61
Odisha	51,345	152.53	50.41	2.11	9.09	238.74	452.93
Punjab	1,837	5.10	1.88	0.03	0.06	8.97	16.04
Rajasthan	16,572	32.56	12.74	0.22	0.72	43.43	89.66
Sikkim	3,344	13.98	3.54	0.27	0.59	30.63	48.99
Tamil Nadu	26,281	84.07	29.25	1.01	5.58	109.43	229.34
Telangana	20,419	72.50	28.39	0.33	3.32	80.64	185.18
Tripura	7,726	15.67	3.27	0.66	2.19	34.32	56.41
Uttar Pradesh	14,679	47.75	14.47	0.04	1.82	50.85	114.94
Uttarakhand	25,103	105.96	36.96	1.32	5.67	145.55	295.45
West Bengal	16,847	48.43	13.92	0.24	2.59	96.38	161.56
Andaman & Nicobar Islands	6,742	39.50	11.90	2.05	3.73	65.06	122.24
Chandigarh	22	0.06	0.02	0.00	0.00	0.12	0.20

Dadra & Nagar Haveli	207	0.45	0.11	0.01	0.03	0.83	1.42
Daman & Diu	20	0.01	0.00	0.00	0.00	0.08	0.09
Lakshadweep	27	0.05	0.00	0.00	0.00	0.10	0.16
Puducherry	54	0.10	0.02	0.00	0.01	0.32	0.45
Total	708,273	2,237.55	698.70	30.13	136.16	3,979.52	7,082.06

*AGB: Above Ground Biomass; BGB: Below Ground Biomass and SOC: Soil Organic Carbon

** In Lakshadweep, most of the forest cover is of *Cocos nucifera* for which no suitable ratio of BGB is available

2.1.2.2. Biological Mechanisms: Vegetation and Soil

Biological carbon sequestration takes place mainly in aquatic and terrestrial ecosystems. In terrestrial ecosystems, the key role is played by plants through photosynthesis. Through this process, CO₂ is taken from the atmosphere and fixed as organic matter in plant tissues such as leaves, stems, roots, and woody biomass (Carbone and Trumbore 2007). Forest ecosystems themselves are among the most important carbon sinks on land, where old forests holding high levels of carbon in biomass and soils (Figure 2.2) (Luyssaert et al. 2008). Younger forests sequester carbon more quickly during growth stages, although their capacity for storage is generally less than that of old forests (Stephenson et al. 2014).

Soil is another important carbon storage reservoir, largely in the form of soil organic carbon (SOC). SOC comes from plant and animal residues decomposing in the soil and is stabilized by interactions with soil minerals (Six et al. 2002). Practices of sustainable land use like conservation tillage, agroforestry, and the use of organic amendments improves the storage of SOC and lower soil CO₂ emissions (Lal 2004b). Also, peatlands and wetlands, with their anaerobic environment, are uniquely effective at sequestering carbon over the long period of time because of their lower rates of decomposition (Schuur et al. 2015).

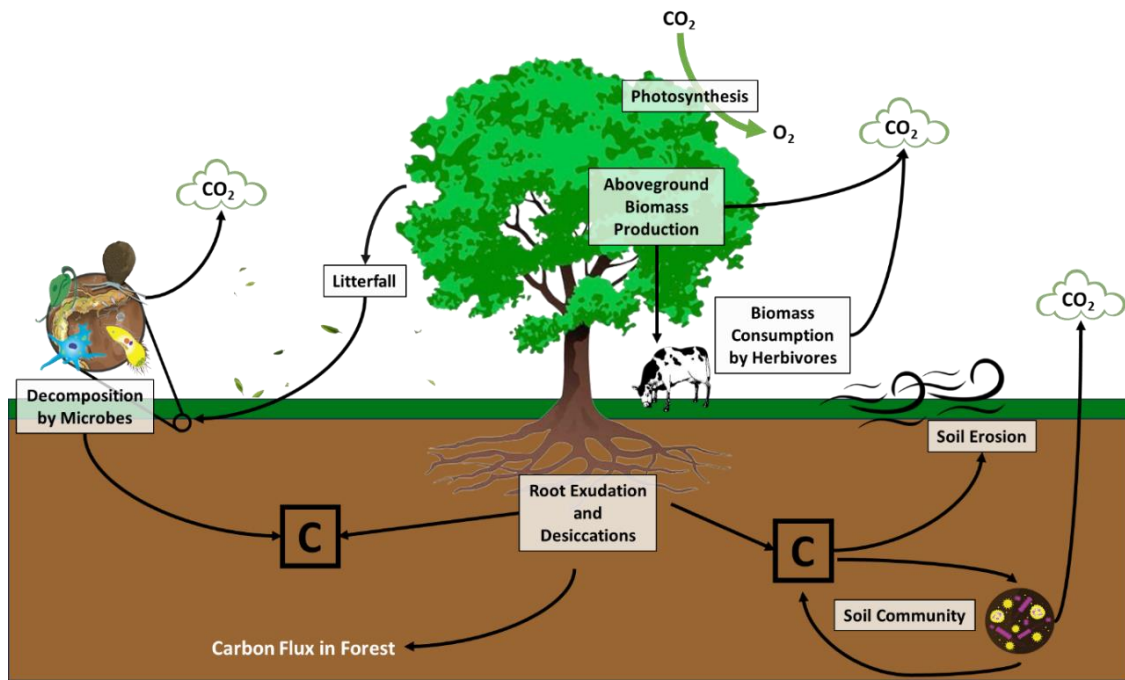


Figure 2.2: Pictorial depiction of forest carbon cycle.

2.1.2.3. Artificial Carbon Sequestration Approaches

In addition to natural processes, artificial or engineered carbon sequestration approaches have acquired significant attention. These comprises carbon capture and storage (CCS) technologies, where CO₂ from industrial operations/processes or power plants is captured prior to release, compressed, and transferred to secure geological establishments for long-term storage (Bui et al. 2018). Other technologies that are still emerging are bioenergy with carbon capture and storage (BECCS) and mineral carbonation, where biomass combustion is combined with CO₂ capture to produce energy and CO₂ reacts with naturally occurring minerals to precipitate stable carbonates, respectively. Although these technologies hold potential, scalability and affordability are current challenges (Smith et al. 2016).

2.2. BIODIVERSITY-CARBON SEQUESTRATION RELATIONSHIP

There is increasing evidence to suggest that biodiversity increases ecosystem carbon storage and stability. Biodiverse ecosystems exhibit greater productivity, which allows for higher carbon capture via photosynthesis (Huxman et al. 2004). This compatibility of biodiversity with carbon storage highlights the need to preserve diverse ecosystems on both ecological stability and climate mitigation grounds (Marshall et al. 2024).

Additionally, functional diversity involving the presence of species with complementary ecological functions. The presence of these species favours optimal usage of resources and resilience to disturbances (Hooper et al. 2005). For example, combining deep-rooted and shallow-rooted plant species provides carbon storage in multiple layers of soil, enhancing overall sequestration potential. Conservation of biodiversity-rich ecosystems like mangroves, tropical rainforests, and wetlands can therefore provide twin benefits of carbon sequestration and conservation of biodiversity (Bai et al. 2022).

Existing research on biodiversity conservation and carbon sequestration adopts different research approaches. For instance, stratified sampling is common in quantifying carbon storage in forestlands like the Shivalik Hills in Haryana (Sharma et al. 2017). This approach is effective for determining the variability across landscapes; however, this approach lack to address the role of microhabitats that uniquely contributes to the biodiversity (Hyseni et al. 2021). Conversely, systematic sampling, employed in research on urban green spaces in Delhi, yields uniform data on carbon storage and biodiversity metrics but may fail to capture the complete ecological variability of larger, heterogeneous areas (Bhalla and Bhattacharya 2015). On comparing these findings, the restoration initiatives in Haryana's Aravalli Hills were found to notably increase the carbon stocks by employing the approach of native plantation (Pal 2001). This practice is very different in comparison to monoculture plantation, which have applied in different area to address the same challenge. Although, this might be effective for carbon sequestration for short period of time, but this approach will not nourish diverse ecological networks in the long run. Few examples that support the above points have been discussed as follow (Mina et al. 2023):

1. **Afforestation Project in Urban Area:** Cities like Bangalore have shown how indigenous tree species in urban afforestation initiatives complements biodiversity while serving as efficient carbon sinks. Such initiatives also increase urban resilience by reducing the urban heat island effect (Jaganmohan et al. 2012).
2. **Agroforestry:** The practices during rubber plantation in Kerala is an example of how trees can be included in the agricultural landscapes to increase soil organic carbon, aid pollinator diversity and provide shade (Mina et al. 2023).

3. **Conservation practices driven by community:** The Chipko Movement in the state of Uttarakhand demonstrates how community action towards forest protection can safeguard biodiversity and ensure sustainable utilization of resources as well as carbon sequestration (Ishizaka 2014).
4. **Restoration of Mangroves:** Activities in Kutch district of Gujarat highlighted the dual benefits of restoring mangrove in sequestering blue carbon and safeguarding coastal ecosystems with rich biodiversity (Upadhyay et al. 2015).
5. **Application of Innovative methods in Conservation:** The application of drones in Andhra Pradesh for monitoring reforestation initiatives has improved the precision of carbon stock estimation, along with that it has allowed the identification of biodiversity hotspots (González-Jaramillo et al. 2019).

These examples provide the valuable insight and provide the list of effective strategies that can applied for conservation of biodiversity and carbon sequestration. The impact of biodiversity loss has been illustrated in figure 2.3.

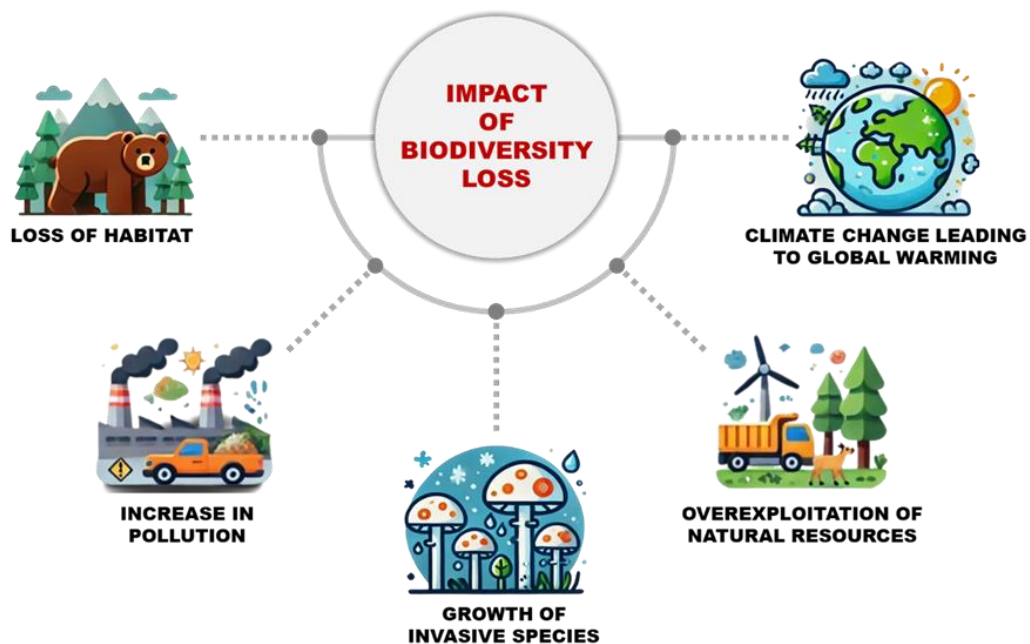


Figure 2.3: Depiction of principal mechanisms contributing to biodiversity decline and associated ecological consequences.

Urban and forest ecosystems are two essential components in managing these environmental issues (Pataki et al. 2011). For instance, forest serve as the natural carbon sinks that are storing around 45% of the earth's terrestrial carbon (Pan et al. 2011). Whereas urban green spaces support biodiversity and aid in mitigating the

effect of urban heat islands (Bowler et al. 2010; Aronson et al. 2017). These ecosystems collectively deliver vital functions such as air filtration, temperature regulation, and soil stabilization all of these are crucial for human wellness and ecological equilibrium (Reid et al. 2005; Pataki et al. 2011). Vegetation of cities enhances forest ecosystems by acting as biodiversity hotspots and facilitating carbon sequestration particularly in heavily populated metropolitan regions. Both ecosystems, despite their importance, are confronting severe threats from climate change, deforestation, habitat fragmentation, and urbanization, hence requiring the urgent execution of conservation plans (Nowak and Crane 2002; Haddad et al. 2015). Figure 2.4 illustrates the effects of climate change on biodiversity and human well-being.

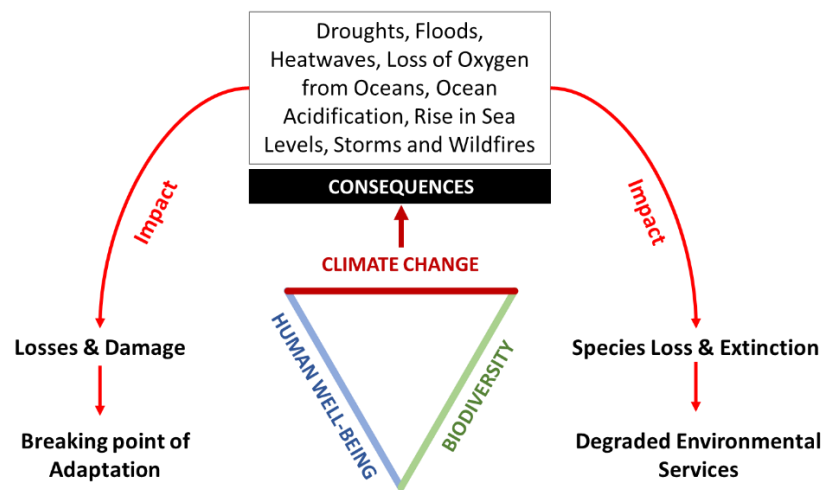


Figure 2.4: Interconnection of Climate change with biodiversity and human well-being.

Evidence indicates that ecosystems with higher plant species diversity shows higher carbon sequestration due to increase in biomass production and utilization of resources efficiently (FAO 2017; UN 2022). Evidently, role of biodiversity is critical in regulation of carbon storage across both urban and forest ecosystems.

2.3. CARBON SEQUESTRATION IN URBAN AND FOREST ECOSYSTEMS

Forest Ecosystems as Carbon Sinks: Forests are the largest on-land reservoirs of carbon, holding about 45% of the terrestrial carbon of the planet (Field and Raupach 2004). This function is closely related to both biodiversity conservation and global carbon cycles since forests store carbon in their biomass and soils and provide

complex ecological communities (Griscom et al. 2017). They store carbon in aboveground biomass (trees, shrubs) and belowground biomass (roots, soil organic matter). Old-grown (primary) forests are especially important since they not only sequester large amounts of carbon but also preserve biodiversity and hydrological cycles (Luyssaert et al. 2008). Deforestation, on the other hand, counteracts these advantages by granting access to stored carbon and releasing it into the atmosphere, accounting for about 10% of global greenhouse gas emissions (Calvin et al. 2023). To offset this, afforestation, reforestation, and sustainable forest management have been promoted worldwide as a complement to climate mitigation efforts (Miller et al. 2022).

Urban Vegetation and Carbon Dynamics Urban ecosystems, while restricted in area size relative to forests, are becoming increasingly important in carbon sequestration. This function is further enhanced by the spread of urban greenery programs, which provide localized carbon sinks and other ecological benefits (Nowak et al. 2013). Urban vegetation, such as parks, green rooftops, street trees, and urban forests, functions as localized carbon sinks by sequestering CO₂ in biomass (Weltecke and Gaertig 2012). Urban soils particularly in green places sequester carbon but to a smaller extent than soils in forests (Pouyat et al. 2006). Urban vegetation leads to decrease of urban heat island effect. This also reduces energy consumption and is also involved in reduces greenhouse gases emission from cooling systems. Integration of green infrastructure in plans during urban planning is important for increasing the carbon sequestration potential of urban areas (EPA 2008). This approach provides localized carbon storage and also decreases the urban heat island effect, enhances air quality and supports biodiversity habitats (Wu et al. 2024).

2.4. URBAN AND FOREST VEGETATION DYNAMICS

a) Urban Vegetation

Urban vegetation has transformed the functioning in urban ecosystem and is responsible for both ecological and social benefits (Gómez-Baggethun and Barton 2013). Urban greenery like green roofs, parks, street trees, and vertical gardens are as carbon sinks that play important role in capturing CO₂ from the air and sequestering it in form of biomass (Wu and Biljecki 2020). Along with carbon sequestration, urban vegetation also offers various other benefits like

- **Enhancement of Air Quality:** Vegetation cleanses air-borne pollutants like nitrogen dioxide (NO₂), and particulate matter, which overall improves the quality of air in urban area (Pouyat et al. 2006).
- **Regulation of Microclimate:** Green spaces and trees mitigate the urban heat island effect by reducing both surface and air temperatures through evapotranspiration and shadowing (EPA 2024).
- **Biodiversity Hotspots:** Urban green spaces serve as refuges for various species, hence enhancing biodiversity in metropolitan environments (MacGregor-Fors et al. 2016).
- **Aesthetic and Social Benefits:** Green cover in urban area improves the mental health, provide recreational prospects, and enhances their aesthetic appeal (Bratman et al. 2012).

Other than these benefits, urbanization also possess different challenges like fragmentation of habitat, decreased vegetation cover, and enhanced pollutant loads. Other than this, urbanization has significantly altered the diversity of native species by replacing them with the alien or non-native species. The human intervention has led to occurrence of native as well as alien species in the urban areas, making urban areas the hotspots of species diversity. Even though many people argue that urbanization has affected diversity of native species and claimed to be responsible for their extinction. Remnants of pre-urban vegetation can be found in urban areas and spaces like parks, gardens, and other green spaces that are playing vital role in preserving both native and novel species of plant.

In recent times, there has been significant increase in exploring the urban vegetation, as they uncover the distinct ways the urban areas are contributing to the biodiversity in spite of the challenges imposed by urbanization (Cook et al. 2012). As a matter of fact, different studies have revealed that urban areas harbour diverse plant species, sometimes few species are present in abundance in urban areas in contrast to the nearby rural areas (Mason 2000). Moreover, urban areas being fragmented from rural areas and continuously being under threat by habitat destruction and pollution, persist to support diverse plants encompassing both native as well as non-native species (Ives et al. 2016). Thus, there is need for proper urban planning that focusses on green infrastructure as their adaptation is required to overcome these challenges and

increase the carbon sequestration capacity of the urban ecosystem (Pickett et al. 2001).

b) Forest Vegetation

Forests are vital in ensuring global ecological balance. Forests serve as significant carbon sinks that allow the storing of CO₂ in the air in the form of biomass and soil. Forests are also biodiversity hotspots with a rich diversity of species that help in maintaining ecosystem stability and resilience (Sabatini et al. 2019). The synergy between carbon storage and biodiversity conservation underlines the necessity of sustainable forest management (Imai et al. 2009).

Even though there has been growing forest cover due to reforestation and afforestation initiatives in some areas, deforestation and habitat loss remain pressing issues (FAO 2020b). Deforestation releases sequestered carbon into the atmosphere and perturbs ecosystem services (USEPA 2023). Such activities need integrated solutions encompassing reforestation with biodiversity protection to maximize carbon sequestration and ecological value (Andres et al. 2023).

2.5. FACTORS AND CO-BENEFITS INFLUENCING CARBON SEQUESTRATION EFFICIENCY

2.5.1. Factors Influencing Carbon Sequestration Efficiency

Composition of species: Carbon storage capability is dependent on the type of. Species that grows fast such as eucalyptus and poplar are excellent in carbon sequestration during their growth. Indigenous species provide long-term carbon storage and ecological stability (Zhang et al. 2012b).

Land-use practices: Agroforestry, cover cropping and no-till farming are sustainable farming strategies that increases soil carbon sequestration. Intensive agriculture and overgrazing decrease carbon storage capacity by lowering soil organic matter (Bedolla-Rivera et al. 2023).

Climate and Soil Conditions: Global warming and increased precipitation tend to enhance carbon sequestration rates in vegetation, while excessive warming can boost decomposition rates, lowering soil carbon levels. Soil texture, mineral composition, and microbiological activity also have important roles in stabilizing SOC (Shi 2024).

Disturbances: Natural disturbances like wildfires and storms as well as human activities including deforestation and urbanization, can significantly alter the processes of carbon cycling and in the majority of situations lead to the release of stored carbon (Fleischmann et al. 2023).

2.5.2. Co-Benefits of Conservation and Climate Mitigation Initiatives

The implementation of natural strategies like biodiversity conservation and climate change management is well-known for providing multiple benefits like:

- 1. Enhanced Ecosystem Resilience:** The presence of different species within an ecosystem improves their ability to resist unfavourable environmental conditions and keep the stored carbon intact (Thompson et al. 2014).
- 2. Improved Water Quality and Availability:** The maintained ecosystems improve the water quality, regulate the water cycles, reduce runoff and improve groundwater recharge that benefits both biodiversity as well as carbon sequestration (Dao et al. 2024).
- 3. Sustainable Livelihoods:** The local communities develop sustainable economic benefits through forest development initiatives and conservation practices, which include carbon emission market activities, product sales and tourism operations (Muttaqin et al. 2019).
- 4. Decline in Disaster Risk:** Mangroves along with forests and wetlands serve as natural barriers which protect human houses as well as ecological systems from floods, storms and landslides (Wickramasinghe 2021)
- 5. Human Well-being:** The setting up of urban green spaces offers benefit to humans by promoting physical activity and ensuring safety. Other than that, they also provide aesthetic perspectives to humans (Jabbar et al. 2022).

Therefore, by recognizing the interrelated benefits of biodiversity conservation and initiatives like climate change mitigations help in achieving the sustainability goals. Further, this integrated approach promotes environmental stewardship and human development (Hoffmann 2022).

2.5.3. Benefits of Deferring Carbon Sequestration

The word “deferment” in general means delay, here in the context of carbon sequestration it refers to the delay in realizing climate or ecological related benefits of conservation and land management strategies. For instance, monoculture plantation provides immediate or short-term benefits but it doesn’t provide the long-term benefits like ecological resilience provided by ecosystems rich in native plant species. In same way, urban greening or reforestation initiatives will take years to mature before yielding substantial carbon storage and show climate mitigation effect. These approaches are effective and highlights the trade-off between instant carbon capturing and enduring ecological stability, making deferment an important factor of consideration during the strategic environmental planning (Delphin *et al.* 2016; Edwards and Cerullo 2024).

2.6. CLIMATE CHANGE AND ITS IMPLICATIONS FOR BIODIVERSITY AND CARBON DYNAMICS

Climate change has been found to profoundly affect biodiversity and carbon dynamics. The rise in global temperatures has modified weather patterns and intensified extreme climatic events, resulting in disruptions to environmental systems, habitat loss, and species redistribution (Bellard et al. 2012; Scheffers et al. 2016). Research indicates that a 3°C increase in global temperature might threaten 20-38% of global vegetation, while a 2°C rise could lead to serious ecosystem damage (IPCC 2018; Warren et al. 2018). Coral reefs and mangroves are two ecosystems very susceptible to temperature fluctuations that face the threat of irreparable damage if global warming exceeds 1.5°C irrespective of conservation initiatives (IPCC 2018; IPCC,2005). These developments endanger not only the species living in these habitats but also the important services these ecosystems offer i.e. lower catastrophe risk, water cleaning, and food security (Narayan et al. 2017; Menéndez et al. 2020).

Additionally, these changes also impact the ecosystems to serve as carbon sinks. Activities like alteration in land-usage and deforestation releases the carbon stored in soil and vegetation into the atmosphere (Baccini et al. 2012; Houghton and Nassikas 2017). Besides that, loss of biodiversity weakens the resilience of ecosystems in carbon sequestration. For instance, transforming of forests into agricultural land leads to habitat loss accompanied by significant increase in carbon emissions (UN 2018;

LSE 2021). In the same way, expansion of urban areas resulted in the replacement of green spaces with non-permeable surfaces, which eventually affected the carbon storage capacity of urban environment (Wang et al. 2023). Therefore, addressing of these issues requires an integrated strategies for biodiversity conservation and climate change mitigation (Jung et al. 2021). Henceforth, initiatives like reforestation, sustainable land-use practices and urban greening could be an effective approach to reverse these damaging effects (Ogunbode and Asifat 2021).

2.7. METHODOLOGY OVERVIEW FOR CARBON SEQUESTRATION ASSESSMENT

For the proper evaluation of carbon sequestration, a unified methodology with field data collection, sampling designs, analytical procedures, and quality control processes are required. The aim of this study is to measure the carbon that is stored within different pools of the ecosystem such as biomass, dead organic matter, soil and litter. It is carried in a way that ensures that the findings of the study are accurate, reproducible, and demonstrative of the study location or region (Pearson et al. 2005).

2.7.1. Sampling Design and Plot Allocation

Since it guarantees that the chosen sites fairly reflect the whole research area sampling design is a crucial part of carbon sequestration assessment (Pearson et al. 2005). Different types of methodologies are used based on the type of vegetation, geographical context and objectives of the study (Figure 2.5) (Schweiger 2020).

2.7.1.1. Simple Random Sampling: Without prior stratification this sampling technique randomly chooses sample plots within the study area. This simple approach guarantees every location's equal probability of choice. It might not fairly depict an area marked by different land use or vegetation (Köhl and Magnussen 2016).

2.7.1.2. Systematic Sampling: This sampling technique efficiently assigns sample plots using either a uniform grid or an interval-based system. Plots can be established for example, at specified intervals along sections. When landscapes are consistent, this method has shown to be successful in lowering the possibility of biased sampling as well. This method guarantees constant coverage of the study region and helps to simplify the fieldwork planning (Pearson et al. 2005).

2.7.1.3. Stratified Sampling: In this sampling method the study area is divided into different groups-based factors such as similarities in land use, topography and types of vegetation. Each stratum is independently sampled to capture the unique characteristics of each group accurately. This method improves the precision of estimates by reducing variability within different strata, making it practically useful across the different landscapes characterized by different types of vegetation. (Köhl and Magnussen 2016).

2.7.1.4. Cluster Sampling: This sampling method arranges the sample sites such that travel time and costs are minimised. This method is very effective in large or far-flung areas even if it can add intra-cluster variance that has to be controlled during analysis. Usually combined with stratification, this method preserves accuracy and data quality while optimizing logistical efficiency (Köhl and Magnussen 2016).

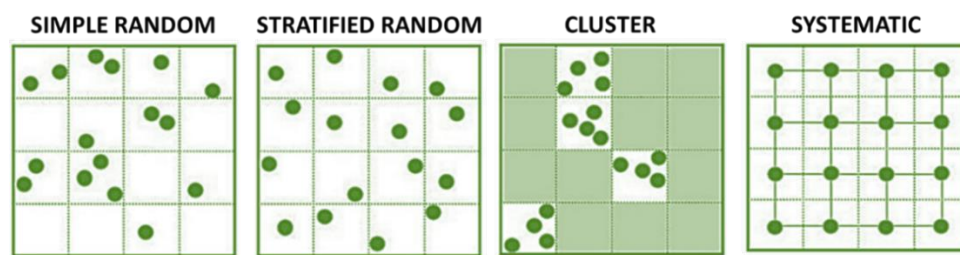


Figure 2.5: Visual depiction of different sampling methods (Hetzler et al. 2020; Schweiger 2020)

2.7.2. Plot layout: For a carbon estimate plot layout in sampling is rather crucial and can be adjusted depending on the demands of the research. The commonly used plot pattern include:

- **Square or Rectangular Plots:** This layout is easy to define and helpful for looking at areas rather heavily covered with forests. This arrangement helps to directly and simply compute areas. Moreover, it is usually used in areas with constant vegetative cover (Kleinn et al. 2010).
- **Circular Plots:** This layout is often used in forest inventory; this type of plot design minimizes edge effects relative to rectangular layouts. On uneven ground where defining straight plan boundaries could be difficult, the circular plot design is very helpful (Kleinn et al. 2010).

- **Transects:** This design records gradients in topography or vegetation using linear plots. In areas where environmental variables like soil composition or elevation change over an interval of time this structure is very helpful (Gillison and Brewer 1985).
- **Nested Plots:** Smaller plots enclosed inside bigger ones allow this approach to evaluate numerous carbon pools—including litter, biomass, and soil all at once. Trees will occupy a one-hectare area and subplots within that will be used for the evaluation of litter and shrubs (Pearson et al. 2005).
- **Radial Plots:** Plot configurations in this type enhance the spatial coverage in a limited area by including multiple radial extensions starting from a central point. Examining biodiversity and carbon sequestration in different environments has benefit from this plot framework (Gillison and Brewer 1985).

2.7.3. Plot size: One important factor taken into account and dependent on the particular carbon pool under assessment is the plot size. Small plots such as 10 m x 10 m or 0.01 are generally employed for shrubs and litter, bigger plots example one hectare are used for trees in a forest setting (Pearson et al. 2005). Thus, the plot size has to combine the need for exact and representative data with logistical feasibility (Grussu et al. 2016).

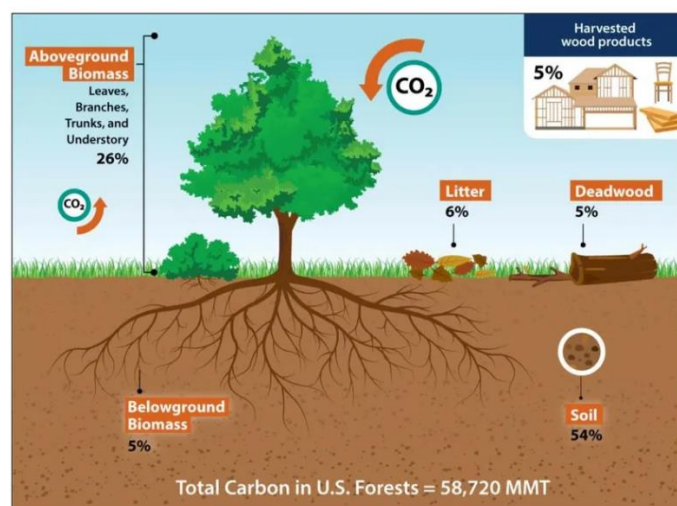


Figure 2.6: Diagrammatical representation of distribution of carbon storage in different carbon pools (<https://extension.psu.edu/forest-carbon-pools-where-are-they>)

2.7.4. Measurement of Carbon Pools

Precise assessment of the carbon pools is important to estimate carbon stocks. The primary carbon pools that are measured include aboveground biomass, belowground biomass, soil organic carbon, dead organic matter, and litter (Figure 2.6).

2.7.4.1. Aboveground Biomass: It encompasses all type of vegetation growing above the ground, which includes trees, shrubs, and sub-canopy vegetation. Tree height, diameter at breast height (DBH), and crown width are computed using instruments/tools like clinometers, DBH tapes, and rangefinders (Woodall et al. 2011; Li et al. 2020a). Figure 2.7 provides illustrative guidelines for DBH measurement in different situations. Biomass is quantified based on allometric equations, which are specific to species and have been derived from large datasets (Ketterings et al. 2001). Global or regional equations can also be used if local data are lacking or unavailable (Walker et al. 2016). Crown density and canopy cover are also included to provide information on forest health and productivity (Zarnoch et al. 2004).

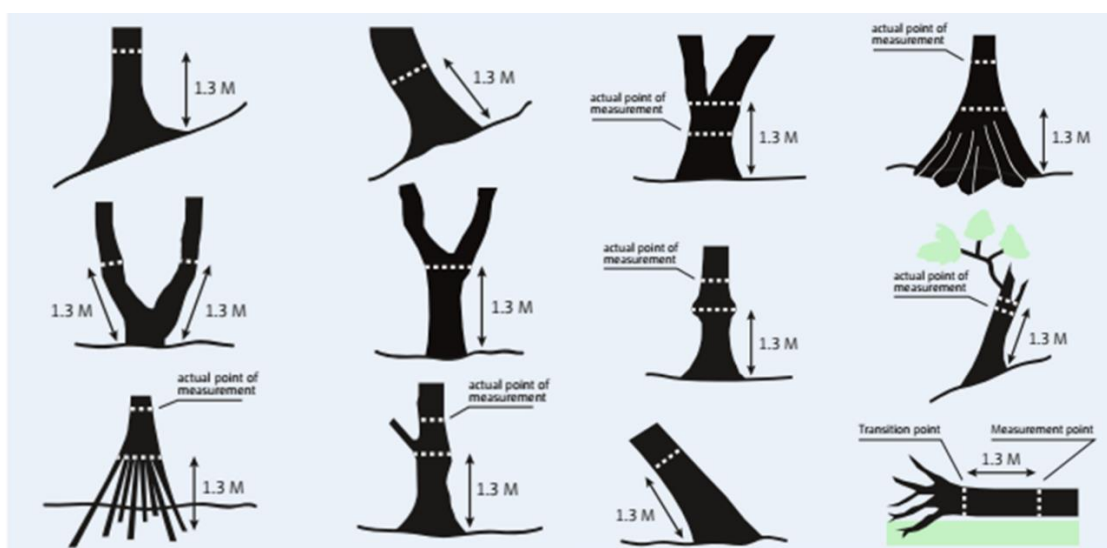


Figure 2.7: Illustration of standardized protocol for measuring DBH in non-standard conditions (UNFCCC 2015).

2.7.4.2. Belowground Biomass: It encompasses plant roots. Direct measurement is done by digging up root systems and measuring their weight, but it is time-consuming process (Magalhães 2015). Alternatively, belowground biomass is approximately determined by using root-to-shoot ratios, which correlate root biomass with aboveground biomass. These ratios are age-, species-, and environmental-

dependent (Cairns et al. 1997). Nowadays, improved ground-penetrating radar (GPR) is being investigated to estimate root biomass without destroying the roots (Li et al. 2020a).

2.7.5. Soil Organic Carbon (SOC): For this measurement, Soil auger or corer samples are taken from varied depths, i.e., 0–30 cm, 30–60 cm (Fu et al. 2024). The samples are first dried, then sieved, and analyzed for carbon content with standard procedures like the dry combustion, Walkley-Black method, or automated elemental analyzers. SOC varies with management practices, land usage, and soil type (Walkley and Black 1934; Meersmans et al. 2009). Bulk density quantifications are also done in order to convert SOC concentrations into stock estimates per unit area (Poeplau et al. 2017).

2.7.6. Dead Organic Matter: Coarse woody debris, deadwood, and standing snags make up this pool. Measurements are done for determining the decay class, density, and volume of deadwood (Herrmann et al. 2024). Small debris is gathered, dried, and weighed to estimate carbon content. Decay measurements provide information on the rate of release of carbon from decomposing wood (Kahl et al. 2015).

2.7.7. Litter: Fallen branches/twigs, Leaf litter, and other organic material on the ground are gathered from subplots, first dried, and then weighed (Harrison 2013). Carbon content is determined in dry weight percentage. Seasonal alternative patterns of litterfall are monitored as well as measured to gain insight about carbon estimate contributed by litter to the soil yearly (Qiu et al. 2023).

2.8. BIBLIOMETRIC ASSESSMENT ON PLANT BIODIVERSITY AND CARBON SEQUESTRATION IN URBAN AND FOREST ECOSYSTEM

Bibliometric analysis provided valuable insight into collaborations among countries, researchers and academic institutions. On assessing the co-authorship patterns and affiliations, this study uncovers the global networks driving research in plant diversity and carbon sequestration. Citation analysis also plays a crucial role, revealing the most influential publications and authors in this field. The approach provides a comprehensive overview of trends in plant diversity and carbon sequestration

research. Further it allows us to track the progressive development in this field as well as provide the opportunity to uncover emerging area of research. Therefore, to gain deep insights and know about recent trend in plant diversity and carbon sequestration studies that data for Scopus database spanning from 2000 to 2024 was taken into consideration.

2.8.1. Search strategy

The bibliometric analysis was done by scrutinizing the articles published in Scopus-indexed journal from January, 2000 to December, 2024. The Scopus database was searched to find all articles related to plant diversity and carbon sequestration in urban and forest ecosystems. The Scopus indexing system was utilized because it enables one to identify and retrieve published articles. Apart from that, it also enables one to export their related bibliographic data. Additionally, for quality assurance, this study only made use of peer-reviewed journal papers (Stasi et al. 2023). The database used to determine relevant papers was Scopus, as it includes a greater volume and varied selection of articles related to plant diversity and carbon sequestration in urban and forest ecosystem compared to PubMed and Web of Science (Boukita et al. 2024). Scopus has also extensively been utilized to conduct bibliometric research on carbon sequestration and plant diversity in these ecosystems (Chàfer et al. 2021; Wang et al. 2023; Boukita et al. 2024). It is a means to evaluate the publishing trends on the subject, an exclusive literature survey was performed targeting research articles reported in peer-reviewed scientific journals only. This would ensure that reliable and high-standard sources were considered for the evaluation. The Scopus database was used because of its enormous collection of abstracts and citations from peer-reviewed publications in different fields and disciplines. On 20 January, 2025, Scopus databased data was retried with the search query "TITLE-ABS-KEY ("plant diversity" OR "carbon sequestration" OR "biodiversity conservation" OR "ecosystem services" OR "urban forestry" AND "forest ecosystems") AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "cp")) AND (LIMIT-TO (LANGUAGE, "English"))" which yield the output with the information of 5141 published articles. The search query was designed using the blend of field qualifiers and boolean operators and. The condition "TITLE-ABS-KEY" in the beginning mandates that the search terms/query must appear in the title, abstract, and keywords of the published articles. The query for

search stated above was designed to focus on topics like “biodiversity conservation”, “carbon sequestration”, “ecosystem services”, “forest ecosystems”, “plant diversity”, and “urban forestry”. These terms were searched using the combination of logical operators (OR and AND) for refining of the results. Further, the document types to articles (“ar”), reviews (“re”), and conference papers (“cp”) were implied in the search query for further refinement. This ensures that the results comprise solely academic articles, reviews, or proceedings for conferences. A language filter was also applied to restrict the search to English-language documents. Lastly, the search is limited to articles published in journals by setting the 'SRCTYPE' parameter to 'j'. The results obtained using this query were exported and scrutinized for duplicates with Mendeley (Version 1.19.8). Only one duplicate entry was found, after removing the duplicate entry a total of 5140 articles were used for further analysis of the data

This study used open-source Biblioshiny (RStudio version 2024.12.0+467), MS Excel and VOSviewer (version 1.6.20) for bibliometric analysis. Biblioshiny facilitates scientific mapping through the Bibliometrix package and VOSviewer software was used for generating interactive visuals based on bibliographic data in a format that are easy to understand. Most common visualizations generated using VOSviewer include bibliographic coupling, co-authorship networks, co-citation relationships, citation patterns and keyword co-occurrence. Further, three-field plot analysis which provide illustration representing the relationship between authors, countries, and sources was generated using Biblioshiny.

2.8.2. Annual distribution and publication pattern

The evaluation of annual publication trends regarding plant biodiversity and carbon sequestration in urban and forest ecosystems offers significant insights about the advancement of research in this field (Figure 2.8). On analyzing, the publication data showed a steady increase in the publications over the years. The first significant rise in publication was accorded in 2000 (19 articles), followed by moderate growth till 2007. However, there has been consistent and significant upsurge in the publications number from 2008 to present. This upward trend demonstrates an exponential growth pattern, with significant surges occurring in the subsequent years. The highest number of publications was recorded in 2021 with 503 articles, showcasing the increased interest and emphasis on plant biodiversity and carbon sequestration research. The following year 2022 and 2023 continued to show significant contributions with 435

and 468 articles published, respectively. Moreover, the year 2024 recorded the count of 560 articles. This persistent growth highlights the increasing global interest on understanding the dynamics of plant diversity and carbon sequestration, especially in urban and forest ecosystems. Furthermore, this upsurge in publications is not signifying the expanding knowledge on the topic but also the growing importance of research in addressing environmental challenges and mitigating climate change.

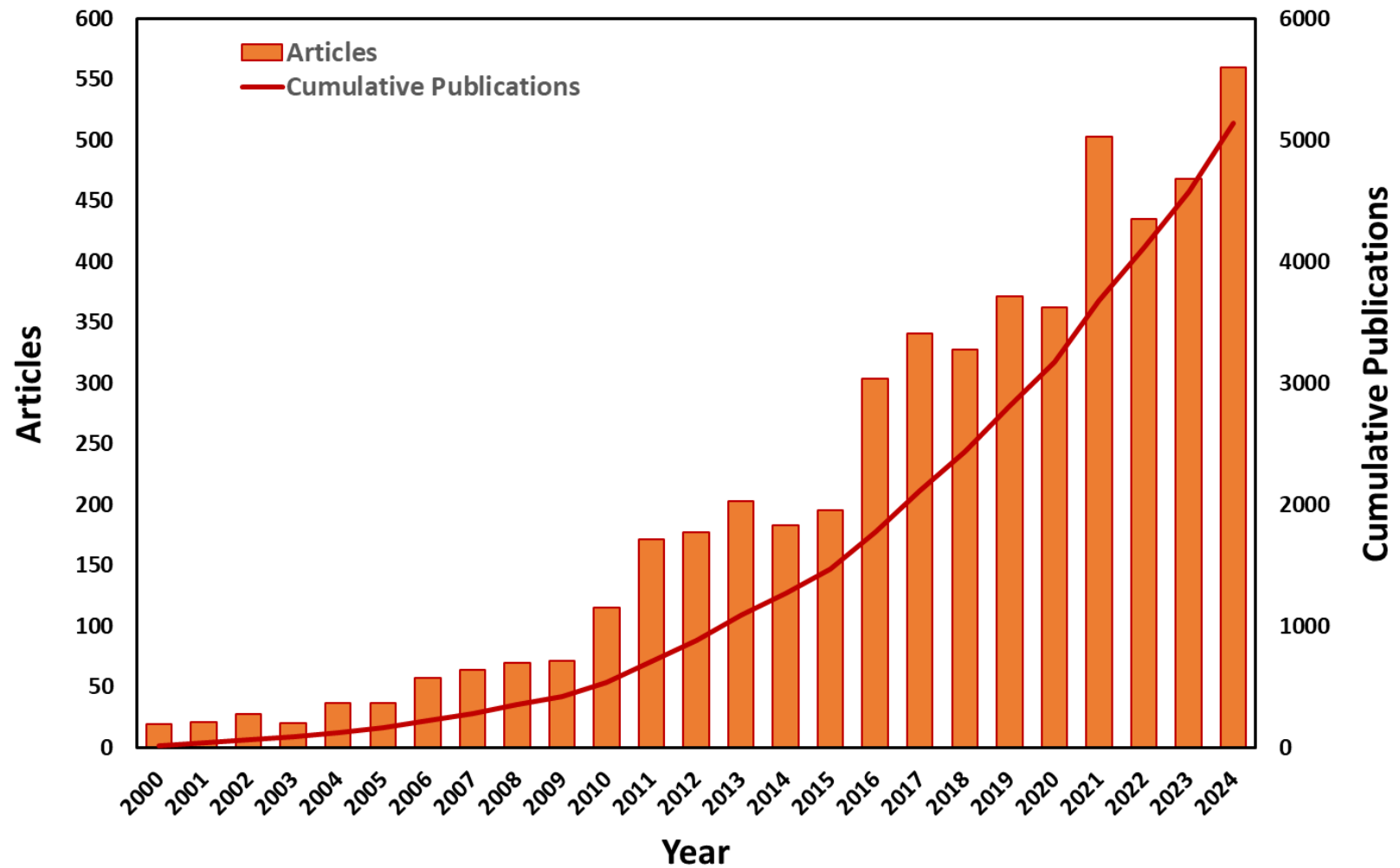


Figure 2.8: Annual Distribution and publication trend on plant biodiversity and carbon sequestration in urban and forest ecosystems. (Source: Scopus Database (Accessed March 2025); Analyzed using MS Excel)

Table 2.2: List of Top countries with ≥ 10 published articles on plant diversity and carbon sequestration in urban and forest ecosystems. The Total Link Strength (TLS) represents the extent of international research collaboration in this field.

Position	Country Name	No. of Documents	Percentage (%) Of Documents	Total Citations	Average Citation	Total Link Strength
1.	United States	1307	15.07	100039	76.54	1606
2.	China	1224	14.12	41265	33.71	807
3.	Germany	524	6.04	21947	41.88	1325
4.	Canada	378	4.36	35310	93.41	679
5.	United Kingdom	315	3.63	29710	94.32	816
6.	Italy	313	3.61	19357	61.84	776
7.	Australia	277	3.19	32339	116.75	647
8.	France	246	2.84	26146	106.28	731
9.	India	242	2.79	5801	23.97	114
10.	Spain	235	2.71	17021	72.43	586
11.	Sweden	223	2.57	15426	69.17	644
12.	Switzerland	221	2.55	18556	83.96	718
13.	Finland	198	2.28	16981	85.76	556
14.	Brazil	189	2.18	10550	55.82	360

15.	Japan	157	1.81	5974	38.05	198
16.	Austria	148	1.71	15096	102.00	538
17.	Netherlands	145	1.67	9038	62.33	603
18.	Belgium	132	1.52	9794	74.20	506
19.	Czech Republic	125	1.44	4274	34.19	426
20.	Poland	103	1.19	2863	27.80	302
21.	Norway	96	1.11	4126	42.98	361
22.	Russian Federation	96	1.11	8529	88.84	211
23.	Indonesia	85	0.98	2367	27.85	140
24.	Mexico	85	0.98	3256	38.31	137
25.	Denmark	78	0.90	6547	83.94	330
26.	Portugal	74	0.85	2546	34.41	225
27.	Turkey	68	0.78	7532	110.76	67
28.	Ethiopia	63	0.73	1617	25.67	68
29.	Malaysia	61	0.70	2776	45.51	95
30.	Iran	58	0.67	550	9.48	56
31.	South Korea	56	0.65	6641	118.59	61
32.	Romania	55	0.63	1053	19.15	161
33.	Slovakia	54	0.62	964	17.85	246

34.	Argentina	51	0.59	7650	150.00	87
35.	Chile	51	0.59	2110	41.37	118
36.	South Africa	50	0.58	2225	44.50	92
37.	Other 37 Countries	887	10.23	37926	1540.14	-
	Total	8670		535902		

2.8.3. Analysis of publication distribution based on article count by country and organization

The total of 8670 publications were collectively published from 74 countries, among which the United States hold the lead position with 1307 (15.07%) publications, followed by China (14.12%) and Germany (6.04%). Beside them, other countries like Canada, United Kingdom also showed the notable contribution with substantial numbers of publication ≥ 300 (Table 2.2 and Figure 2.9). The findings revealed that countries like United States, China and Germany are publishing predominantly, contributing significantly in providing valuable knowledge and insight about this area of research. These countries have not only published good number of articles but have developed strong research collaborations as signified by Total Link Strength (TLS) values. The United States showed the highest value of TLS, i.e., 1606 highlighting its dominant role in global research networks on plant diversity and carbon sequestration. Germany holds the second position as per the TLS value of 1325, whereas, the United Kingdom holds the third position with the TLS value of 816. This information indicates that the large amount of research is being carried out in developed countries, and this emphasizes the importance of cooperation among these nations. Asian nations, especially India, China, and Japan have also contributed a lot to research in this area, emphasizing the role of these nations in research on plant biodiversity and carbon sequestration. India's growing stature in this field can be attributed to its varied ecosystems, including the Himalayas and coastlines, making it a favourable ground for carrying out such research. Additionally, academic quality, governmental programs, and global collaborations have greatly contributed to their output in research, as evident through the growing volume of publications (Bawa et al. 2021; Srivathsa et al. 2023; Baraj et al. 2024).

Moreover, the research explored single-country publications (SCPs) as well as multiple-country publications (MCPs) to assess patterns of collaboration between countries undertaking research on carbon sequestration and plant biodiversity in urban and forest ecosystems (Figure 2.9). As shown in Figure 2.9, China occupies the top rank by the value of SCPs, followed by the United States. China further indicated the maximum MCPs, with significant global cooperation in the sector. India showed preference for SCPs, as compared to MCPs, but value for both SCPs and MCPs were lower than the China, United States and Germany. Notably, countries like Turkey and

Mexico showed lower number of MCPs compared to SCPs on plant biodiversity and carbon sequestration in urban and forest ecosystem (Figure 2.9). Additionally, the most prominent countries working on plant diversity and carbon sequestration are United States, Germany, United Kingdom and China confirmed by global collaboration network and TLS values (Figure 2.10).

As per the data, articles published from the United States has the most citations, i.e., 100309 (average of 76.54). China holds the second position with 41265 citations (average of 33.71) and Germany holds the third position with 21947 citations (average of 41.88). It is interesting to observe that Argentina occupies the 34th position in terms of published articles on carbon sequestration and plant biodiversity in forest and urban ecosystem. Nevertheless, Argentina proved to be a leading player on the basis of average citations with a value of 150. A total of 51 documents have collectively received 7650 citations. Further, South Korea follows with 118.59, Australia with 116.75 and Turkey with 110.76. France holds the fifth position with an average citation of 106.28. In contrast, India has relatively low average citations of 23.97 (Table 2.2).

Further, analysis involves the reviewing of organizations that have contributed at least 7 articles on plant biodiversity and carbon sequestration in urban and forest settings. On evaluation, only 17 organizations fulfilled the criterion of having the ≥ 7 published articles. Within these 17 organizations, only one has contributed over 124 articles, while rest of the organization has the published articles within the range of 35 to 7 (Table 2.3). The study unveiled that University of Chinese Academy of Sciences in Beijing, China has the highest number of published articles, which is 124, followed by Zhejiang A & F University and Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences with 35 and 27 publications, respectively. Notably, the Institute of Botany and the Research Center for Eco-Environmental Sciences stand out in terms of their contributions as it had average citations of 404.89 for 18 articles (7288 citations and 89 TLS). The Cary Institute of Ecosystem Studies, Millbrook, New York, United States hold the second position with an average citation of 367.86 for 7 articles (2575 citations and 1 TLS). Table 2.3 list the top organization with ≥ 7 published articles highlighting their publication and citation counts. Furthermore, to understand the global collaboration network trend of research on plant biodiversity and carbon sequestration research in urban and forest ecosystems, the publication records of countries were reviewed and investigated throughout the defined from 2000 to 2024 (Figure 2.11).

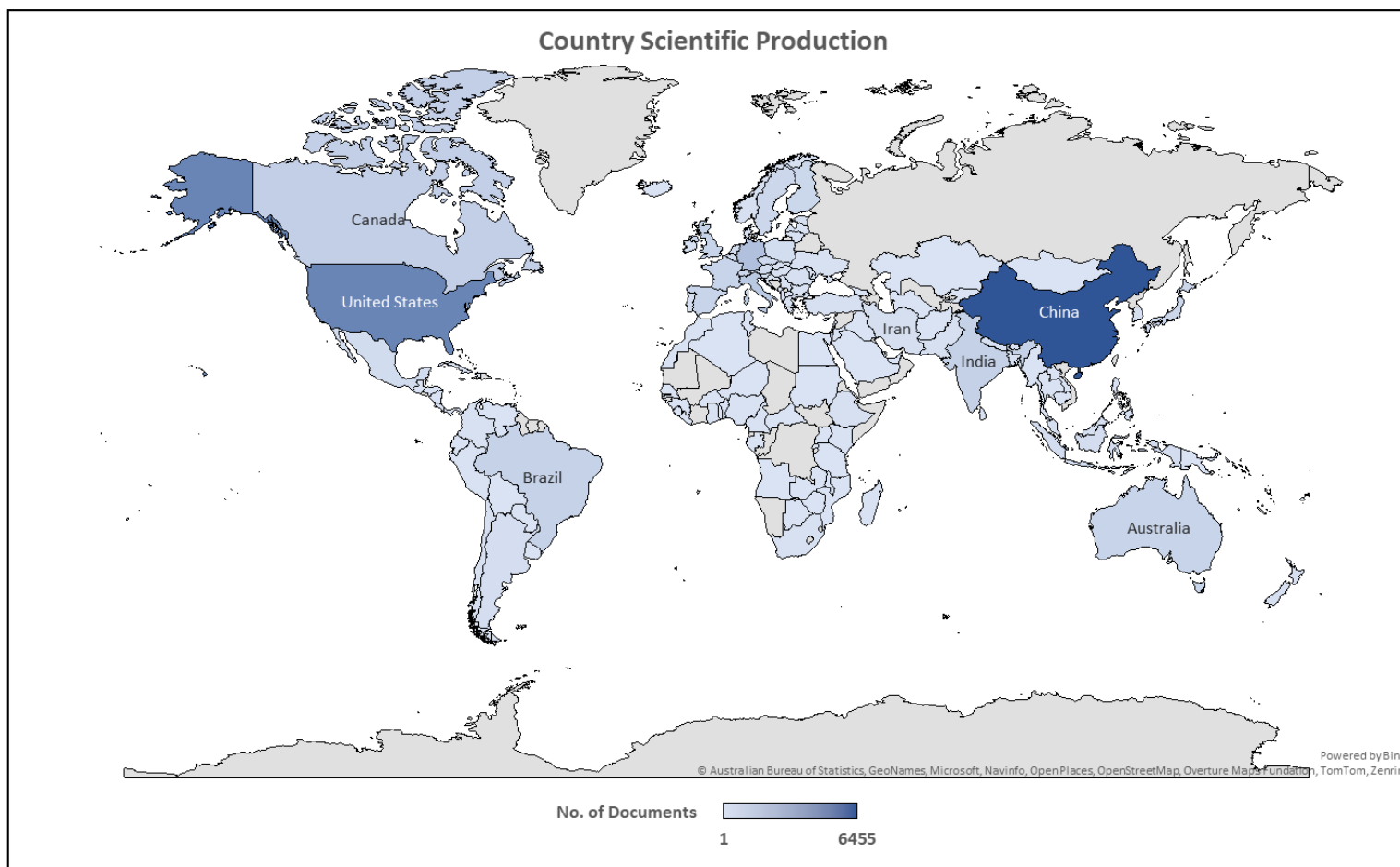


Figure 2.9: Global distribution of research on plant diversity and carbon sequestration in urban and forest ecosystems. The intensity of the blue colour represents the number of publications from each country, where darker shades signify the higher number of publications. (Source: Scopus Database (Accessed March 2025); Analyzed using MS Excel)

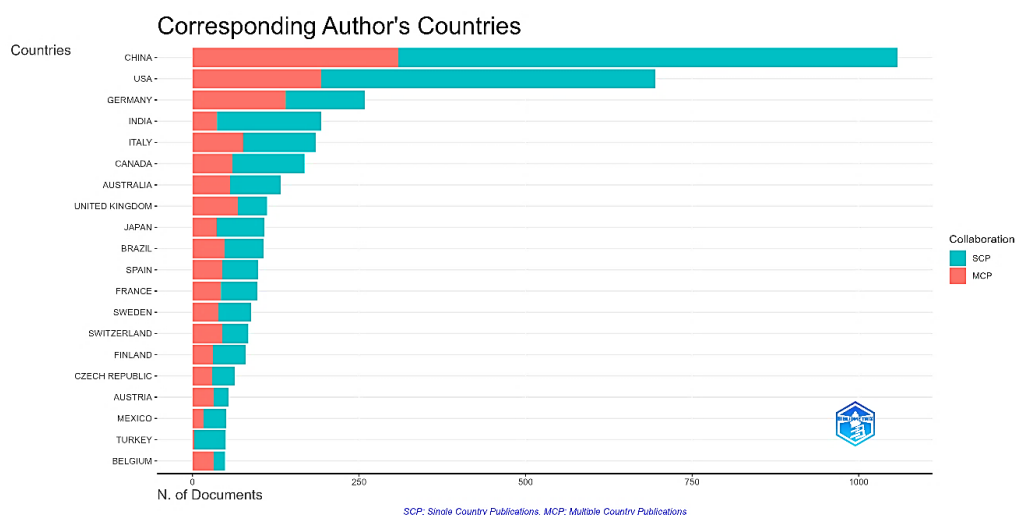


Figure 2.10: Research collaboration across and within countries assessed using MCP and SCP indicators. MCP represents international collaborations, whereas SCP represents studies conducted within a single country. Countries are classified based on the corresponding author's affiliation. (Source: Scopus Database (Accessed March 2025); Analyzed using Biblioshiny (RStudio v2024.12.0+467))

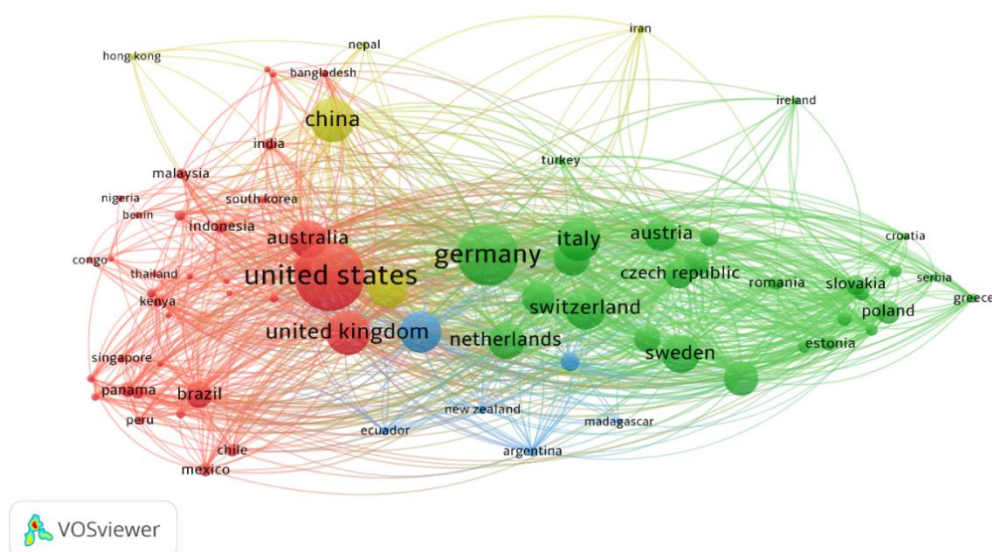


Figure 2.11: Global collaboration network on research related to plant diversity, carbon sequestration in urban and forest ecosystems (including only countries with ≥ 10 publications). Distinct colours indicate clusters of closely connected countries where each country belongs to a single cluster highlighting their collaboration patterns. The line represents research collaborations strength, where, distance between them signifies level of kinship (Source: Scopus Database (Accessed March 2025); Analyzed using VOSviewer (v1.6.20))

Table 2.3: List of top organizations with ≥ 7 published articles related to plant diversity and carbon sequestration in urban and forest ecosystems

Position	Name of the Organization	No. of Documents	Total Citations	Average Citations	Total Link Strength
1.	University of Chinese Academy of Sciences, Shijingshan, Beijing, China	124	3383	27.28	83
2.	Zhejiang A & F University, Hangzhou, Zhejiang, China	35	740	21.14	9
3.	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Andingmen Wai, Beijing, China	27	891	33.00	25
4.	Beijing Forestry University, Haidian, Beijing, China	24	312	13.00	29
5.	Institute of Botany, Chinese Academy of Sciences, Haidian, Beijing, China	18	7288	404.89	89
6.	Institute of Applied Ecology, Chinese Academy of Sciences, Shenhe, Shenyang, China	17	522	30.71	9
7.	Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Haidian, Beijing, China	26	691	57.03	19

8.	German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Puschstraße 4, Leipzig, Germany	10	702	70.20	1
9.	Key Laboratory of Vegetation Restoration and Management of Degraded Ecosystems, South China Botanical Garden, Chinese Academy of Sciences, Tianhe, Guangzhou, China	10	301	30.10	5
10.	Beijing Normal University, Haidian, Beijing, China	9	199	22.11	5
11.	Nanjing Forestry University, Nanjing, Jiangsu, China	9	304	33.78	8
12.	Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Zürcherstrasse, Birmensdorf, Switzerland	9	312	34.67	2
13.	Research Institute of Tropical Forestry, Chinese Academy of Forestry, Guangzhou, Guangdong China	8	118	14.75	3
14.	Cary Institute of Ecosystem Studies, Millbrook, New York, United States	7	2575	367.86	1
15.	North Carolina State University, Raleigh, North Carolina, United States	7	235	33.57	1
16.	University of Maryland, College Park, Maryland, United States	7	111	15.86	2
17.	University of Minnesota, Minneapolis, Minnesota, United States	7	339	48.43	1

2.8.4. Author and co-author relationship

The authors with highest number of publications on plant biodiversity and carbon sequestration in urban and forest ecosystems were selected by analyzing both the publications number and citations count. Among 16213 authors, only 37 published ≥ 25 articles on plant biodiversity and carbon sequestration in urban and forest ecosystems. As per the data, both Zhang Y. and Wang Y. are the dominant researchers in the field of plant biodiversity and carbon sequestration with each having 70 articles with total number of citations of 1337 and 1198, respectively. Li X. holds the third position with 63 articles with total number of citations of 1085. The authors Wang X., Liu Y., Liu S., and Li Y. also contributed significantly with each author having published articles more than 50 with total number of citations of 1299, 1502, 1266 and 872 respectively (Table 2.4). Zhang Z. has published 31 articles which placed him at the 20th position based on number of published articles. However, Zhang Z. has the highest average citation count of 198.97, positioning him at the top based on the citation impact as of 2024. Seidl R. with 33 published articles holds the 18th position and holds the second position with 3623 citations, which results in average citations of 109.79 and TLS value of 0 (Table 2.4).

Furthermore, to understand the global evolution of plant biodiversity and carbon sequestration research in urban and forest ecosystems, the publication records of authors were reviewed and investigated throughout the defined from 2000 to 2024 (Figure 2.12). The Wang Y. was determined to be the leading author in the field plant biodiversity and carbon sequestration as he has contributed the highest number of publications during the period of 2000 to 2024, i.e., 70 from 2006 to 2024. Whereas, Zhang Y. was reported to be significant contributor as 20 articles was published by him in 2024. Authors like Liu J. and Liu Y. show consistent involvement in the field of plant biodiversity and carbon sequestration in urban and forest ecosystem but their citation impact is comparatively lower in comparison to other others. The correlation among the publication number and citation impact makes it clear that Wang Y. and Zhang Y. are the leading authors based on the both, which signifies that they are significant contributors in the field. Overall, this data highlights that consistent publication over time can result in higher citation impact, underscoring the significance of both article production and citations in academic recognition.

Using the TLS metric (Table3) as provided by VOSviewer, the level of author collaboration was evaluated and depicted as network collaboration in Figure 2.13. The result of the study revealed that Li X. has the highest TLS value of 109, followed by Zhou G. and Liu Y with TLS value of 94 and 80 respectively. Moreover, Wang X., Liu S., and Li Y. showed the similar value of 74 for TLS. Additionally, Zhou, G. hold the 11th position based on the published articles but based on the TLS value it stood at third position in top 5 researchers. This suggests that these authors are eminent researchers in the field of plant biodiversity and carbon sequestration research and demonstrate impressive networking and collaboration abilities.

Table 2.4: List of leading authors with ≥ 25 published articles related to plant diversity and carbon sequestration in urban and forest ecosystems. The Total link strength shown in the table represents the cumulative strength of a researcher's collaborative associations with other peers in the domain of plant diversity and carbon sequestration in urban and forest ecosystems

Position	Name of Author	No. of Articles	Total Citations	Average Citation	Total Link Strength
1.	Zhang, Y.	70	1337	19.1	72
2.	Wang, Y.	70	1198	17.11	63
3.	Li, X.	63	1085	17.22	109
4.	Wang, X.	58	1299	22.4	74
5.	Liu, Y.	55	1502	27.31	80
6.	Liu, S.	55	1266	23.02	74
7.	Li, Y.	52	872	16.77	74
8.	Li, J.	48	844	17.58	60
9.	Liu, J.	45	1152	25.6	47
10.	Wang, Z.	42	531	12.64	49

11.	Zhou, G.	41	1328	32.39	94
12.	Zhang, X.	40	953	23.83	42
13.	Wang, J.	39	944	24.21	49
14.	Zhang, J.	39	847	21.72	37
15.	Zhang, L.	39	658	16.87	59
16.	Liu, X.	38	795	20.92	52
17.	Zhou, Y.	34	744	21.88	50
18.	Seidl, R.	33	3623	109.79	0
19.	Yang, Y.	33	747	22.64	23
20.	Zhang, Z.	31	6168	198.97	35
21.	Wang, H.	31	825	26.61	47
22.	Chen, J.	31	686	22.13	35
23.	Wang, S.	30	1180	39.33	44
24.	Wang, Q.	30	1003	33.43	31
25.	Wang, W.	30	808	26.93	32
26.	Li, Z.	30	493	16.43	33
27.	Chen, L.	29	827	28.52	34
28.	Zhang, Q.	29	596	20.55	51
29.	Huang, Z.	29	528	18.21	53
30.	Chen, Y.	28	609	21.75	35
31.	Du, H.	28	593	21.18	63

32.	Wu, J.	27	808	29.93	31
33.	Zhang, H.	27	405	15	22
34.	Xu, L.	26	836	32.15	42
35.	Li, S.	26	692	26.62	21
36.	Zhu, J.	26	613	23.58	23
37.	Wang, C.	25	847	33.88	26

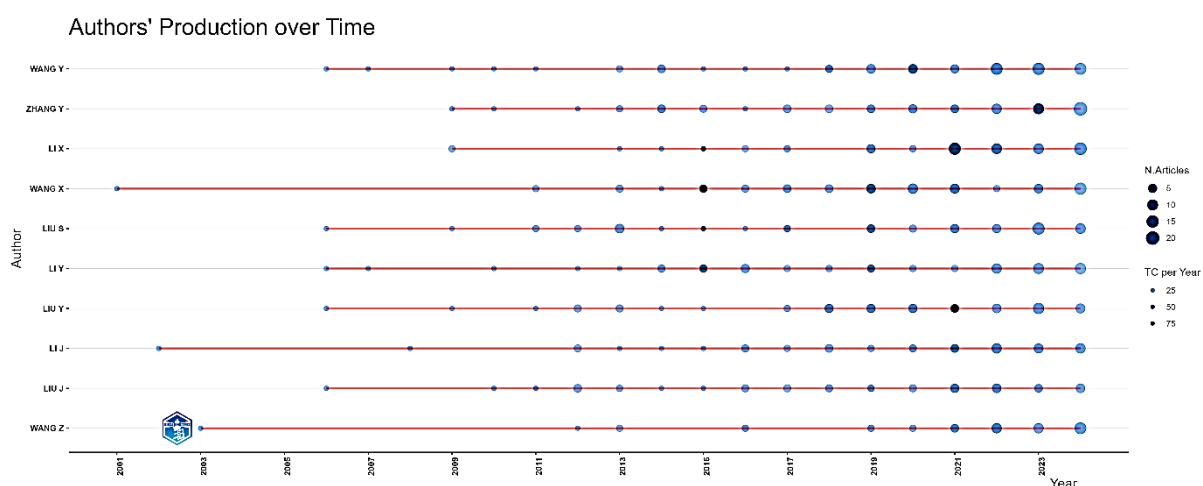


Figure 2.12: The scholarly impact of the top 10 authors across different years is shown by red lines. The dot size signifies the publication count per year, while the gradient colour of the dot (light to dark) represents the total citations per year (TC). (Source: Scopus Database (Accessed March 2025); Analyzed using Biblioshiny (RStudio v2024.12.0+467))

Change Biology (8543 citations) and Ecological Applications (4832) holds the 2nd and 3rd position respectively. This data suggests that no single publisher holds a dominant position in publishing research on plant diversity and carbon sequestration in urban and forest ecosystems. This may be due to the interdisciplinary nature of the field which integrates ecology, forestry, environmental science, and sustainability. Researchers appear to select journals based on their specific area of expertise rather than a specific publisher. Among the enlisted journals, Global Change Biology (impact factor 10.8) and Science of the Total Environment (impact factor 8.2) holds the 1st and 2nd positions based on the impact factor. Other journals in this domain are represented by renowned publishers like Elsevier, Springer, MDPI, and Wiley-Blackwell.

Table 2.5: List of Top 30 journals with highest number of articles on plant diversity and carbon sequestration in urban and forest ecosystems from 2000 to 2024

Position	Name of the Journal	Publishing House	Journal Impact Factor (2023)	No. of Articles	Total Citations	Average Citation
1.	Forest Ecology and Management	Elsevier	3.7	435	24430	56.16
2.	Forests	MDPI	2.4	334	3916	11.72
3.	Ecological Indicators	Elsevier	7.0	121	3629	29.99
4.	Sustainability (Switzerland)	MDPI	3.3	119	1394	11.71
5.	Science of the Total Environment	Elsevier	8.2	97	2283	23.54

6.	Global Change Biology	Wiley- Blackwell	10.8	78	8543	109.53
7.	Journal of Environmental Management	Elsevier	8.0	74	1834	24.78
8.	Ecosystem Services	Elsevier	6.1	68	3007	44.22
9.	Journal of Forestry Research	Springer	3.4	61	1030	16.89
10.	Environmental Research Letters	IOP Publishing	5.8	57	1538	26.98
11.	Biodiversity and Conservation	Springer	3.0	55	2334	42.44
12.	Agricultural and Forest Meteorology	Elsevier	5.6	54	2258	41.81
13.	Ecological Applications	Wiley- Blackwell	4.3	52	4832	92.92
14.	Forest Policy And Economics	Elsevier	4.0	50	1293	25.86
15.	European Journal of Forest Research	Springer	2.6	49	1301	26.55
16.	Canadian	Canadian	1.7	48	944	19.67

	Journal of Forest Research	Science Publishing				
17.	Shengtai Xuebao/ Acta Ecologica Sinica	Elsevier	-	45	506	11.24
18.	Urban Forestry and Urban Greening	Elsevier	6.0	45	2060	45.78
19.	Ecological Economics	Elsevier	6.6	44	1542	35.05
20.	Remote Sensing	MDPI	4.2	44	980	22.27
21.	Journal of Applied Ecology	Wiley- Blackwell	5.0	42	2839	67.60
22.	Plos One	PLOS	2.9	41	1102	26.88
23.	Land Use Policy	Elsevier	6.0	40	1431	35.78
24.	Biological Conservation	Elsevier	4.9	39	2419	62.03
25.	Frontiers in Forests and Global Change	Frontiers	2.7	38	346	9.11
26.	Annals of Forest Science	Springer	2.5	37	996	26.92

27.	Biogeosciences	Copernicus Publications, European Geosciences Union	3.9	36	2066	57.39
28.	Ecological Modelling	Elsevier	2.6	36	1083	30.08
29.	Environmental Monitoring and Assessment	Springer	2.9	33	528	16.00
30.	Catena	Elsevier	5.4	32	1041	32.53

2.8.6. Document and citation relationship

The quality and influence of published article depend on the linkage between journal articles and their citation counts. A higher citation count for an article signifies its recognition and influence within the scientific community. In this study, articles a minimum of 400 citations were considered and the result showed that out of 5140 articles only 41 met this criterion. According to the data, the article published in Science by Hansen et al. (2013) had the highest citations count, totalling to 8110 citations as of 2024 (**Table 2.6**). This study used Earth observation satellite data from 2000 to 2012 to quantify global forest change at a 30-meter resolution. The result from the study unveiled about the 2.3 million km² of forest loss and 0.8 million km² of forest gain. The tropics showed an increasing deforestation trend, while reductions in Brazil were offset by losses in Indonesia, Malaysia, Paraguay, Bolivia, Zambia, Angola, and other regions. Further, the subtropical areas also showed the highest change due to intensive forestry, whereas, boreal forest loss driven by fire and forestry ranked second. The study provides a consistent global record of forest change (Hansen et al. 2013).

The citation count of the published article signifies how frequently the article has been referred and used by researchers in their work. A higher citation counts generally

signifies the impact of the article on the scientific community working in the same field and highlights the significance of the research. Additionally, it highlights the relevance and growing interest in a research field, as areas with high citation tend to attract more publications and scholarly attention. Nevertheless, citation count solely should not be considered as the decisive metric for the selection of prominent publication in the field, as numerous other factors influence the overall impact and visibility (Wang 2013; Wani et al. 2023). The article published by Pan et al (2011) in *Science* and Allen et al (2010) in *Forest Ecology and Management* hold the 2nd and 3rd position due to the highest citation count of 5885 and 5795 respectively (Allen et al. 2010; Pan et al. 2011). Out of top 30 articles related to plant diversity and carbon sequestration in urban and forest ecosystems, only 8 articles were determined to have ≥ 1000 citations (Table 2.6).

Table 2.6: List of Top 30 articles with the highest number of citations on plant diversity and carbon sequestration in urban and forest ecosystems from 2000 to 2024

Position	Title of the Article	Name of the Journal	Total Citations	Average Citations per Year	References
1.	High-Resolution Global Maps of 21st-Century Forest Cover Change	Science	8110	623.85	(Hansen et al. 2013)
2.	A Large and Persistent Carbon Sink in the World's Forests	Science	5885	392.33	(Pan et al. 2011)
3.	A global overview of	Forest Ecology and	5795	362.19	(Allen et al. 2010)

	drought and heat-induced tree mortality reveals emerging climate change risks for forests	Management			
4.	A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO ₂	Frontiers in Ecology and the Environment	2518	167.87	(McLeod et al. 2011)
5.	Climate Change and Forests of the Future: Managing in the Face of Uncertainty	Ecological Applications	1509	79.42	(Millar et al. 2007)
6.	Widespread Increase of Tree Mortality Rates in the Western United States	Science	1377	81	(Mantgem et al. 2009)
7.	Carbon Cycling and Storage in Mangrove Forests	Annual Review of Marine Science	1116	93	(Alongi 2014)

8.	Forest soils and carbon sequestration	Forest Ecology and Management	1114	53.05	(Lal 2005)
9.	Soil fertility limits carbon sequestration by forest ecosystems in a CO ₂ -enriched atmosphere	Nature	908	36.32	(Oren et al. 2001)
10.	Negative plant–soil feedback predicts tree-species relative abundance in a tropical forest	Nature	846	52.88	(Mangan et al. 2010)
11.	Urban forests and pollution mitigation: Analyzing ecosystem services and disservices	Environmental Pollution	843	56.2	(Escobedo et al. 2011)
12.	Long-term decline of the Amazon carbon sink	Nature	821	74.64	(Brienen et al. 2015)
13.	Carbon cycling and storage in world forests:	Global Change Biology	797	36.23	(Pregitzer and Euskirchen 2004)

	biome patterns related to forest age				
14.	The exceptional value of intact forest ecosystems	Nature Ecology and Evolution	778	97.25	(Watson et al. 2018)
15.	Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation	Nature	753	75.3	(Barlow et al. 2016)
16.	Botryosphaeriaceae as endophytes and latent pathogens of woody plants: diversity, ecology and impact	Fungal Biology Reviews	751	39.53	(Slippers and Wingfield 2007)
17.	Indicators of Biodiversity for Ecologically Sustainable Forest Management	Conservation Biology	731	28.12	(Lindenmayer et al. 2000)
18.	Re-evaluation of forest biomass	Proceedings of the	701	41.24	(Keith et al. 2009)

	carbon stocks and lessons from the world's most carbon-dense forests	National Academy of Sciences of the United States of America			
19.	Tree and forest effects on air quality and human health in the United States	Environmental Pollution	687	57.25	(Nowak et al. 2014)
20.	How tree roots respond to drought	Frontiers in Plant Science	605	55	(Brunner et al. 2015)
21.	Restoring natural forests is the best way to remove atmospheric carbon	Nature	570	81.43	(Lewis et al. 2019)
22.	The likely impact of elevated [CO ₂], nitrogen deposition, increased temperature and management on carbon sequestration in temperate and boreal forest ecosystems: a literature review	New Phytologist	562	29.58	(Hyvönen et al. 2007)

23.	Natural disturbance impacts on ecosystem services and biodiversity in temperate and boreal forests	Biological Reviews	559	55.9	(Thom and Seidl 2016)
24.	Does plantation forestry restore biodiversity or create green deserts? A synthesis of the effects of land-use transitions on plant species richness	Biodiversity and Conservation	505	31.56	(Bremer and Farley 2010)
25.	Forest Soil Bacteria: Diversity, Involvement in Ecosystem Processes, and Response to Global Change	Microbiology and Molecular Biology Reviews	494	54.89	(Salvador et al. 2017)
26.	CTFS-ForestGEO: a worldwide network monitoring forests in an era of global change	Global Change Biology	493	44.82	(Anderson-Teixeira et al. 2015)

27.	Forest microclimates and climate change: Importance, drivers and future research agenda	Global Change Biology	485	97	(De Frenne et al. 2021)
28.	Winter forest soil respiration controlled by climate and microbial community composition	Nature	471	23.55	(Monson et al. 2006)
29.	Limited carbon storage in soil and litter of experimental forest plots under increased atmospheric CO ₂	Nature	458	18.32	(Schlesinger and Lichter 2001)
30.	Leaf-out phenology of temperate woody plants: from trees to ecosystems	New Phytologist	457	30.47	(Polgar and Primack 2011)

2.8.7. Co-occurrence of author keywords

For mapping of prominent research themes and trends, the keyword co-occurrence was analyzed to gain insight about the temporal variations in academic focus (Narong and Hallinger 2023; Wani et al. 2023; Giwa et al. 2023). Keywords play a fundamental role in research articles as they highlight core topics and improve discoverability in academic databases. They also enable researchers in finding and identifying relevant studies for literature reviews and enhance the impact and overall visibility of published research (Narong and Hallinger 2023; Wani et al. 2023). Therefore, the selection of right keywords expands the reach of research, improves citation frequency and strengthens its recognition within the research community (Choi et al. 2011).

This study involved the assessment and determination of the keywords that occurred at least 250 times. Of the 14789 keywords, merely 40 met this criterion. The predominant keyword was "forest ecosystem" (3,322 occurrences), followed by "forestry" (2368 occurrences), "ecosystems" (2309 occurrences), "carbon sequestration" (2055 occurrences), biodiversity (1929 occurrences) and climate change (1538 occurrences). These results reveal a growing focus or interest of studies on forest ecosystems, carbon storage, and biodiversity conservation (Figure 2.14). Additionally, network visualization with VOSviewer uncovered significant interconnections among research keywords. Keywords like 'biodiversity', 'climate change', 'ecosystem services', and 'forest management' as emerging core topics in ongoing studies (Figure 2.15). The trends identified in this study reveals about the increased focus on afforestation, carbon sequestration, and sustainable forest management for mitigating the climate change (Gupta et al. 2024; Baskent et al. 2025; Sevillano et al. 2025). The connections among keywords highlight an evolving interdisciplinary framework that integrates ecology, environmental sciences and forestry. By understanding these key research areas, future studies can be refined that will allow the researchers to identify well-established topics and address the existing gaps. Emerging topics like conservation strategies, remote sensing applications, and urban forests offers promising opportunities for further exploration. Additionally, investigating underexplored areas involving how ecosystem services can serve as tool for mitigating climate change which could provide deeper insight into forest-based carbon sequestration and biodiversity conservation.

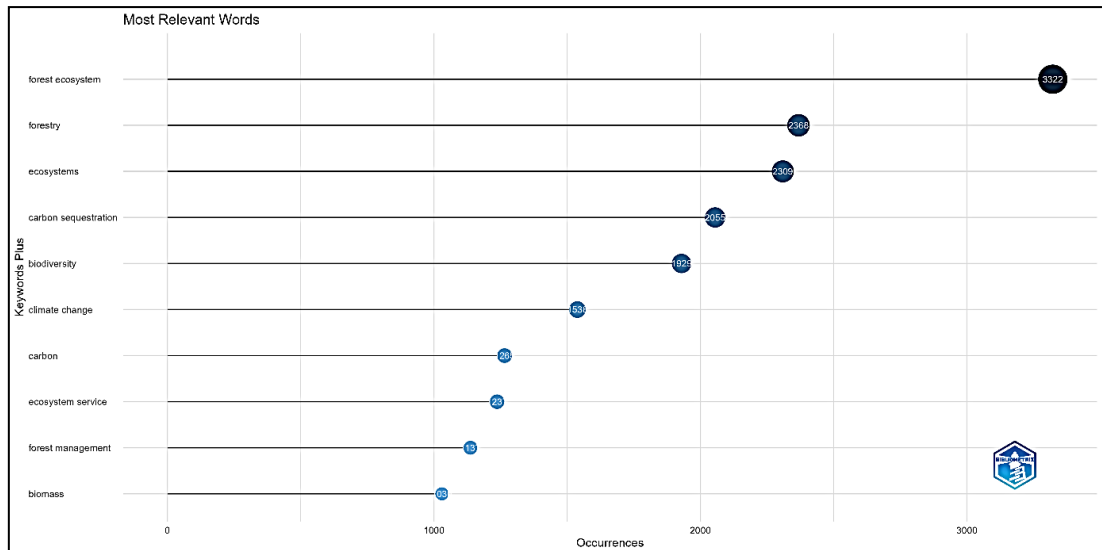


Figure 2.14: Graphical representation of highly recurring keywords on plant diversity and carbon sequestration within urban and forest ecosystems based on their occurrence. (Source: Scopus Database (Accessed March 2025); Analyzed using Biblioshiny (RStudio v2024.12.0+467))

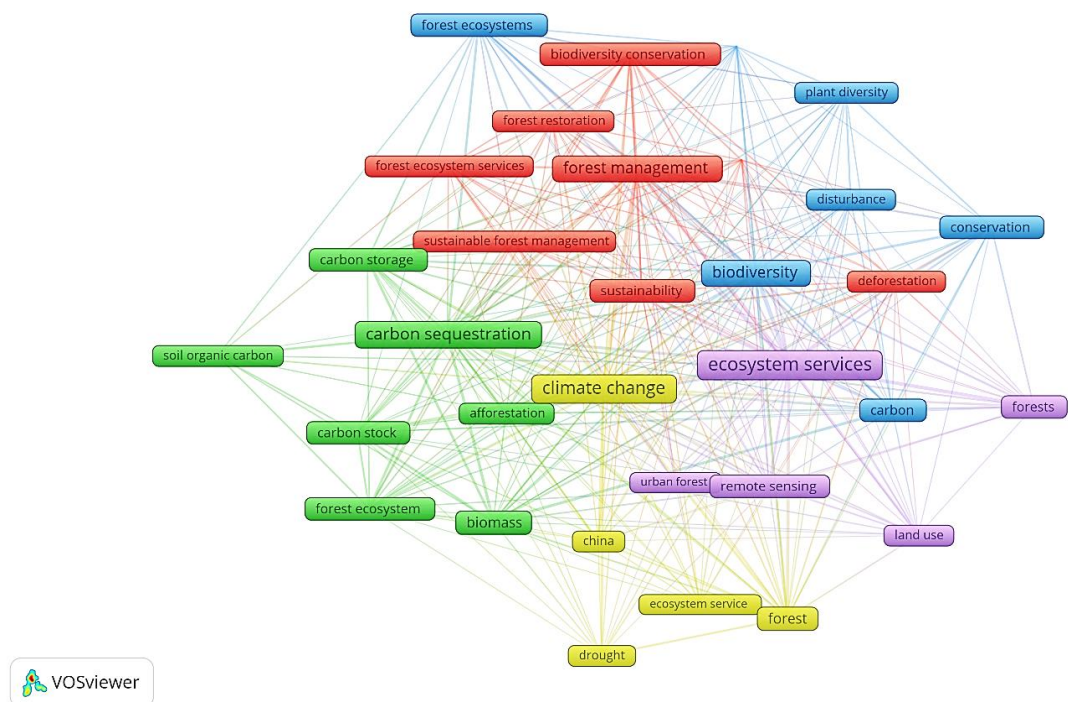


Figure 2.15: Keywords Network visualization (keywords with ≥ 50 occurrences were taken into consideration). Discrete colours represent the closely connected clusters of keywords where each keyword is allotted to a single cluster on the basis of research collaborations. The line connecting the keywords represent research collaborations strength, where distance between them signifies the

relatedness based on thematic focus. (Source: Scopus Database (Accessed March 2025); Analyzed using VOSviewer (v1.6.20))

2.9 Relevance of Reviewed Literature to the Present Study

The bibliometric analysis indicated that the research on plant biodiversity and carbon sequestration has increased significantly in the recent years globally. It covers different ecosystems and is focused on aspects such as biodiversity conservation and carbon storage. Numerous studies have been carried out in India, but they are mostly limited to specific regions and does not cover all ecological zones in a balanced manner. In Haryana, studies linking plant diversity with carbon sequestration are relatively few, and in Sirsa district such work has not been explored in detail in either forest or urban ecosystems together. Due to this lack of region-specific and integrated information, Sirsa district, Haryana, was selected for the present study.

2.10 Research Gap

From the available literature it became evident that a considerable amount of work has been done on biodiversity as well as carbon sequestration though most of these studies have treated the two aspects separately. Very few studies have aimed to examine plant diversity and carbon sequestration together in a combined manner. In addition, much of the work has been carried out in well-studied forest regions, while other areas have not been explored to the same extent. In Haryana, and particularly in Sirsa district, such studies are limited and not available in sufficient detail for both urban and forest ecosystems. Because of this, there is a lack of clear understanding of how plant diversity contributes to carbon sequestration under local conditions. Therefore, the present study has been undertaken to address this gap by analysing plant diversity and carbon sequestration together in both urban and forest ecosystems of Sirsa district.

2.11. Hypothesis of the Study

The Sirsa district of Haryana represents an underexplored urban-forest area for understanding the interplay between plant biodiversity and carbon sequestration. In general, Sirsa is a semi-arid region blended with agricultural areas, urban area and fragmented forest. Due to urbanization, Sirsa is facing severe challenges like

biodiversity loss, habitat degradation, urban heat island effect and increased vulnerability to climate change impacts.

Given the ecological significance of plant diversity and carbon sequestration, it was hypothesized that the urban and forest ecosystems of Sirsa, Haryana harbours different species of plant and has distinct carbon sequestration potentials due to variations in human activities and environmental conditions. The primary hypothesis was to evaluate and compare diversity and carbon sequestration potential of these two ecosystems to understand their role in ecological stability at regional and global level. Further, it was predicted that forest ecosystems which are characterized for their dense vegetation and minimal human intervention will demonstrate high diversity and carbon sequestration potential in contrast to urban ecosystems, which are fragmented and heavily influenced by anthropogenic activities. Further, the study involves the assessment of biomass, carbon content of the soil and biodiversity indices to gain deep insight about ecological factors influencing plant diversity and carbon storage in these environments. Through these hypotheses, the research aims to contribute to sustainable land use practices and inform conservation strategies personalized to semi-arid regions like Sirsa. Additionally, it seeks to integrate local initiatives with global environmental goals to reinforce climate stability and ecological resilience.

CHAPTER 3

AIMS AND OBJECTIVES

Studies regarding plant biodiversity and carbon sequestration potential are scarce in India, particularly in the Sirsa district of Haryana. This study tries to bridge this research gap. The ever-increasing concentration of greenhouse gases such as carbon dioxide in the atmosphere creates an urgent need for evaluation of carbon sinks in the region of Sirsa. The study also aimed to evaluate plant diversity and the function it carries in reducing carbon emissions thus enhancing the understanding of ecological sustainability and climate change mitigation measures in this region. The study's aims are as follows:

- 1) The analyse the plant biodiversity patterns in urban and forest vegetation of Sirsa district.
- 2) To assess the carbon sequestration potential of tree biomass.
- 3) To evaluate the soil carbon sequestration potential.

CHAPTER 4

MATERIALS AND METHODS

The study entitled “Assessment of Plant Diversity and Carbon Sequestration Potential of Urban and Forest Vegetation in Sirsa, Haryana’ was conducted during 2020 to 2024. Extensive systematic field survey was done for the quantification of plant diversity, biomass, and carbon storage across urban and forest landscapes in Sirsa, Haryana. The comprehensive analysis of ecological parameters was aimed to provide a deeper understanding of biodiversity patterns and carbon sequestration potential of this region (Liang et al. 2016; Buotte et al. 2020). The following sections provides a detail information about the material used and methodology employed to achieve the objectives of our study under the following heading:

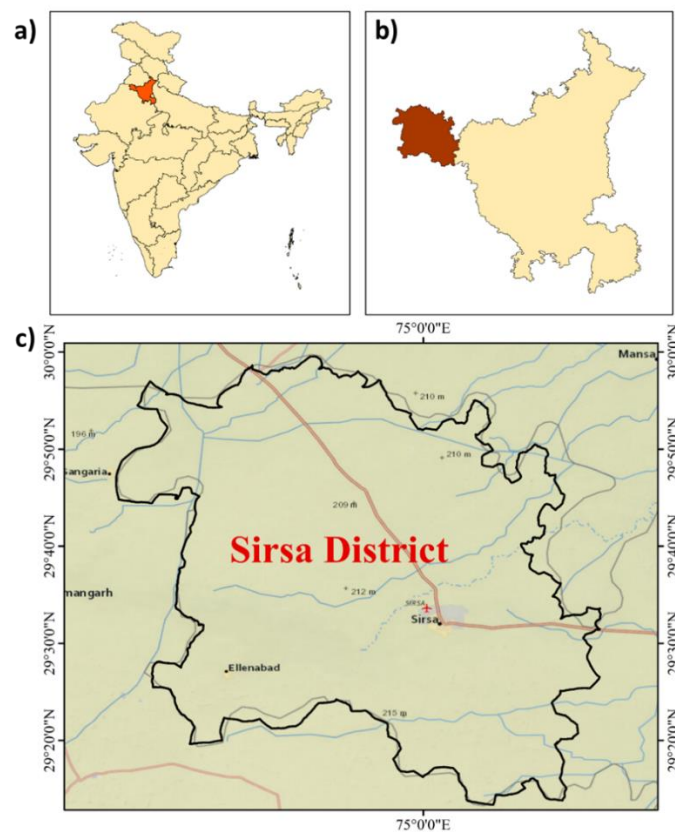


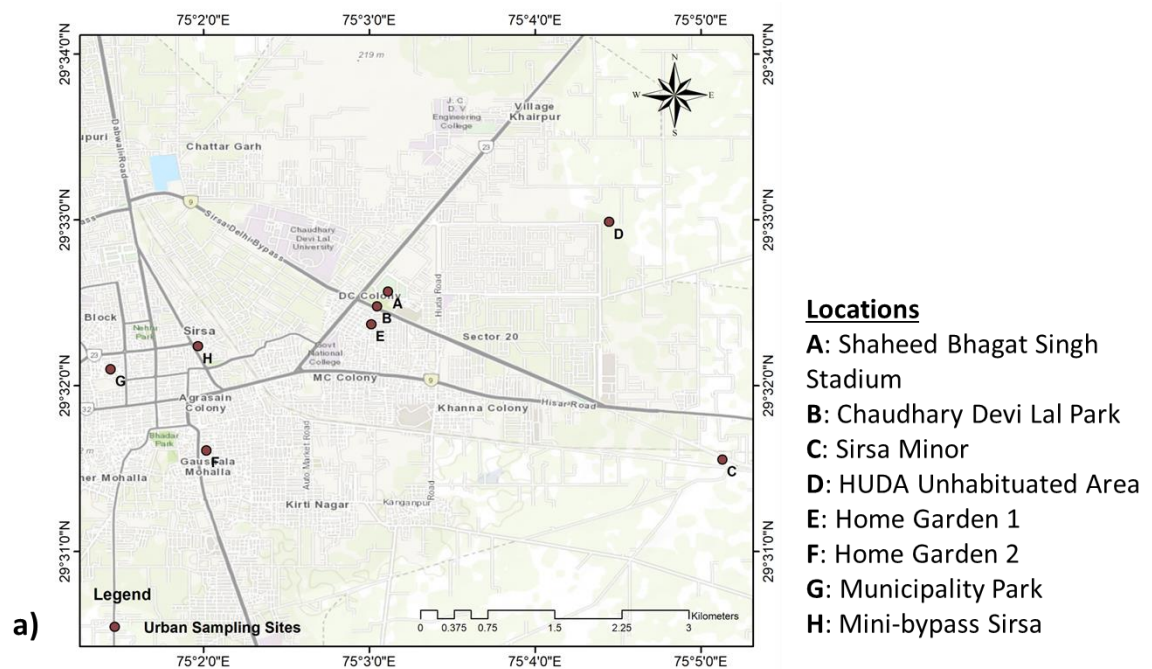
Figure 4.1: Geographical Depiction of a) India highlighting Haryana, b) Haryana highlighting Sirsa, and c) boundaries of District Sirsa, Haryana

4.1. STUDY AREA

Sirsa is a district located on the northwestern region of Haryana, India (Figure 4.1). This district is bordered by Hisar division from the east side, Fatehabad from the

north side, and Rajasthan from the west and south side. Geographically the coordinates of Sirsa district ranges from 29° 14' to 29° 59' N latitudes and 74° 27' to 75° 18'E longitudes and is covering an area of approximately 4,277 km². The physical terrain of this district can be categorized into three distinct regions i.e., (1) the Haryana Plain, (2) the Ghaggar/Nali Alluvial bed, and (3) the sand dune tract. These landforms are largely influenced by the seasonal flow of the Ghaggar River and its tributaries (Satyawar et al. 2014). The district Sirsa experiences a semi-arid climatic condition characterized by an average annual rainfall of 186.3 mm and temperatures ranging from 27°C to 48°C. The flat topography of this district is accompanied by interspersed sand dunes which result in the formation of varied habitat that foster variety of vegetation (Singh and Pawariya 2021).

The urban and forest ecosystems of this district provide a valuable setting for quantifying plant biodiversity and carbon sequestration potential (Central Ground Water Board 2013; Singh et al. 2016). The key sites in current study included both Urban and Forest Areas. Urban areas encompass Shaheed Bhagat Singh Stadium, Chaudhary Devi Lal Park, Sirsa Minor, Municipality Park, HUDA Unhabitated Area, and Home Gardens (1 and 2) and Mini-bypass Sirsa. Whereas, the forest areas encompass Abub Sheher Wildlife Sanctuary, Chaharwala Minor, Daulatpur Khera, Mameran Road, Mangiana Village, Nagoki Canal, Ottu Head, and Panjuana Canal (Figure 4.2).



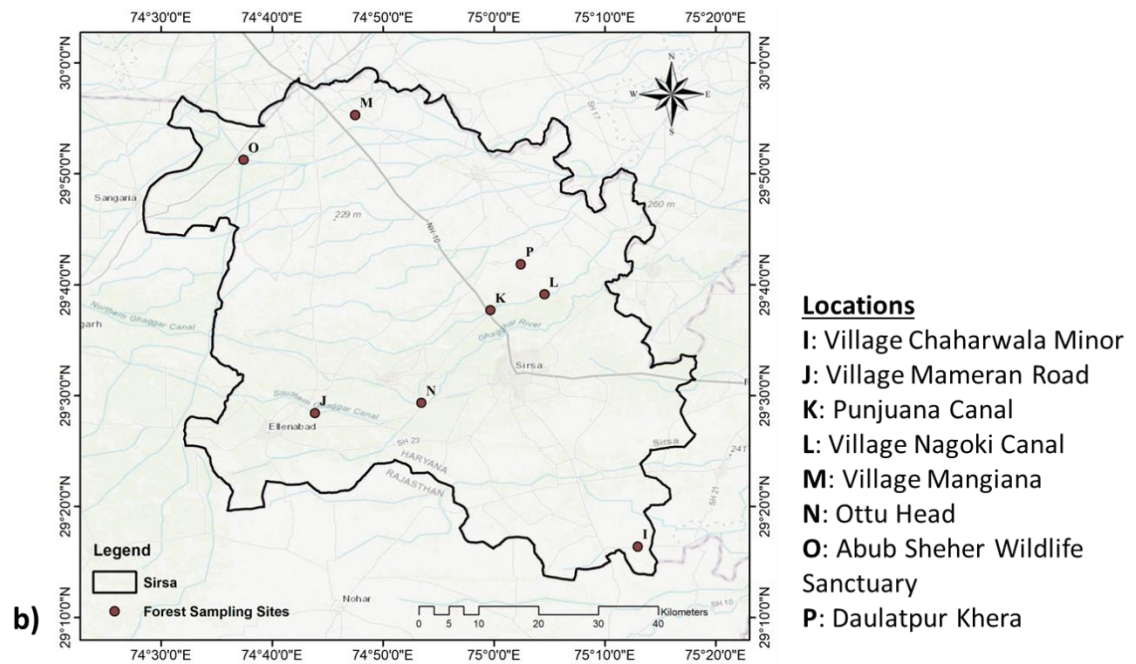


Figure 4.2: Geo-location of urban and forest sampling sites in Sirsa district. a) Sampling locations within Sirsa city representing urban area; b) Sampling locations in rural and forested regions of Sirsa district

4.2. METHODOLOGY FOR ASSESSMENT OF PLANT DIVERSITY (OBJECTIVE 1)

For achieving Objective 1 which is related to assessment of plant biodiversity in urban and forest vegetation of Sirsa Haryana, the following methods were followed:

4.2.1. Vegetation Sampling

4.2.1.1. Sampling Design

For the systematic capturing of the plant/vegetation diversity across Sirsa district, a stratified random sampling method was adopted. This method of sampling ensures that all major types of vegetation and habitats have been adequately represented in the study. This approach minimizes the bias in data collection and provides a more comprehensive understanding of the biodiversity across different ecological zones (Gillison and Brewer 1985; Mitchell 2010). Additionally, quadrats were employed as the key sampling unit to assess vegetation distribution within different strata (Figure 4.3). Trees were investigated in 20 m × 20 m (400 m²) plots that allows precise assessment of biomass and canopy cover. Shrubs were investigated in 5 m × 5 m (25 m²) plots to measure mid-level vegetation crucial for maintaining understory

biodiversity (Stohlgren 2007). Herbs were examined in 1 m × 1 m (1 m²) plots to study the soil-bound flora important for soil health and ecosystem stability. Further, stratification targeted the three vegetative strata i.e., herbaceous layer (<1 m height), shrub layer (1-5 m height) and tree layer (>5 m in height) (Figure 2) (Gilliam 2007). As a precaution, a distance of 1 km was taken for both roadside and river to maintain consistency during data collection as well as analysis (Forman and Alexander 1998; Pauchard and Alaback 2004). This stratified approach allows the reliable assessment of ecological differences in both forest and urban ecosystems. Moreover, it also provides valuable insights about the biodiversity patterns across different vegetation types.

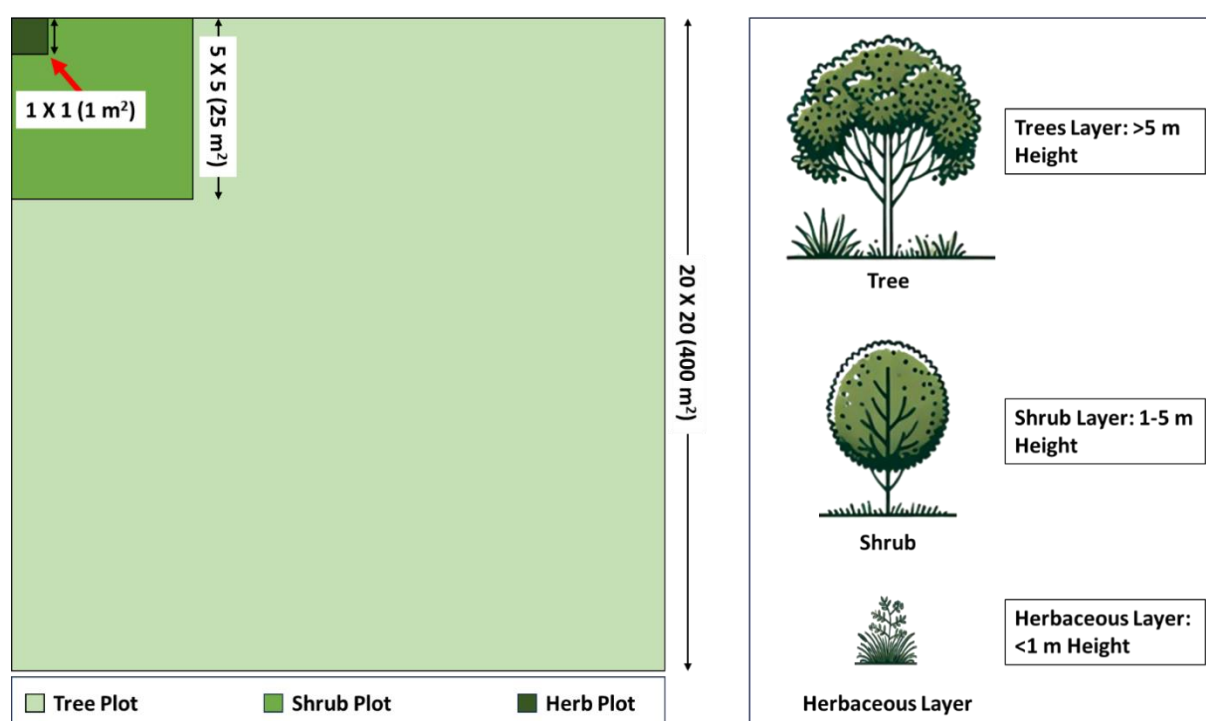


Figure 4.3: Sampling framework layout illustrating quadrat dimensions for stratified vegetation sampling across tree, shrub, and herbaceous layers

4.2.1.2. Data Collection

For each quadrant, data was systematically recorded following a structured protocol to ensure methodological consistency, accuracy, and repeatability across all samples (Gillison and Brewer 1985). For instance, trees were marked with nails and was placed facing towards the direction of the centre or any other known direction of the plot at breast height of 1.3 m. The tree number was marked with chalk (e.g. T001). On marking, trees were counted by following the *clockwise* pattern in the boundary of

plot under investigation. This method was followed to be ensured that none of the tree has been counted twice. The nails and marking with chalk prevented the chances of duplication. In case of shrubs, coloured tape was used which was tied around the base or main stem of the shrub. Additionally, in dense shrub area and new plot, different coloured tapes were used for marking to avoid confusion. The marking on the shrub was done by using tags and numbering was given as S001, S002, etc. The counting of the shrubs was done moving in the zig-zag pattern to ensure that all the marked shrub have been taken into account. The shrub was marked simultaneously after counting to avoid duplication. As the herbs cannot be marked individually, for counting them a 1 X 1 m quadrant frame of PVC pipe was used and its outline was marked with the chalk powder. The cell tape was used to hold the herbs and the number of individuals were counted per species within the marked quadrant. In fact, the area where herb density was high, abundance or % cover metrics was taken into consideration. Moreover, to ensure about the full coverage of the plot, the quadrat of PVC was moved systematically across the plot.

For all the three types of vegetation, the coherent pattern of movement was followed in the plot. The collect of data begins from the one corner and subsequently clockwise movement was followed for trees and zigzag pattern for shrubs and herbs. This ensured the sampling was done consistently across the entire plot. Further, consistency of this method minimizes the observer bias and maintains the integrity of data for subsequent statistical analysis and ecological interpretation. Therefore, by following the standard protocols, the accuracy and reliability of the collected data was maintained throughout the study (Arazy and Malkinson 2021)

4.2.1.3. Morphological Characteristics

Systematic documentation of morphological characteristics of plants like height, plant habit and other physical attributes was done to facilitate species identification and interpret their ecological roles (Pigot et al. 2016). Following the standard procedure, herbarium sheets were prepared for the identification of the species.

4.2.1.4. Quantitative Data

The collection and analysis of quantitative data play pivotal role in providing critical insight about the structural and functional attributes of the plant community. By assessing the metrics like dominance, population abundance, and species distribution,

the current study investigates both the adaptability of individual species and their ecological contributions. Thus, the following parameters were systematically analyzed for holistic and precise ecological evaluation (Capitan et al. 2020; Ross et al. 2023): The primary aim of quantitative evaluation was to gather the information about species composition, distribution and ecological dominance at different study sites.

1. **Frequency (Fr)**: This metric refers to the spread of individual species across the study area, representing their adaptability and ecological niche. It was calculated as:

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats in which species is present}}{\text{Total number of quadrats}} \times 100$$

(Raunkiaer 1918; Greig-Smith 1952)

2. **Density (Den)**: The metric is a critical measure of population distribution, as it measures the number of individuals per unit area and provide the insights about species abundance and overall species population health. It was calculated as:

$$\text{Density (Den)} = \frac{\text{Total number of individual of each species in the quadrats}}{\text{Total number of quadrats}}$$

(Cottam and Curtis 1956)

3. **Abundance (Ab)**: This metric evaluates the total number of individuals of species in their occupied area, provide information about the dominant species within their habitat. It was calculated as:

$$\text{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Number of quadrats in which the species were present}}$$

(Curtis and McIntosh 1950)

4. **Abundance/Frequency Ratio (Ab/Fr ratio)**: This metric determines the pattern of distribution of the species. This ratio gives information about the ecological trends and spatial pattern. It also allows the classification of spatial patterns into uniform, clumped and random. It was calculated as:

$$Ab / Fr \text{ ratio} = \frac{\text{Abundance}}{\text{Frequency}}$$

(Whitford 1949)

5. **Relative Density (%)**: This metric provides the information about the proportion of species with respect to others, presenting its ecological dominance. It was calculated as:

$$\text{Relative Density (RD \%)} = \frac{\text{Density of a species}}{\text{Sum of densities of all species}} \times 100$$

(Phillips 1959; Misra 1968)

6. **Relative Frequency (%)** This metric reveals about the species prevalence providing insight about spatial dominance relative to other species. It was calculated as:

$$\text{Relative Frequency (RF\%)} = \frac{\text{Frequency of a species}}{\text{Sum of frequencies of all species}} \times 100$$

(Phillips 1959; Misra 1968)

7. **Relative Abundance (%)**: This metric provides the prevalence/rarity of a species in regarding to other species. It was calculated as:

$$\text{Relative Abundance (RA \%)} = \frac{\text{Abundance of one species}}{\text{Sum of abundance of all species}} \times 100$$

(Curtis and McIntosh 1950)

8. **Importance Value Index (IVI)**: This metric is the sum of relative density, relative frequency and relative dominance, representing the ecological significance of a species. It was calculated as:

$$IVI = \text{Relative Density} + \text{Relative Frequency} + \text{Relative Abundance}$$

(Phillips 1959; Misra 1968)

9. **Supremacy Diversity**: The metric highlights species dominance within the community by applying logarithmic scale to the IVI. This parameter is the indicative of ecological balance. It was calculated as:

$$\text{Supremacy Diversity} = \log(\text{IVI})$$

(Magurran 2003)

4.2.2. Biodiversity Indices

Biodiversity represents the intricate web and richness of life on this earth which provides us with the aesthetic, economic and ecological benefits. Further, biodiversity relies on the dynamic relationships among the flora and fauna that serve as the foundation for ecological assessments (Cardinale et al. 2012; Mace et al. 2012). To captivate this complexity of plant species diversity and composition, the stratified random sampling method was used. To gain the quantitative insights about biodiversity, metrics like Shannon-Wiener Diversity Index, Simpson's Index, Margalef's Richness Index (Margalef 1958) and Pielou's (Pielou 1966): Evenness Index were applied on the study areas. The formulas applied for calculating key biodiversity metrics are outlined as follows:

1. **Shannon-Wiener Index (H')**: This index evaluates the species evenness and richness, acting as an indicator of ecological resilience. The higher value of this index signifies higher diversity indicating a highly diverse and stable ecosystem. It was calculated as:

$$H' = - \sum P_i \ln P_i$$

Where, $P_i = \frac{n_i}{N}$; n_i = Number of individuals of species i ; and N = Total number of individuals (Shannon 1948).

2. **Simpson's Index (D)**: This index measures the likelihood that two randomly selected individuals belong to different species and serves as a valuable tool for assessing species dominance. It was calculated as:

$$D = \sum P_i^2$$

Where, $P_i = \frac{n_i}{N}$; n_i = Number of individuals of species i ; and N = Total number of individuals (Simpson 1949).

3. **Margalef's Richness Index (R)**: This index aid in determining the species richness within a habitat, providing critical information about the diversity and complexity of ecological system. It was calculated as:

$$R = \frac{S - 1}{\ln N}$$

Where, S = Total number of species; N = Total number of individuals (Margalef 1958).

4. **Pielou's Evenness Index (E)**: The index evaluates the uniformity of species distribution within a habitat providing information about the ecosystem balance. Higher value of this index signifies the balanced and evenly distribution of species population. It was calculated as:

$$E = \frac{H'}{\ln S}$$

Where, H' = Shannon-Wiener index; S = Total number of species (Pielou 1966).

4.3. METHODOLOGY FOR CARBON SEQUESTRATION ASSESSMENT (OBJECTIVE 2)

For achieving Objective 2 which includes assessment of carbon sequestration potential of tree biomass, the following methods were followed.

4.3.1. Basal Area and Relative Dominance

Basal area is a measure of the cross-sectional area of tree trunks at breast height (around 4.5 feet above the ground). This is mainly utilized to estimate forest stand density as well as the timber volume. This measurement is predominantly applicable for trees because of their large contribution to forest structure and biomass. On the other hand, herbs and shrubs with their small size and varied growth forms, are not measured by this method (Stohlgren 2007).

1. **Basal Area**: This metric is derived from the diameter at breast height (DBH), which provides the information of tree biomass and canopy coverage/forest structure within the study area. It was calculated as:

$$\text{Basal Area} = \frac{\pi D^2}{4}$$

Where, D refers to the diameter at breast height (DBH) in meters
(Curtis and McIntosh 1950).

2. **Relative Dominance**: This metric evaluates the species basal area with respect to others, providing the insight about the structural and ecological significance of the species in the community. It was calculated as:

$$\text{Relative Dominance (RDO)} = \frac{\text{Basal area of a species}}{\text{Sum of basal area of all species}} \times 100$$

(Phillips 1959; Misra 1968).

4.3.2. Carbon Sequestration Analysis

Owing to the increasing atmospheric concentration of carbon, carbon sequestration has emerged as a pivotal strategy for mitigating the effects of climate change (Sierra et al. 2021). Carbon sequestration does this by capturing and storing the carbon present in the atmosphere in different terrestrial pools (Lal 2008). The precise evaluation of carbon stocks in environment is important for understanding their involvement in global carbon cycles and assessing the potential for carbon offset projects (Issa et al. 2020). Thus, this study focuses on investigating the carbon sequestration potential of different ecosystems by quantifying the carbon stored in both above ground biomass and below ground biomass, encompassing trees and organic matter of soil (Meng et al. 2021). Moreover, through the integration of laboratory analysis and field measurements, the study aimed to provide an estimate about the biomass, carbon stock and soil carbon content. In addition, different statistical methods including confidence interval estimation was employed to address uncertainties and ensure accurate carbon stock assessments across the study area (Petrokofsky et al. 2012). This research approach leads to comprehensive estimation of carbon storage of vegetation using field-based measurement and use of established scientific equations.

4.3.2.1. Tree Biomass and Carbon Stock Estimation

Tree biomass and carbon stock were estimated based on species-specific allometric equations that associate diameter at breast height (dbh) with biomass (Henry et al. 2010; Mulatu et al. 2024). Thus, measurement of dbh was recorded at 1.3 meters height above the ground with the help of diameter tape (Elzinga et al. 2005). Whereas, carbon stock was estimated by assuming that half of the biomass constituted carbon according to the established standard scientific norms (Thomas and Martin 2012; Doraisami et al. 2024). In current study, allometric equations was used as it is a non-destructive method for estimation of tree biomass and carbon stock associated with it.

The centres of each plot were marked using metal or PVC pipes to ensure proper delineation. Moreover, the field measurement was taken by following a systematic clockwise pattern, starting from a predefined point within each plot to maintain uniformity and avoid duplication (Osborne 1942).

4.3.2.2. Methodology for Biomass Estimation Using Volume and Wood Density

Above-ground biomass (AGB) estimation was determined using a volume-based approach, combining wood densities values, species-specific volumetric equations, and integrating tree measurements. This approach provides an accurate representation of carbon storage capacity and biomass distribution with the study area. The procedure started with the measurement of tree size, where diameter at breast height was recorded at 1.3 meters height above the ground via diameter tape by following standard forestry procedure (Chave et al. 2005). This approach served as the basic parameter for biomass calculations and volume estimation.

After DBH measurement, species-specific volumetric equations obtained from peer-reviewed literature were used for estimating tree volume, which accounts for the variation in species characteristics and tree structure (Brown 1997; Chaturvedi and Raghubanshi 2015). In case, when species-specific volume equation was not available, generalized volumetric equation valid for the corresponding geographic region were employed. These equations were selected on the basis of their applicability to other similar species and forest types in order to attain a reasonable accuracy of estimation (FAO 2020b). The AGB was calculated using the formula:

$$AGB = V \times WD$$

Where, AGB: Above-ground biomass in kg; V: Volume determined by using species-specific or generalized equation available in published literature and WD: Wood density (kg/m^3) derived from published literature (Chave et al. 2005). The utilization of this formula ensures that biomass estimates take into consideration differences in tree structure and species differences. In general, this method is employed for heterogenous vegetation where species-specific variation of wood density significantly influences the estimation of biomass.

Further validation and adjustment procedure was followed to improve the accuracy of biomass estimates. Biomass estimates were confirmed by comparing the values with published literature and established methodologies (Brown 1997). Moreover, adjustments were made when required to match the calculations with species-specific growth patterns, ecological conditions and structural variations (Chaturvedi and Raghubanshi 2015). These refinements helped to ensure that the biomass estimates were robust and representative of the actual forest structure.

4.3.2.3. Underground Tree Biomass

Belowground biomass (BGB) is generally assessed from aboveground biomass (AGB) as a function of root-to-shoot ratio (R:S), which is a common allometric method. Thus, BGB can be calculated using the formula:

$$BGB = AGB \times R:S$$

Where, R:S ratio is often reported as 0.20, even though it varies with environmental conditions, species, and vegetation type (Mokany et al. 2006). The approach provides a proficient estimate of BGB and reduces the need of direct and time-consuming field measurements (Mokany et al. 2006; Rogers et al. 2019). Moreover, the utilization of root-to-shoot approach for BGB estimation simplifies the calculation and maintain the acceptable accuracy.

4.4. METHODOLOGY FOR SOIL CARBON ASSESSMENT (OBJECTIVE 3)

For achieving Objective 3 which focuses on evaluation of soil carbon sequestration potential following methods were followed.

4.4.1. Soil Organic Carbon (SOC) analysis

For analyzing the variability in soil organic carbon (SOC) in the different land types. Soil samples were collected from 30 cm depth using soil sampler following the standard procedure (ESMC 2021; Schumacher et al. 1990). The sample from this depth allows the detailed analysis of SOC and is often employed in the soil sampling procedures. Moreover, random composite sampling technique was used to attain representativeness (Morgan and Ackerson 2022). From each sampling site, multiple samples were collected, homogenized by pooling and stored in a container for further analysis (Parrish et al. 1990). This composite sampling improves the representativeness across different land-use types and reduces variability in soil carbon estimations.

4.4.1.1. Sample Preparation

50 g of soil sample was oven-dried for 48 hrs at 105°C before analysis to measure the moisture loss as well as stabilize organic matter content (Dass 2014). After drying, the standard procedure for SOC determination was followed, which provides assurance that no change in organic carbon composition occurred during drying but only water loss (Schumacher 2002).

Weight of the sample was taken after drying the sample and weight loss was determined to estimate organic matter loss by using the formula:

$$\begin{aligned} & \text{Moisture Content (\%)} \\ &= \frac{\text{Weight before drying} - \text{Weight after drying}}{\text{Weight before drying}} \times 100 \end{aligned}$$

(Kirkham 2023).

Further steps were followed according to Ball (1964). Moreover, SOC was calculated by considering the organic matter typically constitutes of 58% of carbon. This percentage of carbon is based on the established soil carbon quantification techniques. The SOC was calculated using the formula:

$$SOC = (\text{OrganicMatter} \times 58)/100$$

(Nelson and Sommers 1982).

4.4.1.2. For scaling up of SOC according to ecosystem

For scaling up the SOC value to per hectare, bulk density of soil was taken into consideration. For the urban region, bulk density was considered to be **1.5 g/cm³** due to compact (Dass 2014). Whereas, the forest region was considered to have a bulk density of **1.3 g/cm³** because of high organic content (Singh et al. 2010). The SOC stock per hectare was calculated using the formula (FAO 2020a):

$$\text{SOC stock (Mg ha}^{-1}\text{)} = \frac{\text{SOC} \times \text{Bulk Density} \times \text{Soil Depth (cm)}}{10}$$

(Fowler et al. 2023)

4.4.1.3. Extrapolation up to the District Level

Total SOC stock of Sirsa district was estimated with reference to the proportion of urban (30%) and forest (10%) land cover. Proportion of urban and forest area were estimated according to land-use classification (Verma et al. 2014). The SOC stock of the district was calculated using then formula:

$$\text{Total SOC Stock} = \sum (\text{SOC stock (Mg ha}^{-1}\text{)} \times \text{Area (ha)})$$

(Tadiello et al. 2022)

4.4.2. Data Analysis and Carbon Stock Calculation

Data analysis was done to calculate the carbon stock for each carbon pool as well as the total carbon stored within the study area. The analysis involves biomass estimation, measurement of soil carbon (Petrokofsky et al. 2012).

1. Biomass and Carbon Estimation

Biomass was calculated using the formula:

$$\text{Biomass} = \text{Volume} \times \text{Wood density (Yang et al. 2023b)}$$

2. Calculation of Carbon in Vegetation

The carbon in vegetation was determined by assuming that half of the biomass is made up of carbon. Thus, carbon in vegetation was calculated using the formula:

$$C_{veg} = \frac{Biomass (g)}{2}$$

where, C_{veg} = vegetation carbon content (g); Biomass = calculated or measured biomass of vegetation (g) (Tang et al. 2018)

CHAPTER 5

RESULT AND DISCUSSION

Objective 1: To analyse the plant biodiversity pattern in urban and forest vegetation of Sirsa district.

5.1. DESCRIPTION OF STUDY SITES AND SAMPLING STRATEGY

The sample was collected from the range of key site involving both urban and forest areas. Urban areas encompass Shaheed Bhagat Singh Stadium (Site A), Chaudhary Devi Lal Park (Site B), Sirsa Minor (Site C), HUDA Unhabitated Area (Site D), Home Gardens 1 (Site E), Home Gardens 2 (Site F), Municipality Park (Site G), and Mini-bypass Sirsa (Site H). Whereas, the forest areas encompass Village Chaharwala Minor (Site I), Village Mameran Road (Site J), Panjuana Canal (Site K), Village Nagoki Canal (Site L), Village Mangiana (Site M), Ottu Head (Site N), Abub Sheher Wildlife Sanctuary (Site O), and Daulatpur Khera (Site P). To ensure accurate representation of the data, stratified random sampling and quadrant based-sampling method were used. Further, the collected data was comprehended in a systematic manner following structure protocol and herbarium sheets were prepared. The figure 5.1 provides the glimpse of data of collection and **annexure 1** shows the photographic records and species identification of the selected herbarium specimens.



Figure 5.1: Photographs during data collection. a) Overview of plant diversity in forest region; b) Overview of plant diversity in Urban region (Park); c) Documentation of the data; d) Surveying of the diversity; e) Inspection of Tree for identification by local; f) Measurement of girth of the tree.

5.2. PLANT SPECIES COMPOSITION IN URBAN AND FOREST AREAS

To assess the structural and functional characteristics of the plant communities within the study sites, quantitative information was gathered and analyzed through key ecological metrics. The key metrics include frequency, density, abundance, abundance/frequency ratio, basal area, relative dominance, relative density, relative frequency, importance value index (IVI) and supremacy diversity. These key metrics were calculated to gain insight about the species dominance and their ecological significance in both urban and forest area

5.2.1. Urban Area

5.2.1.1. Plant Diversity and Distribution

The distribution of plant species across various families within the urban region of Sirsa district reveals significant variation in species presence and abundance. This study found a total of 98 plant species distributed among 45 different plant families, showcasing a diverse range of plant types adapted to the urban environment (Table 5.1). Among the families represented, the *Fabaceae* family exhibited the highest number of species, with a total of 12 species observed. Notable plants in this family include *Holoptelea integrifolia* (Papdi), *Dalbergia sissoo* (Sheesham), *Vachellia nilotica* (Kikar), and *Saraca asoca* (Ashoka), contributing significantly to the urban plant diversity. This inference highlights about their ecological significance in nitrogen fixation and improving soil fertility (Goodall et al. 2014; Gong et al. 2023). After *Fabaceae* family, *Apocynaceae*, *Asteraceae*, *Cannabaceae* and *Solanaceae* family showed the prominence in the urban setting. The *Apocynaceae* family encompassing 5 species named *Calotropis procera* (Aak), *Tabernaemontana divaricate* (Chandni), *Nerium oleander* (Kaner), *Catharanthus roseus* (Sadabahar) and *Alstonia scholaris* (Saptparni) with considerable numbers of individuals, i.e., 32, 31, 25, 21 and 5, respectively. Additionally, the *Asteraceae* family is well-represented, encompassing four species. Species like *Tagetes erecta* (Genda) with 40 individuals and *Parthenium hysterophorus* (Congress grass) with 12 individuals were prominent within this family. Further, the presence of species like *Azadirachta indica*

(Neem) and *Ficus religiosa* (Pipal) represented the convergence of ecological functionality and cultural heritage, highlighting the cordial integration of biodiversity and human traditions in urban settings (Avolio et al. 2020). Additionally, the presence of ornamental species like *Bougainvillea glabra* and *Catharanthus roseus* contributes to the aesthetic appeal of urban spaces (Muhlisin et al. 2021). The *Cannabaceae* family, representing the invasive species named *Cannabis sativa* raises the concern for effective management (Jehangir et al. 2024). The Family *Araliaceae*, *Cactaceae*, *Crassulaceae*, *Elaeocarpaceae*, *Lythraceae*, *Proteaceae*, and *Sapotaceae* showed the presence of least number of plant species i.e., one from each family. The figure 5.2 showing the bar chart provide a visual representation of number of species within each family which highlights the relative dominance of certain families within the urban area. Furthermore, figure 5.3 illustrates the plant species documented during the plant diversity assessment within the urban area.

Table 5.1: Summary of Distribution of Plant Species among families in Urban Region of Sirsa District according to APG IV guidelines

Order	Family	Genus	Botanical Name	Local Name	Individuals found
<i>Alismatales</i>	<i>Araceae</i>	<i>Epipremnum</i>	<i>Epipremnum aureum</i>	Moneyplant	1
		<i>Monstera</i>	<i>Monstera deliciosa</i>	Fruit salad plant	3
		<i>Philodendron</i>	<i>Philodendron xanadu</i>	Philodendron xanadu	1
		<i>Syngonium</i>	<i>Syngonium podophyllum</i>	Signoia	1
<i>Apiales</i>	<i>Araliaceae</i>	<i>Polyscias</i>	<i>Polyscias fruticosa</i>	Aralia	1
<i>Arecales</i>	<i>Arecaceae</i>	<i>Dypsis</i>	<i>Dypsis lutescens</i>	Erica Palm	9
		<i>Trachycarpus</i>	<i>Trachycarpus fortunei</i>	Chinese windmill palm	8
<i>Asparagales</i>	<i>Asparagaceae</i>	<i>Agave</i>	<i>Agave desmettiana</i>	Dwarf Century Plant	5
		<i>Beaucarnea</i>	<i>Beaucarnea recurvata</i>	Lolina	2
		<i>Chlorophytum</i>	<i>Chlorophytum comosum</i>	Spider plant	6
		<i>Dracaena</i>	<i>Dracaena angolensis</i>	Cylindrical snake plant	8

		<i>Dracaena</i>	<i>Dracaena trifasciata</i>	Snake plant	11
	<i>Asphodelaceae</i>	<i>Aloe</i>	<i>Aloe barbadensis</i>	Aloe vera	8
<i>Asterales</i>	<i>Asteraceae</i>	<i>Chrysanthemum</i>	<i>Chrysanthemum indicum</i>	Guldaudi	7
		<i>Dahlia</i>	<i>Dahlia pinnata</i>	Dahlia	4
		<i>Parthenium</i>	<i>Parthenium hysterophorus</i>	Congress grass	12
		<i>Tagetes</i>	<i>Tagetes erecta</i>	Genda	40
<i>Boraginales</i>	<i>Cordiaceae</i>	<i>Cordia</i>	<i>Cordia dichotoma</i>	Lehsua	2
<i>Caryophyllales</i>	<i>Amaranthaceae</i>	<i>Achyranthes</i>	<i>Achyranthes aspera</i>	Puth kanta	6
		<i>Aerva</i>	<i>Aerva javanica</i>	Bui	11
		<i>Amaranthus</i>	<i>Amaranthus hypochondriacus</i>	Pigweed	7
	<i>Cactaceae</i>	<i>Echinocactus</i>	<i>Echinocactus grusonii</i>	Barrel cactus	1
	<i>Menispermaceae</i>	<i>Tinospora</i>	<i>Tinospora cordifolia</i>	Giloy	3
<i>Commelinales</i>	<i>Commelinaceae</i>	<i>Tradescantia</i>	<i>Tradescantia pallida</i>	Purple queen	2

		<i>Tradescantia</i>	<i>Tradescantia zebrina</i>	Inch plant	3
<i>Cycadales</i>	<i>Cycadaceae</i>	<i>Cycas</i>	<i>Cycas revoluta</i>	Palm-Kanghi	5
<i>Euphorbiales</i>	<i>Euphorbiaceae</i>	<i>Ricinus</i>	<i>Ricinus communis</i>	Arind	30
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia</i>	<i>Acacia cetechu</i>	Kher	1
		<i>Albizia</i>	<i>Albizia lebbeck</i>	Sarinh	6
		<i>Bauhinia</i>	<i>Bauhinia variegata</i>	Kachnar	5
		<i>Cassia</i>	<i>Cassia fistula</i>	Amaltas	8
		<i>Dalbergia</i>	<i>Dalbergia sissoo</i>	Sheesham	24
		<i>Delonix</i>	<i>Delonix regia</i>	Gulmohar	3
		<i>Prosopis</i>	<i>Prosopis cineraria</i>	Janti	4
		<i>Prosopis</i>	<i>Prosopis juliflora</i>	Pahadi Kikar	6
		<i>Saraca</i>	<i>Saraca asoca</i>	Ashoka	20
		<i>Vachellia</i>	<i>Vachellia nilotica</i>	Kikar	24

<i>Gentianales</i>	<i>Apocynaceae</i>	<i>Alstonia</i>	<i>Alstonia scholaris</i>	Saptparni	5
		<i>Calotropis</i>	<i>Calotropis procera</i>	Aak	32
		<i>Catharanthus</i>	<i>Catharanthus roseus</i>	Sadabahar	21
		<i>Nerium</i>	<i>Nerium oleander</i>	Kaner	25
		<i>Tabernaemontana</i>	<i>Tabernaemontana divaricata</i>	Chandni	31
<i>Lamiales</i>	<i>Bignoniaceae</i>	<i>Kigelia</i>	<i>Kigelia africana</i>	Kigelia	4
		<i>Tecoma</i>	<i>Tecoma stans</i>	Yellow trumpet	5
		<i>Tecomella</i>	<i>Tecomella undulata</i>	Rohida	1
	<i>Oleaceae</i>	<i>Jasminum</i>	<i>Jasminum arborescens</i>	Chameli	4
		<i>Jasminum</i>	<i>Jasminum sambac</i>	Jasmine	3
		<i>Nyctanthes</i>	<i>Nyctanthes arbor-tristis</i>	Harshingar	3
<i>Magnoliales</i>	<i>Magnoliaceae</i>	<i>Magnolia</i>	<i>Magnolia champaca</i>	Champak	10
<i>Malpighiales</i>	<i>Elaeocarpaceae</i>	<i>Elaeocarpus</i>	<i>Elaeocarpus ganitrus</i>	Rudrakash	1

	<i>Euphorbiaceae</i>	<i>Codiaeum</i>	<i>Codiaeum variegatum</i>	Croton	5
		<i>Jatropha</i>	<i>Jatropha curcas</i>	Jatropha	6
	<i>Phyllanthaceae</i>	<i>Phyllanthus</i>	<i>Phyllanthus emblica</i>	Amla	2
<i>Malvales</i>	<i>Malvaceae</i>	<i>Hibiscus</i>	<i>Hibiscus rosa-sinensis</i>	China Rose	3
		<i>Pterospermum</i>	<i>Pterospermum acerifolium</i>	Kanak champa	3
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa</i>	<i>Moringa oleifera</i>	Sohanjana	5
<i>Myrtales</i>	<i>Combretaceae</i>	<i>Terminalia</i>	<i>Terminalia arjuna</i>	Arjun	3
	<i>Lythraceae</i>	<i>Punica</i>	<i>Punica granatum</i>	Anar	1
	<i>Myrtaceae</i>	<i>Callistemon</i>	<i>Callistemon citrinus</i>	Bottlebrush	7
		<i>Eucalyptus</i>	<i>Eucalyptus globulus</i>	Safeda	11
		<i>Psidium</i>	<i>Psidium guajava</i>	Amrood	4
		<i>Syzygium</i>	<i>Syzygium cumini</i>	Jamun	8
<i>Pinales</i>	<i>Araucariaceae</i>	<i>Araucaria</i>	<i>Araucaria araucana</i>	Aerocaria	3

	<i>Cupressaceae</i>	<i>Platyclusus</i>	<i>Platyclusus orientalis</i>	Platyclusus	2
	<i>Pinaceae</i>	<i>Pinus</i>	<i>Pinus roxburghii</i>	Indian pine	2
<i>Poales</i>	<i>Poaceae</i>	<i>Phalaris</i>	<i>Phalaris minor</i>	Guli Danda Ghass	4
		<i>Saccharum</i>	<i>Saccharum spontaneum</i>	Kans	5
<i>Proteales</i>	<i>Proteaceae</i>	<i>Grevillea</i>	<i>Grevillea robusta</i>	Silver oak	1
<i>Ranunculales</i>	<i>Papaveraceae</i>	<i>Papaver</i>	<i>Papaver somniferum</i>	Poppyflower	5
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus</i>	<i>Ziziphus mauritiana</i>	Beri	10
<i>Rosales</i>	<i>Cannabaceae</i>	<i>Cannabis</i>	<i>Cannabis sativa</i>	Bhang	59
	<i>Moraceae</i>	<i>Ficus</i>	<i>Ficus benamina</i>	Ficus	12
		<i>Ficus</i>	<i>Ficus racemose</i>	Anjeer	3
		<i>Ficus</i>	<i>Ficus religiosa</i>	Pipal	12
		<i>Morus</i>	<i>Morus alba</i>	Shehtoot	4
	<i>Rosaceae</i>	<i>Prunus</i>	<i>Prunus persica</i>	Aadu	3

		<i>Rosa</i>	<i>Rosa rubigionosa</i>	English Rose	2
		<i>Rosa</i>	<i>Rosa indica</i>	Rose	14
	<i>Ulmaceae</i>	<i>Holoptelea</i>	<i>Holoptelea integrifolia</i>	Papdi	36
<i>Sapindales</i>	<i>Anacardiaceae</i>	<i>Mangifera</i>	<i>Mangifera indica</i>	Aam	2
	<i>Meliaceae</i>	<i>Azadirachta</i>	<i>Azadirachta indica</i>	Neem	15
		<i>Chukrasia</i>	<i>Chukrasia velutina</i>	Chukrasia	1
		<i>Melia</i>	<i>Melia azedarach</i>	Bakain	5
	<i>Rutaceae</i>	<i>Aegle</i>	<i>Aegle marmelos</i>	Bellpatar	2
		<i>Citrus</i>	<i>Citrus × limon</i>	Nimbu	4
		<i>Murraya</i>	<i>Murraya koenigii</i>	Curri plant	1
<i>Sapotales</i>	<i>Sapotaceae</i>	<i>Manilkara</i>	<i>Manilkara zapota</i>	Chiku	1
<i>Saxifragales</i>	<i>Crassulaceae</i>	<i>Bryophyllum</i>	<i>Bryophyllum pinnatum</i>	Patharchat	1
<i>Solanales</i>	<i>Boraginaceae</i>	<i>Alkanna</i>	<i>Alkanna tinctoria</i>	Ratanjot	1

	<i>Convolvulaceae</i>	<i>Cuscuta</i>	<i>Cuscuta reflexa</i>	Amarbael	2
	<i>Nyctaginaceae</i>	<i>Bougainvillea</i>	<i>Bougainvillea glabra</i>	Bougainvillea	16
		<i>Bougainvillea</i>	<i>Bougainvillea peruviana</i>	Yellow Bougainville	7
	<i>Solanaceae</i>	<i>Capsicum</i>	<i>Capsicum annuum</i>	Green chilli	2
		<i>Datura</i>	<i>Datura innoxia</i>	Datura	36
		<i>Petunia</i>	<i>Petunia</i> × <i>atkinsiana</i>	Petunia	3
		<i>Withania</i>	<i>Withania somnifera</i>	Ashwagandha	10
<i>Zingiberales</i>	<i>Cannaceae</i>	<i>Canna</i>	<i>Canna lily</i>	Keli Lal	13
	<i>Musaceae</i>	<i>Musa</i>	<i>Musa paradisiaca</i>	Banana	3

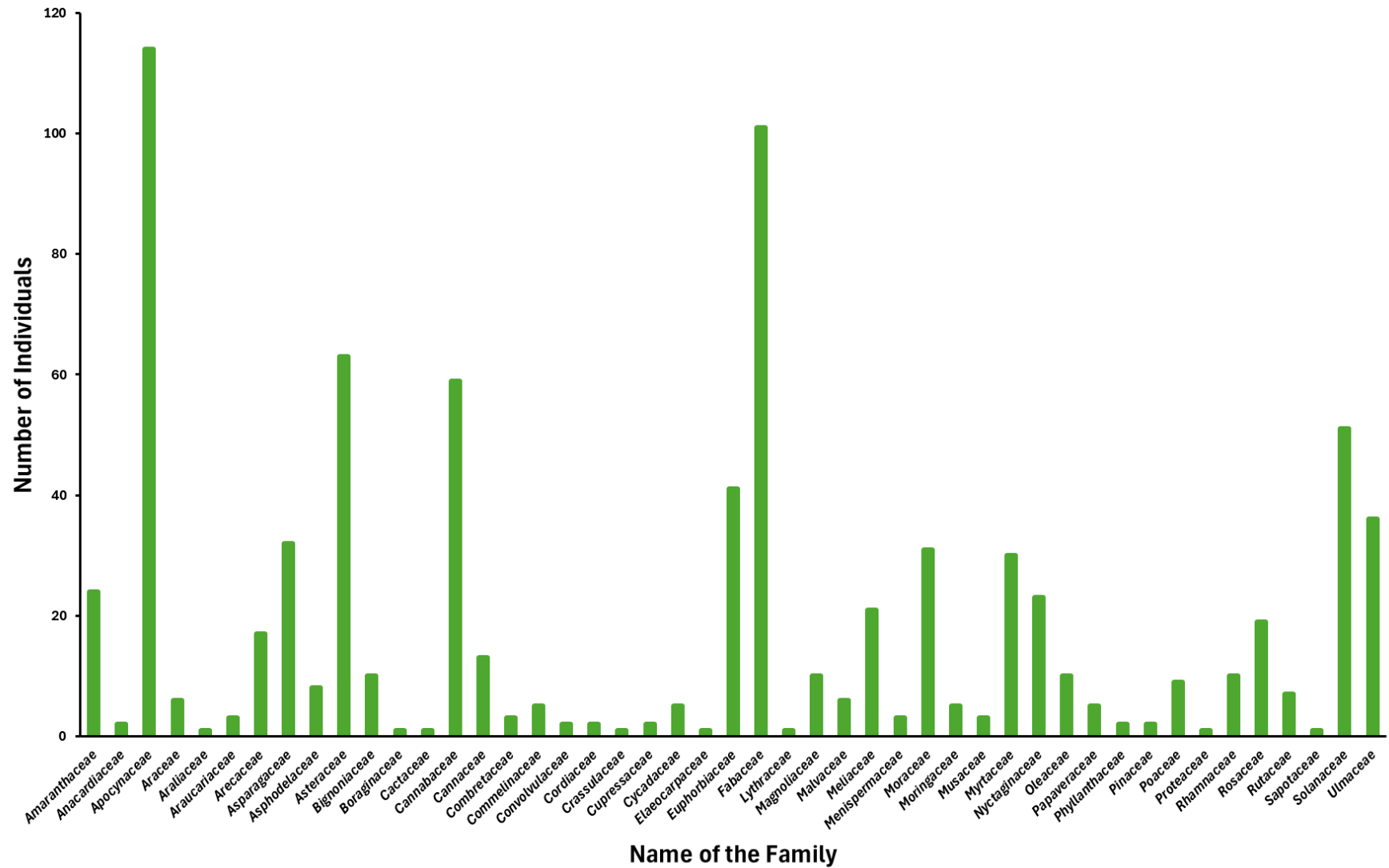


Figure 5.2: Bar chart depicting the distribution of individuals among different plant families in urban ecosystem



Agave desmettiana
(Dwarf Century Plant)



Saraca asoca
(Ashoka)



Melia azedarach
(Bakain)



Ficus benghalensis
(Bargad)



Callistemon citrinus
(Bottlebrush)



Echinocactus grusonii
(Cactus)



Jasminum sambac
(Chameli)



Magnolia champaca
(Champak)



Nyctanthes arbor-tristis
(Harshingar)



Syzygium cumini
(Jamun)



Nerium oleander
(Kaner)



Vachellia nilotica
(Kikar)



Cordia dichotoma
(Lehsua)



Mangifera indica
(Mango)



Jasminum sambac
(Mogra)



Azadirachta indica
(Neem)



Figure 5.3: Photographs of explored plant species during biodiversity assessment illustrating the diversity of cultural, ornamental and ecologically important species in urban ecosystems

5.2.1.2. Spatial Variation in Urban Area

The spatial variation analysis of the different sites shows notable differences in plant diversity and the significance of individual species (Table 5.2). Site A (Shaheed Bhagat Singh Stadium) was determined to be species-dense as it encompasses 35 different plant species. Additionally, it was regarded as significantly important site because of the presence of the species like *Saraca asoca*, and *Nerium oleander*. These species have both medicinal and ornamental value which makes the Site A (Shaheed Bhagat Singh Stadium) as a focal point of aesthetic and ecological significance. Moreover, the presence of *Azadirachta indica* (neem) in Site A also points out significance in both traditional medicine and pest control. Moreover, site A (Shaheed Bhagat Singh Stadium) being maintained area tend to have more diverse plant species as resources are spent on allocated green spaces and landscapes (Hope et al. 2003).

Next comes the Site B (Chaudhary Devi Lal Park) which harbours 29 species displaying the high diversity and features species like *Magnolia champaca* known for its fragrant flowers and *Catharanthus roseus* which is widely used for medicinal purposes. The Site C (Sirsa Minor) was determined to be home of 24 species which includes plants species like *Datura innoxia*, *Ricinus communis* and *Syzygium cumini*. These species contribute to the ecological richness of the site and have medicinal value. Site D (HUDA Unhabitated Area) encompasses 22 species which includes combination of woody and ornamental plants. Among them, *Dalbergia sissoo* was highly valued owing to its value as a timber tree. Likewise, presence of *Bougainvillea glabra* also show its contribution to this site by adding vibrant colour to this site making it both ecologically diverse and aesthetically beautiful. Site E (Home Garden 1) which was hosting 27 species holds the significance due to the presence of *Aloe barbadensis* that is renowned for its extensive application in skincare and medicinal treatments. The presence of *Dracaena angolensis* at this site was valued for its ornamental value and hardy nature. Site F (Home Garden 2) is home for 12 species which include key species of plants like *Aloe barbadensis* having medicinal value along with ornamental species like *Dracaena angolensis* and *Jasminum sambac*. These ornamental species at this site highlights the aesthetic appeal of this site. Site G (Municipality Park) harbours 21 species which includes plants like *Citrus × limon* (lemon) and *Mangifera indica* (mango) that have both economic and ecological importance. Further, the occurrence of *Datura innoxia* and *Syzygium cumini* at this site improves their ecological value. Lastly, Site H (Mini-bypass Sirsa) which encompasses 20 species which includes plants like *Cannabis sativa* and *Ricinus communis* having economical, industrial and medicinal value. The presence of *Vachellia nilotica* at this site highlights its ecological significance as it plays important role in enhancing soil health via nitrogen fixation. The variation in plant diversity among the different sites have been influenced by urbanization. Even studies on urban environment have reported about the decline in native plant species (English et al. 2022). Further, it has been noted that plant diversity distribution often differs along urban-rural gradients. Study conducted in Zhengzhou, China revealed specific spatial patterns in plant diversity influenced by factors like housing prices, impervious surface area and per capita GDP. These finding underlines the intricate relationship between plant diversity and urbanization which highlights the need for the conservation initiatives (Zhang et al. 2024).

Overall, this analysis highlights the different level of plant diversity across different sites where few sites were hosting the high numbers of ornamental, medicinal, and economically important species. Sites like A (Shaheed Bhagat Singh Stadium), B (Chaudhary Devi Lal Park), and C (Sirsa Minor) were determined to be highly diverse and ecologically rich. Whereas, sites like D (HUDA Unhabitated Area) and H (Minibypass Sirsa) presented the mix of ornamental, medicinal and woody plant species with significant ecological roles. These variation in species composition and diversity directly influence the vegetation structure of urban ecosystem. As the pattern in species dominance as well as distribution play the significant role in determining biomass accumulation and carbon sequestration potential of these sites.

5.2.2. Forest Area

5.2.2.1 Plant Diversity and Distribution

According to the data presented in Table 5.2, the forest region of Sirsa District showed the presence of wide range of plant species that are scattered over the different families. The table 5.2 provides the lists plant species belonging to different families with their respective number of individuals. In forest region, the *Fabaceae* family once again showed the predominance with a total of 8 species observed. Notable plants in this family include *Prosopis juliflora* (Pahadi Kikar), *Acacia nilotica* (Kikar), *Dalbergia sissoo* (Sheesham), *Holoptelea integrifolia* (Papdi), *Albizia lebbeck* (Sarin), *Prosopis cineraria* (Janti), *Cassia fistula* (Amaltas) and *Clitoria ternatea* (Aprajita). This inference highlights about their role in maintaining the ecological balance in the forest region. After *Fabaceae* family, *Cannabaceae*, *Myrtaceae*, *Solanaceae*, *Meliaceae* and *Amaranthaceae* family showed the prominence in the forest setting. The *Cannabaceae* family harbours 1 species named *Cannabis sativa* (Bhang) that accounts for the highest number of individuals, i.e., 64 in the forest region. Additionally, *Myrtaceae* family encompassing three species like *Eucalyptus globulus* (Safeda), *Syzygium cumini* (Jamun) and *Psidium guajava* (Amrood) with 45, 14 and 1 individuals respectively within this family. Moreover, the presence of plant species like *Azadirachta indica* (Neem), *Acacia nilotica* (Kikar), *Eucalyptus globulus* (Safeda), *Terminalia arjuna* (Arjun), *Ficus benghalensis* (Bargad), and *Ficus religiosa* (Pipal) representing the convergence of ecological functionality and cultural heritage. The presence of the plant species like *Withania*

somnifera (Ashwagandha), *Terminalia arjuna* (Arjun), *Ziziphus mauritiana* (Ber), *Cannabis sativa* (Bhang), *Tinospora cordifolia* (Giloy) and *Azadirachta indica* (Neem) highlights the importance of medicinal plants within forest region. Other than that, presence of plant species like *Syzygium cumini* (Jamun) and *Psidium guajava* (Amrood) contribute to both ecological balance and human consumption. Further, the occurrence of *Ficus racemose* (Anjeer) and *Ficus benghalensis* (Bargad) in the forest region serve as a food source for humans and wildlife. These species also act as ecological niches that provide shelter and food to birds and animals (Bhogal et al. 2025; Dorage and Bagal 2025). In addition, the presence of ornamental species like *Bougainvillea glabra* (Bougainvillea) and *Moringa oleifera* (Sohanjana) contributes to the aesthetic appeal of forest region (Dhandapani et al. 2024; Ramesh et al. 2024). The figure 5.4 showing the bar chart provide a visual representation of number of species within each family which highlights the relative dominance of certain families within the forest area. Furthermore, figure 5.5 illustrates the plant species documented during the plant diversity assessment within the forest area.

Table 5.2: Summary of Distribution of Plant Species among families in Forest Region of Sirsa District according to APG IV guidelines

Order	Family	Genus	Botanical Name	Local Name	No. of individuals
<i>Amaranthales</i>	<i>Amaranthaceae</i>	<i>Achyranthes</i>	<i>Achyranthes aspera</i>	Puth Kanta	32
		<i>Amaranthus</i>	<i>Amaranthus viridis</i>	Chaulai	3
<i>Asparagales</i>	<i>Asparagaceae</i>	<i>Asparagus</i>	<i>Asparagus racemosus</i>	Satwar	1
<i>Asterales</i>	<i>Asteraceae</i>	<i>Parthenium</i>	<i>Parthenium hysterophorus</i>	Congress Grass	19
		<i>Taraxacum</i>	<i>Taraxacum officinale</i>	Dandelion	2
<i>Boraginales</i>	<i>Cordiaceae</i>	<i>Cordia</i>	<i>Cordia dichotoma</i>	Dela	4
<i>Brassicales</i>	<i>Brassicaceae</i>	<i>Descurainia</i>	<i>Descurainia sophia</i>	Sofis	3
<i>Caryophyllales</i>	<i>Chenopodiaceae</i>	<i>Chenopodium</i>	<i>Chenopodium album</i>	Bathua	7
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia</i>	<i>Acacia nilotica</i>	Kikar	27
		<i>Albizia</i>	<i>Albizia lebbeck</i>	Sarinh	12
		<i>Cassia</i>	<i>Cassia fistula</i>	Amaltas	1

		<i>Clitoria</i>	<i>Clitoria ternatea</i>	Aprajita	1
		<i>Dalbergia</i>	<i>Dalbergia sissoo</i>	Sheesham	25
		<i>Prosopis</i>	<i>Prosopis cineraria</i>	Janti	4
		<i>Prosopis</i>	<i>Prosopis juliflora</i>	Pahadi Kikar	31
<i>Gentianales</i>	<i>Apocynaceae</i>	<i>Calotropis</i>	<i>Calotropis procera</i>	Aak	19
		<i>Catharanthus</i>	<i>Catharanthus roseus</i>	Sada Suhagan	1
		<i>Nerium</i>	<i>Nerium oleander</i>	Kaner	1
	<i>Menispermaceae</i>	<i>Tinospora</i>	<i>Tinospora cordifolia</i>	Giloy	3
<i>Malpighiales</i>	<i>Phyllanthaceae</i>	<i>Phyllanthus</i>	<i>Phyllanthus emblica</i>	Amla	1
<i>Malvales</i>	<i>Malvaceae</i>	<i>Abutilon</i>	<i>Abutilon indicum</i>	Indian Mallow	1
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa</i>	<i>Moringa oleifera</i>	Sohanjana	6
<i>Myrtales</i>	<i>Combretaceae</i>	<i>Terminalia</i>	<i>Terminalia arjuna</i>	Arjun	5
		<i>Terminalia</i>	<i>Terminalia bellirica</i>	Baheda	3

	<i>Lythraceae</i>	<i>Lawsonia</i>	<i>Lawsonia inermis</i>	Mehandi	5
	<i>Myrtaceae</i>	<i>Eucalyptus</i>	<i>Eucalyptus globulus</i>	Safeda	45
		<i>Psidium</i>	<i>Psidium guajava</i>	Amrood	1
		<i>Syzygium</i>	<i>Syzygium cumini</i>	Jamun	14
	<i>Nyctaginaceae</i>	<i>Bougainvillea</i>	<i>Bougainvillea glabra</i>	Bougainvillea	3
<i>Pinales</i>	<i>Cupressaceae</i>	<i>Thuja</i>	<i>Thuja occidentalis</i>	Vidyapadhai Thuja	5
<i>Poales</i>	<i>Poaceae</i>	<i>Avena</i>	<i>Avena fatua</i>	Jangli Jae	1
		<i>Cenchrus</i>	<i>Cenchrus biflorus</i>	Bharunt/ Indian Sandbur	7
		<i>Digitaria</i>	<i>Digitaria sanguinalis</i>	Crab Grass	10
		<i>Echinochloa</i>	<i>Echinochloa crus-galli</i>	Barnyard Grass	18
<i>Primulales</i>	<i>Primulaceae</i>	<i>Anagallis</i>	<i>Anagallis arvensis</i>	Krishan Neel	5
<i>Ranunculales</i>	<i>Papaveraceae</i>	<i>Argemone</i>	<i>Argemone mexicana</i>	Satyanashi/ Mexican Prickly Poppy	22

<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus</i>	<i>Ziziphus mauritiana</i>	Beri	14
<i>Rosales</i>	<i>Cannabaceae</i>	<i>Cannabis</i>	<i>Cannabis sativa</i>	Bhang	64
	<i>Moraceae</i>	<i>Ficus</i>	<i>Ficus benghalensis</i>	Bargad	4
		<i>Ficus</i>	<i>Ficus racemose</i>	Anjeer	2
		<i>Ficus</i>	<i>Ficus religiosa</i>	Pipal	5
		<i>Morus</i>	<i>Morus alba</i>	Shehtoot	13
	<i>Ulmaceae</i>	<i>Holoptelea</i>	<i>Holoptelea integrifolia</i>	Papdi	21
<i>Salvadorales</i>	<i>Salvadoraceae</i>	<i>Salvadora</i>	<i>Salvadora oleoides</i>	Jaal	3
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta</i>	<i>Azadirachta indica</i>	Neem	48
		<i>Melia</i>	<i>Melia azedarach</i>	Bakain	5
	<i>Rutaceae</i>	<i>Zanthoxylum</i>	<i>Zanthoxylum armatum</i>	Pahadi Neem	9
<i>Solanales</i>	<i>Solanaceae</i>	<i>Datura</i>	<i>Datura innoxia</i>	Datura	26
		<i>Datura</i>	<i>Datura stramonium</i>	Sadahdhatura	13

		<i>Solanum</i>	<i>Solanum dulcamara</i>	Night Shade	9
		<i>Withania</i>	<i>Withania somnifera</i>	Ashwagandha	8
<i>Zygophyllales</i>	<i>Zygophyllaceae</i>	<i>Tribulus</i>	<i>Tribulus terrestris</i>	Bhakdi	5

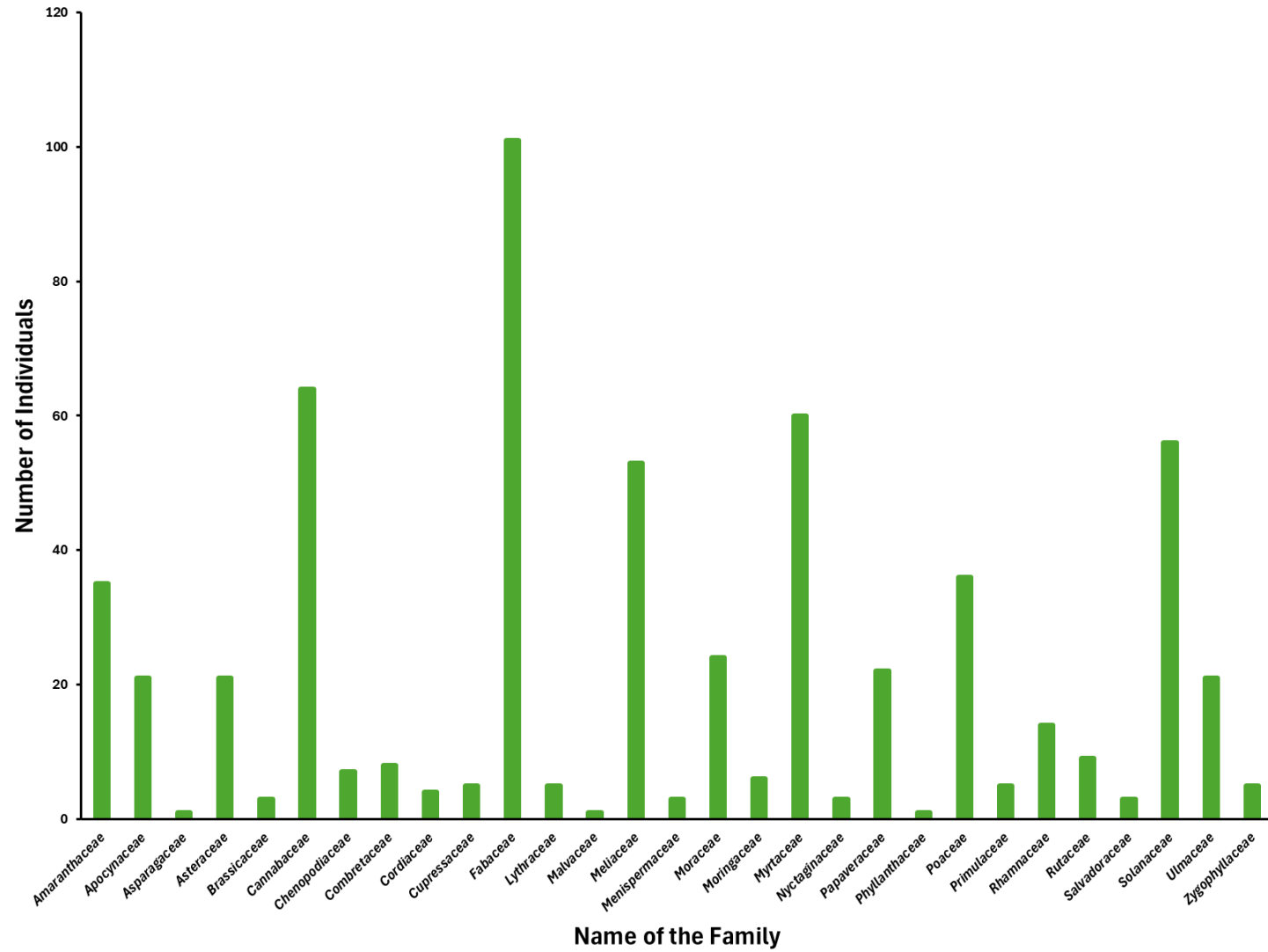


Figure 5.4: Bar chart depicting the distribution of individuals among different plant families in forest ecosystem

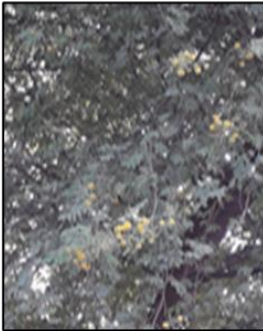
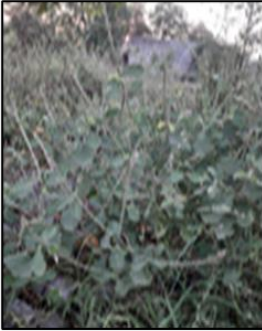
			
<i>Calotropis procera</i> (Aak)	<i>Phyllanthus emblica</i> (Amla)	<i>Psidium guajava</i> (Amrood)	<i>Melia azedarach</i> (Bakain)
			
<i>Ficus benghalensis</i> (Bargad)	<i>Ziziphus mauritiana</i> (Beri)	<i>Parthenium hysterophorus</i> (Congress Grass)	<i>Datura innoxia</i> (Datura)
			
<i>Syzygium cumini</i> (Jamun)	<i>Prosopis cineraria</i> (Janti)	<i>Acacia nilotica</i> (Kikar)	<i>Azadirachta indica</i> (Neem)
			
<i>Ficus religiosa</i> (Pipal)	<i>Achyranthes aspera</i> (Puth kanta)	<i>Eucalyptus globulus</i> (Safeda)	<i>Albizia lebbbeck</i> (Sarinh)



Figure 5.5: Photographs of explored plant species during biodiversity assessment illustrating the diversity of cultural, economically and medicinally important species in forest ecosystems

5.2.2.2. Spatial Variation in Forest Area

The spatial variation analysis of the various sites shows reveals significant differences in plant diversity and the importance of individual species (Table 5.4). Site I (Village Chaharwala Minor) was determined to encompass 21 species, which include species like *Azadirachta indica*, *Calotropis procera*, and *Ficus benghalensis*. These species presence shows their ecological contribution as well as medicinal importance. Next comes the site J (Village Mameran Road) which harbours 20 species and features species like *Cannabis sativa*, *Azadirachta indica*, *Cassia fistula*, *Ficus benghalensis* and *Tinospora cordifolia*, which highlights the medicinal and ecological significance within this site (Carson and Schnitzer 2008). Site K (Panjuana Canal) was determined to be species-dense at in encompasses 27 different plant species. Additionally, it was regarded as significantly important site as it is home of plant species like *Azadirachta indica*, *Datura innoxia*, *Ficus benghalensis* and *Syzygium cumini*. These species have both economical and medicinal value which makes the site K (Panjuana Canal) as a central point of ecological and economical significance within forest region. Site L (Village Nagoki Canal) holds the second position based on the species-density as it encompasses 23 species which includes combination of medicinal and ornamental plants. Among them, *Azadirachta indica*, *Withania somnifera* and *Ziziphus mauritiana* are highly valued for their medicinal value. Similarly, presence of *Holoptelea integrifolia* increase the aesthetic appeal of this site (Aerts and Honnay 2011). Site M (Village Mangiana) which was hosting 16 holds the significance due to

the presence of medicinal plants like *Azadirachta indica*, and *Prosopis juliflora*. Other than medicinal benefits the presence of these species also improves the health of soil. Site N (Ottu Head) harbours 22 species which include plant species like *Azadirachta indica*, *Bougainvillea glabra*, *Holoptelea integrifolia*, *Syzygium cumini* and *Ziziphus mauritiana*, that have both ecological and economic importance (Nautiyal et al. 2010). The diversity at this site shows ecological richness and highlight the importance of conservation. Site O (Abub Sheher Wildlife Sanctuary) and P (Daulatpur Khera) are both home for 21 species that have economical, industrial and medicinal. Site O (Abub Sheher Wildlife Sanctuary) was accorded to encompass plant species like *Azadirachta indica*, *Tinospora cordifolia*, and *Withania somnifera* that are renowned for their medicinal potential (Martinho and Ferreira 2020). Further, the presence of plant species like *Dalbergia sissoo* and *Datura innoxia*, improves their ecological value of the site O (Abub Sheher Wildlife Sanctuary) (Rojas-Sandoval 2023). Lastly, the Site P (Daulatpur Khera) is home for plant species like *Azadirachta indica*, *Calotropis procera*, *Dalbergia sissoo*, *Datura innoxia*, *Morus alba*, and *Syzygium cumini*, having economical, industrial and medicinal value (Salehi et al. 2019).

Overall, this analysis highlights the different level of plant diversity across different sites where few sites were hosting the high numbers of ornamental, medicinal, and economically important species. The *Azadirachta indica* and *Dalbergia sissoo* were determined to be consistently present at all sites. Additionally, the occurrence of *Holoptelea integrifolia*, *Phyllanthus emblica*, and *Withania somnifera* highlights the importance of site in traditional medicine as well as ecology. Site like K (Panjuana Canal), L (Village Nagoki Canal) and N (Ottu Head) were determined to be *highly* diverse and ecologically rich. Whereas, sites like I (Village Chaharwala Minor), J (Village Mameran Road), O (Abub Sheher Wildlife Sanctuary) and P (Daulatpur Khera) presented the mix of ornamental and medicinal plant species with significant ecological roles that contributes to biodiversity and soil health (Mishra et al. 2015; Kaur et al. 2017). The observed difference in species richness and dominance among different sites indicate that forest areas have high diversity. This enhanced diversity contributes to more biomass production and higher carbon sequestration potential as compared to urban areas.

5.3. ECOLOGICAL INDICES (PHYTOSOCIOLOGICAL)

5.3.1. Urban Vegetation

5.3.1.1. Ecological Indices of Urban area

The phytosociological parameters like relative abundance (RA), relative density (RD), relative frequency (RF), importance value index (IVI) and Supremacy Diversity (SDiv) have been calculated for all the species in order to gain insights about species dominance and their ecological significance within urban region (Table 5.3).

1. Relative Abundance (RA %)

Based on the data, *Cannabis sativa* showed RA% of 7.49 which highlights their dominance in the site C (Sirsa Minor) and H (Mini-bypass Sirsa) due to its rapid growth, high environmental tolerance and reproductive ability. These properties of *Cannabis sativa* enable it to thrive in diverse environments. Another species which showed dominance in urban region were determined to be *Tagetes erecta* (RA% = 5.08) in site B (Chaudhary Devi Lal Park) and G (Municipality Park) and *Calotropis procera* (RA% = 4.06) in site D (HUDA Unhabituated Area) and H (Mini-bypass Sirsa). The presence of these species at these sites suggests they have the adaptability to colonize in disturbed areas as well as well-maintained areas. The presence of *Tagetes erecta* in urban region highlights their ornamental and cultural importance and *Calotropis procera* presence highlights their medicinal importance. *Datura innoxia* (RA% = 3.05) also showed the dominance in site C (Sirsa Minor), G (Municipality Park) and H (Mini-bypass Sirsa) showcase their rapid establishment and seed production in crowded areas. Presence of *Holoptelea integrifolia* (in A (Shaheed Bhagat Singh Stadium), B (Chaudhary Devi Lal Park), D (HUDA Unhabituated Area), G (Municipality Park), and H (Mini-bypass Sirsa)) and *Ziziphus mauritiana* (in A (Shaheed Bhagat Singh Stadium), D (HUDA Unhabituated Area), G (Municipality Park), and H (Mini-bypass Sirsa)) with moderate RA % value of 1.83 and 0.64 suggests its significant contribution in the urban ecosystem but the species are not dominant as compared to other species listed in table 5.3. The species like *Acacia catechu*, *Epipremnum aureum*, *Bryophyllum pinnatum*, *Philodendron xanadu*, *Alkanna tinctoria*, *Tecomella undulata*, *Elaeocarpus ganitrus*, *Syngonium podophyllum*, *Grevillea robusta* showed the low RA % of 0.12 signifies the rare and

limited distribution. The species were predominantly found at the site A (Shaheed Bhagat Singh Stadium) or B (Chaudhary Devi Lal Park) or E (Home Garden 1).

2. Relative Density (RD %)

Based on the data, again *Cannabis sativa* showed RD % of 7.35 which makes it the densely distributed species at the site C (Sirsa Minor) and H (Mini-bypass Sirsa) owing to the attributes like robust reproducibility and adaptability to different environmental and soil conditions. *Tagetes erecta* showed RD % of 4.98 which also makes it the second densely distributed species at the site B (Chaudhary Devi Lal Park) and G (Municipality Park) signifying its widespread distribution as well as establishment. *Datura innoxia* and *Holoptelea integrifolia* both were determined to have the RD % of 4.48. *Datura innoxia* presence was recorded at the site C (Sirsa Minor), G (Municipality Park) and H (Mini-bypass Sirsa), whereas *Holoptelea integrifolia* presence was recorded at the site A (Shaheed Bhagat Singh Stadium), B (Chaudhary Devi Lal Park), D (HUDA Unhabituated Area), G (Municipality Park), and H (Mini-bypass Sirsa) highlighting their ability to reproduce rapidly as well as establish their ecological importance. *Calotropis procera* showed RD % of 3.99 and notably accorded their presence at site D (HUDA Unhabituated Area) and H (Mini-bypass Sirsa) contributing to the community in urban region. On the other hand, plant species like *Punica granatum*, *Polyscias fruticose*, *Echinocactus grusonii*, *Manilkara zapota*, *Chukrasia velutina*, *Murraya koenigii*, *Acacia catechu*, *Epipremnum aureum*, *Bryophyllum pinnatum*, *Philodendron xanadu*, *Alkanna tinctoria*, *Tecomella undulata*, *Elaeocarpus ganitrus*, *Syngonium podophyllum* and *Grevillea robusta* were determined to have RD % of 0.12. This lower RD % value signifies that these species are less competitive within the sampling sites.

3. Relative Frequency (RF %)

Based on the data, *Dalbergia sissoo* was determined to have the highest RF % of 3.16 suggesting the presence of this species nearly in every sampling site. This species presence was recorded for site A (Shaheed Bhagat Singh Stadium), B (Chaudhary Devi Lal Park), C (Sirsa Minor), D (HUDA Unhabituated Area), G (Municipality Park), and H (Mini-bypass Sirsa) indicating that it can thrive in diverse habitats. Followed by plant species like *Holoptelea integrifolia*, *Saraca asoca*, *Azadirachta indica* and *Syzygium cumini* that have been recorded to have the RF % of 2.63. This

value also suggests the presence of this species in most of the sampling site and highlight their ecological importance. The plant species like *Cannabis sativa*, *Tagetes erecta*, *Calotropis procera*, *Moringa oleifera*, *Citrus × limon*, *Ficus racemose* and *Tinospora cordifolia* were determined to have moderate RF % of 1.05. This RF % value signifies their notable presence and highlight their ecological role within urban ecosystem. *Bougainvillea glabra*, *Terminalia arjuna*, *Phyllanthus emblica*, *Acacia catechu* and *Tecomella undulata* were determined to have lowest RF % of 0.12 suggesting their limited as well as localized habitat preferences.

4. Importance Value Index (IVI)

Based on the data, again *Cannabis sativa* was determined to have the highest value of IVI, i.e., 15.89 suggesting its ecological dominance. This species plays critical role at the sites C (Sirsa Minor) and H (Mini-bypass Sirsa). The plant species like *Tagetes erecta*, *Datura innoxia* and *Calotropis procera* were determined to have the IVI value of 11.11, 9.11 and 9.1 respectively indicating it to be significant contributor at the sites like B (Chaudhary Devi Lal Park), C (Sirsa Minor), D (HUDA Unhabitated Area), G (Municipality Park) and H (Mini-bypass Sirsa). This IVI value suggest their high abundance, density, and frequency making them the important species of urban ecosystem. *Holoptelea integrifolia*, *Tabernaemontana divaricate*, *Ricinus communis* and *Dalbergia sissoo* were determined to have IVI value of 8.94, 7.93, 7.86 and 7.16 respectively. These IVI values highlight the importance of these plant species in the community structure. The plant species like *Punica granatum*, *Polyscias fruticose*, *Echinocactus grusonii*, *Manilkara zapota*, *Chukrasia velutina*, *Murraya koenigii*, *Acacia catechu*, *Epipremnum aureum*, *Bryophyllum pinnatum*, *Philodendron xanadu*, *Alkanna tinctoria*, *Tecomella undulata*, *Elaeocarpus ganitrus*, *Syngonium podophyllum* and *Grevillea robusta* were determined to have low IVI value of 0.9. This low IVI value suggests that these plant species are less abundant, less dense and less frequently found within urban ecosystem. Hence, it indicates that they have very low impact or influence on the overall urban ecosystem.

5. Supremacy Diversity (SDiv)

Based on the data, *Cannabis sativa* leads in supremacy diversity (SDiv) value of 1.2 suggesting its dominance at the site C (Sirsa Minor) and H (Mini-bypass Sirsa). The high value of SDiv for *Cannabis sativa* highlights its competitive nature and dense

population within urban ecosystem (Wartenberg et al. 2021). *Tagetes erecta* was determined to hold the second position with SDiv value of 1.05 showing its dominance at the site B (Chaudhary Devi Lal Park) and G (Municipality Park) (McKinney 2006). Both *Datura innoxia* and *Calotropis procera* were determined to SDiv value of 0.96 also suggesting the strong dominance of these species. The dominance of *Datura innoxia* was accorded for the site B (Chaudhary Devi Lal Park) and G (Municipality Park), whereas, *Calotropis procera* dominance was accorded for the site C (Sirsa Minor), G (Municipality Park) and H (Mini-bypass Sirsa). These value highlights the substantial role of these plant species in shaping the urban ecosystem (Yang et al. 2023a). Plant species like *Prosopis juliflora* and *Albizia lebbeck* were determined to have mid-range SDiv value of 0.45 indicating their moderate presence and highlighting their ecological importance within urban ecosystem (Zhang et al. 2012a). Further, plant species like *Tradescantia pallida*, *Punica granatum*, *Polyscias fruticose*, *Echinocactus grusonii*, *Manilkara zapota*, *Chukrasia velutina*, *Murraya koenigii*, *Acacia catechu*, *Epipremnum aureum*, *Bryophyllum pinnatum*, *Philodendron xanadu*, *Alkanna tinctoria*, *Tecomella undulata*, *Elaeocarpus ganitrus*, *Syngonium podophyllum* and *Grevillea robusta* were determined to have very low value of SDiv, i.e., -0.04 suggesting that they have minimal influence on the urban community structure (Shochat et al. 2010).

Table 5.3: Phytosociological Parameters analysis of eight Urban sites of Sirsa Region according to APG IV guidelines

Order	Family	Botanical Name	No. of Sites & Code	Den	Fr	Ab	Ab/Fr Ratio	RD %	RF %	RA %	IVI	SDiv
<i>Alismatales</i>	<i>Araceae</i>	<i>Epipremnum aureum</i>	E (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
		<i>Monstera deliciosa</i>	E (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22
		<i>Philodendron xanadu</i>	E (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
		<i>Syngonium podophyllum</i>	E (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
<i>Apiales</i>	<i>Araliaceae</i>	<i>Polyscias fruticosa</i>	A (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
<i>Arecales</i>	<i>Arecaceae</i>	<i>Dypsis lutescens</i>	B, D, E (3)	1.13	37.5	3.00	0.08	1.12	1.58	0.76	3.46	0.54
		<i>Trachycarpus fortunei</i>	C, E (2)	1.00	25.0	4.00	0.16	1.00	1.05	1.02	3.07	0.49

<i>Asparagales</i>	<i>Asphodelaceae</i>	<i>Aloe barbadensis</i>	E, F, G (3)	1.00	37.5	2.67	0.07	1.00	1.58	0.68	3.25	0.51
	<i>Asparagaceae</i>	<i>Agave desmettiana</i>	E, F (2)	0.63	25.0	2.50	0.10	0.62	1.05	0.64	2.31	0.36
		<i>Beaucarnea recurvata</i>	E (1)	0.25	12.5	2.00	0.16	0.25	0.53	0.51	1.28	0.11
		<i>Chlorophytum comosum</i>	E, F (2)	0.75	25.0	3.00	0.12	0.75	1.05	0.76	2.56	0.41
		<i>Dracaena angolensis</i>	E, F (2)	1.00	25.0	4.00	0.16	1.00	1.05	1.02	3.07	0.49
		<i>Dracaena trifasciata</i>	E, F (2)	1.38	25.0	5.50	0.22	1.37	1.05	1.40	3.82	0.58
<i>Asterales</i>	<i>Asteraceae</i>	<i>Chrysanthemum indicum</i>	A, B (2)	0.88	25.0	3.50	0.14	0.87	1.05	0.89	2.81	0.45
		<i>Dahlia pinnata</i>	B (1)	0.50	12.5	4.00	0.32	0.50	0.53	1.02	2.04	0.31
		<i>Parthenium hysterophorus</i>	C, H (2)	1.50	25.0	6.00	0.24	1.49	1.05	1.52	4.07	0.61

		<i>Tagetes erecta</i>	B, G (2)	5.00	25.0	20.00	0.80	4.98	1.05	5.08	11.1 1	1.05
<i>Boraginales</i>	<i>Cordiaceae</i>	<i>Cordia dichotoma</i>	D (1)	0.25	12.5	2.00	0.16	0.25	0.53	0.51	1.28	0.11
<i>Caryophyllales</i>	<i>Amaranthaceae</i>	<i>Achyranthes aspera</i>	H (1)	0.75	12.5	6.00	0.48	0.75	0.53	1.52	2.80	0.45
		<i>Aerva javanica</i>	C, D, H (3)	1.38	37.5	3.67	0.10	1.37	1.58	0.93	3.88	0.59
		<i>Amaranthus hypochondriacus</i>	C, H (2)	0.88	25.0	3.50	0.14	0.87	1.05	0.89	2.81	0.45
	<i>Cactaceae</i>	<i>Echinocactus grusonii</i>	E (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
	<i>Menispermaceae</i>	<i>Tinospora cordifolia</i>	G, E (2)	0.38	25.0	1.50	0.06	0.37	1.05	0.38	1.81	0.26
<i>Commelinales</i>	<i>Commelinaceae</i>	<i>Tradescantia pallida</i>	E (1)	0.25	12.5	2.00	0.16	0.25	0.53	0.51	1.28	0.11
		<i>Tradescantia zebrina</i>	E (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22

<i>Cycadales</i>	<i>Cycadaceae</i>	<i>Cycas revoluta</i>	C, D (2)	0.63	25.0	2.50	0.10	0.62	1.05	0.64	2.31	0.36
<i>Euphorbiales</i>	<i>Euphorbiaceae</i>	<i>Ricinus communis</i>	C, D, H (3)	3.75	37.5	10.00	0.27	3.74	1.58	2.54	7.86	0.90
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia cetechu</i>	A (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
		<i>Albizia lebbeck</i>	B, C, D (3)	0.75	37.5	2.00	0.05	0.75	1.58	0.51	2.83	0.45
		<i>Bauhinia variegata</i>	A, B (2)	0.63	25.0	2.50	0.10	0.62	1.05	0.64	2.31	0.36
		<i>Cassia fistula</i>	A, B, D, G (4)	1.00	50.0	2.00	0.04	1.00	2.11	0.51	3.61	0.56
		<i>Dalbergia sissoo</i>	A, B, C, D, G, H (6)	3.00	75.0	4.00	0.05	2.99	3.16	1.02	7.16	0.86
		<i>Delonix regia</i>	A (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22
		<i>Prosopis cineraria</i>	A, C, G, H (4)	0.50	50.0	1.00	0.02	0.50	2.11	0.25	2.86	0.46
		<i>Prosopis juliflora</i>	C, D, H (3)	0.75	37.5	2.00	0.05	0.75	1.58	0.51	2.83	0.45
		<i>Saraca asoca</i>	A, B, D, E,	2.50	62.5	4.00	0.06	2.49	2.63	1.02	6.14	0.79

			F (5)									
		<i>Vachellia nilotica</i>	A, C, H (3)	3.00	37.5	8.00	0.21	2.99	1.58	2.03	6.60	0.82
<i>Gentianales</i>	<i>Apocynaceae</i>	<i>Alstonia scholaris</i>	A, B (2)	0.63	25.0	2.50	0.10	0.62	1.05	0.64	2.31	0.36
		<i>Calotropis procera</i>	D, H (2)	4.00	25.0	16.00	0.64	3.99	1.05	4.06	9.10	0.96
		<i>Catharanthus roseus</i>	A, B, E (3)	2.63	37.5	7.00	0.19	2.62	1.58	1.78	5.97	0.78
		<i>Nerium oleander</i>	A, B, D, H (4)	3.13	50.0	6.25	0.13	3.11	2.11	1.59	6.81	0.83
		<i>Tabernaemontana divaricata</i>	A, B, E, F (4)	3.88	50.0	7.75	0.16	3.86	2.11	1.97	7.93	0.90
<i>Lamiales</i>	<i>Bignoniaceae</i>	<i>Kigelia africana</i>	D, H (2)	0.50	25.0	2.00	0.08	0.50	1.05	0.51	2.06	0.31
		<i>Tecoma stans</i>	A (1)	0.63	12.5	5.00	0.40	0.62	0.53	1.27	2.42	0.38
		<i>Tecomella undulata</i>	B (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04

	<i>Oleaceae</i>	<i>Jasminum arborescens</i>	A, E (2)	0.50	25.0	2.00	0.08	0.50	1.05	0.51	2.06	0.31
		<i>Jasminum sambac</i>	F (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22
		<i>Nyctanthes arbor-tristis</i>	A (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22
<i>Magnoliales</i>	<i>Magnoliaceae</i>	<i>Magnolia champaca</i>	A, B (2)	1.25	25.0	5.00	0.20	1.25	1.05	1.27	3.57	0.55
<i>Malpighiales</i>	<i>Elaeocarpaceae</i>	<i>Elaeocarpus ganitrus</i>	E (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
	<i>Euphorbiaceae</i>	<i>Codiaeum variegatum</i>	F (1)	0.63	12.5	5.00	0.40	0.62	0.53	1.27	2.42	0.38
		<i>Jatropha curcas</i>	A (1)	0.75	12.5	6.00	0.48	0.75	0.53	1.52	2.80	0.45
	<i>Phyllanthaceae</i>	<i>Phyllanthus emblica</i>	G (1)	0.25	12.5	2.00	0.16	0.25	0.53	0.51	1.28	0.11
<i>Malvales</i>	<i>Malvaceae</i>	<i>Hibiscus rosa-sinensis</i>	B (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22

		<i>Pterospermum acerifolium</i>	A (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa oleifera</i>	A, B (2)	0.63	25.0	2.50	0.10	0.62	1.05	0.64	2.31	0.36
<i>Myrtales</i>	<i>Combretaceae</i>	<i>Terminalia arjuna</i>	A (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22
	<i>Lythraceae</i>	<i>Punica granatum</i>	G (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
	<i>Myrtaceae</i>	<i>Callistemon citrinus</i>	A, B (2)	0.88	25.0	3.50	0.14	0.87	1.05	0.89	2.81	0.45
		<i>Eucalyptus globulus</i>	C (1)	1.38	12.5	11.00	0.88	1.37	0.53	2.79	4.69	0.67
		<i>Psidium guajava</i>	C, G (2)	0.50	25.0	2.00	0.08	0.50	1.05	0.51	2.06	0.31
		<i>Syzygium cumini</i>	A, B, C, G, H (5)	1.00	62.5	1.60	0.03	1.00	2.63	0.41	4.03	0.61
<i>Pinales</i>	<i>Araucariaceae</i>	<i>Araucaria araucana</i>	E, F (2)	0.38	25.0	1.50	0.06	0.37	1.05	0.38	1.81	0.26
	<i>Cupressaceae</i>	<i>Platycladus</i>	F (1)	0.25	12.5	2.00	0.16	0.25	0.53	0.51	1.28	0.11

		<i>orientalis</i>										
	<i>Pinaceae</i>	<i>Pinus roxburghii</i>	B (1)	0.25	12.5	2.00	0.16	0.25	0.53	0.51	1.28	0.11
<i>Poales</i>	<i>Poaceae</i>	<i>Phalaris minor</i>	C (1)	0.50	12.5	4.00	0.32	0.50	0.53	1.02	2.04	0.31
		<i>Saccharum spontaneum</i>	C (1)	0.63	12.5	5.00	0.40	0.62	0.53	1.27	2.42	0.38
<i>Proteales</i>	<i>Proteaceae</i>	<i>Grevillea robusta</i>	A (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
<i>Ranunculales</i>	<i>Papaveraceae</i>	<i>Papaver somniferum</i>	B (1)	0.63	12.5	5.00	0.40	0.62	0.53	1.27	2.42	0.38
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	A, D, G, H (4)	1.25	50.0	2.50	0.05	1.25	2.11	0.64	3.99	0.60
<i>Rosales</i>	<i>Cannabaceae</i>	<i>Cannabis sativa</i>	C, H (2)	7.38	25.0	29.50	1.18	7.35	1.05	7.49	15.8 9	1.20
	<i>Moraceae</i>	<i>Ficus benjamina</i>	A, B, C (3)	1.50	37.5	4.00	0.11	1.49	1.58	1.02	4.09	0.61
		<i>Ficus racemose</i>	A, D (2)	0.38	25.0	1.50	0.06	0.37	1.05	0.38	1.81	0.26
		<i>Ficus religiosa</i>	A, B, C, H	1.50	50.0	3.00	0.06	1.49	2.11	0.76	4.36	0.64

			(4)									
		<i>Morus alba</i>	A, C, G (3)	0.50	37.5	1.33	0.04	0.50	1.58	0.34	2.42	0.38
	<i>Rosaceae</i>	<i>Prunus persica</i>	D (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22
		<i>Rosa indica</i>	B, G (2)	1.75	25.0	7.00	0.28	1.74	1.05	1.78	4.57	0.66
		<i>Rosa rubigionosa</i>	E (1)	0.25	12.5	2.00	0.16	0.25	0.53	0.51	1.28	0.11
	<i>Ulmaceae</i>	<i>Holoptelea integrifolia</i>	A, B, D, G, H (5)	4.50	62.5	7.20	0.12	4.48	2.63	1.83	8.94	0.95
<i>Sapindales</i>	<i>Anacardiaceae</i>	<i>Mangifera indica</i>	B, G (2)	0.25	25.0	1.00	0.04	0.25	1.05	0.25	1.56	0.19
	<i>Meliaceae</i>	<i>Azadirachta indica</i>	A, B, C, G, H (5)	1.88	62.5	3.00	0.05	1.87	2.63	0.76	5.26	0.72
		<i>Chukrasia velutina</i>	A (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
		<i>Melia azedarach</i>	A, C, G (3)	0.63	37.5	1.67	0.04	0.62	1.58	0.42	2.63	0.42
	<i>Rutaceae</i>	<i>Aegle marmelos</i>	B, E (2)	0.25	25.0	1.00	0.04	0.25	1.05	0.25	1.56	0.19

		<i>Citrus × limon</i>	D, G (2)	0.50	25.0	2.00	0.08	0.50	1.05	0.51	2.06	0.31
		<i>Murraya koenigii</i>	E (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
<i>Sapotales</i>	<i>Sapotaceae</i>	<i>Manilkara zapota</i>	G (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
<i>Saxifragales</i>	<i>Crassulaceae</i>	<i>Bryophyllum pinnatum</i>	E (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
<i>Solanales</i>	<i>Boraginaceae</i>	<i>Alkanna tinctoria</i>	A (1)	0.13	12.5	1.00	0.08	0.12	0.53	0.25	0.90	-0.04
	<i>Convolvulaceae</i>	<i>Cuscuta reflexa</i>	D (1)	0.25	12.5	2.00	0.16	0.25	0.53	0.51	1.28	0.11
	<i>Nyctaginaceae</i>	<i>Bougainvillea glabra</i>	D (1)	2.00	12.5	16.00	1.28	1.99	0.53	4.06	6.58	0.82
		<i>Bougainvillea peruviana</i>	D (1)	0.88	12.5	7.00	0.56	0.87	0.53	1.78	3.18	0.50
	<i>Solanaceae</i>	<i>Capsicum annuum</i>	E (1)	0.25	12.5	2.00	0.16	0.25	0.53	0.51	1.28	0.11
		<i>Datura innoxia</i>	C, G, H (3)	4.50	37.5	12.00	0.32	4.48	1.58	3.05	9.11	0.96
		<i>Petunia ×</i>	B, F (2)	0.38	25.0	1.50	0.06	0.37	1.05	0.38	1.81	0.26

		<i>atkinsiana</i>										
		<i>Withania somnifera</i>	C, H (2)	1.25	25.0	5.00	0.20	1.25	1.05	1.27	3.57	0.55
<i>Zingiberales</i>	<i>Cannaceae</i>	<i>Canna lily</i>	D (1)	1.63	12.5	13.00	1.04	1.62	0.53	3.30	5.45	0.74
	<i>Musaceae</i>	<i>Musa paradisiaca</i>	G (1)	0.38	12.5	3.00	0.24	0.37	0.53	0.76	1.66	0.22

*Den: Density; Fr: Frequency; Ab: Abundance; Ab/Fr Ratio; RD %: Relative Density %; RF: Relative Frequency %; RA%: Relative Abundance %; IVI: Importance Value Index; SDiv: Supremacy Diversity; A: Shaheed Bhagat Singh Stadium; B: Chaudhary Devi Lal Park; C: Sirsa Minor; D: HUDA Unhabituated Area; E: Home Garden 1; F: Home Garden 2; G: Municipality Park; H: Mini-bypass Sirsa.

5.3.2. Forest Vegetation

5.3.2.1. Ecological Indices

The phytosociological parameters like relative abundance (RA), relative density (RD), relative frequency (RF), importance value index (IVI) and Supremacy Diversity (SDiv) have been calculated for all the species in order to gain insights about species dominance and their ecological significance within forest region (Table 5.4).

1. Relative Abundance (RA %)

Based on the data, *Cannabis sativa* showed RA% of 6.05 which highlights their dominance in the site J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), M (Village Mangiana), N (Ottu Head), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera) owing to its attributes like rapid growth and reproductive ability as well as high environmental tolerance potential. These properties of *Cannabis sativa* enable it to thrive in diverse environments (Sorrentino 2021). Another species which showed dominance in forest region were determined to be *Eucalyptus globulus* (RA% = 4.25) in site J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), M (Village Mangiana), N (Ottu Head), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera) and *Azadirachta indica* (RA% = 3.97) in all the site. The presence of these species at these sites suggests they have the adaptability to colonize in disturbed as well as well-maintained areas (Kumar and Navaratnam 2013). The presence of *Eucalyptus globulus* in forest region highlights its ecological importance and *Azadirachta indica* presence highlights its medicinal importance. *Datura innoxia* (RA% = 3.44) also showed the dominance in site I (Village Chaharwala Minor), K (Panjuana Canal), L (Village Nagoki Canal), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera) showcase their rapid establishment and seed production. Presence of *Albizia lebbeck* (in J (Village Mameran Road), K (Panjuana Canal), M (Village Mangiana), N (Ottu Head), and O (Abub Sheher Wildlife Sanctuary)) and *Ziziphus mauritiana* (in I (Village Chaharwala Minor), J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), N (Ottu Head), and O (Abub Sheher Wildlife Sanctuary)) with moderate RA % value of 1.59 and 1.54 suggests its significant contribution in the forest ecosystem. Even though these species are not dominant in contrast to other species listed in table 5.4. The species like *Cassia fistula*, *Phyllanthus emblica*, *Psidium guajava*,

Clitoria ternatea, *Ficus benghalensis*, *Taraxacum officinale*, *Abutilon indicum*, *Avena fatua*, *Prosopis cineraria*, *Nerium oleander*, *Ficus religiosa*, *Catharanthus roseus*, *Asparagus racemosus* showed the low RA % of 0.66 signifies the rare and limited distribution. The species were predominantly found at the site J (Village Mameran Road) or K (Panjuana Canal) or N (Ottu Head) or O (Abub Sheher Wildlife Sanctuary).

2. Relative Density (RD %)

Based on the data, again *Cannabis sativa* showed RD % of 10.72 which makes it the densely distributed species at the site J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), M (Village Mangiana), N (Ottu Head), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera) owing to the traits like adaptability to different environmental, rapid reproducibility and soil conditions. *Azadirachta indica* showed RD % of 8.04 which also makes it the second densely distributed species at all the site signifying its widespread distribution as well as establishment. *Calotropis procera* and *Parthenium hysterophorus* both were determined to have the RD % of 3.18. *Calotropis procera* presence was recorded at the site I (Village Chaharwala Minor), K (Panjuana Canal), L (Village Nagoki Canal), and P (Daulatpur Khera), whereas *Parthenium hysterophorus* presence was recorded at the site I (Village Chaharwala Minor), J (Village Mameran Road), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera) highlighting their ability to reproduce rapidly as well as establish their ecological importance (Sorrentino 2021). Both *Syzygium cumini* and *Ziziphus mauritiana* showed RD % of 2.35 and notably accorded their presence at site J (Village Mameran Road), K (Panjuana Canal), M (Village Mangiana), N (Ottu Head), and P (Daulatpur Khera) for *Syzygium cumini* and I (Village Chaharwala Minor), J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), N (Ottu Head), and O (Abub Sheher Wildlife Sanctuary) for *Ziziphus mauritiana* contributing to the community in forest region. On the other hand, plant species like *Cassia fistula*, *Phyllanthus emblica*, *Psidium guajava*, *Clitoria ternatea*, *Abutilon indicum*, *Avena fatua*, *Nerium oleander*, *Catharanthus roseus* and *Asparagus racemosus* were determined to have RD % of 0.17. This lower RD % value signifies that these species are less competitive within the sampling sites (Kumar and Navaratnam 2013).

3. Relative Frequency (RF %)

Based on the data, *Azadirachta indica* was determined to have the highest RF % of 4.68 suggesting the presence of this species nearly in every sampling site. This species presence was recorded for site I (Village Chaharwala Minor), J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), M (Village Mangiana), N (Ottu Head), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera) indicating that it can thrive in diverse habitats (Rojas-Sandoval and Acevedo-Rodríguez 2014). Followed by plant species like *Cannabis sativa*, *Eucalyptus globulus*, *Achyranthes aspera*, *Dalbergia sissoo* and *Argemone mexicana* that have been recorded to have the RF % of 4.09. This value suggests the presence of this species in most of the sampling site and highlight their ecological importance. The plant species like *Datura stramonium*, *Digitaria sanguinalis* and *Zanthoxylum armatum* were determined to have moderate RF % of 1.75. This RF % value signifies their notable presence and highlight their ecological role within forest ecosystem. *Asparagus racemosus*, *Bougainvillea glabra*, *Cassia fistula*, *Catharanthus roseus*, *Ficus racemose*, *Nerium oleander*, *Phyllanthus emblica*, *Psidium guajava* and *Thuja occidentalis* were determined to have lowest RF % of 0.58 suggesting their limited as well as localized habitat preferences.

4. Importance Value Index (IVI)

Based on the data, again *Cannabis sativa* was determined to have the highest value of IVI, i.e., 20.87 suggesting its ecological dominance. This species plays critical role at the sites J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), M (Village Mangiana), N (Ottu Head), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera) (Fordjour et al. 2023). The plant species like *Azadirachta indica*, *Eucalyptus globulus*, *Achyranthes aspera*, *Prosopis juliflora* and *Acacia nilotica* were determined to have the IVI value of 16.69, 15.89, 12.48, 12.12 and 11.01 respectively indicating it to be significant contributor at the sites like I (Village Chaharwala Minor), J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), M (Village Mangiana), N (Ottu Head), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera). This IVI value suggest their high abundance, density, and frequency making them the important species of forest ecosystem. *Datura innoxia*, *Dalbergia sissoo*, *Argemone Mexicana*, *Holoptelea integrifolia* and *Calotropis procera* were determined to have IVI value of 10.72, 10.64, 9.86, 9.22 and 8.67

respectively. These IVI values highlight the importance of these plant species in the community structure. The plant species like *Cassia fistula*, *Phyllanthus emblica*, *Psidium guajava*, *Clitoria ternatea*, *Abutilon indicum*, *Avena fatua*, *Nerium oleander*, *Catharanthus roseus* and *Asparagus racemosus* were determined to have low IVI value of 1.41. This low IVI value suggests that these plant species are less abundant, less dense and less frequently found within forest ecosystem. Hence, it indicates that they have very low impact or influence on the overall forest ecosystem.

5. Supremacy Diversity (SDiv)

Based on the data, *Cannabis sativa* leads in supremacy diversity (SDiv) value of 1.32 suggesting its dominance at the site J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), M (Village Mangiana), N (Ottu Head), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera). The high value of SDiv for *Cannabis sativa* highlights its competitive nature and dense population within forest ecosystem (Small 2015). *Azadirachta indica* was determined to hold the second position with SDiv value of 1.22 showing its dominance at all the sites. *Eucalyptus globulus* and *Achyranthes aspera* were determined to SDiv value of 1.22 and 1.2 respectively, suggesting the strong dominance of these species (Florence 2004). The dominance of *Eucalyptus globulus* was accorded for the site J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), M (Village Mangiana), N (Ottu Head), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera), whereas, *Achyranthes aspera* dominance was accorded for the site I (Village Chaharwala Minor), J (Village Mameran Road), K (Panjuana Canal), L (Village Nagoki Canal), M (Village Mangiana), O (Abub Sheher Wildlife Sanctuary), and P (Daulatpur Khera). These value highlights the substantial role of these plant species in shaping the forest ecosystem (Pandey 2007). Plant species like *Ficus religiosa* and *Moringa oleifera* were determined to have mid-range SDiv value of 0.65 and 0.62 respectively, indicating their moderate presence and highlighting their ecological importance within forest ecosystem. Further, plant species like *Cassia fistula*, *Phyllanthus emblica*, *Psidium guajava*, *Clitoria ternatea*, *Abutilon indicum*, *Avena fatua*, *Nerium oleander*, *Catharanthus roseus* and *Asparagus racemosus* were determined to have very low value of SDiv, i.e., 0.15 suggesting that they have minimal influence on the forest community structure (Sharma and Raghubanshi 2009).

Table 5.4: Phytosociological Parameters analysis of eight forest sites of Sirsa Region according to APG IV guidelines

Order	Family	Botanical Name	No. of Sites & Code	Den	Fr	Ab	Ab/Fr ratio	RD %	RF %	RA %	IVI	SDiv
<i>Amaranthales</i>	<i>Amaranthaceae</i>	<i>Achyranthes aspera</i>	I, J, K, L, M, O, P (7)	4.00	87.5	4.57	0.05	5.36	4.09	3.03	12.48	1.10
		<i>Amaranthus viridis</i>	I, P (2)	0.38	25	1.5	0.06	0.50	1.17	0.99	2.66	0.43
<i>Asparagales</i>	<i>Asparagaceae</i>	<i>Asparagus racemosus</i>	L (1)	0.13	12.5	1	0.08	0.17	0.58	0.66	1.41	0.15
<i>Asterales</i>	<i>Asteraceae</i>	<i>Parthenium hysterophorus</i>	I, J, O, P (4)	2.38	50	4.75	0.10	3.18	2.34	3.14	8.67	0.94
		<i>Taraxacum officinale</i>	I, K (2)	0.25	25	1	0.04	0.34	1.17	0.66	2.17	0.34
<i>Boraginales</i>	<i>Cordiaceae</i>	<i>Cordia dichotoma</i>	P (1)	0.50	12.5	4	0.32	0.67	0.58	2.65	3.90	0.59
<i>Brassicales</i>	<i>Brassicaceae</i>	<i>Descurainia sophia</i>	O (1)	0.38	12.5	3	0.24	0.50	0.58	1.99	3.07	0.49

<i>Caryophyllales</i>	<i>Chenopodiaceae</i>	<i>Chenopodium album</i>	L, N, P (4)	0.88	50	1.75	0.04	1.17	2.34	1.16	4.67	0.67
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia nilotica</i>	I, J, K, L, N, P (6)	3.38	75	4.5	0.06	4.52	3.51	2.98	11.0 1	1.04
		<i>Albizia lebbeck</i>	J, K, M, N, O (5)	1.50	62.5	2.4	0.04	2.01	2.92	1.59	6.52	0.81
		<i>Cassia fistula</i>	K (1)	0.13	12.5	1	0.08	0.17	0.58	0.66	1.41	0.15
		<i>Clitoria ternatea</i>	O (1)	0.13	12.5	1	0.08	0.17	0.58	0.66	1.41	0.15
		<i>Dalbergia sissoo</i>	I, K, L, M, N, O, P (7)	3.13	87.5	3.57	0.04	4.19	4.09	2.36	10.6 4	1.03
		<i>Prosopis cineraria</i>	I, K, M, N (4)	0.50	50	1	0.02	0.67	2.34	0.66	3.67	0.56

		<i>Prosopis juliflora</i>	J, K, L, M, O, P (6)	3.88	75	5.17	0.07	5.19	3.51	3.42	12.1 2	1.08
<i>Gentianales</i>	<i>Apocynaceae</i>	<i>Calotropis procera</i>	I, K, L, P (4)	2.38	50	4.75	0.10	3.18	2.34	3.14	8.67	0.94
		<i>Catharanthus roseus</i>	L (1)	0.13	12.5	1	0.08	0.17	0.58	0.66	1.41	0.15
		<i>Nerium oleander</i>	N (1)	0.13	12.5	1	0.08	0.17	0.58	0.66	1.41	0.15
	<i>Menispermaceae</i>	<i>Tinospora cordifolia</i>	J, O (2)	0.38	25	1.5	0.06	0.50	1.17	0.99	2.66	0.43
<i>Malpighiales</i>	<i>Phyllanthaceae</i>	<i>Phyllanthus emblica</i>	J (1)	0.13	12.5	1	0.08	0.17	0.58	0.66	1.41	0.15
<i>Malvales</i>	<i>Malvaceae</i>	<i>Abutilon indicum</i>	N (1)	0.13	12.5	1	0.08	0.17	0.58	0.66	1.41	0.15
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa oleifera</i>	J, K (2)	0.75	25	3	0.12	1.01	1.17	1.99	4.16	0.62
<i>Myrtales</i>	<i>Combretaceae</i>	<i>Terminalia arjuna</i>	J, K (2)	0.63	25	2.5	0.10	0.84	1.17	1.65	3.66	0.56
		<i>Terminalia bellirica</i>	K (1)	0.38	12.5	3	0.24	0.50	0.58	1.99	3.07	0.49
	<i>Lythraceae</i>	<i>Lawsonia inermis</i>	N (1)	0.63	12.5	5	0.40	0.84	0.58	3.31	4.73	0.68

	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	J, K, L, M, N, O, P (7)	5.63	87.5	6.43	0.07	7.54	4.09	4.25	15.8 9	1.20
		<i>Psidium guajava</i>	O (1)	0.13	12.5	1	0.08	0.17	0.58	0.66	1.41	0.15
		<i>Syzygium cumini</i>	J, K, M, N, P (5)	1.75	62.5	2.8	0.04	2.35	2.92	1.85	7.12	0.85
	<i>Nyctaginaceae</i>	<i>Bougainvillea glabra</i>	N (1)	0.38	12.5	3	0.24	0.50	0.58	1.99	3.07	0.49
<i>Pinales</i>	<i>Cupressaceae</i>	<i>Thuja occidentalis</i>	N (1)	0.63	12.5	5	0.40	0.84	0.58	3.31	4.73	0.68
<i>Poales</i>	<i>Poaceae</i>	<i>Avena fatua</i>	I (1)	0.13	12.5	1	0.08	0.17	0.58	0.66	1.41	0.15
		<i>Cenchrus biflorus</i>	I, L (2)	0.88	25	3.5	0.14	1.17	1.17	2.32	4.66	0.67
		<i>Digitaria sanguinalis</i>	I, L, M (3)	1.25	37.5	3.33	0.09	1.68	1.75	2.21	5.64	0.75
		<i>Echinochloa crus-galli</i>	K, L, M, O	2.25	50	4.5	0.09	3.02	2.34	2.98	8.33	0.92

			(4)									
<i>Primulales</i>	<i>Primulaceae</i>	<i>Anagallis arvensis</i>	I, K (2)	0.63	25	2.5	0.10	0.84	1.17	1.65	3.66	0.56
<i>Ranunculales</i>	<i>Papaveraceae</i>	<i>Argemone mexicana</i>	I, J, K, L, N, O, P (7)	2.75	87.5	3.14	0.04	3.69	4.09	2.08	9.86	0.99
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	I, J, K, L, N, O (6)	1.75	75	2.33	0.03	2.35	3.51	1.54	7.40	0.87
<i>Rosales</i>	<i>Cannabaceae</i>	<i>Cannabis sativa</i>	J, K, L, M, N, O, P (7)	8.00	87.5	9.14	0.10	10.7 2	4.09	6.05	20.8 7	1.32
	<i>Moraceae</i>	<i>Ficus benghalensis</i>	I, J, K, O (4)	0.50	50	1	0.02	0.67	2.34	0.66	3.67	0.56
		<i>Ficus racemose</i>	O (1)	0.25	12.5	2	0.16	0.34	0.58	1.32	2.24	0.35
		<i>Ficus religiosa</i>	I, J, K,	0.63	62.5	1	0.02	0.84	2.92	0.66	4.42	0.65

			N, P (5)									
		<i>Morus alba</i>	J, K, L, M, N, P (6)	1.63	75	2.17	0.03	2.18	3.51	1.43	7.12	0.85
	<i>Ulmaceae</i>	<i>Holoptelea integrifolia</i>	K, L, M, N, P (5)	2.63	62.5	4.2	0.07	3.52	2.92	2.78	9.22	0.96
<i>Salvadorales</i>	<i>Salvadoraceae</i>	<i>Salvadora oleoides</i>	O (1)	0.38	12.5	3	0.24	0.50	0.58	1.99	3.07	0.49
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	I, J, K, L, M, N, O, P (8)	6.00	100	6	0.06	8.04	4.68	3.97	16.6 9	1.22
		<i>Melia azedarach</i>	I, J, L, P (4)	0.63	50	1.25	0.03	0.84	2.34	0.83	4.00	0.60
	<i>Rutaceae</i>	<i>Zanthoxylum armatum</i>	M, N, O (3)	1.13	37.5	3	0.08	1.51	1.75	1.99	5.25	0.72

<i>Solanales</i>	<i>Solanaceae</i>	<i>Datura innoxia</i>	I, K, L, O, P (5)	3.25	62.5	5.2	0.08	4.36	2.92	3.44	10.7 2	1.03
		<i>Datura stramonium</i>	L, M, N (3)	1.63	37.5	4.33	0.12	2.18	1.75	2.87	6.80	0.83
		<i>Solanum dulcamara</i>	K, L, M, N, P (5)	1.13	62.5	1.8	0.03	1.51	2.92	1.19	5.62	0.75
		<i>Withania somnifera</i>	J, L, O, P (4)	1.00	50	2	0.04	1.34	2.34	1.32	5.00	0.70
<i>Zygophyllales</i>	<i>Zygophyllaceae</i>	<i>Tribulus terrestris</i>	I, K (2)	0.63	25	2.5	0.10	0.84	1.17	1.65	3.66	0.56

*Den: Density; Fr: Frequency; Ab: Abundance; Ab/Fr Ratio; RD %: Relative Density %; RF: Relative Frequency %; RA%: Relative Abundance %; IVI: Importance Value Index; SDiv: Supremacy Diversity; I: Village Chaharwala Minor; J: Village Mameran Road; K: Panjuana Canal; L: Village Nagoki Canal; M: Village Mangiana; N: Ottu Head; O: Abub Sheher Wildlife Sanctuary; P: Daulatpur Khera.

5.4. BIODIVERSITY INDICES

The plant species biodiversity was assessed across the different site in urban and forest ecosystem (8 sites each) using Shannon-Wiener Index (H') and Simpson Index (D). These two index metrics provided the valuable insights about the evenness and species richness.

5.4.1. Biodiversity indices of different site in urban area

The plant species diversity was assessed for all the eight site within the urban region in the Sirsa district. Table 5.5 provide the summary of the result encompassing total individuals as well as the biodiversity index values of respective site within urban region. The values of Shannon-Wiener Index (H') displayed variations within different sites ranging from 2.39 to 3.22 signifying the differences in species diversity. The site A (Shaheed Bhagat Singh Stadium) was determined to have the highest value of H' i.e., 3.22 suggesting the presence of different species of plant in contrast to other sites. This high value signifies that large number of species are present at this site and individual species are evenly distributed within these diverse plant species. On contrary, the site F (Home Garden 2) was determined to have the lowest value of H' i.e., 2.39 suggesting the presence of less number of species or skewed distribution of the individuals. Other than that, the site C (Sirsa Minor) and G (Municipality Park) were determined to have the H' value of 2.57 and 2.6, respectively, indicating the moderate diversity at these sites. The remaining sites were determined to have the H' value within the range of 2.39 to 3.13 indicating the species diversity at moderate level but not as high as determined for site A. The H' values of our study were determined to be within the range of 2.39 to 3.22 that corroborate with the results for urban areas in the USA (range 2.1 to 3.9), Nigeria (range 2.24 to 3.56) and Bangalore, India (2.68) (Sharma and Raghubanshi 2009; Nagendra and Gopal 2010; Pandey and Kumar 2018).

In contrast to H' , the Simpson Index (D) displayed less variation with values ranging from 0.06 to 0.13 (Table 5.5). This biodiversity index helps in determining the dominance of plant species within a community in which low values mean high diversity. The site E (Home Garden 1) was determined to have the lowest value of D , i.e., 0.05, signifying high diversity of plant species and less dominance by any individual species. Both the site A (Shaheed Bhagat Singh Stadium) and B

(Chaudhary Devi Lal Park) were determined to have the same value of D , i.e., 0.06, suggesting the distribution of plant species in balanced manner. In contrast, site C (Sirsa Minor), G (Municipality Park) and H (Mini-bypass Sirsa) were determined to have the D values of 0.13, 0.12 and 0.12, respectively which signifies that these sites have uneven species distribution with certain species being dominant. These results were determined to be in agreement with H' values of these sites suggesting reduction in overall diversity. The D values of our study were determined to be within the range of 0.05 to 0.13 which corroborate with the results for urban areas in the Portland, Oregon (range 0.05 to 0.38) and Novi Sad, Serbia (range 0.04 to 0.08) (Manoj et al. 2019; Lakicevic et al. 2022). These two index metrics provide value insight about species richness as well as evenness within the urban region as illustrated in figure 5.6.

Table 5.5: Diversity Indices of eight site in urban region of Sirsa district

Site Name	Site Code	Total Individuals	Shannon-Wiener Index (H')	Simpson Index (D)
Shaheed Bhagat Singh Stadium	A	136	3.22	0.06
Chaudhary Devi Lal Park	B	113	3.05	0.06
Sirsa Minor	C	119	2.57	0.13
HUDA Unhabituated Area	D	155	2.69	0.09
Home Garden 1	E	53	3.13	0.05
Home Garden 2	F	36	2.39	0.1
Municipality Park	G	62	2.6	0.12
Mini-bypass Sirsa	H	129	2.47	0.12

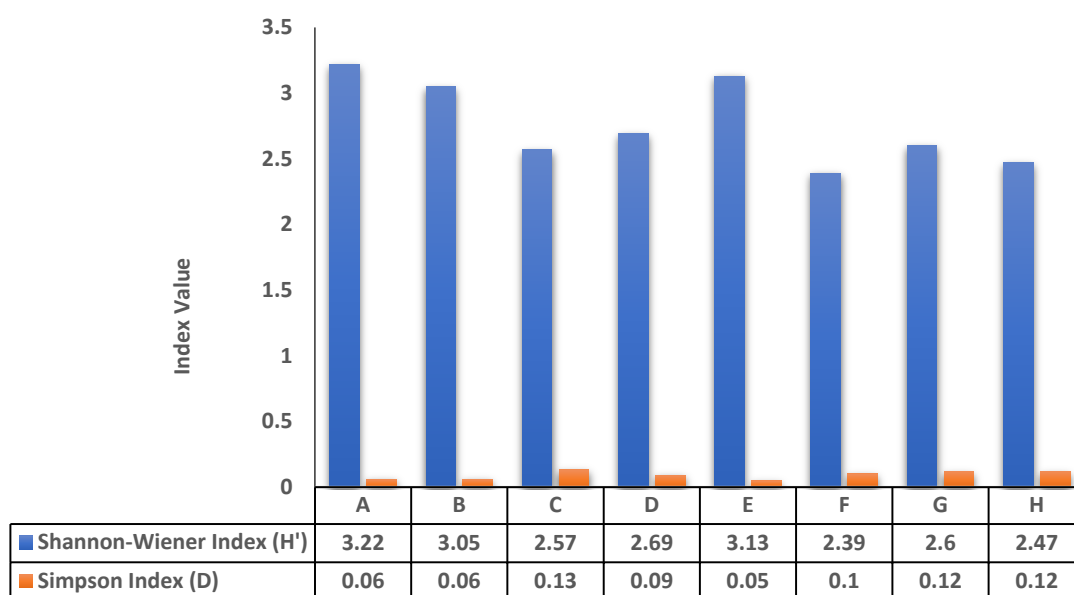


Figure 5.6: Comparison of Shannon-Wiener (H') and Simpson (D) indices across eight different sites in Urban region of Sirsa District

5.4.2. Biodiversity indices of different site in forest area

The plant species diversity was assessed for all the eight site within the forest region in the Sirsa district. Table 5.6 provide the summary of the result encompassing total individuals as well as the biodiversity index values of respective site within forest region. The values of Shannon-Wiener Index (H') showed variations within different sites in forest region ranging from 2.62 to 3.09 indicating the differences in species diversity. The Site K (Panjuana Canal) was determined to have the highest H' value of 3.09 suggesting relatively high species diversity as compared to other sites. The other sites showed H' value relatively close to each other. Site I (Village Chaharwala Minor), Site N (Ottu Head) and Site O (Abub Sheher Wildlife Sanctuary) were determined to have the H' value of 2.85, 2.8 and 2.78 respectively, suggesting the moderate diversity of plant species. In contrast, site M (Village Mangiana) was determined to have the lowest H' value of 2.62 indicating that this site has relatively lower diversity of plant species as compared to other sites. The remaining sites were determined to have the H' value within the range of 2.74 to 2.76, suggesting that species diversity was moderately lower but all these remaining sites have diversity quite similar to each other. The H' values of our study were determined to be within the range of 2.62 to 3.09 that corroborate with the results for forest areas near the Moyar River in southern India (range 2.0 to 3.27), Riparian Forest, Cameroon (range

2.21 to 3.45) and Riparian Vegetation along the River Cauvery, Southern India (5.6) (Sunil et al. 2016).

In contrast to H' , the Simpson Index (D) showed very restricted variation with values within the range of 0.05 to 0.08. This index of biodiversity enables us to determine the dominance of plant species within a community in which low values mean high diversity. According to the Simpson index, site K (Panjuana Canal) was determined to have the lowest value of D, i.e., 0.05, signifying high species diversity and low probability that two species chosen at random belong to the same species. The site I (Village Chaharwala Minor) was determined to have the D value of 0.07 indicating the lower biodiversity. In contrast, the Simpson index of the remaining sites was determined to be 0.08, suggesting that these sites had the higher probability of having plant individuals belonging to the same species when selected at random confirming the overall lower biodiversity. The findings of our study align with the result of Che et al. (2025) who also reported the low value of the Simpson index and stated that areas with less human intervention showed similar trend. Their finding also indicated that areas with lower Simpson index had high ecological complexity and was not dominated by any particular species (Che et al. 2025). However, study conducted by Li et al. (2018) showed the contrary finding as they reported the moderate value of Simpson index within the range of 0.35 to 0.96. The values determined in this study suggest that the region of study experiences habitat disturbance along with that it has species dominance. Thus, Li et al. (2018) concluded that their study area has overall lower biodiversity (Li et al. 2018). These two index metrics provide value insight about species richness as well as evenness within the urban region as illustrated in figure 5.7.

Table 5.6: Diversity Indices of eight site in forest region of Sirsa district

Site Name	Site Code	Total Individual s	Shannon- Wiener Index (H')	Simpson Index (D)
Village Chaharwala Minor	I	63	2.85	0.07
Village Mameran Road	J	51	2.74	0.08
Panjuana Canal	K	86	3.09	0.05
Village Nagoki Canal	L	78	2.76	0.08
Village Mangiana	M	90	2.62	0.08
Ottu Head	N	81	2.80	0.08
Abub Sheher Wildlife Sanctuary	O	79	2.78	0.08
Daulatpur Khera	P	69	2.75	0.08

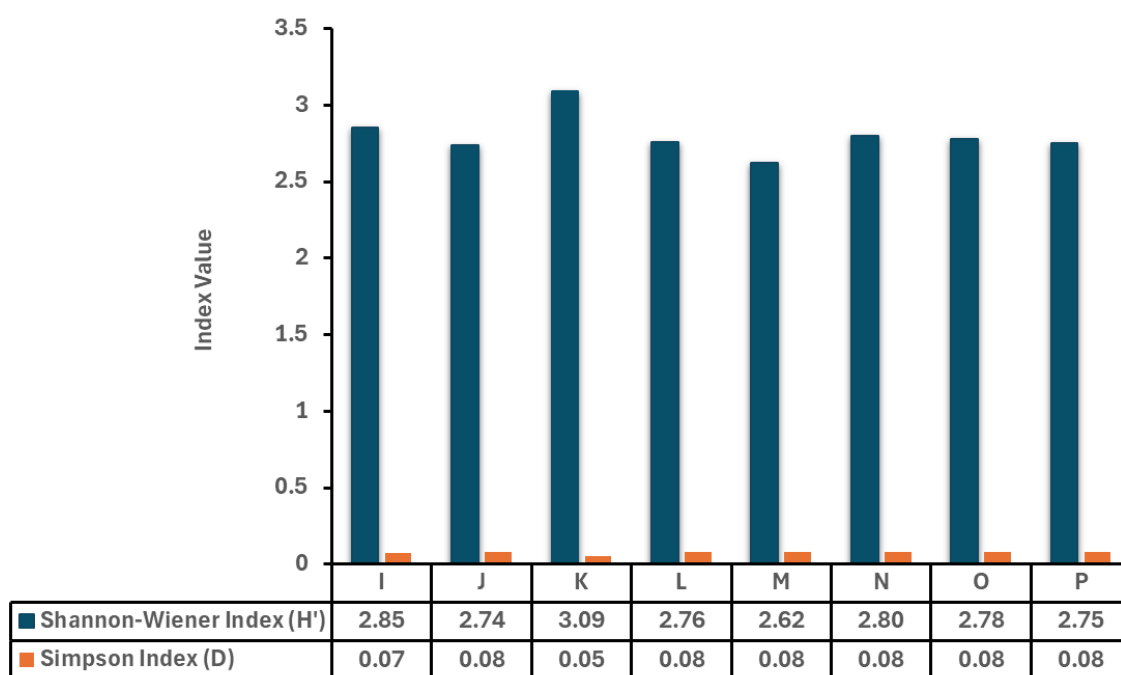


Figure 5.7: Comparison of Shannon-Wiener (H') and Simpson (D) indices across eight different sites in Forest region of Sirsa District

5.4.3. Comparative analysis of biodiversity indices for urban and forest ecosystem.

Comparison of biodiversity indices for urban and forest ecosystems exhibits apparent differences in species distribution and diversity (Table 5.7). On assessment, the urban ecosystem was determined to have the higher values for Shannon Wiener Index (4.21) and Margalef index (14.5) indicating species richness and even distribution of the species. This is further validated by the low Simpsons Index (0.02) which signifies the lower dominance and higher species diversity. These results are consistent with finding of Cowett and Bassuk (2017; 2020), who studied the diversity of street trees within urban areas of New Jersey, New York, Pennsylvania and Massachusetts. Their findings highlighted that urban regions prefer a small number of species specifically those that are more adaptable to disturbances and human intervention (Cowett and Bassuk 2017; Cowett and Bassuk 2020). Conversely, the forest ecosystem was determined to have the lower values for Shannon Wiener Index (3.42), lower value of Margalef Index (7.98), and very low value of Simpson's Index (0.05). These values signify that forest ecosystem has higher biodiversity and balanced community structure. The findings of our study corroborate with findings of Sunil et al. (2016) which showed the range of the value close to our study. Their findings indicated that

forest ecosystem usually have higher biodiversity and species are evenly distributed in the forest region because of less human intervention (Sunil et al. 2016). Further, the value of Pielou Index of forest ecosystem (0.87) was determined to slightly lower than the urban ecosystem (0.92), which indicates that forest ecosystem harbours less number species but species are evenly distributed. The findings of our study align with the result of Pielou Index for the Riparian Forest of Lake Barombi Kotto, Cameroon (Miranda Egbe et al. 2021). These findings reveal urban ecosystem to be more adaptable and species rich. Whereas, forest ecosystem was determined to have more stable and balanced ecological structure. The comparison implies that each ecosystem possesses distinct characteristics of biodiversity that play vital role in regulating the overall ecological health. These differences accorded in biodiversity indices between urban and forest ecosystems reflect variations in vegetation structure and species distribution. Ultimately, such differences influence biomass accumulation and carbon sequestration in these ecosystems.

Table 5.7: Summary of different diversity indices within urban and forest ecosystem

Biodiversity Indices	Urban Ecosystem	Forest Ecosystem
Shannon Wiener Index	4.21	3.42
Simpsons Index	0.02	0.05
Margalef index	14.5	7.98
Pielou Index	0.92	0.87

Objective 2: To assess the carbon sequestration potential of tree biomass.

5.5. TREE BIOMASS AND CARBON STOCK ESTIMATION

5.5.1. Determination of Basal Area and Relative Dominance (RDO) values of tree species in Urban area

The Basal Area and Relative Dominance (RDO) values of tree species within the urban area of Sirsa District are indicative of a significant variability in their contributions to the overall structure of this ecosystem. The *Ficus religiosa* was determined to have the highest basal area of 30.10 m² and RDO % of 15.71, which clearly indicates the dominance of this species in the urban area (Table 5.8). Species like *Dalbergia sissoo* with basal area of 27.94 m² and RDO % of 14.58 as well as *Vachellia nilotica* with basal area of 22.17 m² and RDO % of 11.57 highlights their notable contribution to the canopy coverage and biomass in the urban ecosystem. Few other characteristic species of urban ecosystem include *Azadirachta indica*, *Prosopis cineraria*, and *Holoptelea integrifolia* were determined to have the basal areas ranging between 12.52 m² to 10.23 m² and RDO % values within the range of 6.53 to 5.34. These species play important role in improving air quality, providing natural habitat to birds and reducing soil erosion. In contrast, species like *Grevillea robusta* and *Nyctanthes arbor-tristis* were determined to have the basal area value of 0.22 m² and 0.12 m², as well as RDO % values of 0.12 and 0.06 respectively. These values indicates that these plant species have minimal contribution in overall urban ecosystem. Further, lower dominance of these species within urban ecosystem is due to factors like competition with highly dominant species, soil condition and water availability. Moreover, the disparity in basal area and RDO % across species indicate that few species have dominance within the urban area. Plant species like *Ficus religiosa*, *Dalbergia sissoo* and *Vachellia nilotica* predominate the urban ecosystem in term of canopy coverage and biomass. These tress play vital role in carbon sequestration, offer shade and reduce the heat island effect in the urban area.

Table 5.8: Summary of Basal Area and Relative Dominance (%) value of Trees in Urban region of Sirsa District according to APG IV guidelines

Order	Family	Botanical Name	Local Name	Basal area (m²)	Relative Dominance % (RDO %)
<i>Boraginales</i>	<i>Cordiaceae</i>	<i>Cordia dichotoma</i>	Lehsua	0.45	0.24
<i>Cycadales</i>	<i>Cycadaceae</i>	<i>Cycas revoluta</i>	Palm-Kanghi	0.36	0.19
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia cetechu</i>	Kher	1.42	0.74
		<i>Albizia lebbeck</i>	Sarinh	4.25	2.22
		<i>Cassia fistula</i>	Amaltas	2.72	1.42
		<i>Dalbergia sissoo</i>	Sheesham	27.94	14.58
		<i>Delonix regia</i>	Gulmohar	2.18	1.14
		<i>Prosopis cineraria</i>	Janti	12.31	6.42
		<i>Prosopis juliflora</i>	Pahadi kikar	5.10	2.66
		<i>Saraca asoca</i>	Ashoka	7.99	4.17
		<i>Vachellia nilotica</i>	Kikar	22.17	11.57

<i>Gentianales</i>	<i>Apocynaceae</i>	<i>Alstonia scholaris</i>	Saptparni	1.33	0.69
<i>Lamiales</i>	<i>Bignoniaceae</i>	<i>Kigelia africana</i>	Kigelia	2.86	1.49
		<i>Tecomella undulata</i>	Rohida	0.77	0.40
	<i>Oleaceae</i>	<i>Nyctanthes arbor-tristis</i>	Harshingar	0.12	0.06
<i>Magnoliales</i>	<i>Magnoliaceae</i>	<i>Magnolia champaca</i>	Champak	0.49	0.26
<i>Malpighiales</i>	<i>Euphorbiaceae</i>	<i>Jatropha curcas</i>	Jatropha	1.71	0.89
	<i>Phyllanthaceae</i>	<i>Phyllanthus emblica</i>	Amla	0.35	0.18
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa oleifera</i>	Sohanjana	1.52	0.79
<i>Myrtales</i>	<i>Combretaceae</i>	<i>Terminalia arjuna</i>	Arjun	8.10	4.23
	<i>Myrtaceae</i>	<i>Callistemon citrinus</i>	Bottlebrush	0.57	0.30
		<i>Eucalyptus globulus</i>	Safeda	7.08	3.69
		<i>Psidium guajava</i>	Amrood	0.43	0.23
		<i>Syzygium cumini</i>	Jamun	5.02	2.62

<i>Pinales</i>	<i>Pinaceae</i>	<i>Pinus roxburghii</i>	Indian pine	0.59	0.31
<i>Proteales</i>	<i>Proteaceae</i>	<i>Grevillea robusta</i>	Silver oak	0.22	0.12
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	2.49	1.30
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus benjamina</i>	Ficus	7.03	3.67
		<i>Ficus racemosa</i>	Anjeer	0.78	0.41
		<i>Ficus religiosa</i>	Pipal	30.10	15.71
		<i>Morus alba</i>	Shehtoot	2.20	1.15
	<i>Ulmaceae</i>	<i>Holoptelea integrifolia</i>	Papdi	10.23	5.34
<i>Sapindales</i>	<i>Anacardiaceae</i>	<i>Mangifera indica</i>	Aam	2.06	1.07
	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	12.52	6.53
		<i>Chukrasia velutina</i>	Chukrasia	0.59	0.31
		<i>Melia azedarach</i>	Bakain	5.13	2.68
	<i>Rutaceae</i>	<i>Aegle marmelos</i>	Bellpatar	0.45	0.23

5.5.2. Determination of Basal Area and Relative Dominance (RDO) values of tree species in Forest area

Eucalyptus globulus was determined to have the highest basal area of 65.92 m² and RDO % of 16.4, followed by *Azadirachta indica* with basal area of 63.06 m² and RDO % of 15.69 (Table 5.9). These values indicate that these species dominate within the forest community. Moreover, these plant species contribute extensively to the canopy coverage and biomass indicating their ecological importance in forming the forest ecosystem. Species like *Acacia nilotica* with basal area of 51.81 m² and RDO % of 12.89, *Dalbergia sissoo* with basal area of 46.55 m² and RDO % of 11.58 and *Ficus religiosa* with basal area of 34.3 m² and RDO % of 8.53 highlights their notable contribution to forest structure and functioning. Few other characteristic species of urban ecosystem include *Syzygium cumini*, *Ficus benghalensis*, *Prosopis juliflora* and *Albizia lebbbeck* were determined to have the basal areas ranging between 30.9 m² to 15.86 m² and RDO % values within the range of 7.69 to 3.95. In contrast, species like *Psidium guajava* and *Nerium oleander* were determined to have the basal area value of 0.09 m² and 0.05 m², as well as RDO % values of 0.02 and 0.16 respectively. These values indicates that these plant species have minimal contribution in overall forest ecosystem. Even though, these species are present in forest but they are not dominant in terms of canopy coverage and biomass. It is interesting to note that there is huge variation in basal area and RDO % signifying variation in tree sizes and level of dominance of selected species within forest ecosystem.

Table 5.9: Summary of Basal Area and Relative Dominance (%) value of Trees in Forest region of Sirsa District according to APG IV guidelines

Order	Family	Botanical Name	Local Name	Basal area	Relative Dominance % (RDO)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia nilotica</i>	Kikar	51.81	12.89
		<i>Albizia lebbeck</i>	Sarinh	15.86	3.95
		<i>Cassia fistula</i>	Amaltas	0.52	0.13
		<i>Dalbergia sissoo</i>	Sheesham	46.55	11.58
		<i>Prosopis cineraria</i>	Janti	13.01	3.24
		<i>Prosopis juliflora</i>	Pahadi Kikar	21.15	5.26
<i>Gentianales</i>	<i>Apocynaceae</i>	<i>Nerium oleander</i>	Kaner	0.05	0.01
<i>Malpighiales</i>	<i>Phyllanthaceae</i>	<i>Phyllanthus emblica</i>	Amla	0.37	0.09
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa oleifera</i>	Sohanjana	0.93	0.23
<i>Myrtales</i>	<i>Combretaceae</i>	<i>Terminalia arjuna</i>	Arjun	4.66	1.16
		<i>Terminalia bellirica</i>	Baheda	2.40	0.60

	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Safeda	65.92	16.40
		<i>Psidium guajava</i>	Amrood	0.09	0.02
		<i>Syzygium cumini</i>	Jamun	30.90	7.69
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	1.40	0.35
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus benghalensis</i>	Bargad	24.11	6.00
		<i>Ficus racemose</i>	Anjeer	0.25	0.06
		<i>Ficus religiosa</i>	Pipal	34.30	8.53
		<i>Morus alba</i>	Shehtoot	3.86	0.96
	<i>Ulmaceae</i>	<i>Holoptelea integrifolia</i>	Papdi	5.87	1.46
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	63.06	15.69
		<i>Melia azedarach</i>	Bakain	5.65	1.41
	<i>Rutaceae</i>	<i>Zanthoxylum armatum</i>	Pahadi Neem	9.23	2.30

5.6. CARBON SEQUESTRATION IN URBAN AND FOREST ECOSYSTEM

5.6.1. Estimation of carbon sequestration in urban area

Sequestered carbon was determined using DBH value (refer **Annexure 2**) and Allometric equation (refer **Annexure 6**). In case, where allometric equation were unavailable in that case volumetric equations were used which requires wood density. The wood density information has been comprehended in **Annexure 4**.

5.6.1.1. Site A: Shaheed Bhagat Singh Stadium

The table 5.10 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site A. *Ficus religiosa* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 61.09 tons, carbon stock value of 30.54 tons, and CO₂ sequestration value of 112.10 tons. These values indicate that this species play crucial role in carbon sequestration within urban ecosystem at the site A. This also highlights the importance of this species in the environment sustainability. *Delonix regia* and *Terminalia arjuna* were also determined to have substantial carbon sequestration ability. *Delonix regia* accounts for total biomass value of 54.87 tons, carbon stock value of 27.44 tons, and CO₂ sequestration value of 100.69 tons. Whereas, *Terminalia arjuna* accounts for total biomass value of 51.53 tons, carbon stock value of 25.76 tons, and CO₂ sequestration value of 94.55 tons. Few other selected species like *Azadirachta indica*, *Prosopis cineraria* and *Syzygium cumini* also contributes to CO₂ sequestration. *Prosopis cineraria* accounts for total biomass value of 14.67 tons, carbon stock value of 7.33 tons, and CO₂ sequestration value of 26.91 tons. *Azadirachta indica* accounts for total biomass value of 11.18 tons, carbon stock value of 5.59 tons, and CO₂ sequestration value of 20.51 tons. *Syzygium cumini* accounts for total biomass value of 2.81 tons, carbon stock value of 1.41 tons, and CO₂ sequestration value of 5.16 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, *Acacia catechu* and *Vachellia nilotica*. *Acacia catechu* accounts for total biomass value of 9.24 tons, carbon stock value of 4.62 tons, and CO₂ sequestration value of 16.96 tons. *Vachellia nilotica* accounts for total biomass value of 4.15 tons, carbon stock value of 2.08 tons, and CO₂ sequestration value of 7.62 tons. The data of this site unveils the critical role of

plant species in biodiversity as well as highlight their ability to mitigate climate change. The high CO₂ sequestration value of *Ficus religiosa*, *Delonix regia* and *Terminalia arjuna* highlights their potential application in large-scale environmental conservation initiatives specifically designed for minimizing carbon footprints. Figure 5.8 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site A.

Table 5.10: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site A (Shaheed Bhagat Singh Stadium) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia cetechu</i>	Kher	9.24	0.00	9.24	4.62	0.00	4.62	16.96
		<i>Cassia fistula</i>	Amaltas	2.93	0.59	3.52	1.47	0.29	1.76	6.46
		<i>Dalbergia sissoo</i>	Sheesham	9.01	1.80	10.82	4.51	0.90	5.41	19.85
		<i>Delonix regia</i>	Gulmohar	45.73	9.15	54.87	22.86	4.57	27.44	100.69
		<i>Prosopis cineraria</i>	Janti	12.22	2.44	14.67	6.11	1.22	7.33	26.91
		<i>Saraca</i>	Ashoka	1.98	0.40	2.37	0.99	0.20	1.19	4.35

		<i>asoca</i>								
		<i>Vachellia nilotica</i>	Kikar	3.46	0.69	4.15	1.73	0.35	2.08	7.62
<i>Gentianales</i>	<i>Apocynaceae</i>	<i>Alstonia scholaris</i>	Saptarni	2.94	0.59	3.53	1.47	0.29	1.77	6.48
<i>Lamiales</i>	<i>Oleaceae</i>	<i>Nyctanthes arbor-tristis</i>	Harshingar	0.58	0.12	0.69	0.29	0.06	0.35	1.27
<i>Magnoliales</i>	<i>Magnoliaceae</i>	<i>Magnolia champaca</i>	Champak	1.73	0.35	2.07	0.86	0.17	1.04	3.80
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa oleifera</i>	Sohanjana	2.75	0.55	3.31	1.38	0.28	1.65	6.07
<i>Myrtales</i>	<i>Combretaceae</i>	<i>Terminalia arjuna</i>	Arjun	42.94	8.59	51.53	21.47	4.29	25.76	94.55
	<i>Myrtaceae</i>	<i>Callistemon citrinus</i>	Bottlebrush	0.12	0.02	0.15	0.06	0.01	0.07	0.27
		<i>Syzygium</i>	Jamun	2.34	0.47	2.81	1.17	0.23	1.41	5.16

		<i>cumini</i>								
<i>Proteales</i>	<i>Proteaceae</i>	<i>Grevillea robusta</i>	Silver oak	1.02	0.20	1.23	0.51	0.10	0.61	2.25
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	6.52	1.30	7.82	3.26	0.65	3.91	14.35
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus benjamina</i>	Ficus	15.66	3.13	18.79	7.83	1.57	9.40	34.48
		<i>Ficus racemosa</i>	Anjeer	2.74	0.55	3.29	1.37	0.27	1.64	6.04
		<i>Ficus religiosa</i>	Pipal	50.91	10.18	61.09	25.45	5.09	30.54	112.10
		<i>Morus alba</i>	Shehtoot	2.43	0.69	3.12	1.22	0.35	1.56	5.73
	<i>Ulmaceae</i>	<i>Holoptelea intergrifolia</i>	Papdi	6.59	1.32	7.90	3.29	0.66	3.95	14.50
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	9.32	1.86	11.18	4.66	0.93	5.59	20.51

		<i>Chukrasia velutina</i>	Chukrasia	1.17	0.23	1.41	0.59	0.12	0.70	2.58
		<i>Melia azedarach</i>	Bakain	1.37	0.27	1.64	0.68	0.14	0.82	3.01

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

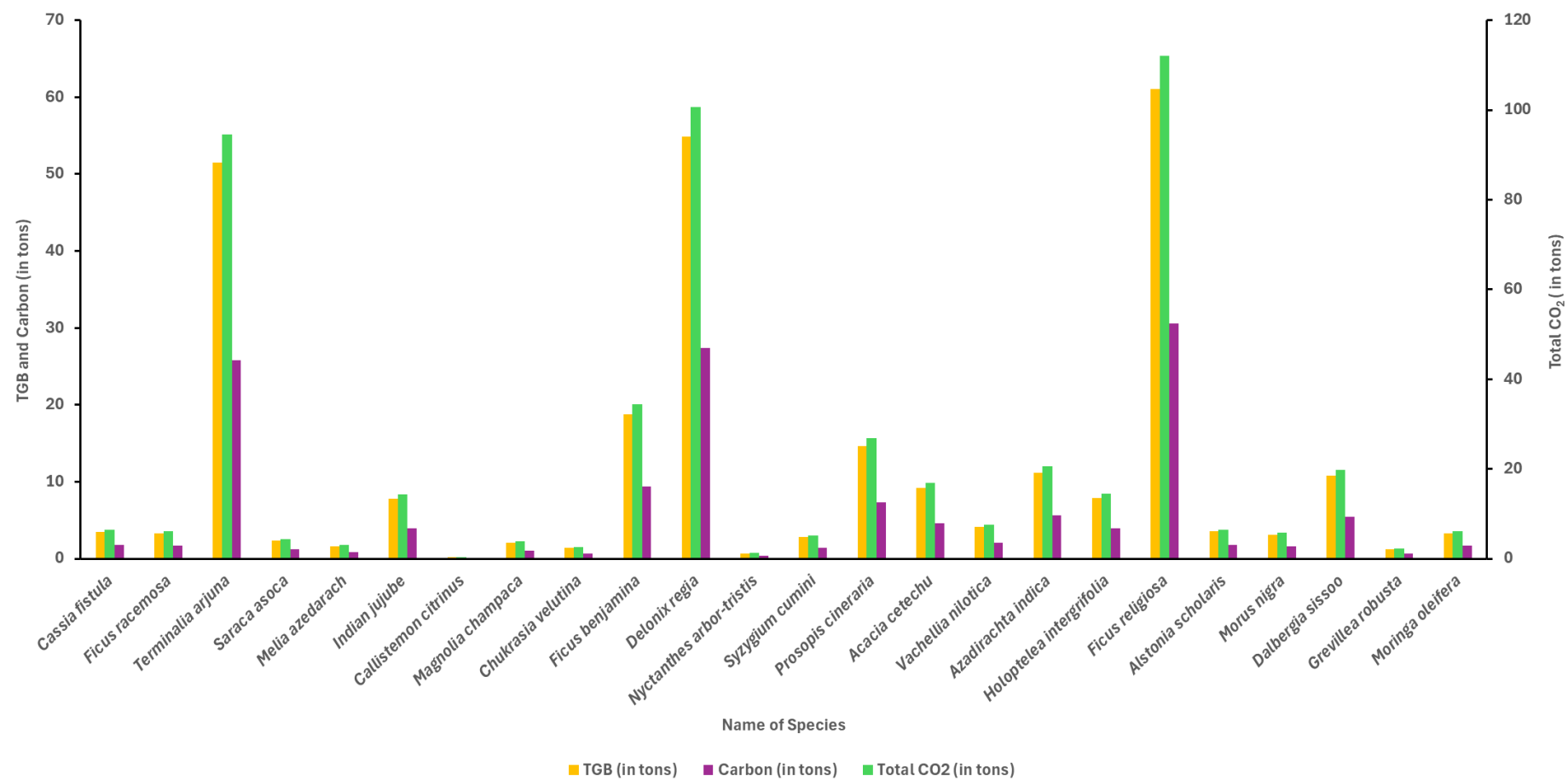


Figure 5.8: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site A (Shaheed Bhagat Singh Stadium)

5.6.1.2. Site B: Chaudhary Devi Lal Park

The table 5.11 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site B. *Ficus benjamina* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 31.23 tons, carbon stock value of 15.61 tons, and CO₂ sequestration value of 57.3 tons. These values highlight the crucial role this species in carbon sequestration at the site B. This also underlines the importance of this species in climate change mitigation. *Dalbergia sissoo* and *Ficus religiosa* were also determined to have substantial carbon sequestration ability. *Dalbergia sissoo* accounts for total biomass value of 30.27 tons, carbon stock value of 15.14 tons, and CO₂ sequestration value of 55.55 tons. Whereas, *Ficus religiosa* accounts for total biomass value of 25.13 tons, carbon stock value of 12.56 tons, and CO₂ sequestration value of 46.11 tons. Few other selected species like *Saraca asoca*, *Albizia lebbeck* and *Holoptelea intergrifolia* also contributes to CO₂ sequestration. *Saraca asoca* accounts for total biomass value of 10.93 tons, carbon stock value of 5.47 tons, and CO₂ sequestration value of 20.06 tons. *Albizia lebbeck* accounts for total biomass value of 6.77 tons, carbon stock value of 3.38 tons, and CO₂ sequestration value of 12.41 tons. *Holoptelea intergrifolia* accounts for total biomass value of 3.82 tons, carbon stock value of 1.91 tons, and CO₂ sequestration value of 7.01 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, and *Syzygium cumini*. *Azadirachta indica* accounts for total biomass value of 3.4 tons, carbon stock value of 1.7 tons, and CO₂ sequestration value of 6.24 tons. *Syzygium cumini* accounts for total biomass value of 3.37 tons, carbon stock value of 1.69 tons, and CO₂ sequestration value of 6.19 tons. The data of this site unveils the critical role of plant species in biodiversity as well as highlight their ability to mitigate climate change. The high CO₂ sequestration value of *Ficus benjamina*, *Dalbergia sissoo* and *Ficus religiosa* highlights their potential application at global scale for combating climate change. Figure 5.9 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site B.

Table 5.11: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site B (Chaudhary Devi Lal Park) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Albizia lebbeck</i>	Sarinh	5.64	1.13	6.77	2.82	0.56	3.38	12.41
		<i>Cassia fistula</i>	Amaltas	1.21	0.24	1.46	0.61	0.12	0.73	2.67
		<i>Dalbergia sissoo</i>	Sheesham	25.23	5.05	30.27	12.61	2.52	15.14	55.55
		<i>Saraca asoca</i>	Ashoka	9.11	1.82	10.93	4.56	0.91	5.47	20.06
<i>Lamiales</i>	<i>Bignoniaceae</i>	<i>Tecomella undulata</i>	Rohida	1.88	0.38	2.25	0.94	0.19	1.13	4.14
<i>Magnoliales</i>	<i>Magnoliaceae</i>	<i>Magnolia champaca</i>	Champak	0.66	0.13	0.80	0.33	0.07	0.40	1.46
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa oleifera</i>	Sohanjana	0.36	0.07	0.43	0.18	0.04	0.22	0.79
<i>Myrtales</i>	<i>Myrtaceae</i>	<i>Callistemon citrinus</i>	Bottlebrush	0.42	0.09	0.50	0.21	0.04	0.25	0.93
		<i>Syzygium cumini</i>	Jamun	2.81	0.56	3.37	1.41	0.28	1.69	6.19

<i>Pinales</i>	<i>Pinaceae</i>	<i>Pinus roxburghii</i>	Indian pine	2.26	0.45	2.71	1.13	0.23	1.36	4.98
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus benjamina</i>	Ficus	26.02	5.20	31.23	13.01	2.60	15.61	57.30
		<i>Ficus religiosa</i>	Pipal	20.94	4.19	25.13	10.47	2.09	12.56	46.11
	<i>Ulmaceae</i>	<i>Holoptelea integrifolia</i>	Papdi	3.18	0.64	3.82	1.59	0.32	1.91	7.01
<i>Sapindales</i>	<i>Anacardiaceae</i>	<i>Mangifera indica</i>	Aam	16.22	3.24	19.46	8.11	1.62	9.73	35.71
	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	2.83	0.57	3.40	1.42	0.28	1.70	6.24
	<i>Rutaceae</i>	<i>Aegle marmelos</i>	Bellpatar	0.57	0.15	0.72	0.28	0.07	0.36	1.31

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

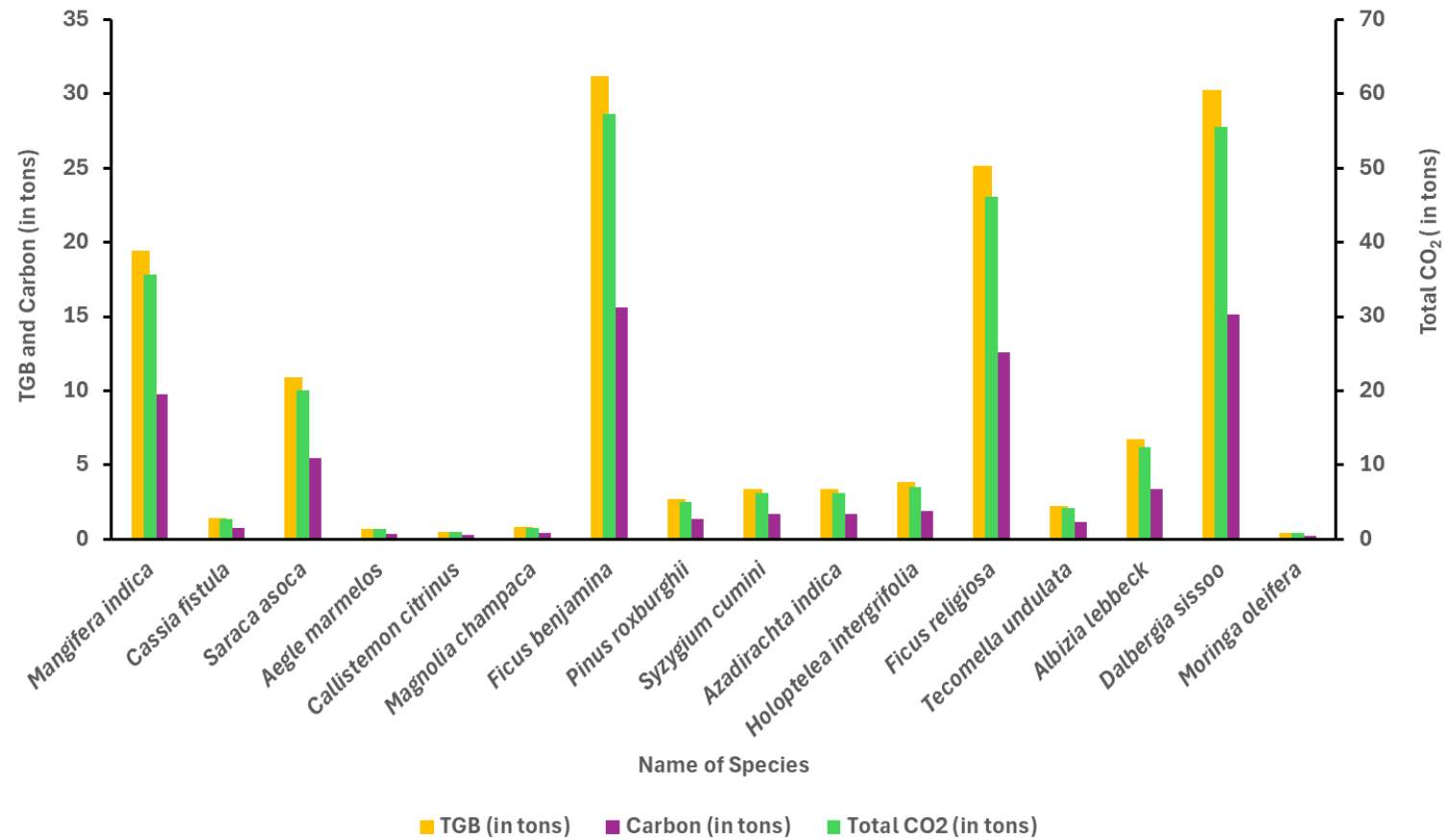


Figure 5.9: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site B (Chaudhary Devi Lal Park)

5.6.1.3. Site C: Sirsa Minor

The table 5.12 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site C. *Eucalyptus globulus* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 45.37 tons, carbon stock value of 22.68 tons, and CO₂ sequestration value of 83.25 tons. These values highlight the crucial role this species in carbon sequestration at the site C. This also underlines the importance of this species in reducing CO₂ level in the atmosphere. *Ficus religiosa*, *Prosopis juliflora* and *Ficus benjamina* were also determined to have substantial carbon sequestration ability. *Ficus religiosa* accounts for total biomass value of 32.73 tons, carbon stock value of 16.37 tons, and CO₂ sequestration value of 60.07 tons. *Prosopis juliflora* accounts for total biomass value of 23.59 tons, carbon stock value of 11.79 tons, and CO₂ sequestration value of 43.29 tons. Whereas, *Ficus benjamina* accounts for total biomass value of 19.63 tons, carbon stock value of 9.81 tons, and CO₂ sequestration value of 36.02 tons. Few other selected species like *Albizia lebbbeck*, *Dalbergia sissoo* and *Syzygium cumini* also contributes to CO₂ sequestration. *Albizia lebbbeck* accounts for total biomass value of 8.97 tons, carbon stock value of 4.48 tons, and CO₂ sequestration value of 16.46 tons. *Dalbergia sissoo* accounts for total biomass value of 7.8 tons, carbon stock value of 3.9 tons, and CO₂ sequestration value of 14.31 tons. *Syzygium cumini* accounts for total biomass value of 4.29 tons, carbon stock value of 2.14 tons, and CO₂ sequestration value of 7.87 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, *Melia azedarach* and *Vachellia nilotica*. *Azadirachta indica* accounts for total biomass value of 1.39 tons, carbon stock value of 0.69 tons, and CO₂ sequestration value of 2.54 tons. *Melia azedarach* accounts for total biomass value of 2.34 tons, carbon stock value of 1.17 tons, and CO₂ sequestration value of 4.3 tons. *Vachellia nilotica* accounts for total biomass value of 1.45 tons, carbon stock value of 0.72 tons, and CO₂ sequestration value of 2.65 tons. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration. The high CO₂ sequestration value of *Eucalyptus globulus*, *Ficus religiosa* and *Prosopis juliflora* highlights their potential application at global scale for combating climate change making them valuable species for reforestation initiatives. Figure 5.10 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site C.

Table 5.12: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site C (Sirsa Minor) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Cycadales</i>	<i>Cycadaceae</i>	<i>Cycas revoluta</i>	Palm-Kanghi	1.40	0.28	1.68	0.70	0.14	0.84	3.08
<i>Fabales</i>	<i>Fabaceae</i>	<i>Albizia lebbbeck</i>	Sarinh	7.47	1.49	8.97	3.74	0.75	4.48	16.46
		<i>Dalbergia sissoo</i>	Sheesham	6.50	1.30	7.80	3.25	0.65	3.90	14.31
		<i>Prosopis cineraria</i>	Janti	2.81	0.56	3.37	1.41	0.28	1.69	6.19
		<i>Prosopis juliflora</i>	Pahadi Kikar	19.66	3.93	23.59	9.83	1.97	11.79	43.29
		<i>Vachellia nilotica</i>	Kikar	1.21	0.24	1.45	0.60	0.12	0.72	2.65

<i>Myrtales</i>	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Safeda	37.81	7.56	45.37	18.90	3.78	22.68	83.25
		<i>Psidium guajava</i>	Amrood	0.61	0.12	0.73	0.30	0.06	0.37	1.34
		<i>Syzygium cumini</i>	Jamun	3.57	0.71	4.29	1.79	0.36	2.14	7.87
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus benjamina</i>	Ficus	16.36	3.27	19.63	8.18	1.64	9.81	36.02
		<i>Ficus religiosa</i>	Pipal	27.28	5.46	32.73	13.64	2.73	16.37	60.07
		<i>Morus alba</i>	Shehtoot	1.58	0.45	2.03	0.79	0.23	1.01	3.72
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	1.15	0.23	1.39	0.58	0.12	0.69	2.54
		<i>Melia azedarach</i>	Bakain	1.95	0.39	2.34	0.98	0.20	1.17	4.30

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

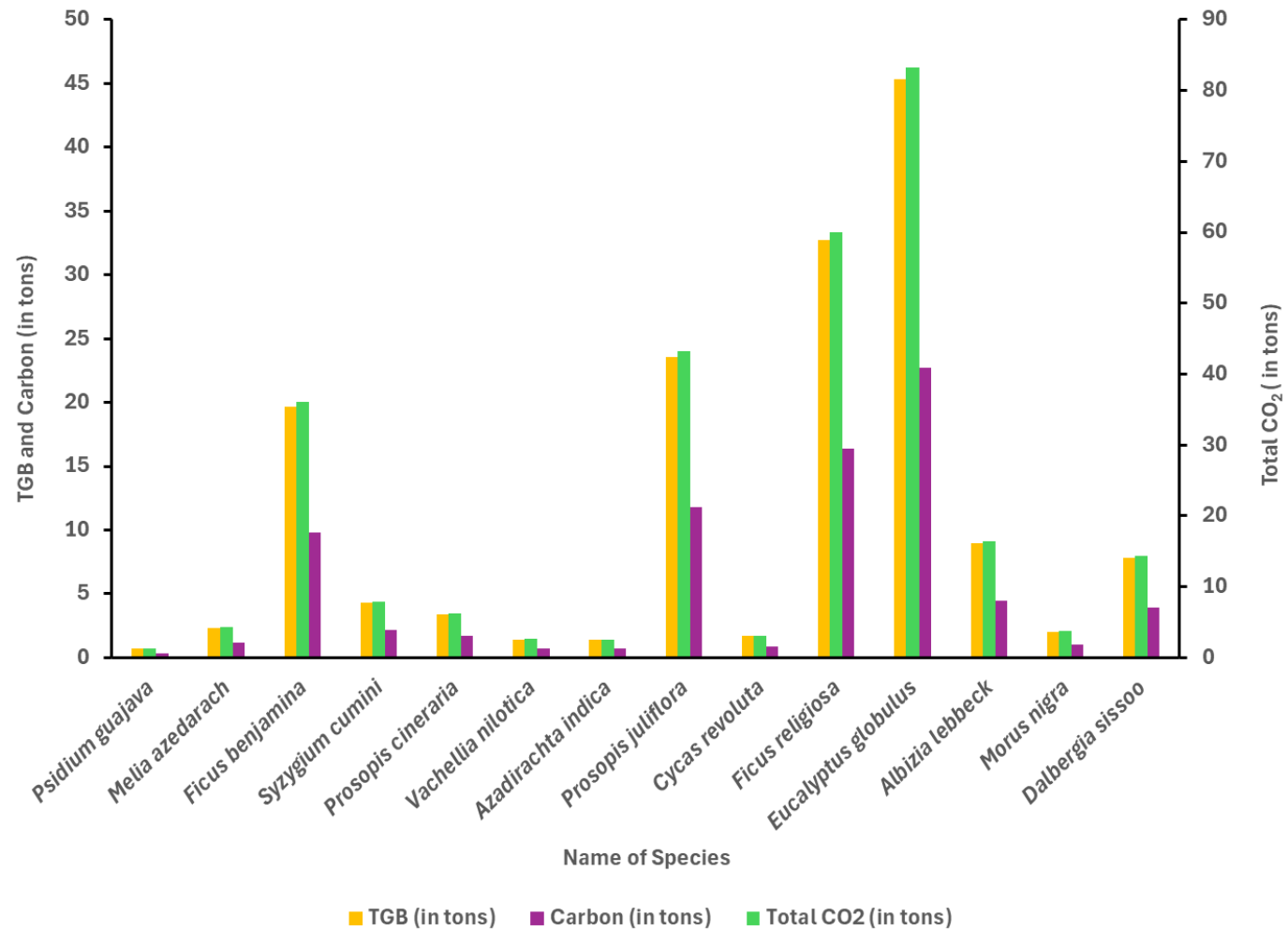


Figure 5.10: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site C (Sirsa Minor)

5.6.1.4. Site D: HUDA Unhabitated Area

The table 5.13 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site D. *Prosopis juliflora* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 29.42 tons, carbon stock value of 14.71 tons, and CO₂ sequestration value of 53.99 tons. These values highlight the crucial role this species in carbon sequestration at the site D. This also underlines the importance of this species in reducing CO₂ level in the atmosphere. *Dalbergia sissoo*, *Albizia lebbeck* and *Kigelia africana* were also determined to have substantial carbon sequestration ability. *Dalbergia sissoo* accounts for total biomass value of 25.93 tons, carbon stock value of 12.97 tons, and CO₂ sequestration value of 47.59 tons. *Albizia lebbeck* accounts for total biomass value of 8.43 tons, carbon stock value of 4.21 tons, and CO₂ sequestration value of 15.46 tons. Whereas, *Kigelia africana* accounts for total biomass value of 8.09 tons, carbon stock value of 4.04 tons, and CO₂ sequestration value of 14.84 tons. Few other selected species like *Saraca asoca* and *Ziziphus mauritiana* also contributes to CO₂ sequestration. *Saraca asoca* accounts for total biomass value of 5.84 tons, carbon stock value of 2.92 tons, and CO₂ sequestration value of 10.72 tons. *Ziziphus mauritiana* accounts for total biomass value of 3.94 tons, carbon stock value of 1.97 tons, and CO₂ sequestration value of 7.23 tons. At this site, few species hold medicinal and ecological value which include *Cassia fistula* and *Ficus racemosa*. *Cassia fistula* accounts for total biomass value of 1.71 tons, carbon stock value of 0.85 tons, and CO₂ sequestration value of 3.14 tons. *Ficus racemosa* accounts for total biomass value of 1.26 tons, carbon stock value of 0.63 tons, and CO₂ sequestration value of 2.31 tons. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration and reducing CO₂ level in the atmosphere. The high CO₂ sequestration value of *Prosopis juliflora* and *Dalbergia sissoo* highlights their potential application at global scale for combating climate change. Figure 5.11 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site D.

Table 5.13: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site D (HUDA Unhabitated Area) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Albizia lebbeck</i>	Sarinh	7.02	1.40	8.43	3.51	0.70	4.21	15.46
		<i>Cassia fistula</i>	Amaltas	1.42	0.28	1.71	0.71	0.14	0.85	3.14
		<i>Dalbergia sissoo</i>	Sheesham	21.61	4.32	25.93	10.81	2.16	12.97	47.59
		<i>Prosopis juliflora</i>	Pahadi Kikar	24.52	4.90	29.42	12.26	2.45	14.71	53.99
		<i>Saraca asoca</i>	Ashoka	4.87	0.97	5.84	2.43	0.49	2.92	10.72
<i>Lamiales</i>	<i>Bignoniaceae</i>	<i>Kigelia africana</i>	Kigelia	6.74	1.35	8.09	3.37	0.67	4.04	14.84
	<i>Boraginaceae</i>	<i>Cordia dichotoma</i>	Lehsua	1.58	0.06	1.64	0.79	0.03	0.82	3.01
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus</i>	Beri	3.28	0.66	3.94	1.64	0.33	1.97	7.23

		<i>mauritiana</i>								
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus racemosa</i>	Anjeer	1.05	0.21	1.26	0.52	0.10	0.63	2.31
	<i>Ulmaceae</i>	<i>Holoptelea intergrifolia</i>	Papdi	2.36	0.47	2.84	1.18	0.24	1.42	5.21

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

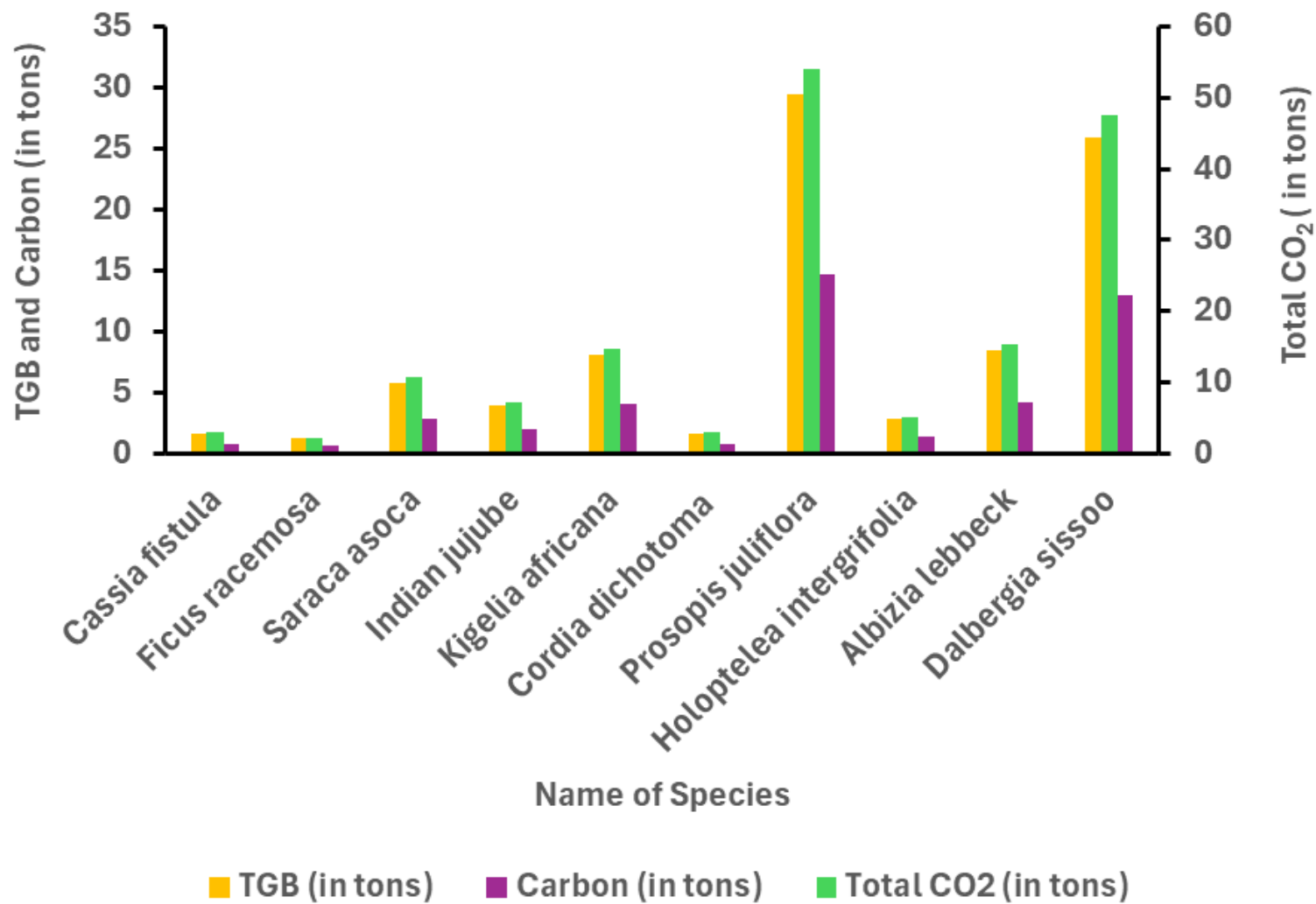


Figure 5.11: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site D (HUDA Unhabituated Area)

Table 5.14: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site E (Home Garden 1) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Saraca asoca</i>	Ashoka	2.01	0.40	2.41	1.00	0.20	1.21	4.43
<i>Sapindales</i>	<i>Rutaceae</i>	<i>Aegle marmelos</i>	Bellpatar	0.72	0.14	0.86	0.36	0.07	0.43	1.58

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

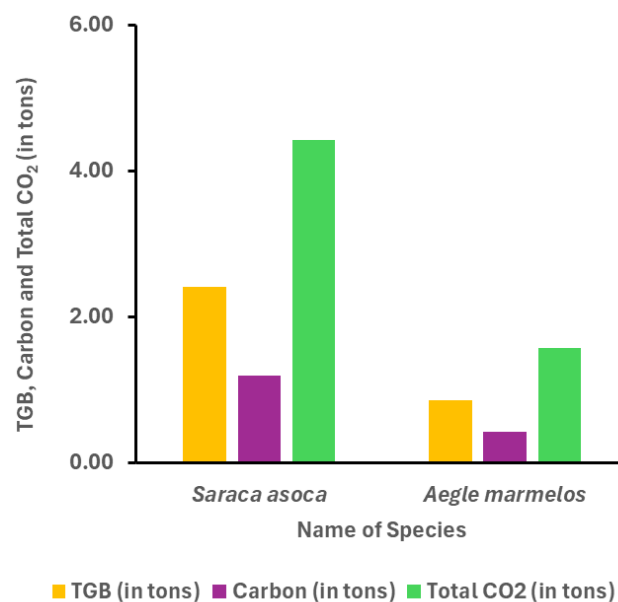


Figure 5.12: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site E (Home Garden 1)

Table 5.15: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site F (Home Garden 2) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Saraca asoca</i>	Ashoka	2.47	0.49	2.97	1.24	0.25	1.48	5.45

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

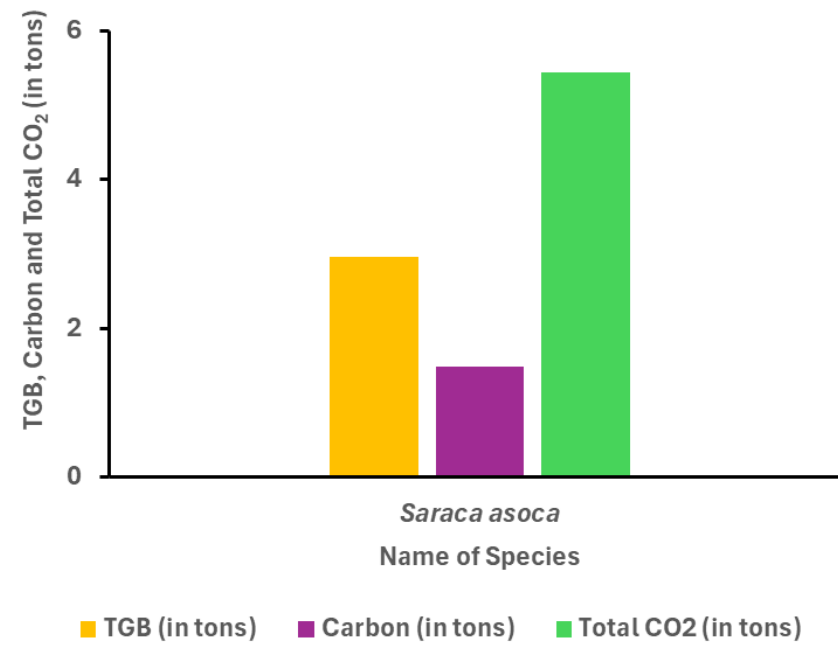


Figure 5.13: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site F (Home Garden 2)

Table 5.16: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site G (Municipality Park) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Cassia fistula</i>	Amaltas	2.00	0.40	2.40	1.00	0.20	1.20	4.40
		<i>Dalbergia sissoo</i>	Sheesham	14.51	2.90	17.41	7.25	1.45	8.70	31.94
		<i>Prosopis cineraria</i>	Janti	2.13	0.43	2.55	1.06	0.21	1.28	4.69
<i>Malpighiales</i>	<i>Phyllanthaceae</i>	<i>Phyllanthus emblica</i>	Amla	1.84	0.37	2.20	0.92	0.18	1.10	4.04
<i>Myrtales</i>	<i>Myrtaceae</i>	<i>Psidium guajava</i>	Amrood	3.27	0.65	3.92	1.63	0.33	1.96	7.19
		<i>Syzygium cumini</i>	Jamun	7.21	1.44	8.65	3.60	0.72	4.32	15.87

<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	0.84	0.17	1.00	0.42	0.08	0.50	1.84
<i>Rosales</i>	<i>Moraceae</i>	<i>Morus alba</i>	Shehtoot	0.83	0.58	1.41	0.41	0.29	0.70	2.59
	<i>Ulmaceae</i>	<i>Holoptelea intergrifolia</i>	Papdi	0.39	0.08	0.47	0.20	0.04	0.24	0.87
<i>Sapindales</i>	<i>Anacardiaceae</i>	<i>Mangifera indica</i>	Aam	13.46	2.69	16.15	6.73	1.35	8.08	29.64
	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	3.66	0.73	4.39	1.83	0.37	2.19	8.05
		<i>Melia azedarach</i>	Bakain	0.21	0.04	0.25	0.10	0.02	0.12	0.45

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

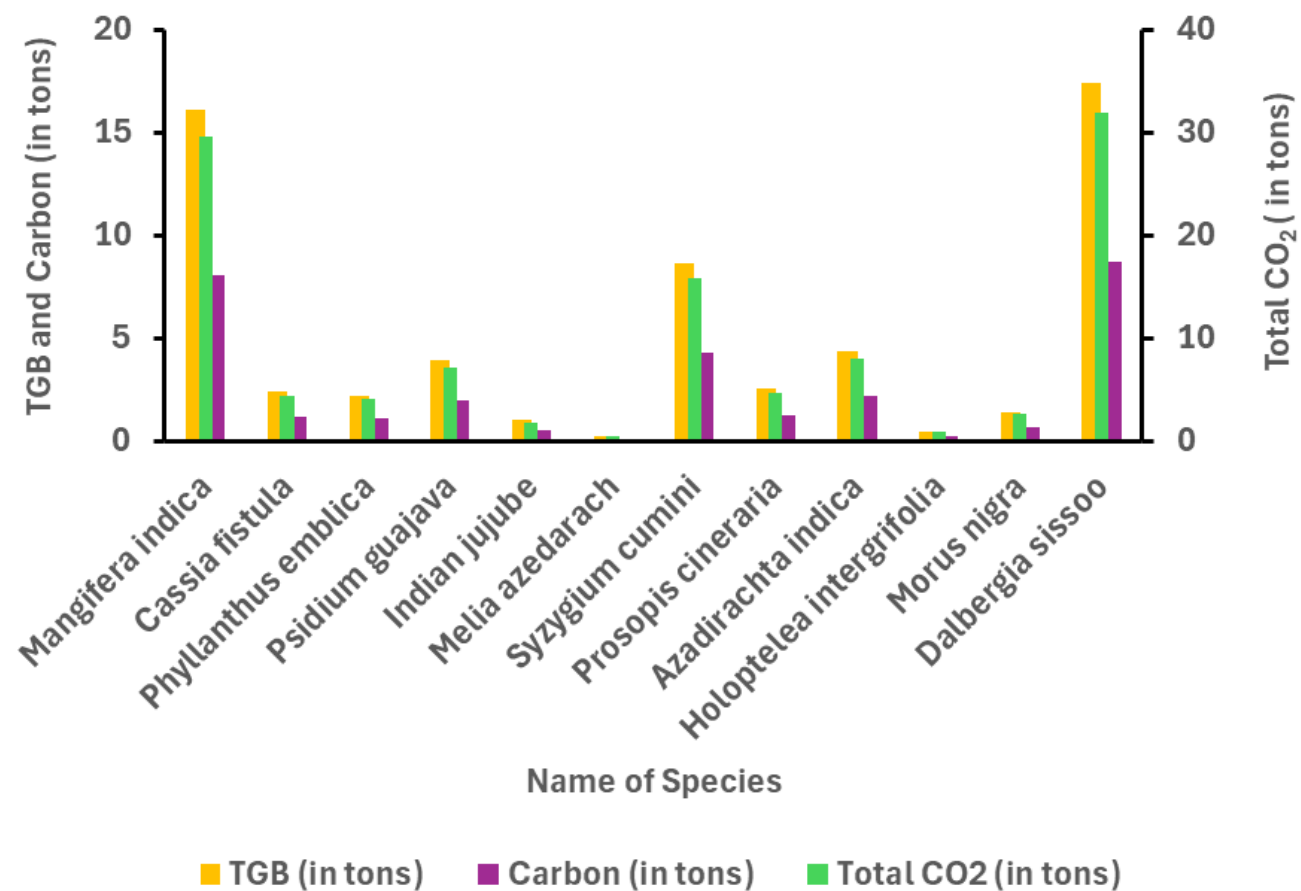


Figure 5.14: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site G (Municipality Park)

Table 5.17: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site H (Mini-bypass) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia nilotica</i>	Kikar	10.12	2.02	12.15	5.06	1.01	6.07	22.29
		<i>Dalbergia sissoo</i>	Sheesham	7.05	1.41	8.46	3.52	0.70	4.23	15.52
		<i>Prosopis cineraria</i>	Janti	1.41	0.28	1.69	0.70	0.14	0.85	3.10
		<i>Prosopis juliflora</i>	Pahadi Kikar	9.35	1.87	11.22	4.67	0.93	5.61	20.58
<i>Lamiales</i>	<i>Bignoniaceae</i>	<i>Kigelia africana</i>	Kigelia	6.74	1.35	8.09	3.37	0.67	4.04	14.84
<i>Myrtales</i>	<i>Myrtaceae</i>	<i>Syzygium cumini</i>	Jamun	6.14	1.23	7.37	3.07	0.61	3.68	13.52
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	0.65	0.13	0.78	0.32	0.06	0.39	1.43
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus religiosa</i>	Pipal	20.21	4.04	24.25	10.11	2.02	12.13	44.51
	<i>Ulmaceae</i>	<i>Holoptelea intergrifolia</i>	Papdi	2.46	0.49	2.95	1.23	0.25	1.47	5.41
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	4.59	0.92	5.51	2.29	0.46	2.75	10.10

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

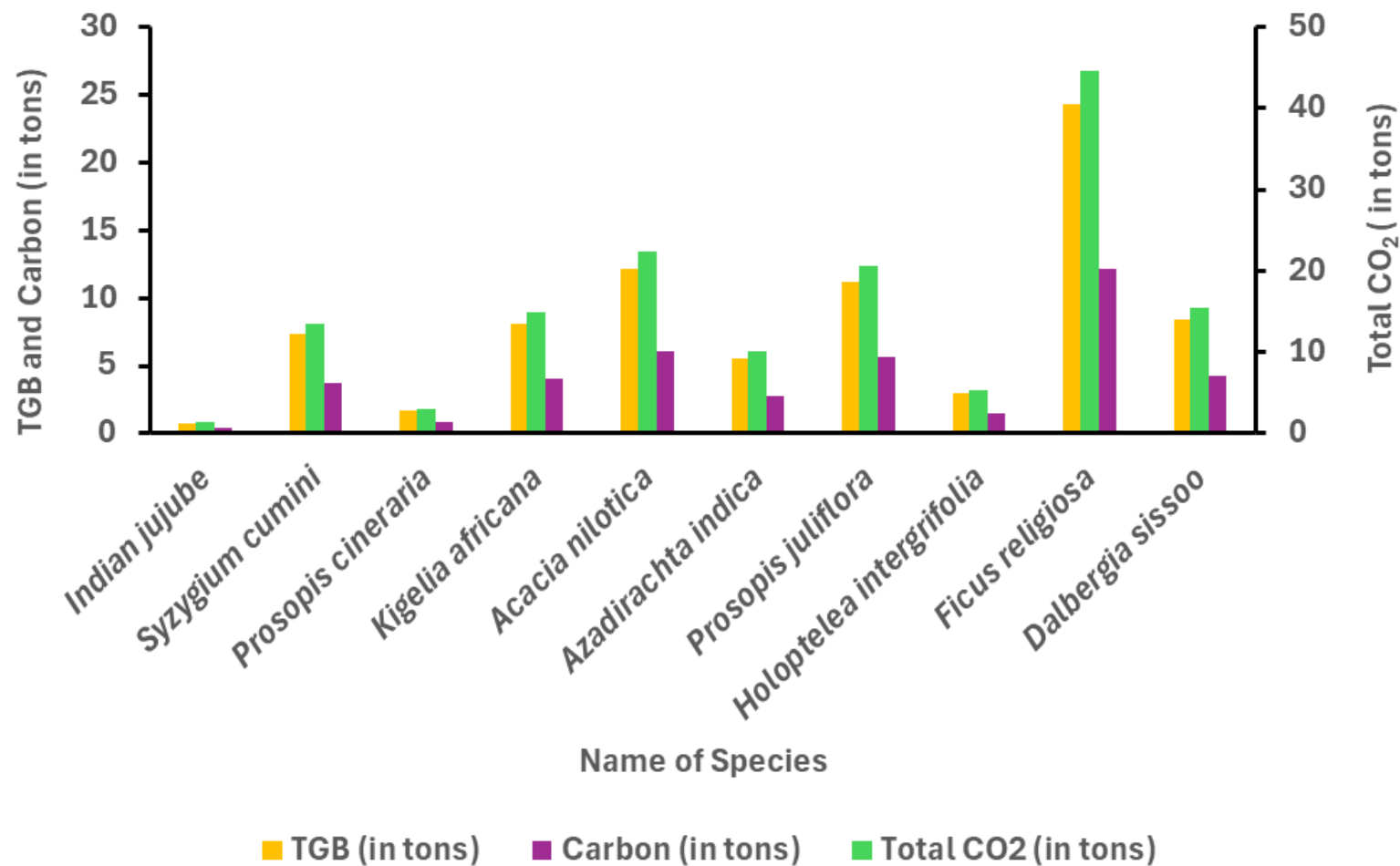


Figure 5.15: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site H (Mini-bypass Sirsa)

5.6.1.5. Site E: Home Garden 1

The table 5.14 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site E. Site E harbour two plant species that play crucial role in carbon sequestration contributing in carbon balance and improving overall health of the environment. *Saraca asoca* and *Aegle marmelos* were determined to be significant contributor in context of carbon sequestration at this site. *Saraca asoca* accounts for total biomass value of 2.41 tons, carbon stock value of 1.21 tons, and CO₂ sequestration value of 4.43 tons. *Aegle marmelos* accounts for total biomass value of 0.86 tons, carbon stock value of 0.07 tons, and CO₂ sequestration value of 1.58 tons. Figure 5.12 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site E.

5.6.1.6. Site F: Home Garden 2

The table 5.15 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site F. *Saraca asoca* that play important role in carbon sequestration contributing in carbon balance. *Saraca asoca* accounts for total biomass value of 2.97 tons, carbon stock value of 1.48 tons, and CO₂ sequestration value of 5.45 tons. Figure 5.13 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site F.

5.6.1.7. Site G: Municipality Park

The table 5.16 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site G. *Dalbergia sissoo* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 17.41 tons, carbon stock value of 8.7 tons, and CO₂ sequestration value of 31.94 tons. These values highlight the crucial role of this species in carbon sequestration at the site G. This also underlines the importance of this species in reducing CO₂ level in the atmosphere. *Mangifera indica* and *Syzygium cumini* were also determined to have substantial carbon sequestration ability. *Mangifera indica* accounts for total biomass value of 16.15 tons, carbon stock value of 8.08 tons, and CO₂ sequestration value of 29.64 tons. *Syzygium cumini* accounts for total biomass value of 8.65 tons, carbon stock value of 4.32 tons, and CO₂

sequestration value of 15.87 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, *Psidium guajava*, *Phyllanthus emblica* and *Ziziphus mauritiana*. *Azadirachta indica* accounts for total biomass value of 4.39 tons, carbon stock value of 2.19 tons, and CO₂ sequestration value of 8.05 tons. *Psidium guajava* accounts for total biomass value of 3.92 tons, carbon stock value of 1.96 tons, and CO₂ sequestration value of 7.19 tons. *Phyllanthus emblica* accounts for total biomass value of 2.2 tons, carbon stock value of 1.1 tons, and CO₂ sequestration value of 4.04 tons. *Ziziphus mauritiana* accounts for total biomass value of 1 ton, carbon stock value of 0.5 ton, and CO₂ sequestration value of 1.84 tons. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration. The high CO₂ sequestration value of *Dalbergia sissoo* highlights its potential application at global scale for combating climate change. Figure 5.14 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site G.

5.6.1.8. Site H: Mini-bypass Sirsa

The table 5.17 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site H. *Ficus religiosa* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 24.25 tons, carbon stock value of 12.13 tons, and CO₂ sequestration value of 44.51 tons. These values highlight the crucial role of this species in carbon sequestration at the site H. This also underlines the importance of this species in mitigating climate changes and reducing CO₂ level in the atmosphere. *Acacia nilotica* and *Prosopis juliflora* were also determined to have substantial carbon sequestration ability. *Acacia nilotica* accounts for total biomass value of 12.15 tons, carbon stock value of 6.07 tons, and CO₂ sequestration value of 22.29 tons. *Prosopis juliflora* accounts for total biomass value of 11.22 tons, carbon stock value of 5.61 tons, and CO₂ sequestration value of 20.58 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, *Syzygium cumini* and *Ziziphus mauritiana*. *Azadirachta indica* accounts for total biomass value of 5.51 tons, carbon stock value of 2.75 tons, and CO₂ sequestration value of 10.1 tons. *Syzygium cumini* accounts for total biomass value of 7.37 tons, carbon stock value of 3.68 tons, and CO₂ sequestration value of 13.52 tons. *Ziziphus mauritiana* accounts for total biomass value of 0.78 ton, carbon stock value of 0.39 ton, and CO₂ sequestration value of 1.43

tons. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration. The high CO₂ sequestration value of *Ficus religiosa* highlights its potential application at global scale for combating climate change. Figure 5.15 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site H.

5.6.2. Estimation of carbon sequestration in forest area

Sequestered carbon was determined using DBH value (refer **Annexure 3**) and Allometric equation (refer **Annexure 7**). In case, where allometric equation were unavailable in that case volumetric equations were used which requires wood density. The woody density information has been comprehended in **Annexure 5**.

5.6.2.1. Site I: Village Chaharwala Minor

The table 5.18 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site I. The site I harbours a total of 8 tree species that have ecological importance. *Ficus religiosa* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 61.59 tons, carbon stock value of 30.79 tons, and CO₂ sequestration value of 113.01 tons. These values highlight the crucial role of this species in carbon sequestration at the site I. This also underlines the importance of this species in mitigating climate changes and reducing CO₂ level in the atmosphere. *Dalbergia sissoo* and *Ficus benghalensis* were also determined to have substantial carbon sequestration ability. *Dalbergia sissoo* accounts for total biomass value of 38.24 tons, carbon stock value of 19.12 tons, and CO₂ sequestration value of 70.18 tons. *Ficus benghalensis* accounts for total biomass value of 33.08 tons, carbon stock value of 16.54 tons, and CO₂ sequestration value of 60.7 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, *Prosopis cineraria*, *Acacia nilotica* and *Ziziphus mauritiana*. *Azadirachta indica* accounts for total biomass value of 8.17 tons, carbon stock value of 4.08 tons, and CO₂ sequestration value of 14.99 tons. *Prosopis cineraria* accounts for total biomass value of 5.02 tons, carbon stock value of 2.51 tons, and CO₂ sequestration value of 9.22 tons. *Acacia nilotica* accounts for total biomass value of 4.64 tons, carbon stock value of 2.32 tons, and CO₂ sequestration value of 8.52 tons. *Ziziphus mauritiana* accounts for total biomass value of 2.64 tons, carbon stock value of 1.32 ton, and CO₂ sequestration

value of 4.84 tons. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration. The high CO₂ sequestration value of *Ficus religiosa* highlights its potential application at global scale for combating climate change. Figure 5.16 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site I.

Table 5.18: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site I (Village Chaharwala Minor) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia nilotica</i>	Kikar	3.87	0.77	4.64	1.93	0.39	2.32	8.52
		<i>Prosopis cineraria</i>	Janti	4.19	0.84	5.02	2.09	0.42	2.51	9.22
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	2.20	0.44	2.64	1.10	0.22	1.32	4.84
<i>Rosales</i>	<i>Moraceae</i>	<i>Dalbergia sissoo</i>	Sheesham	31.87	6.37	38.24	15.94	3.19	19.12	70.18
		<i>Ficus benghalensis</i>	Bargad	27.57	5.51	33.08	13.78	2.76	16.54	60.70
		<i>Ficus religiosa</i>	Pipal	51.32	10.26	61.59	25.66	5.13	30.79	113.01
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	6.81	1.36	8.17	3.40	0.68	4.08	14.99
		<i>Melia azedarach</i>	Bakain	2.48	0.50	2.98	1.24	0.25	1.49	5.46

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

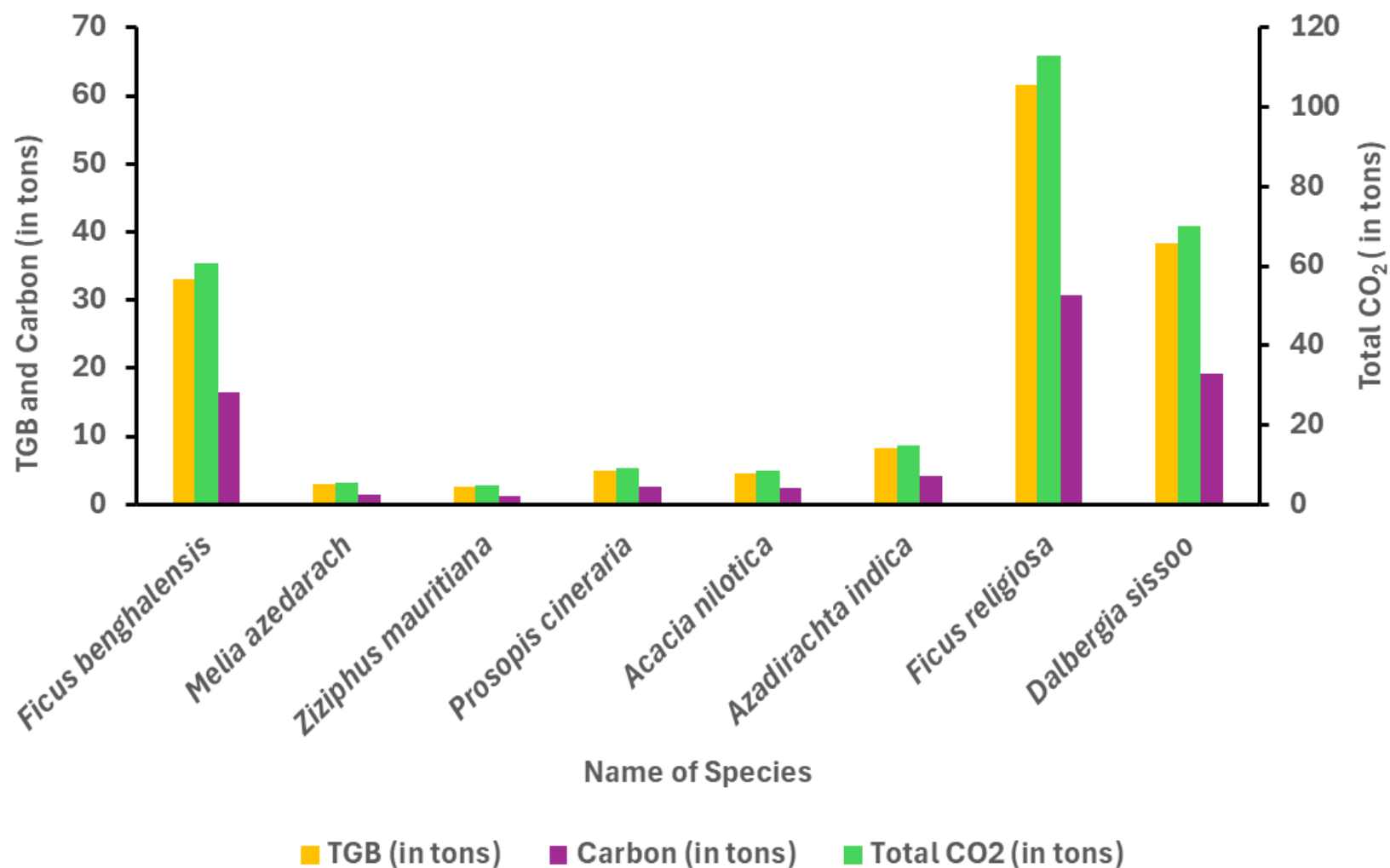


Figure 5.16: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site I (Village Chaharwala Minor)

5.6.2.2. Site J: Village Mameran Road

The table 5.19 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site J. The site J harbours a total of 14 tree species that have ecological importance. *Ficus benghalensis* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 24.89 tons, carbon stock value of 12.44 tons, and CO₂ sequestration value of 45.67 tons. These values highlight the crucial role of this species in carbon sequestration at the site J. This also underlines the importance of this species in mitigating climate changes and reducing CO₂ level in the atmosphere. *Terminalia arjuna* and *Acacia nilotica* were also determined to have substantial carbon sequestration ability. *Terminalia arjuna* accounts for total biomass value of 19.17 tons, carbon stock value of 9.58 tons, and CO₂ sequestration value of 35.17 tons. *Acacia nilotica* accounts for total biomass value of 11.4 tons, carbon stock value of 5.7 tons, and CO₂ sequestration value of 20.93 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, *Moringa oleifera*, *Phyllanthus emblica*, *Syzygium cumini* and *Ziziphus mauritiana*. *Azadirachta indica* accounts for total biomass value of 2.31 tons, carbon stock value of 1.16 tons, and CO₂ sequestration value of 4.25 tons. *Moringa oleifera* accounts for total biomass value of 0.14 ton, carbon stock value of 0.07 ton, and CO₂ sequestration value of 0.25 tons. *Phyllanthus emblica* accounts for total biomass value of 2.55 tons, carbon stock value of 1.27 tons, and CO₂ sequestration value of 4.67 tons. *Syzygium cumini* accounts for total biomass value of 1.85 tons, carbon stock value of 0.93 ton, and CO₂ sequestration value of 3.4 tons. *Ziziphus mauritiana* accounts for total biomass value of 0.11 ton, carbon stock value of 0.05 ton, and CO₂ sequestration value of 0.19 ton. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration. The high CO₂ sequestration value of *Ficus benghalensis* highlights its potential application at global scale for mitigating climate change. Figure 5.17 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site J.

Table 5.19: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site J (Village Mameran Road) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Brassicales</i>	<i>Brassicaceae</i>	<i>Morus alba</i>	Shehtoot	0.14	0.04	0.17	0.07	0.02	0.09	0.31
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia nilotica</i>	Kikar	9.05	2.35	11.40	4.53	1.18	5.70	20.93
		<i>Albizia lebbeck</i>	Sarinh	0.72	0.19	0.91	0.36	0.09	0.45	1.67
		<i>Prosopis juliflora</i>	Pahadi Kikar	1.44	0.37	1.81	0.72	0.19	0.91	3.32
<i>Malpighiales</i>	<i>Phyllanthaceae</i>	<i>Phyllanthus emblica</i>	Amla	2.12	0.42	2.55	1.06	0.21	1.27	4.67
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa oleifera</i>	Sohanjana	0.11	0.03	0.14	0.05	0.01	0.07	0.25
<i>Myrtales</i>	<i>Combretaceae</i>	<i>Terminalia arjuna</i>	Arjun	15.97	3.19	19.17	7.99	1.60	9.58	35.17
	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Safeda	7.81	2.03	9.84	3.91	1.02	4.92	18.06

		<i>Syzygium cumini</i>	Jamun	1.47	0.38	1.85	0.74	0.19	0.93	3.40
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	0.08	0.02	0.11	0.04	0.01	0.05	0.19
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus benghalensis</i>	Bargad	20.74	4.15	24.89	10.37	2.07	12.44	45.67
		<i>Ficus religiosa</i>	Pipal	1.85	0.48	2.33	0.92	0.24	1.16	4.27
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	1.84	0.48	2.31	0.92	0.24	1.16	4.25
		<i>Melia azedarach</i>	Bakain	0.30	0.08	0.38	0.15	0.04	0.19	0.69

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

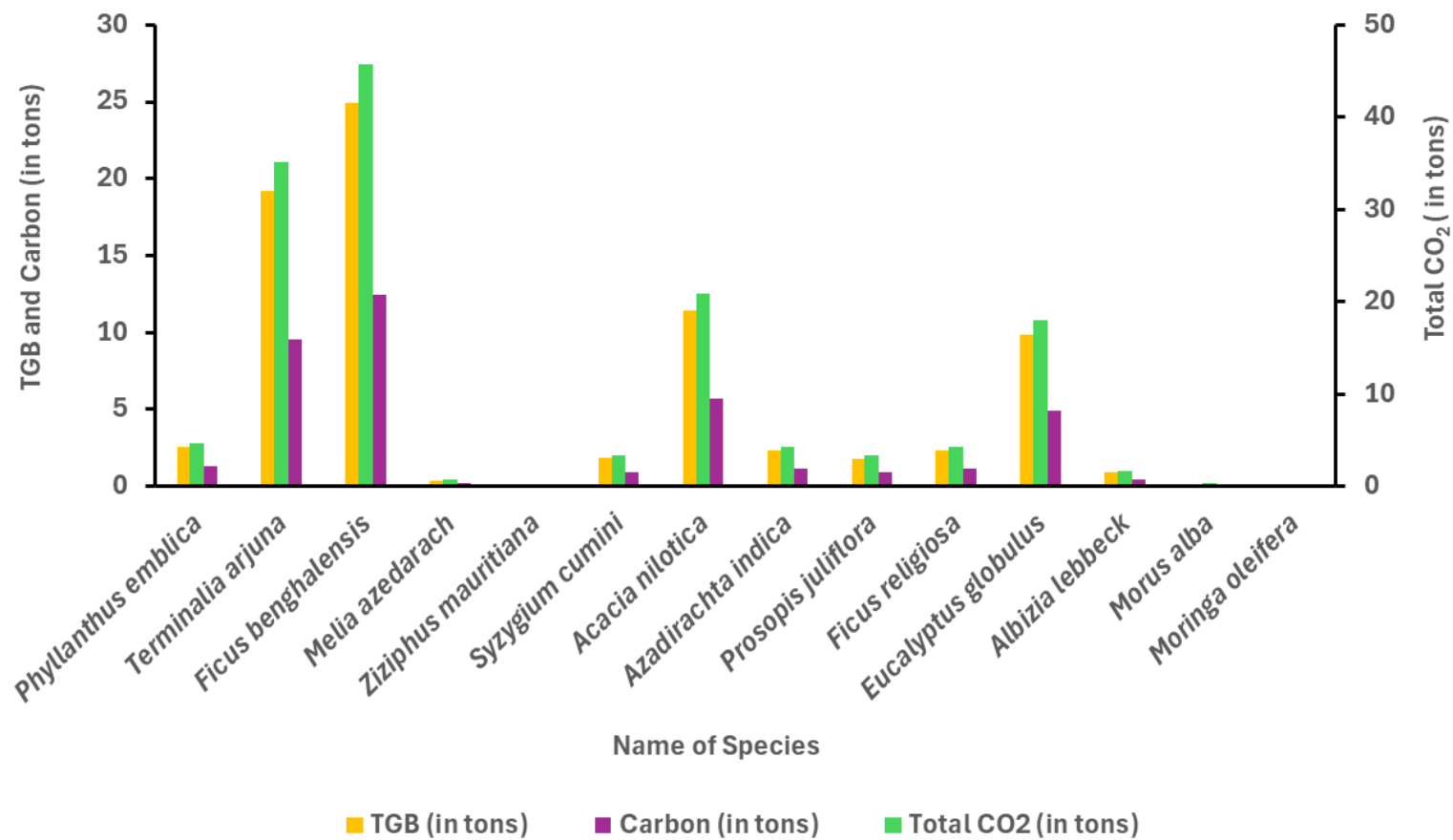


Figure 5.17: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site J (Village Mameran Road)

5.6.2.3. Site K: Panjuana Canal

The table 5.20 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site K. The site K is home for the total of 17 tree species that have ecological importance. *Ficus religiosa* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 68.07 tons, carbon stock value of 34.03 tons, and CO₂ sequestration value of 124.9 tons. These values highlight the crucial role of this species in carbon sequestration at the site K. This also underlines the importance of this species in reducing CO₂ level in the atmosphere. *Eucalyptus globulus* and *Ficus benghalensis* were also determined to have substantial carbon sequestration ability. *Eucalyptus globulus* accounts for total biomass value of 57.3 tons, carbon stock value of 28.65 tons, and CO₂ sequestration value of 105.15 tons. *Ficus benghalensis* accounts for total biomass value of 50.72 tons, carbon stock value of 25.36 tons, and CO₂ sequestration value of 93.07 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, *Moringa oleifera*, *Syzygium cumini* and *Ziziphus mauritiana*. *Azadirachta indica* accounts for total biomass value of 13.21 tons, carbon stock value of 6.6 tons, and CO₂ sequestration value of 24.24 tons. *Moringa oleifera* accounts for total biomass value of 0.74 ton, carbon stock value of 0.37 ton, and CO₂ sequestration value of 1.36 tons. *Syzygium cumini* accounts for total biomass value of 24.88 tons, carbon stock value of 12.44 tons, and CO₂ sequestration value of 45.65 tons. *Ziziphus mauritiana* accounts for total biomass value of 2.28 tons, carbon stock value of 1.14 tons, and CO₂ sequestration value of 4.18 ton. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration. The high CO₂ sequestration value of *Ficus religiosa* highlights its potential application at global scale for mitigating climate change. Figure 5.18 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site K.

Table 5.20: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site K (Panjuana Canal) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia nilotica</i>	Kikar	8.68	1.74	10.42	4.34	0.87	5.21	19.11
		<i>Albizia lebbeck</i>	Sarinh	16.26	3.25	19.51	8.13	1.63	9.75	35.79
		<i>Cassia fistula</i>	Amaltas	1.47	0.38	1.86	0.74	0.19	0.93	3.41
		<i>Dalbergia sissoo</i>	Sheesham	21.83	4.37	26.19	10.91	2.18	13.10	48.07
		<i>Prosopis cineraria</i>	Janti	6.19	1.24	7.43	3.09	0.62	3.71	13.63
		<i>Prosopis juliflora</i>	Pahadi Kikar	14.37	2.87	17.25	7.19	1.44	8.62	31.65
<i>Moringales</i>	<i>Moringaceae</i>	<i>Moringa oleifera</i>	Sohanjana	0.62	0.12	0.74	0.31	0.06	0.37	1.36
<i>Myrtales</i>	<i>Combretaceae</i>	<i>Terminalia arjuna</i>	Arjun	11.89	2.38	14.26	5.94	1.19	7.13	26.17

		<i>Terminalia bellirica</i>	Baheda	12.61	2.52	15.13	6.30	1.26	7.56	27.76
	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Safeda	47.75	9.55	57.30	23.88	4.78	28.65	105.15
		<i>Syzygium cumini</i>	Jamun	20.73	4.15	24.88	10.37	2.07	12.44	45.65
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	1.90	0.38	2.28	0.95	0.19	1.14	4.18
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus benghalensis</i>	Bargad	42.26	8.45	50.72	21.13	4.23	25.36	93.07
		<i>Ficus religiosa</i>	Pipal	56.72	11.34	68.07	28.36	5.67	34.03	124.90
		<i>Morus alba</i>	Shehtoot	2.95	2.07	5.02	1.48	1.03	2.51	9.21
	<i>Ulmaceae</i>	<i>Holoptelea intergrifolia</i>	Papdi	0.94	0.19	1.13	0.47	0.09	0.56	2.07
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	11.01	2.20	13.21	5.50	1.10	6.60	24.24

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

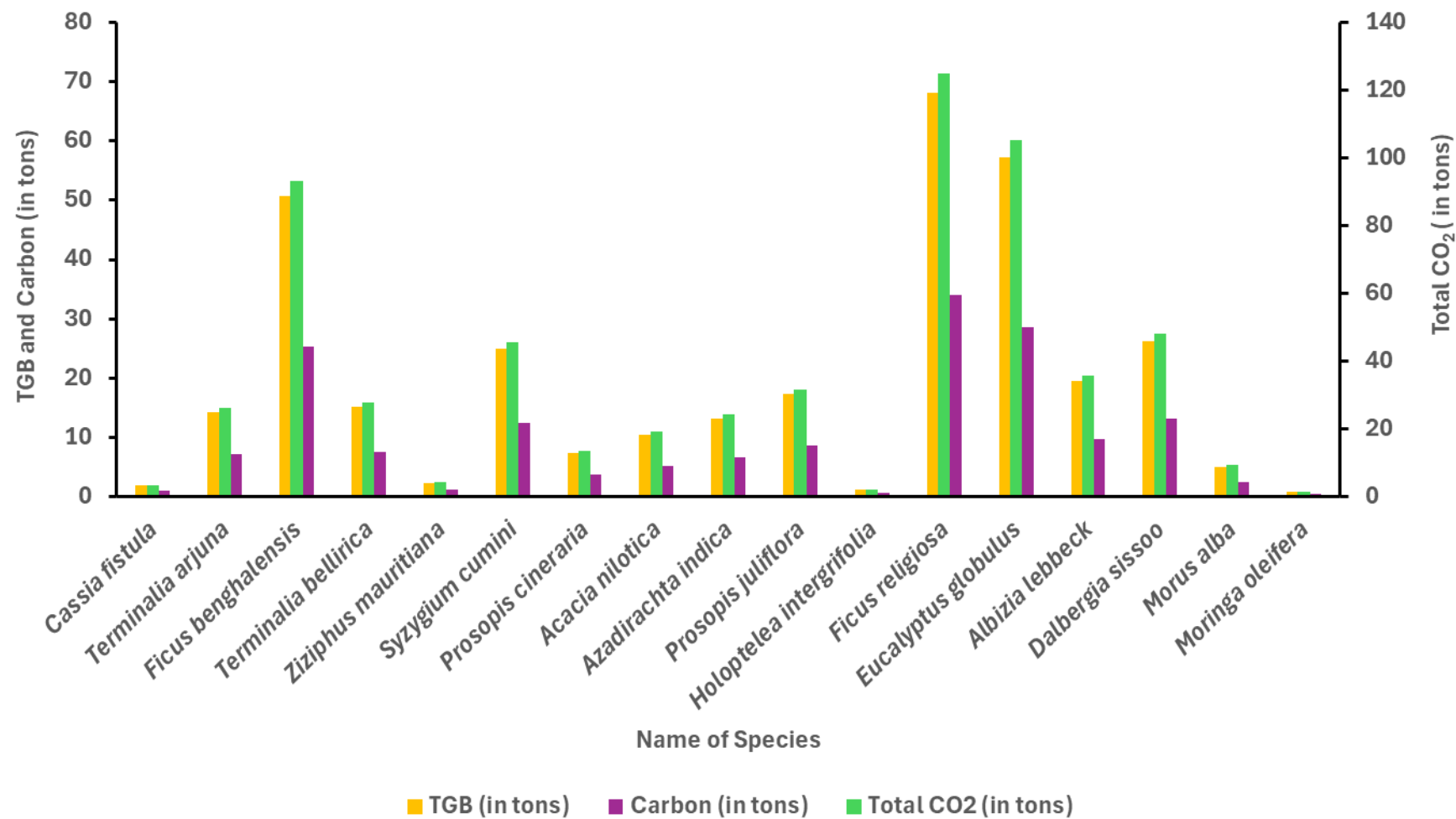


Figure 5.18: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site K (Panjuana Canal)

5.6.2.4. Site L: Village Nagoki Canal

The table 5.21 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site L. The site L encompasses a total of 9 tree species that have ecological importance. *Eucalyptus globulus* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 142.23 tons, carbon stock value of 71.22 tons, and CO₂ sequestration value of 261.37 tons. These values highlight the crucial role of this species in carbon sequestration at the site L. This also underlines the importance of this species in mitigating climate change and reducing CO₂ level in the atmosphere. *Azadirachta indica* and *Prosopis juliflora* were also determined to have substantial carbon sequestration ability. *Azadirachta indica* accounts for total biomass value of 19.62 tons, carbon stock value of 9.81 tons, and CO₂ sequestration value of 36 tons. *Prosopis juliflora* accounts for total biomass value of 19.48 tons, carbon stock value of 9.74 tons, and CO₂ sequestration value of 35.74 tons. At this site, few species hold medicinal and ecological value which include *Acacia nilotica*, *Azadirachta indica*, *Holoptelea intergrifolia* and *Ziziphus mauritiana*. *Acacia nilotica* accounts for total biomass value of 1.58 tons, carbon stock value of 0.79 ton, and CO₂ sequestration value of 2.91 tons. *Holoptelea intergrifolia* accounts for total biomass value of 1.11 tons, carbon stock value of 0.56 ton, and CO₂ sequestration value of 2.05 tons. *Ziziphus mauritiana* accounts for total biomass value of 0.7-ton, carbon stock value of 0.35 ton, and CO₂ sequestration value of 1.28 tons. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration. The high CO₂ sequestration value of *Eucalyptus globulus* highlights its potential application at global scale for mitigating climate change. Figure 5.19 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site L.

Table 5.21: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site L (Village Nagoki Canal) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia nilotica</i>	Kikar	1.32	0.26	1.58	0.66	0.13	0.79	2.91
		<i>Dalbergia sissoo</i>	Sheesham	11.89	2.38	14.27	5.94	1.19	7.13	26.18
		<i>Prosopis juliflora</i>	Pahadi Kikar	16.23	3.25	19.48	8.11	1.62	9.74	35.74
<i>Myrtales</i>	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Safeda	118.70	23.74	142.43	59.35	11.87	71.22	261.37
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	0.58	0.12	0.70	0.29	0.06	0.35	1.28
<i>Rosales</i>	<i>Moraceae</i>	<i>Morus alba</i>	Shehtoot	3.17	0.63	3.81	1.59	0.32	1.90	6.99
	<i>Ulmaceae</i>	<i>Holoptelea</i>	Papdi	0.93	0.19	1.11	0.46	0.09	0.56	2.05

		<i>intergrifolia</i>								
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	16.35	3.27	19.62	8.17	1.63	9.81	36.00
		<i>Melia azedarach</i>	Bakain	2.44	0.49	2.93	1.22	0.24	1.46	5.37

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

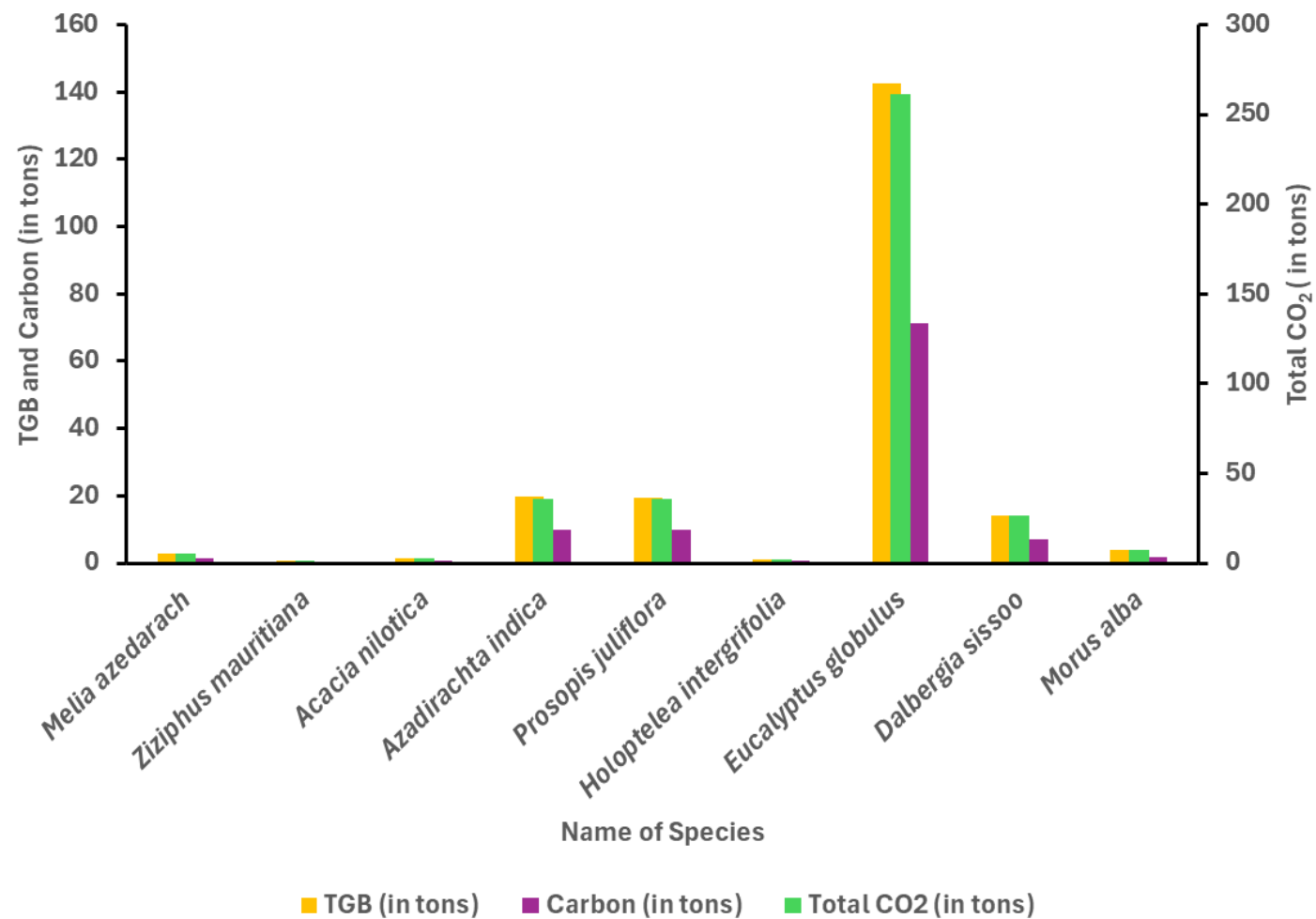


Figure 5.19: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site L (Village Nagoki Canal)

5.6.2.5. Site M: Village Mangiana

The table 5.22 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site M. The site M harbours a total of 10 tree species that have ecological importance. *Eucalyptus globulus* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 68.74 tons, carbon stock value of 34.37 tons, and CO₂ sequestration value of 126.14 tons. These values highlight the crucial role of this species in carbon sequestration at the site M. This also underlines the importance of this species in mitigating climate change. *Prosopis juliflora* and *Syzygium cumini* were also determined to have substantial carbon sequestration ability. *Prosopis juliflora* accounts for total biomass value of 39.14 tons, carbon stock value of 19.57 tons, and CO₂ sequestration value of 71.82 tons. *Syzygium cumini* accounts for total biomass value of 61.42 tons, carbon stock value of 30.71 tons, and CO₂ sequestration value of 112.71 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, *Holoptelea intergrifolia*, *Prosopis cineraria* and *Xanthozylum armatum*. *Azadirachta indica* accounts for total biomass value of 31.76 tons, carbon stock value of 15.88 ton, and CO₂ sequestration value of 58.28 tons. *Holoptelea intergrifolia* accounts for total biomass value of 6.81 tons, carbon stock value of 3.41 tons, and CO₂ sequestration value of 12.5 tons. *Prosopis cineraria* accounts for total biomass value of 8.63 tons, carbon stock value of 4.31 tons, and CO₂ sequestration value of 15.83 tons. *Xanthozylum armatum* accounts for total biomass value of 18.5 tons, carbon stock value of 9.25 tons, and CO₂ sequestration value of 33.95 tons. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration. The high CO₂ sequestration value of *Eucalyptus globulus* highlights its potential application at global level for mitigating climate change. Figure 5.20 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site M.

Table 5.22: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site M (Village Mangiana) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Albizia lebbbeck</i>	Sarinh	14.44	2.89	17.33	7.22	1.44	8.67	31.80
		<i>Dalbergia sissoo</i>	Sheesham	24.11	4.82	28.93	12.05	2.41	14.46	53.08
		<i>Prosopis cineraria</i>	Janti	7.19	1.44	8.63	3.59	0.72	4.31	15.83
		<i>Prosopis juliflora</i>	Pahadi Kikar	32.62	6.52	39.14	16.31	3.26	19.57	71.82
<i>Myrtales</i>	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Safeda	57.29	11.46	68.74	28.64	5.73	34.37	126.14
		<i>Syzygium cumini</i>	Jamun	51.14	10.28	61.42	25.57	5.14	30.71	112.71
<i>Rosales</i>	<i>Moraceae</i>	<i>Morus alba</i>	Shehtoot	4.30	3.01	7.31	2.15	1.51	3.66	13.42
	<i>Ulmaceae</i>	<i>Holoptelea intergrifolia</i>	Papdi	5.68	1.14	6.81	2.84	0.57	3.41	12.50

<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	26.47	5.29	31.76	13.23	2.65	15.88	58.28
	<i>Rutaceae</i>	<i>Xanthozylum armatum</i>	Pahadi Neem	15.42	3.08	18.50	7.71	1.54	9.25	33.95

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

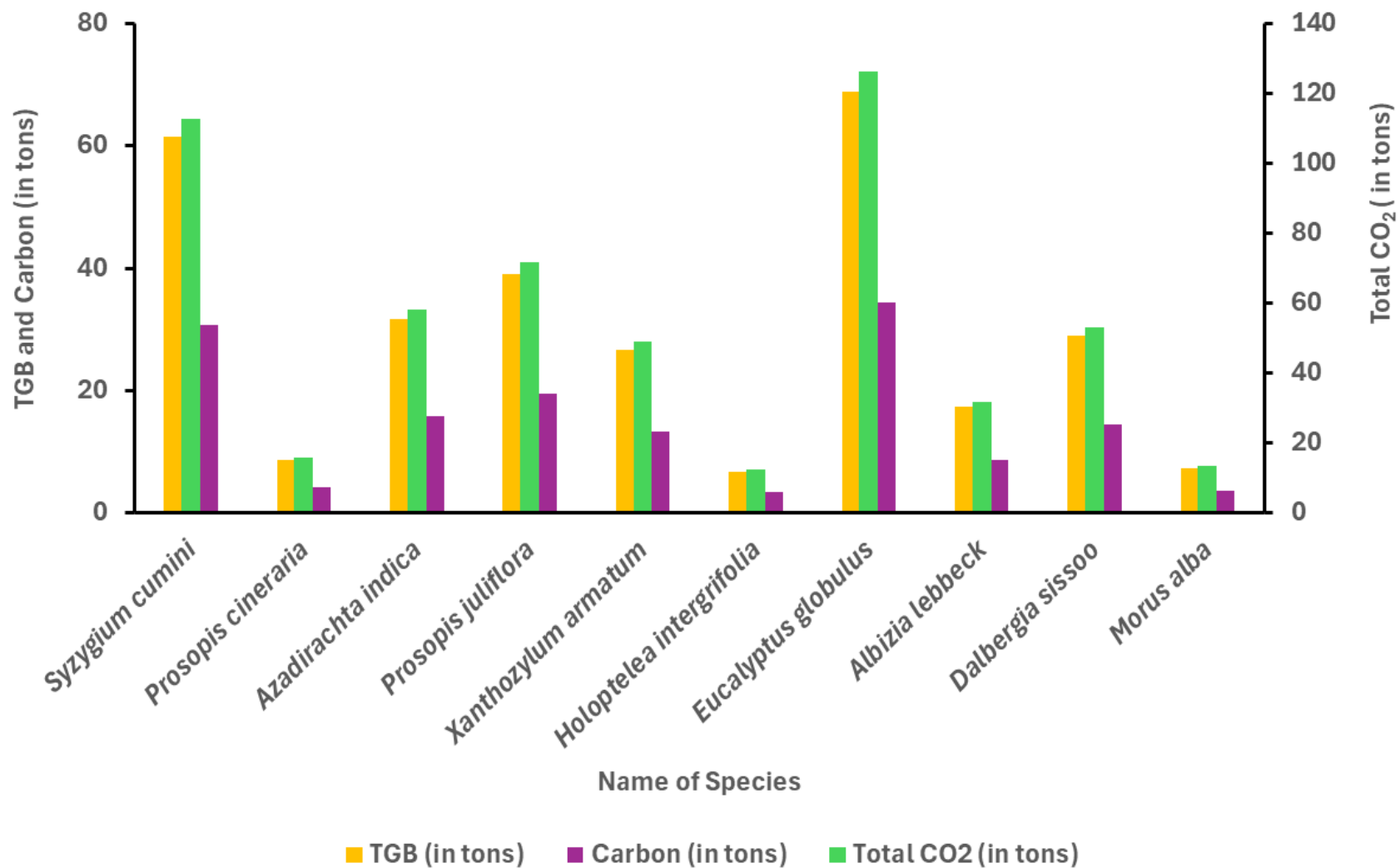


Figure 5.20: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site M (Village Mangiana)

5.6.2.6. Site N: Ottu Head

The table 5.23 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site N. The site N harbours a total of 12 tree species that have ecological importance. *Ficus religiosa* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 42.96 tons, carbon stock value of 21.48 tons, and CO₂ sequestration value of 78.83 tons. These values highlight the critical role of this species in carbon sequestration at the site N. This also underlines the importance of this species in mitigating climate change. *Eucalyptus globulus* and *Albizia lebbbeck* were also determined to have substantial carbon sequestration ability. *Eucalyptus globulus* accounts for total biomass value of 28.82 tons, carbon stock value of 14.41 tons, and CO₂ sequestration value of 52.89 tons. *Albizia lebbbeck* accounts for total biomass value of 22.04 tons, carbon stock value of 11.02 tons, and CO₂ sequestration value of 40.44 tons. At this site, few species hold medicinal and ecological value which include *Acacia nilotica*, *Azadirachta indica*, *Holoptelea intergrifolia*, *Prosopis cineraria*, *Syzygium cumini*, *Xanthozylum armatum* and *Ziziphus mauritiana*. *Acacia nilotica* accounts for total biomass value of 4.96 tons, carbon stock value of 2.48 tons, and CO₂ sequestration value of 9.11 tons. *Azadirachta indica* accounts for total biomass value of 13.82 tons, carbon stock value of 6.91 tons, and CO₂ sequestration value of 25.36 tons. *Holoptelea intergrifolia* accounts for total biomass value of 0.53-ton, carbon stock value of 0.26 ton, and CO₂ sequestration value of 0.96 ton. *Prosopis cineraria* accounts for total biomass value of 2.48 tons, carbon stock value of 1.24 tons, and CO₂ sequestration value of 4.55 tons. *Syzygium cumini* accounts for total biomass value of 9.14 tons, carbon stock value of 4.57 tons, and CO₂ sequestration value of 16.77 tons. *Xanthozylum armatum* accounts for total biomass value of 10.13 tons, carbon stock value of 5.07 tons, and CO₂ sequestration value of 18.59 tons. *Ziziphus mauritiana* accounts for total biomass value of 0.78-ton, carbon stock value of 0.39 ton, and CO₂ sequestration value of 1.43 tons. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration. The high CO₂ sequestration value of *Ficus religiosa*, *Eucalyptus globulus* and *Albizia lebbbeck* highlights their potential application at global level for mitigating climate change and reducing CO₂ in the atmosphere. Figure 5.21 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site N.

Table 5.23: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site N (Ottu Head) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia nilotica</i>	Kikar	4.14	0.83	4.96	2.07	0.41	2.48	9.11
		<i>Albizia lebbeck</i>	Sarin	18.37	3.67	22.04	9.18	1.84	11.02	40.44
		<i>Dalbergia sissoo</i>	Sheesham	9.50	1.90	11.40	4.75	0.95	5.70	20.91
		<i>Prosopis cineraria</i>	Janti	2.07	0.41	2.48	1.03	0.21	1.24	4.55
<i>Myrtales</i>	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Safeda	24.02	4.80	28.82	12.01	2.40	14.41	52.89
		<i>Syzygium cumini</i>	Jamun	7.61	1.52	9.14	3.81	0.76	4.57	16.77
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	0.65	0.13	0.78	0.33	0.07	0.39	1.43
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus religiosa</i>	Pipal	35.80	7.16	42.96	17.90	3.58	21.48	78.83
		<i>Morus alba</i>	Shehtoot	0.99	0.20	1.19	0.49	0.10	0.59	2.18

	<i>Ulmaceae</i>	<i>Holoptelea integrifolia</i>	Papdi	0.44	0.09	0.53	0.22	0.04	0.26	0.96
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	11.52	2.30	13.82	5.76	1.15	6.91	25.36
	<i>Rutaceae</i>	<i>Xanthozylum armatum</i>	Pahadi Neem	8.44	1.69	10.13	4.22	0.84	5.07	18.59

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

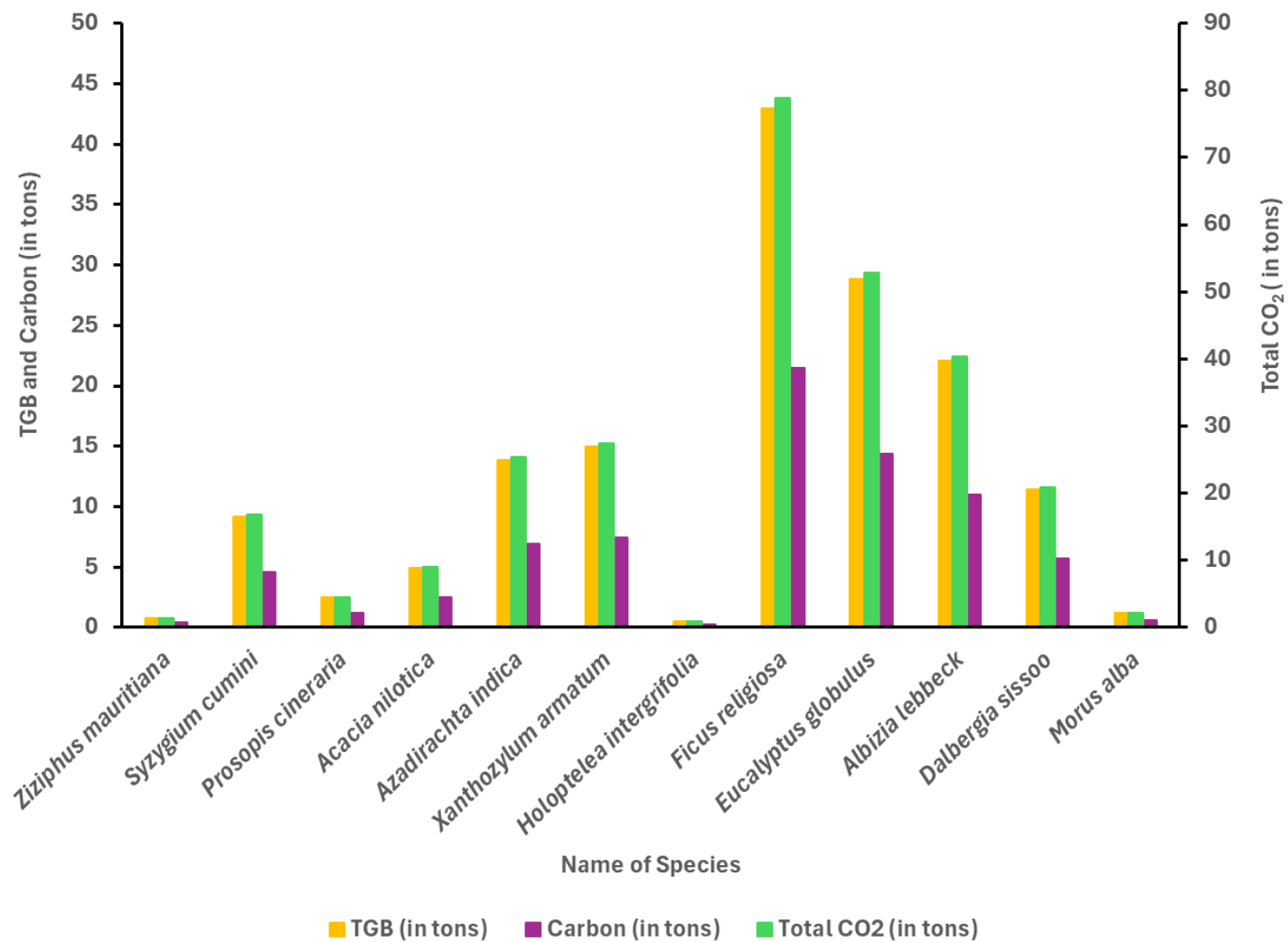


Figure 5.21: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site N (Ottu Head)

5.6.2.7. Site O: Abub Sheher Wildlife Sanctuary

The table 5.24 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site O. The site O is home for a total of 10 tree species that have ecological importance. *Prosopis juliflora* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 92.69 tons, carbon stock value of 46.35 tons, and CO₂ sequestration value of 170.09 tons. These values highlight the essential role of this species in carbon sequestration at the site O. This also underlines the importance of this species in mitigating climate change. *Eucalyptus globulus* and *Xanthozylum armatum* were also determined to have substantial carbon sequestration ability. *Eucalyptus globulus* accounts for total biomass value of 41.67 tons, carbon stock value of 20.83 tons, and CO₂ sequestration value of 76.46 tons. *Xanthozylum armatum* accounts for total biomass value of 42.43 tons, carbon stock value of 21.21 tons, and CO₂ sequestration value of 77.85 tons. At this site, few species hold medicinal and ecological value which include *Azadirachta indica*, *Ficus carica*, *Psidium guajava* and *Ziziphus mauritiana*. *Azadirachta indica* accounts for total biomass value of 14.4 tons, carbon stock value of 7.2 tons, and CO₂ sequestration value of 26.42 tons. *Ficus carica* accounts for total biomass value of 1.24 tons, carbon stock value of 0.62 ton, and CO₂ sequestration value of 2.28 tons. *Psidium guajava* accounts for total biomass value of 0.88 ton, carbon stock value of 0.44 ton, and CO₂ sequestration value of 1.61 tons. *Ziziphus mauritiana* accounts for total biomass value of 0.41 ton, carbon stock value of 0.2 ton, and CO₂ sequestration value of 0.75 ton. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration and reducing CO₂ levels in the atmosphere. The high CO₂ sequestration value of *Prosopis juliflora*, *Xanthozylum armatum*, *Eucalyptus globulus* and *Ficus benghalensis* highlights their potential application at global level for mitigating climate change and reducing CO₂ in the atmosphere. Figure 5.22 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site O.

Table 5.24: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site O (Abub Sheher Wildlife Sanctuary) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Albizia lebbeck</i>	Sarinh	20.23	4.05	24.28	10.12	2.02	12.14	44.55
		<i>Dalbergia sissoo</i>	Sheesham	22.72	4.54	27.27	11.36	2.27	13.63	50.04
		<i>Prosopis juliflora</i>	Pahadi Kikar	77.24	15.45	92.69	38.62	7.72	46.35	170.09
<i>Myrtales</i>	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Safeda	34.72	6.94	41.67	17.36	3.47	20.83	76.46
		<i>Psidium guajava</i>	Amrood	0.73	0.15	0.88	0.37	0.07	0.44	1.61
<i>Rhamnales</i>	<i>Rhamnaceae</i>	<i>Ziziphus mauritiana</i>	Beri	0.34	0.07	0.41	0.17	0.03	0.20	0.75
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus benghalensis</i>	Bargad	30.64	7.97	38.61	15.32	3.98	19.31	70.85
		<i>Ficus carica</i>	Anjeer	1.03	0.21	1.24	0.52	0.10	0.62	2.28
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	12.00	2.40	14.40	6.00	1.20	7.20	26.42
	<i>Rutaceae</i>	<i>Xanthozylum armatum</i>	Pahadi Neem	35.36	7.07	42.43	17.68	3.54	21.21	77.85

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

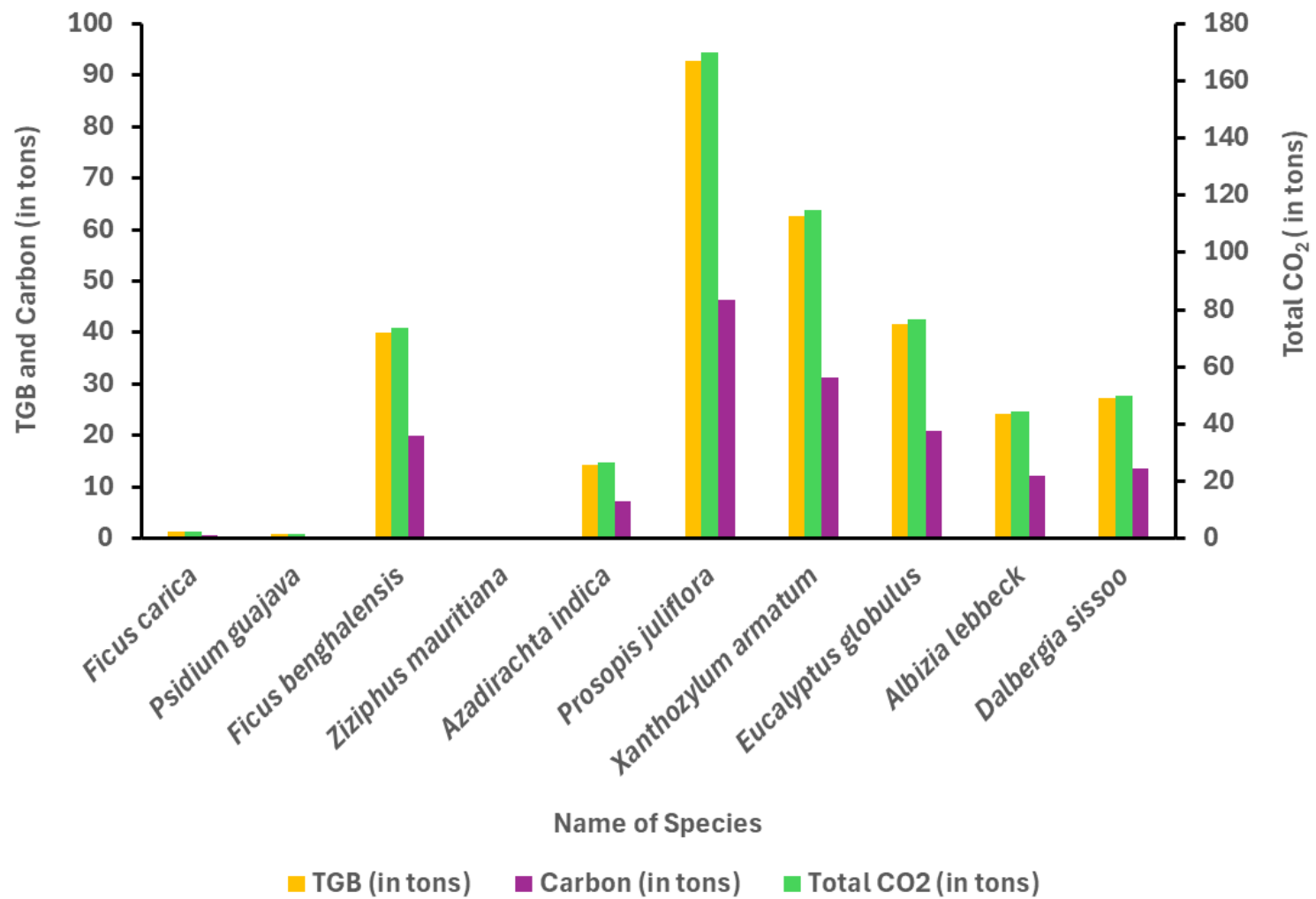


Figure 5.22: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site O (Abub Sheher Wildlife Sanctuary)

5.6.2.8. Site P: Daulatpur Khera

The table 5.25 summarize the information like biomass value, carbon stock and CO₂ sequestration about the species of trees in the Site P. The site P is home for a total of 10 tree species that have ecological importance. *Prosopis juliflora* was determined to be significant contributor in context of carbon sequestration accounting for total biomass value of 51.51 tons, carbon stock value of 25.75 tons, and CO₂ sequestration value of 94.52 tons. These values highlight the essential role of this species in carbon sequestration at the site P. This also underlines the importance of this species in mitigating climate change. *Dalbergia sissoo*, *Eucalyptus globulus* and *Ficus religiosa* were also determined to have substantial carbon sequestration ability. *Dalbergia sissoo* accounts for total biomass value of 22.79 tons, carbon stock value of 11.4 tons, and CO₂ sequestration value of 41.82 tons. *Eucalyptus globulus* accounts for total biomass value of 17.77 tons, carbon stock value of 8.89 tons, and CO₂ sequestration value of 32.61 tons. *Ficus religiosa* accounts for total biomass value of 28.74 tons, carbon stock value of 14.37 tons, and CO₂ sequestration value of 52.74 tons. At this site, few species hold medicinal and ecological value which include *Acacia nilotica*, *Azadirachta indica*, *Holoptelea intergrifolia* and *Syzygium cumini*. *Acacia nilotica* accounts for total biomass value of 8.35 tons, carbon stock value of 4.18 tons, and CO₂ sequestration value of 15.33 tons. *Azadirachta indica* accounts for total biomass value of 12 tons, carbon stock value of 6 tons, and CO₂ sequestration value of 22.02 tons. *Holoptelea intergrifolia* accounts for total biomass value of 0.8-ton, carbon stock value of 0.4 ton, and CO₂ sequestration value of 1.46 tons. *Syzygium cumini* accounts for total biomass value of 10.91 tons, carbon stock value of 5.46 tons, and CO₂ sequestration value of 20.02 tons. The data of this site unveils the critical role of plant species in mitigating climate change via carbon sequestration and reducing CO₂ levels in the atmosphere. The high CO₂ sequestration value of *Prosopis juliflora* and *Ficus religiosa* highlights their potential application at global level for mitigating climate change and reducing CO₂ in the atmosphere. Figure 5.23 illustrating the bar chart provide a visual depiction of total ground biomass, carbon stock and total CO₂ value of plant species at the Site P.

Table 5.25: Summary of Total Ground Biomass, Carbon Stock and Total CO₂ of the Site P (Daulatpur Khera) according to APG IV guidelines

Order	Family	Botanical Name	Local Name	AGB (in tons)	BGB (in tons)	TGB (in tons)	AGB Carbon (in tons)	BGB Carbon (in tons)	Carbon Stock (in tons)	Total CO ₂ (in tons)
<i>Fabales</i>	<i>Fabaceae</i>	<i>Acacia nilotica</i>	Kikar	6.96	1.39	8.35	3.48	0.70	4.18	15.33
		<i>Dalbergia sissoo</i>	Sheesham	18.99	3.80	22.79	9.50	1.90	11.40	41.82
		<i>Prosopis juliflora</i>	Pahadi Kikar	42.92	8.58	51.51	21.46	4.29	25.75	94.52
<i>Myrtales</i>	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Safeda	14.81	2.96	17.77	7.40	1.48	8.89	32.61
		<i>Syzygium cumini</i>	Jamun	9.09	1.82	10.91	4.55	0.91	5.46	20.02
<i>Rosales</i>	<i>Moraceae</i>	<i>Ficus religiosa</i>	Pipal	23.95	4.79	28.74	11.98	2.40	14.37	52.74
		<i>Morus alba</i>	Shehtoot	0.96	0.67	1.63	0.48	0.34	0.81	2.99
	<i>Ulmaceae</i>	<i>Holoptelea integrifolia</i>	Papdi	0.67	0.13	0.80	0.33	0.07	0.40	1.46
<i>Sapindales</i>	<i>Meliaceae</i>	<i>Azadirachta indica</i>	Neem	10.00	2.00	12.00	5.00	1.00	6.00	22.02
		<i>Melia azedarach</i>	Bakain	0.80	0.16	0.96	0.40	0.08	0.48	1.76

*AGB: Above-ground Biomass; BGB: Below-ground Biomass; TGB: Total-ground Biomass

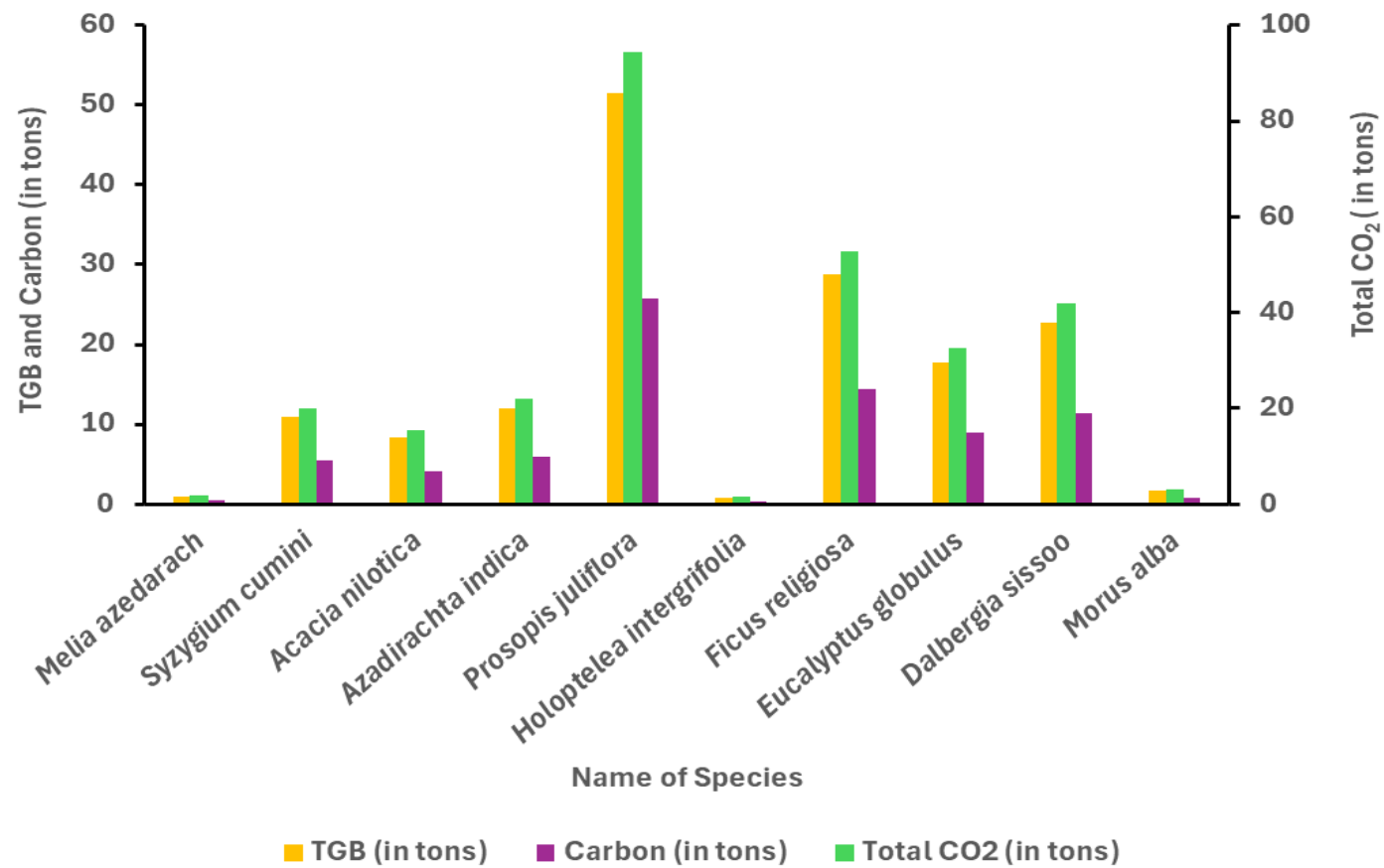


Figure 5.23: Bar graph depicting total ground biomass, carbon stock and total CO₂ of the Site P (Daulatpur Khera)

5.7. Comparison Analysis of Carbon Sequestration Between Urban and Forest Vegetation

Comparative evaluation of carbon sequestration across urban (sites A-H) and forest (sites I-P) areas revealed site-wise variations. These variations are governed by differences in plant diversity, species dominance and structural composition. Among urban sites, comparatively higher carbon sequestration was accorded in Shaheed Bhagat Singh Stadium (Site A), Chaudhary Devi Lal Park (Site B) and Sirsa minor (Site C). These sites also showed higher Shannon-Weiner Index (H') values i.e., 3.22 as well as higher species richness. The presence of economically important and moderately dominant species such as *Dalbergia sissoo*, *Azadirachta indica*, and *Holoptelea integrifolia* contributed significantly to biomass accumulation and carbon storage. On the other hand, remaining urban sites such as Home Garden 2 (Site F) and Mini-bypass Sirsa (Site H) showed comparatively lower diversity and uneven species distribution, which explains reduced carbon sequestration potential from urban sites.

Constantly, higher carbon sequestration potential was observed across most forest sites. Sites such as Panjuana Canal (Site K), Village Nagoki Canal (Site L) and Ottu Head (Site N) reported higher species richness and dominance. Likewise, these sites also showed higher biomass accumulation. Dominant species such as *Eucalyptus globulus*, *Azadirachta indica*, *Acacia nilotica*, and *Prosopis juliflora* were determined to have higher number of individuals and basal area. This significantly increased carbon accumulation at these sites. Additionally, these sites experience minimal anthropogenic disturbance, which further supports efficient carbon sequestration.

Overall, site-wise comparison indicated that sites with higher species diversity and ecological dominance exhibit higher carbon sequestration potential. Whereas, sites with lower diversity and fragmented vegetation shows reduced carbon sequestration potential. Forest ecosystems are known to have high structural complexity, species dominance and biomass accumulation. Thus, they demonstrate higher carbon sequestration potential as compared to urban ecosystems. Although, the well-maintained and diverse urban areas contribute significantly to carbon sequestration. However, forest areas remain more efficient in carbon accumulation due to higher species richness, dominance and ecological stability. This clearly indicates that variation in biodiversity directly influence biomass accumulation and carbon sequestration in both urban and forest ecosystems.

Objective 3: To Evaluate the Soil Carbon Sequestration Potential.

5.8. Soil Organic Carbon (SOC) Estimation

The land area accorded for Sirsa district was calculated from official records, according to which the Sirsa district occupies 427,700 hectares of land. Out of this total land, urban sector occupies 1,967.42 hectares of land accounting for about 0.46% of the entire land area, whereas remaining land (i.e., 425,732.58 hectares of land) was classified as the forest land (Table). The data used in this calculation was obtained from the Sirsa District Website (<https://sirsa.gov.in/>) and based on the available data the further classification was done.

For SOC per hectare estimation, routine soil sampling and analysis methods were used. Soil samples were taken from 16 sites, eight urban and eight forest, to provide a representative dataset of various land-use types. The upper 30 cm of the soil was measured for organic carbon content by using standard soil science techniques (Schumacher et al. 1990; ESMC 2021). Further, SOC calculations being done under the presumption that organic carbon makes up around 58% of total organic matter (Nelson and Sommers 1982). SOC values in tons per hectare were calculated from these analyses, the urban soils were determined to have SOC value averaging 44.37 tons per hectare and forest soil were determined to have SOC value averaging 83.69 tons per hectare (Table 5.26). These values align with previously published literature on soil organic carbon storage in varying ecosystems which highlights the credibility of the methodology employed (Raha et al. 2022)

Table 5.26: Summary of SOC estimates for Urban and Forest area in the Sirsa District

Land Type	Land Area (ha)	SOC per Hectare (tons/ha)	Total SOC (tons)
Urban	1,967.42	44.37	87,273.33
Forest	425,732.58	83.69	35,636,726.98
Total SOC	427,700	Average: 83.5	35,723,999.31

5.9. COMPARISON OF SOIL ORGANIC CARBON BETWEEN URBAN AND FOREST VEGETATION

The total SOC stock for the Sirsa district was determined by multiplying the SOC per hectare with the corresponding land area for urban and forest ecosystem.

Urban Area

The results show that urban area of Sirsa account for total SOC of 87,273.33 tons. Soil bulk density plays a critical role in the estimation of SOC. As per the published literature, urban soils have an average bulk density of 1.5 g/cm^3 due to compaction. These finding highlight the impact of land usage on storage of soil carbon. Urbanization and deforestation are well-known factors that reduce SOC stocks with time. The significantly lower SOC value of urban area, highlights the effects of land development, soil sealing and reduced organic matter inputs.

Forest Area

In contrast, forest area was determined to have substantially higher total SOC value, i.e., 35,636,726.98 tons. This results to an overall estimate of SOC of 35.72 million tons for the entire district. The estimates obtained from our study aligns with global trends in which forest areas usually show high SOC stock value because of more organic input and less soil disturbance in contrast to urban areas (Guo and Gifford 2002; Lal 2004b). According to the published literature, forest soils have an average bulk density of 1.3 g/cm^3 which is an indicator of higher organic matter content and less compaction.

The findings of our results align with previously published study, which assessed the SOC dynamics in three tropical dry deciduous forest types in Central India. They also reported the SOC stock within the range of 48.7 to 89.1 tons C/ha (Raha et al. 2022). Chhabra et al. (2003) reported the estimates of SOC densities for different Indian forest types. According to study, the tropical dry deciduous forests have the SOC density of 37.5 tons/ha, whereas littoral and swamp forests have the SOC density value of 92.1 tons/ha. Comparing these estimates, forest SOC of Sirsa district holds higher position at the higher range. This indicates that land management activities and forest composition in Sirsa district have a major contribution in carbon sequestration.

Moreover, forest areas have been found to exhibit high carbon storage capacity, highlighting the critical importance of natural ecosystems in carbon sequestration and mitigation of climate change. These results align with previous studies which emphasize on how deforestation, land degradation as well as urban expansion leads to reduced carbon stocks and further contribute to increased CO₂ emissions (Post et al. 1982; FAO 2020a). This enhanced carbon storage in forest is closely linked with the higher plant diversity and structure complexity. These factors promote greater biomass production and enhanced litter input, which ultimately results in accumulation of soil organic carbon (SOC) in forest ecosystems

5.10. RELATIONSHIP BETWEEN PLANT BIODIVERSITY AND CARBON SEQUESTRATION

The relation between plant biodiversity and sequestered carbon was analysed using site-wise values of Shannon-Wiener (H') index, Importance Value Index (IVI) and corresponding carbon estimates derived from biomass in urban sites (A-H) and forest sites (I-P). In urban sites, Shannon-Wiener (H') Index values ranged from 2.39 to 3.22 which indicates variation in biodiversity. Shaheed Bhagat Singh Stadium (Site A) showed the highest H' value of 3.22 which corresponds with higher biomass accumulation and carbon sequestration potential. Sites with moderate H' values within the range of 2.5-3.1 demonstrated intermediate storage of carbon. In contrast, Home Garden 2 (Site F) was determined to have lowest value of H' i.e., 2.39, indicating uneven distribution of species and lowest diversity. This results in reduced biomass accumulation and carbon sequestration potential.

The similar pattern was observed for forest sites (I-P), where variation in species richness and diversity influenced accumulation of biomass and carbon sequestration. Panjuana Canal (Site K) showed the highest value of H' i.e. 3.09, corresponding to higher biomass accumulation and carbon sequestration. Whereas, Village Mangiana (Site M) was determined to have lowest H' values of 2.62 indicating comparatively reduced carbon sequestration potential despite the abundance of the individual. This highlights the importance of species diversity over the abundance of individuals.

Further, the relationship between biodiversity and carbon storage is supported by the Importance Value Index (IVI) that signifies ecological dominance. Species with higher IVI values contribute significantly more to biomass accumulation and carbon

sequestration because of high abundance, density and frequency. For instance, *Cannabis sativa* (IVI = 15.89), *Tagetes erecta* (IVI = 11.11), and *Holoptelea integrifolia* (IVI = 8.94) were determined to show higher contribution to biomass accumulation and carbon sequestration. On the other hand, species with lower IVI values showed minimal contribution to carbon sequestration.

Overall, these findings suggest that plant biodiversity sturdily influences vegetation structure, ecological dominance, and accumulation of biomass in both urban and forest areas. These factors are collectively responsible for regulation of carbon sequestration in these areas. Higher species diversity leads to efficient resource utilization and biomass accumulation which leads to enhanced carbon sequestration potential. Conversely, lower diversity and uneven distribution leads to reduced biomass accumulation and carbon sequestration potential. Furthermore, site-wise analysis demonstrated a positive relationship between vegetation diversity (H' and IVI) and carbon sequestration in both urban and forest ecosystem. Likewise, higher diversity and ecological dominance are associated with increased biomass accumulation and carbon storage.

CHAPTER 6

SUMMARY AND CONCLUSION

Plant diversity and carbon sequestration are ecological processes which are closely related to each other as carbon storage potential of a vegetation type is determined by species composition and their dominance pattern. This study was carried out in Sirsa district, Haryana from 2020-2024 to evaluate the plant diversity and carbon sequestration potential of urban and forest vegetation. The study was conducted in sixteen sites which comprised eight urban and eight forest sites. Analysis was conducted using random stratified sampling and quadrat method and various biodiversity indices such as Shannon–Wiener Index, Simpson Index (D), Margalef Index and Pielou Index were applied.

For tree species carbon sequestration was estimated through above ground biomass, below ground biomass and carbon stock. Soil organic carbon of respective study sites was also estimated.

With respect to the first objective, study concluded clear variation in biodiversity pattern between urban and forest diversity. A total of 52 plant species belonging to 29 families were found in forest area which was lower than 98 plant species belonging to 45 families that were found in urban area. The highest number of species in urban area was discovered at Site A (35 species) while lowest in Site F (12 species). Shannon-Wiener index in urban area ranged from 2.39 to 3.22, with maximum value at Site A, indicating highest diversity. Simpson index ranged from 0.05 to 0.12 which indicates relatively low dominance and balanced distribution of species. Pooled biodiversity indices for urban areas were Shannon–Wiener Index = 4.21, Simpson Index = 0.02, Margalef Index = 14.5, and Pielou Index = 0.92, these values clearly indicate greater species richness and evenness. Forest areas showed lower species richness and Site K showed highest diversity with Shannon-Wiener value = 3.09. The Shannon index values of forest vegetation varied from 2.62 to 3.09, while Simpson Index ranged from 0.05 to 0.08. The pooled biodiversity indices for forest vegetation were found to be Shannon–Wiener Index = 3.42, Simpson Index = 0.05, Margalef Index = 7.98, and Pielou Index = 0.87. These results showed that urban vegetation contains higher species richness while forest areas contained lower richness but have

a stable ecological composition. *Cannabis sativa* and *Tagetes erecta* were found to be dominant in urban vegetation while *Eucalyptus globulus* in forest vegetation.

With respect to second objective, the study found that carbon sequestration potential varied greatly among species and sites. It was strongly influenced by the structure of vegetation. In urban areas species such as *Delonix regia*, *Ficus religiosa* and *Terminalia arjuna* were identified as major contributors to carbon sequestration. Whereas, in forest areas plant species like *Eucalyptus globulus*, *Dalbergia sissoo* and *Ficus benghalensis* were found to be major contributors.

Species-wise biomass and carbon calculation clearly indicated that carbon sequestration was more dependent on structural development of tree species and not on the species count. At site K (Panjuana Canal), *Ficus religiosa* was found to store 68.07 tons of biomass and 34.03 tons carbon stocks and showed very high sequestration potential. Similarly at Site P (Daulatpur Khera), *Prosopis juliflora* was found to store 51.51 tons of total biomass and 25.75 tons of carbon stock. *Ficus religiosa* contained 28.74 tons of biomass and 14.37 tons of carbon stock and *Dalbergia sissoo* contained 22.79 tons of biomass. Species like *Eucalyptus globulus* and *Ficus benghalensis* also contained the substantial amount of carbon. Sites like K and P with a greater dominance of woody tree species with higher biomass accumulation were also found to have higher carbon stored. On the other hand, sites with lower structural development showed reduced amount of sequestered carbon.

A functional relationship between biodiversity and carbon sequestration was determined as sites which showed greater ecological dominance were found to store higher biomass and carbon. This biodiversity-carbon relationship in current study was expressed not only by species number but also through dominance, vegetation structure and biomass. The study showed that the plant diversity which contributes more to carbon sequestration was not associated with species diversity only but was associated with dominant, and high biomass tree species.

Forest ecosystem contained higher carbon sequestration as it contained more structurally developed trees with higher biomass accumulation. In contrast, urban vegetation was richer in number of species and more evenly distributed. However, it was found to have limited carbon storage due to lower biomass accumulation, small tree size and reduced structural development.

With respect to the third objective, a strong contrast was found between urban and forest vegetation. Sirsa occupies 427,700 hectares of which 1967.42 hectares falls under urban areas and the rest of 425,732.58 hectares comes under forest areas. The average soil organic carbon (SOC) in urban soils was found to be 44.37 tons/ha while the SOC of forests was estimated at 83.69 tons/ha. Consequently, total SOC in urban was estimated at 87272.33 tons, while the SOC of forest areas found to be 35,636,999.31 tons which totalled to a whole district value of 35,723,999.31 tons. This clearly showed that forest soils significantly stored more SOC than urban soil. Higher SOC in forest was explained by factors like denser vegetation cover, favourable ecological conditions for long-term accumulation and larger organic matter input.

The study clearly showed that plant biodiversity and carbon sequestration were related, but the relationship was not exclusively dependent on number of species alone. Though urban vegetation showed greater richness and evenness, still forests contained higher sequestration due to species with strong structural development, high biomass and larger soil carbon accumulation,

These findings emphasized on the need for conservation of forest vegetation and improvement of urban green cover. Both plant diversity and carbon sequestration varied significantly between urban and forest vegetation. Moreover, forest vegetation functioned as stronger carbon sink, while urban vegetation contributed more to species richness and evenness.

Conclusively, the findings revealed that urban and forest ecosystems within Sirsa District held considerable potential for biodiversity conservation and climate change mitigation. Effective management of plant species with high carbon sequestration ability could contribute to global initiatives aimed at combating environmental deterioration and promote sustainability.

The present study established that vegetation with species dominance, greater structural development and biomass accumulation played a decisive role in carbon sequestration rather than species richness alone.

CHAPTER 7

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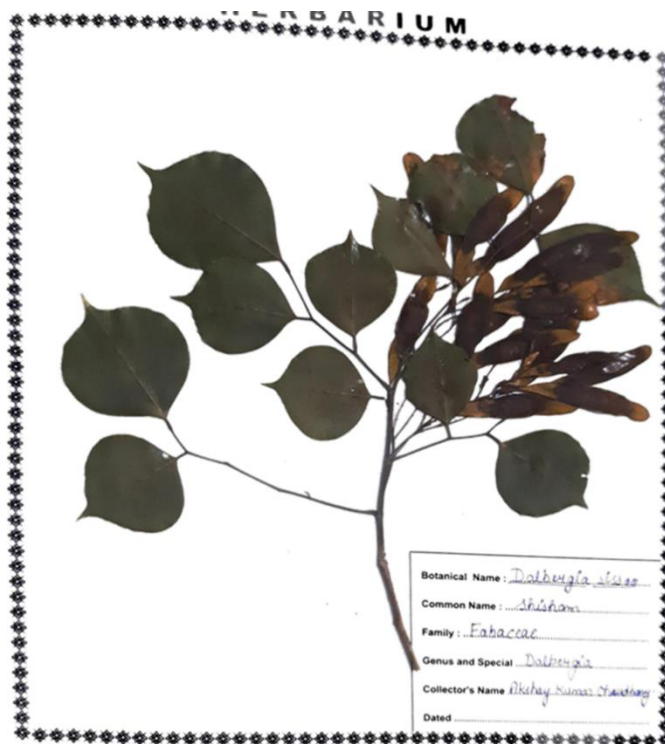
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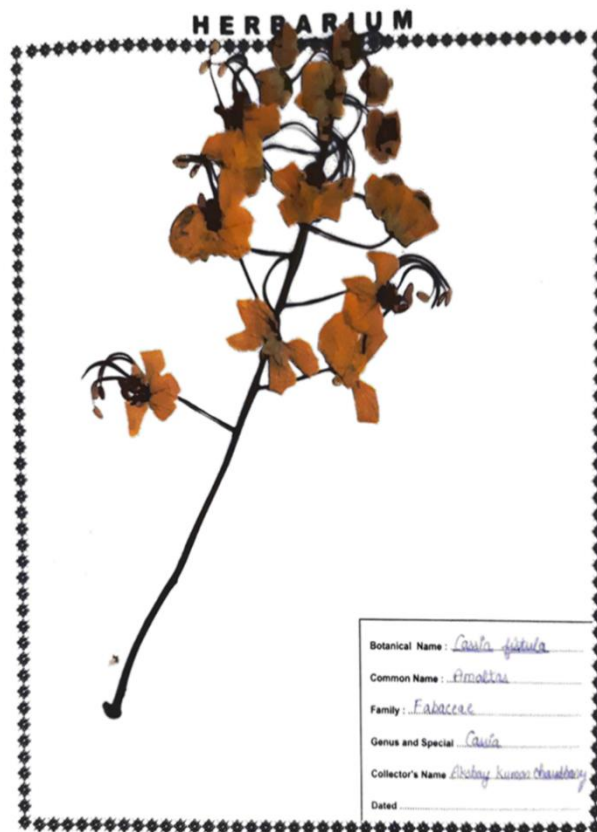
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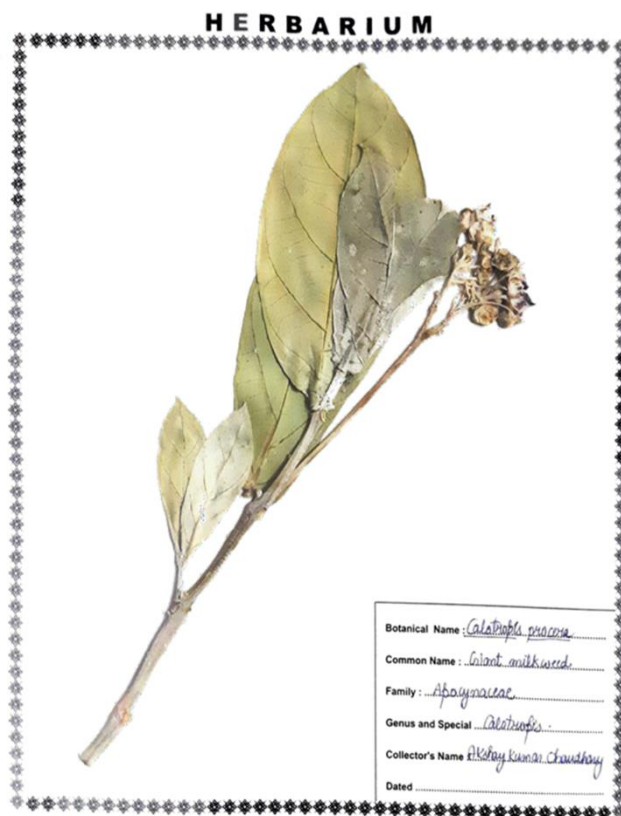
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APPENDIX

Annexure 1: Photographic records and species identification of herbarium specimens









HERBARIUM



Botanical Name: Bauhinia glabra
 Common Name: Paper flower
 Family: Nyctaginaceae
 Genus and Special: Bauhinia
 Collector's Name: Nishay Kumar Chaudhary
 Dated: _____

HERBARIUM



Botanical Name: Abutilon indicum
 Common Name: Kanghi
 Family: Malvaceae
 Genus and Special: Abutilon
 Collector's Name: Nishay Kumar Chaudhary
 Dated: _____



Annexure 2: Summary of the DBH values based on the individuals found in each site in urban area

Site	Common Name	Botanical Name	No. of Individuals	DBH value of Individuals																
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A	Amaltas	<i>Cassia fistula</i>	3	27	28	31	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Anjeer	<i>Ficus racemosa</i>	2	23	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Arjun	<i>Terminalia arjuna</i>	3	40	96	72	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ashoka	<i>Saraca asoca</i>	2	27	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Bakain	<i>Melia azedarach</i>	1	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Beri	<i>Ziziphus mauritiana</i>	5	32	21	27	20	16	-	-	-	-	-	-	-	-	-	-	-	-
	Bottlebrush	<i>Callistemon citrinus</i>	2	14	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Champak	<i>Magnolia champaca</i>	8	9	8	12	3	8	7	13	11	-	-	-	-	-	-	-	-	-
	Chukrasia	<i>Chukrasia velutina</i>	1	34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ficus	<i>Ficus benjamina</i>	3	33	43	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Gulmohar	<i>Delonix regia</i>	3	29	38	45	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Harshingar	<i>Nyctanthes arbor-tristis</i>	3	8	7	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jamun	<i>Syzygium cumini</i>	2	13	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Janti	<i>Prosopis cineraria</i>	2	115	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kher	<i>Acacia cetechu</i>	1	53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kikar	<i>Vachellia nilotica</i>	5	60	27	37	43	52	-	-	-	-	-	-	-	-	-	-	-	-
Neem	<i>Azadirachta indica</i>	4	57	68	50	34	-	-	-	-	-	-	-	-	-	-	-	-	-
Papdi	<i>Holoptelea integrifolia</i>	15	33	33	37	11	10	26	41	22	9	13	20	22	17	19	21	-	-
Pipal	<i>Ficus religiosa</i>	5	29	82	75	67	87	-	-	-	-	-	-	-	-	-	-	-	-
Saptparni	<i>Alstonia scholaris</i>	2	32	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Shehtoot	<i>Morus alba</i>	2	25	41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sheesham	<i>Dalbergia sissoo</i>	7	46	22	27	30	28	24	22	-	-	-	-	-	-	-	-	-	-

	Silver oak	<i>Grevillea robusta</i>	1	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sohanjana	<i>Moringa oleifera</i>	2	39	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	Aam	<i>Mangifera indica</i>	1	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Amaltas	<i>Cassia fistula</i>	1	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ashoka	<i>Saraca asoca</i>	7	30	22	33	41	53	20	28	-	-	-	-	-	-	-	-	-	-
	Bellpatar	<i>Aegle marmelos</i>	1	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Bottlebrush	<i>Callistemon citrinus</i>	5	18	13	11	10	12	-	-	-	-	-	-	-	-	-	-	-	-
	Champak	<i>Magnolia champaca</i>	2	13	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ficus	<i>Ficus benamina</i>	5	28	33	27	41	43	-	-	-	-	-	-	-	-	-	-	-	-
	Indian pine	<i>Pinus roxburghii</i>	2	27	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Jamun	<i>Syzygium cumini</i>	1	38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Neem	<i>Azadirachta indica</i>	2	37	42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Papdi	<i>Holoptelea</i>	5	28	41	31	27	15	-	-	-	-	-	-	-	-	-	-	-	-

		<i>integrifolia</i>																		
	Pipal	<i>Ficus religiosa</i>	3	68	47	62	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Rohida	<i>Tecomella undulata</i>	1	39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sarinh	<i>Albizia lebbbeck</i>	1	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	5	47	58	67	62	51	-	-	-	-	-	-	-	-	-	-	-	-
	Sohanjana	<i>Moringa oleifera</i>	3	13	11	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	Amrood	<i>Psidium guajava</i>	1	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Bakain	<i>Melia azedarach</i>	2	28	67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ficus	<i>Ficus benamina</i>	4	31	32	24	39		-	-	-	-	-	-	-	-	-	-	-	-
	Jamun	<i>Syzygium cumini</i>	1	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Janti	<i>Prosopis cineraria</i>	1	61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kikar	<i>Vachellia nilotica</i>	2	39	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Neem	<i>Azadirachta indica</i>	1	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	Pahadi kikar	<i>Prosopis juliflora</i>	2	52	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Palm- Kanghi	<i>Cycas revoluta</i>	3	14	17	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pipal	<i>Ficus religiosa</i>	2	73	90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Safeda	<i>Eucalyptus globulus</i>	11	30	21	47	41	28	29	50	37	23	31	42	-	-	-	-	-	-
	Sarinh	<i>Albizia lebbeck</i>	2	37	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Shehtoot	<i>Morus alba</i>	1	41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	2	37	54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	Amaltas	<i>Cassia fistula</i>	2	19	29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Anjeer	<i>Ficus racemosa</i>	1	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ashoka	<i>Saraca asoca</i>	6	19	27	21	24	17	16	-	-	-	-	-	-	-	-	-	-	-
	Beri	<i>Ziziphus mauritiana</i>	2	23	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kigelia	<i>Kigelia africana</i>	2	32	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	Lehsua	<i>Cordia dichotoma</i>	2	19	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pahadi Kikar	<i>Prosopis juliflora</i>	2	43	51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Papdi	<i>Holoptelea integrifolia</i>	6	19	22	27	23	25	21	-	-	-	-	-	-	-	-	-	-	-
	Sarinh	<i>Albizia lebbeck</i>	3	29	31	34	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	5	67	43	52	63	34	-	-	-	-	-	-	-	-	-	-	-	-
E	Ashoka	<i>Saraca asoca</i>	2	31	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Bellpatar	<i>Aegle marmelos</i>	1	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	Ashoka	<i>Saraca asoca</i>	3	20	19	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G	Aam	<i>Mangifera indica</i>	1	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Amaltas	<i>Cassia fistula</i>	2	23	34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Amla	<i>Phyllanthus emblica</i>	2	13	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Amrood	<i>Psidium guajava</i>	3	13	17	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	Beri	<i>Ziziphus mauritiana</i>	1	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Bakain	<i>Melia azedarach</i>	2	19	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Jamun	<i>Syzygium cumini</i>	2	47	39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Janti	<i>Prosopis cineraria</i>	1	53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Neem	<i>Azadirachta indica</i>	2	49	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Papdi	<i>Holoptelea integrifolia</i>	1	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Shehtoot	<i>Morus alba</i>	1	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	3	48	52	67	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H	Beri	<i>Ziziphus mauritiana</i>	2	10	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Jamun	<i>Syzygium cumini</i>	2	20	53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Janti	<i>Prosopis cineraria</i>	1	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kigelia	<i>Kigelia africana</i>	2	32	53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Kikar	<i>Acacia nilotica</i>	17	90	30	40	40	35	38	38	33	37	22	22	20	19	41	55	54	45
Neem	<i>Azadirachta indica</i>	6	39	19	21	30	25	27	-	-	-	-	-	-	-	-	-	-	-
Pahadi Kikar	<i>Prosopis juliflora</i>	2	24	38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Papdi	<i>Holoptelea integrifolia</i>	9	25	23	18	25	15	17	16	17	11	-	-	-	-	-	-	-	-
Pipal	<i>Ficus religiosa</i>	2	79	62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sheesham	<i>Dalbergia sissoo</i>	2	59	34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

*-: No value; A: Shaheed Bhagat Singh Stadium; B: Chaudhary Devi Lal Park; C: Sirsa Minor; D: HUDA Unhabitated Area; E: Home Garden 1; F: Home Garden 2; G: Municipality Park; H: Mini-bypass Sirsa.

Annexure 3: Summary of the DBH values based on the individuals found in each site in forest area

Site	Common Name	Botanical Name	No. of Individuals	DBH value of Individuals															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
I	Bargad	<i>Ficus benghalensis</i>	1	103	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Bakain	<i>Melia azedarach</i>	2	49	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Beri	<i>Ziziphus mauritiana</i>	3	20	19	14	-	-	-	-	-	-	-	-	-	-	-	-	-
	Janti	<i>Prosopis cineraria</i>	1	74	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kikar	<i>Acacia nilotica</i>	3	80	67	49	-	-	-	-	-	-	-	-	-	-	-	-	-
	Neem	<i>Azadirachta indica</i>	2	74	59	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pipal	<i>Ficus religiosa</i>	3	71	87	73	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	4	57	88	90	40	-	-	-	-	-	-	-	-	-	-	-	-
J	Amla	<i>Phyllanthus</i>	1	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

		<i>emblica</i>																	
Arjun	<i>Terminalia arjuna</i>	2	43	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bargad	<i>Ficus benghalensis</i>	1	90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bakain	<i>Melia azedarach</i>	1	48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Beri	<i>Ziziphus mauritiana</i>	1	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jamun	<i>Syzygium cumini</i>	2	74	62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kikar	<i>Acacia nilotica</i>	5	80	44	63	67	40	-	-	-	-	-	-	-	-	-	-	-	-
Neem	<i>Azadirachta indica</i>	2	74	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pahadi Kikar	<i>Prosopis juliflora</i>	3	32	53	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pipal	<i>Ficus religiosa</i>	2	68	59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Safeda	<i>Eucalyptus globulus</i>	8	53	49	63	30	27	32	56	87	-	-	-	-	-	-	-	-	-

	Sarinh	<i>Albizia lebbeck</i>	2	39	57	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Shehtoot	<i>Morus alba</i>	1	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sohanjana	<i>Moringa oleifera</i>	2	16	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K	Amaltas	<i>Cassia fistula</i>	1	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Arjun	<i>Terminalia arjuna</i>	3	40	39	39	-	-	-	-	-	-	-	-	-	-	-	-	-
	Bargad	<i>Ficus benghalensis</i>	1	127	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Baheda	<i>Terminalia bellirica</i>	3	43	40	36	-	-	-	-	-	-	-	-	-	-	-	-	-
	Beri	<i>Ziziphus mauritiana</i>	4	14	12	19	10	-	-	-	-	-	-	-	-	-	-	-	-
	Jamun	<i>Syzygium cumini</i>	4	36	60	51	57	-	-	-	-	-	-	-	-	-	-	-	-
	Janti	<i>Prosopis cineraria</i>	1	90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kikar	<i>Acacia nilotica</i>	7	87	48	59	68	60	54	71	-	-	-	-	-	-	-	-	-

	Neem	<i>Azadirachta indica</i>	5	70	51	53	27	50	-	-	-	-	-	-	-	-	-	-	-
	Pahadi Kikar	<i>Prosopis juliflora</i>	3	37	29	30	-	-	-	-	-	-	-	-	-	-	-	-	-
	Papdi	<i>Holoptelea integrifolia</i>	2	19	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pipal	<i>Ficus religiosa</i>	4	84	69	52	75	-	-	-	-	-	-	-	-	-	-	-	-
	Safeda	<i>Eucalyptus globulus</i>	9	50	47	45	49	57	41	34	42	23	-	-	-	-	-	-	-
	Sarinh	<i>Albizia lebbek</i>	3	57	46	32	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	3	90	67	40	-	-	-	-	-	-	-	-	-	-	-	-	-
	Shehtoot	<i>Morus alba</i>	2	30	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sohanjana	<i>Moringa oleifera</i>	4	14	14	10	13	-	-	-	-	-	-	-	-	-	-	-	-
L	Bakain	<i>Melia azedarach</i>	1	57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Beri	<i>Ziziphus mauritiana</i>	2	12	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	Kikar	<i>Acacia nilotica</i>	1	67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Neem	<i>Azadirachta indica</i>	9	74	63	28	35	25	28	61	38	42	-	-	-	-	-	-	-
	Pahadi Kikar	<i>Prosopis juliflora</i>	1	53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Papdi	<i>Holoptelea integrifolia</i>	4	20	15	17	18	-	-	-	-	-	-	-	-	-	-	-	-
	Safeda	<i>Eucalyptus globulus</i>	16	63	45	49	72	68	36	64	45	54	33	15	31	35	60	81	22
	Sheesham	<i>Dalbergia sissoo</i>	4	30	55	39	49	-	-	-	-	-	-	-	-	-	-	-	-
	Shehtoot	<i>Morus alba</i>	5	15	20	21	18	27	-	-	-	-	-	-	-	-	-	-	-
M	Jamun	<i>Syzygium cumini</i>	5	105	86	31	85	75	-	-	-	-	-	-	-	-	-	-	-
	Janti	<i>Prosopis cineraria</i>	1	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Neem	<i>Azadirachta indica</i>	12	28	51	44	49	49	40	40	74	65	41	49	74	-	-	-	-
	Pahadi Kikar	<i>Prosopis juliflora</i>	5	30	27	34	37	49	-	-	-	-	-	-	-	-	-	-	-
	Pahadi Neem	<i>Xanthozylum</i>	3	44	34	43	-	-	-	-	-	-	-	-	-	-	-	-	-

		<i>armatum</i>																	
	Papdi	<i>Holoptelea integrifolia</i>	10	38	20	19	27	42	16	18	19	33	30	-	-	-	-	-	-
	Safeda	<i>Eucalyptus globulus</i>	9	52	37	31	46	90	20	59	29	24	-	-	-	-	-	-	-
	Sarinh	<i>Albizia lebbbeck</i>	4	36	54	27	29	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	4	59	64	57	70	-	-	-	-	-	-	-	-	-	-	-	-
	Shehtoot	<i>Morus alba</i>	3	31	32	22	-	-	-	-	-	-	-	-	-	-	-	-	-
N	Beri	<i>Ziziphus mauritiana</i>	3	8	9	11	-	-	-	-	-	-	-	-	-	-	-	-	-
	Jamun	<i>Syzygium cumini</i>	2	50	38	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Janti	<i>Prosopis cineraria</i>	1	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kikar	<i>Acacia nilotica</i>	6	35	52	64	37	36	39	-	-	-	-	-	-	-	-	-	-
	Neem	<i>Azadirachta indica</i>	9	35	60	57	32	29	32	22	27	28	-	-	-	-	-	-	-

	Pahadi Neem	<i>Xanthozylum armatum</i>	3	28	32	34	-	-	-	-	-	-	-	-	-	-	-	-	-
	Papdi	<i>Holoptelea integrifolia</i>	3	11	13	17	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pipal	<i>Ficus religiosa</i>	3	74	60	62	-	-	-	-	-	-	-	-	-	-	-	-	-
	Safeda	<i>Eucalyptus globulus</i>	5	64	48	28	32	24	-	-	-	-	-	-	-	-	-	-	-
	Sarinh	<i>Albizia lebbeck</i>	2	56	62	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	2	50	61	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Shehtoot	<i>Morus alba</i>	1	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
O	Anjeer	<i>Ficus carica</i>	2	17	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Amrood	<i>Psidium guajava</i>	1	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Bargad	<i>Ficus benghalensis</i>	1	113	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Beri	<i>Ziziphus</i>	1	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

		<i>mauritiana</i>																	
	Neem	<i>Azadirachta indica</i>	4	62	71	69	40	-	-	-	-	-	-	-	-	-	-	-	-
	Pahadi Kikar	<i>Prosopis juliflora</i>	7	40	43	59	44	51	33	40	-	-	-	-	-	-	-	-	-
	Pahadi neem	<i>Xanthozylum armatum</i>	3	58	72	42	-	-	-	-	-	-	-	-	-	-	-	-	-
	Safeda	<i>Eucalyptus globulus</i>	7	34	40	47	42	52	29	50	-	-	-	-	-	-	-	-	-
	Sarinh	<i>Albizia lebbeck</i>	1	86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	5	33	40	67	77	42	-	-	-	-	-	-	-	-	-	-	-
P	Bakain	<i>Melia azedarach</i>	1	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Jamun	<i>Syzygium cumini</i>	1	69	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kikar	<i>Acacia nilotica</i>	5	90	67	45	62	77	-	-	-	-	-	-	-	-	-	-	-
	Neem	<i>Azadirachta indica</i>	5	50	65	43	49	32	-	-	-	-	-	-	-	-	-	-	-
	Pahadi Kikar	<i>Prosopis juliflora</i>	12	37	30	29	23	25	22	21	28	27	42	29	20	-	-	-	-

	Papdi	<i>Holoptelea integrifolia</i>	2	19	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pipal	<i>Ficus religiosa</i>	2	56	74	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Safeda	<i>Eucalyptus globulus</i>	2	40	61	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheesham	<i>Dalbergia sissoo</i>	3	49	82	57	-	-	-	-	-	-	-	-	-	-	-	-	-
	Shehtoot	<i>Morus alba</i>	1	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

*-: No value; I: Village Chaharwala Minor; J: Village Mameran Road; K: Panjuana Canal; L: Village Nagoki Canal; M: Village Mangiana; N: Ottu Head; O: Abub Sheher Wildlife Sanctuary; P: Daulatpur Khera.

Annexure 4: Enlist of the Wood Density (g/cm³) values of the species found in urban area from previously published literature.

S. No.	Common Name	Botanical name	Wood Density (g/cm ³)	Reference
1	Amaltas	<i>Cassia fistula</i>	0.64	(Meena et al. 2019)
2	Anjeer	<i>Ficus racemosa</i>	0.45	(Meena et al. 2019)
3	Arjun	<i>Terminalia arjuna</i>	0.68	(FAO-WDVTSTR 1997)
4	Ashoka	<i>Saraca asoca</i>	0.60	(FAO-WDVTSTR 1997)
5	Bellpatar	<i>Aegle marmelos</i>	0.83	(Nowak 2021)
6	Beri	<i>Ziziphus mauritiana</i>	0.76	(FAO-WDVTSTR 1997)
7	Bottlebrush	<i>Callistemon citrinus</i>	0.75	(Nowak 2021)
8	Janti	<i>Prosopis cineraria</i>	0.66	(Nowak 2021)
9	Kher	<i>Acacia cetechu</i>	0.88	(FAO-WDVTSTR 1997)
10	Kigelia	<i>Kigelia africana</i>	0.72	(FAO-WDVTSTR 1997)
11	Lehsua	<i>Cordia dichotoma</i>	0.53	(FAO-WDVTSTR 1997)

12	Papdi	<i>Holoptelea integrifolia</i>	0.64	(Meena et al. 2019)
13	Pipal	<i>Ficus religiosa</i>	0.39	(FAO-WDVTSTR 1997)
14	Rohida	<i>Tecomella undulata</i>	0.68	(NICRA-ICAR 2018)
15	Saptparni	<i>Alstonia scholaris</i>	0.36	(FAO-WDVTSTR 1997)
16	Sarinh	<i>Albizia lebbeck</i>	0.55	(FAO-WDVTSTR 1997)
17	Shehtoot	<i>Morus alba</i>	0.70	(ICRAF 2021)

Annexure 5: Enlist of the Wood Density (g/cm³) values of the species found in forest area from previously published literature

S. No.	Common Name	Botanical name	Wood Density (g/cm ³)	Reference
1	Amaltas	<i>Cassia fistula</i>	0.64	(Meena et al. 2019)
2	Anjeer	<i>Ficus carica</i>	0.45	(Meena et al. 2019)
3	Arjun	<i>Terminalia arjuna</i>	0.68	(FAO-WDVTSTR 1997)
4	Baheda	<i>Terminalia bellirica</i>	0.72	(FAO-WDVTSTR 1997)
5	Bargad	<i>Ficus benghalensis</i>	0.49	(Nowak 2021)
6	Beri	<i>Ziziphus mauritiana</i>	0.76	(FAO-WDVTSTR 1997)
7	Janti	<i>Prosopis cineraria</i>	0.66	(FAO-WDVTSTR 1997)
8	Pahadi Neem	<i>Xanthozylum armatum</i>	0.65	(Nowak 2021)
9	Papdi	<i>Holoptelea integrifolia</i>	0.64	(Meena et al. 2019)
10	Pipal	<i>Ficus religiosa</i>	0.39	(FAO-WDVTSTR 1997)
11	Sarinh	<i>Albizia lebbeck</i>	0.55	(FAO-WDVTSTR 1997)
12	Shehtoot	<i>Morus alba</i>	0.70	(ICRAF 2021)

Annexure 6: Formulas used for calculation of biomass/volume of urban species

S.No.	Common Name	Botanical name	Volume/Biomass Equation used	References
1	Aam	<i>Mangifera indica</i>	$AGB = 42.69 - (12.8 * D) + (1.242 * D^2)$	(Salunkhe et al. 2021)
2	Amaltas	<i>Cassia fistula</i>	$V = 0.066 + 0.287D^2$	(Meena et al. 2019)
3	Amla	<i>Phyllanthus emblica</i>	$AGB = 0.104 * (D^{2.347})$	(Pothong et al. 2022)
4	Amrood	<i>Psidium guajava</i>	$AGB = 0.235 * D^{2.3}$	(Naik et al. 2021)
5	Anjeer	<i>Ficus racemosa</i>	$V = (0.03629 + (3.95389 * D) - (0.84421 * \sqrt{D}))^2$	(FSI 1996)
6	Arjun	<i>Terminalia arjuna</i>	$V = -0.033 - 0.526 * D + 6.396 * (D^2)$	(Rahman et al. 2001)
7	Ashoka	<i>Saraca asoca</i>	$V = -0.07109 + 2.99732 * D - 0.26953 * \sqrt{D}$	(FSI 1996)
8	Bakain	<i>Melia azedarach</i>	$AGB = 0.057785 * (D^{1.645}) * (H^{1.146})$	(Zhu et al. 2022)
9	Bellpatar	<i>Aegle marmelos</i>	$V = 0.0509 * (D^{2.42})$	(Chave et al. 2005)
10	Beri	<i>Ziziphus mauritiana</i>	$V = 0.027354 + (4.663714 * D^2)$	(FSI 2011)
11	Bottlebrush	<i>Callistemon citrinus</i>	$Biomass = 0.4 * (D^2 * h * \text{wood density})$	(McPherson et al. 2016)

12	Champak	<i>Magnolia champaca</i>	$AGB = 0.382 * (D^2)$	(Giri et al. 2019)
13	Chukrasia	<i>Chukrasia velutina</i>	$ABG = 0.11 * ((D^2) * H)^{0.89}$	(Basuki et al. 2009)
14	Ficus	<i>Ficus benamina</i>	$ABG = 0.0673 * 0.65 * (D^{2.6})$	(Chave et al. 2005)
15	Gulmohar	<i>Delonix regia</i>	$\ln \text{Biomass} = 1.245 (\ln (D^2)) - 1.758$	(Narayan and Mehera 2020)
16	Harshingar	<i>Nyctanthes arbor-tristis</i>	$AGB = 0.0509 * (D^{2.5}) * (H^{0.9})$	(Pati et al. 2022)
17	Indian pine	<i>Pinus roxburghii</i>	$AGB = 0.000012 * (D^{2.923})$	(Sharma et al. 2020)
18	Jamun	<i>Syzygium cumini</i>	$AGB = \text{EXP}(1.9724 * \text{LN}(D) - 1.0717)$	(Udayakumar et al. 2016)
19	Janti	<i>Prosopis cineraria</i>	$V = 0.00471 + 1.79326 D^2$	(USDAFS 2021)
20	Kher	<i>Acacia cetechu</i>	$V = -0.048108 + (5.873169 * D^2)$	(Mahajan et al. 2021)
21	Kigelia	<i>Kigelia africana</i>	$V = 0.0509 * (D^{2.42})$	(Chave et al. 2005)
22	Kikar	<i>Vachellia nilotica</i>	$AGB = 0.360 \times D^{1.598}$	(Rizvi et al. 2020)
23	Lehsua	<i>Cordia dichotoma</i>	$V = 0.00471 + 1.79326 * (D^2)$	(Meena et al. 2019)

24	Neem	<i>Azadirachta indica</i>	$AGB = \text{EXP}(-0.456 + 1.673 * \text{LN}(D))$	(Valery et al. 2023)
25	Pahadi kikar	<i>Prosopis juliflora</i>	$AGB = 0.090 * (D^{2.471})$	(Muturi et al. 2012)
26	Palm-Kanghi	<i>Cycas revoluta</i>	$AGB = 0.0673 * 0.5 * (D^{2.6})$	(NCEGPT 2025.)
27	Papdi	<i>Holoptelea integrifolia</i>	$V = 0.00471 + 1.79326D^2$	(Meena et al. 2019)
28	Pipal	<i>Ficus religiosa</i>	$V = (0.03629 + (3.95389 * D^{89}) - (0.84421 * \text{SQRT}(D^{89})))^2$	(FSI 1996)
29	Rohida	<i>Tecomella undulata</i>	$V = 0.000065 * D^{2.319}$	(Tewari 2007)
30	Safeda	<i>Eucalyptus globulus</i>	$AGB = 0.284 * (D^{2.085})$	(Mtambo and Missanjo 2015)
31	Saptparni	<i>Alstonia scholaris</i>	$V = 0.0509 * (D^{2.42})$	(Brown 1997)
32	Sarinh	<i>Albizia lebbeck</i>	$V = (-0.07109 + (2.99732 * D) - (0.26953 * \text{SQRT}(D)))^2$	(FSI 1996)
33	Shehtoot	<i>Morus alba</i>	$V = 2550.47 * D - 401.99$	(Vento et al. 2019)
34	Shisham	<i>Dalbergia sissoo</i>	$AGB = 4.892 - 1.226 D + 0.245 D^2$	(Rizvi et al. 2020)
35	Silver oak	<i>Grevillea robusta</i>	$AGB = 0.248 * (D^2) + 6.243 * D - 15.45$	(Owate 2018)
36	Sohanjana	<i>Moringa oleifera</i>	$AGB = \text{EXP}(-2.34 + 2.117 * \text{LN}(D))$	(Valery et al. 2023)

Annexure 7: Formulas used for calculation of biomass/volume of forest species

S.No.	Traditional Name	Botanical name	Volume/Biomass Equation used	References
1	Amaltas	<i>Cassia fistula</i>	$V = 0.066 + 0.287D^2$	(Meena et al. 2019)
2	Amla	<i>Phyllanthus emblica</i>	$AGB = 0.104 * (D^{2.347})$	(Pothong et al. 2022)
3	Amrood	<i>Psidium guajava</i>	$AGB = 0.235 * D^{2.30}$	(Naik et al. 2021)
4	Anjeer	<i>Ficus carica</i>	$V = (0.03629 + (3.95389 * D) - (0.84421 * \sqrt{D}))^2$	(FSI 1996)
5	Arjun	<i>Terminalia arjuna</i>	$V = -0.033 - 0.526 * D + 6.396 * (D^2)$	(DRPCA, 2018)
6	Baheda	<i>Terminalia bellirica</i>	$V = 0.26454 - 3.05249 * A1 + 12.35740 * A1^2$	(FSI 2011)
7	Bakain	<i>Melia azedarach</i>	$AGB = 0.057785 * (D^{1.645}) * (H^{1.146})$	(Zhu et al. 2022)
8	Bargad	<i>Ficus benghalensis</i>	$V = (0.088074 - 1.449236 * A1 + 8.760534 * A1^2)$	(FSI 1996)
9	Beri	<i>Ziziphus mauritiana</i>	$V = 0.027354 + 4.663714 * D^2$	(FSI 2011)
10	Jamun	<i>Syzygium cumini</i>	$AGB = \exp(1.9724 * \ln(D) - 1.0717)$	(Udayakumar et al. 2016)

11	Janti	<i>Prosopis cineraria</i>	$V = 0.00471 + 1.79326D^2$	(USDAFS 2021)
12	Kikar	<i>Acacia nilotica</i>	$AGB = 0.360 \times D^{1.598}$	(Rizvi et al. 2020)
13	Neem	<i>Azadirachta indica</i>	$AGB = \text{EXP}(-0.456 + 1.673 * \text{LN}(D))$	(Valery et al. 2023)
14	Pahadi Kikar	<i>Prosopis juliflora</i>	$AGB = 0.090 * (D^{2.471})$	(Muturi et al. 2012)
15	Pahadi Neem	<i>Xanthozylum armatum</i>	$V = (-0.518911 + 3.815328 * A1)^2$	(FSI 1996)
16	Papdi	<i>Holoptelea integrifolia</i>	$V = 0.00471 + 1.79326D^2$	(Meena et al. 2019)
17	Pipal	<i>Ficus religiosa</i>	$V = (0.03629 + (3.95389 * D89) - (0.84421 * \text{SQRT}(D89)))^2$	(FSI 1996)
18	Safeda	<i>Eucalyptus globulus</i>	$AGB = 0.284 * (D^{2.085})$	(Mtambo and Missanjo 2015)
19	Sarinh	<i>Albizia lebbeck</i>	$V = (-0.07109 + (2.99732 * D) - (0.26953 * \text{SQRT}(D)))^2$	(FSI 1996)
20	Sheesham	<i>Dalbergia sissoo</i>	$AGB = 4.892 - 1.226 D + 0.245 D^2$	(Rizvi et al. 2020)
21	Shehtoot	<i>Morus alba</i>	$V = 2550.47 * D - 401.99$	(Vento et al. 2019)
22	Sohanjana	<i>Moringa oleifera</i>	$AGB = \text{EXP}(-2.34 + 2.117 * \text{LN}(DBH))$	(Valery et al. 2023)

List of Publications

1. **Chaudhary, A. K., & Devashree, Y.** (2022). Some Less Known Medicinal Plants of Haryana. *Journal of Natural Remedies*, 22(4), 563–579. <https://doi.org/10.18311/jnr/2022/28958>
2. **Chaudhary, A. K., & Joshi, R.** (2024). Assessing Plant Species Diversity and Its Ecological Contributions in the Urban Landscapes of Sirsa, Haryana, India: An Exploratory Study. *Research Journal of Chemistry and Environment*. (Accepted for publication).

List of Conferences

- Participated and gave a **Poster Presentation** at the *International Conference on Microbial Bioprospecting Towards Sustainable Development Goals*, jointly organized by Association of Microbiologist of India-LPU Unit and Society of Chemical and Synthetic Biology at Lovely Professional University, Punjab, India (2023).
- Participated and gave an **Oral Presentation** at the *International Webinar on Geography, Disaster Management and Sustainable Development*, jointly organized by International Academy of Science and Research (IASR), Indian Institute of Ecology and Environment (IIEE), New Delhi (2023).
- Participated as a Listener at the *International Workshop on Combatting Microplastics Challenge in the Global Context* (2023).
- Participated as a Listener at the *International Webinar on “Ways to Save Planet Earth”*, jointly organized by International Academy of Science and Research (IASR), Scientific and environmental research institute (SERI) (2022).
- Participated and gave an **Oral Presentation** at the *International Conference on Environment, Agriculture and Biotechnology (ICEABT)*, jointly organized by Academics Conference Network in Chandigarh, India (2021).
- Participated as a Listener at the *International Conference on Environment, Agriculture and Biotechnology (ICEABT)*, organized in Mumbai, India (2021).