URBAN FOREST ASSESSMENT AND MANAGEMENT USING I-TREE TOOLS: A

CASE STUDY OF NEW DELHI, INDIA

Major Project Dissertation

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DECLARATION

This is to certify that the work that forms the basis of this project URBAN FOREST ASSESSMENT AND MANAGEMENT USING I-TREE TOOLS: A CASE STUDY OF NEW DELHI, INDIA is an original work carried out by me and has not been submitted anywhere else for the award of any degree.

I certify that all sources of information and data are fully acknowledged in the project Dissertation.

MUSKAN SONI

Date: 2 June 2025

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LIST OF ABBREVIATIONS:

Abbreviation	Full Form
AQI	Air Quality Index
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DBH	Diameter at Breast Height
DDA	Delhi Development Authority
FSI	Forest Survey of India
GIS	Geographic Information System
GHG	Greenhouse Gas
i-Tree Eco	Urban Forest Effects Model (part of i-Tree suite)
IPCC	Intergovernmental Panel on Climate Change
ISFR	India State of Forest Report
LAI	Leaf Area Index
MCD	Municipal Corporation of Delhi
NDMC	New Delhi Municipal Council
NO_2	Nitrogen Dioxide
NCT	National Capital Territory
O_3	Ozone
PM10	Particulate Matter $\leq$10 microns
PM2.5	Particulate Matter $\leq$2.5 microns
SO_2	Sulfur Dioxide
TOF	Trees Outside Forests

UGS	Urban Green Space
UHI	Urban Heat Island
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
UFORE	Urban Forest Effects Model (former name of i-Tree Eco)
USDA	United States Department of Agriculture

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ABSTRACT:

Urban forests play a pivotal role in addressing environmental issues in fast-growing cities like Delhi, India, where air pollution, urban heat islands (UHI), and declining biodiversity pose significant threats to sustainable development. This research evaluates the ecosystem services provided by Deer Park, a 95.30-acre green space in South Delhi, employing the i-Tree Eco model to measure air pollutant removal (PM2.5, CO, NO_2, SO_2, O_3), carbon storage, and contributions to biodiversity. Known for its rich mix of native and non-native tree species, Deer Park is an essential ecological and community asset, though it faces pressures from urban expansion and invasive species such as *Prosopis juliflora*. By combining field data (e.g., tree diameter, height, crown size) with local climate and pollution metrics, the study quantifies the park's ability to enhance air quality, sequester carbon, and mitigate UHI impacts. Results indicate substantial pollutant capture and carbon retention, with native species like *Azadirachta indica* demonstrating superior performance compared to exotics. Nonetheless, challenges such as disjointed governance and low community engagement impede effective conservation. This study underscores the importance of data-driven urban forestry policies, providing actionable recommendations for policymakers to strengthen Delhi's green infrastructure, foster climate resilience, and promote environmental equity amid rapid urbanization.

Keywords

Urban forestry, ecosystem services, air pollution removal, carbon sequestration, urban heat island, biodiversity, i-Tree Eco, Deer Park, Delhi, native species, invasive

species, green infrastructure, climate resilience, environmental justice, urban planning.

1. INTRODUCTION:

India's rapid urbanization has reshaped its landscapes, with cities expanding at an unprecedented pace to accommodate a growing population. The National Capital Territory (NCT) of Delhi, spanning approximately 1,483 square kilometers in the Indo-Gangetic plains (28°24′17″ N to 28°53′00″ N latitude, 76°50′24″ E to 77°20′37″ E longitude), exemplifies the environmental and social challenges of this transformation. As India's political and administrative hub, Delhi is home to over 20 million people and faces significant pressures from population density, urban sprawl, and environmental degradation (Bhalla & Bhattacharya, 2015). Situated between the Aravalli Hills and the Yamuna River, Delhi experiences a semi-arid subtropical climate with extreme temperatures (reaching 45°C in summer) and persistent air pollution, exacerbated by vehicular emissions, industrial activities, and seasonal crop residue burning (Chaudhry et al., 2011; Chowdhury et al., 2017). Despite these challenges, Delhi's urban green spaces, which include 8% forest cover and 20% green cover across 18,000 parks and gardens, play a critical role in mitigating environmental issues and enhancing urban livability (Randhawa & Bhattacharya, 2023).

Urban forestry, defined as the management of trees and green spaces in urban environments, has emerged as a vital strategy for addressing the multifaceted challenges of urbanization. Urban forests provide essential ecosystem services, including air pollution removal, carbon sequestration, temperature regulation, stormwater interception, and biodiversity conservation, which are particularly crucial in densely populated megacities like Delhi (Nagendra & Gopal, 2010; Nowak et al., 2014). These services contribute to climate resilience, public health, and the aesthetic and recreational value of cities, making urban green spaces (UGS) indispensable components of sustainable urban planning (Escobedo & Nowak, 2009;

Alvarado, 2025). However, urban forestry in India remains underdeveloped compared to global standards, constrained by high population density, limited research, fragmented management by agencies such as the Municipal Corporation of Delhi (MCD) and Delhi Development Authority (DDA), and challenges like poor species selection and inadequate post-planting care (Chaudhry et al., 2011; Menon & Kohli, 2022). The loss of green cover, with a reported -1.5% annual decline in forest cover, and the spread of invasive species like *Prosopis juliflora* further threaten the ecological integrity of Delhi's urban forests (Randhawa & Bhattacharya, 2023; Kalpavriksh & DDA, 2009).

This study focuses on Deer Park, Hauz Khas, a 95.30-acre urban green space in South Delhi, often referred to as the "lungs of South Delhi" due to its ecological significance (Delhi Forest Department, 2025). Deer Park is a biodiversity-rich urban forest, hosting a diverse array of native tree species such as *Cassia fistula* and *Nyctanthes arbor-tristis*, alongside exotic species like *Acacia auriculiformis*. The park also supports grasslands and wildlife, including spotted deer and peacocks, making it an ideal site for studying urban forest ecosystem services (Bhalla & Bhattacharya, 2015; Bhattacharya, 2009). Strategically located near educational institutions, residential areas, and tourist attractions, Deer Park serves as both a recreational hub and a critical ecological asset. However, low public awareness of its biodiversity and challenges such as encroachment and poor maintenance underscore the need for data-driven management strategies to maximize its benefits (Paul & Nagendra, 2017).

Air pollution is a pervasive issue in Delhi, consistently ranking the city among the world's most polluted urban areas. Key pollutants, including particulate matter (PM2.5 and PM10), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2), pose severe risks to human health, contributing to increased incidences of asthma, chronic obstructive pulmonary disease (COPD), cardiovascular diseases, and premature mortality (Balakrishnan et al., 2019; Chowdhury et al., 2017). The city's air quality index (AQI) frequently exceeds national and international safety standards, driven by a combination of vehicular emissions, industrial activities, and seasonal agricultural burning (Guttikunda & Gurjar, 2012; Sharma et al., 2016). The economic costs of air pollution, including healthcare expenses and lost productivity, further highlight the urgency of effective mitigation strategies (Baró et al., 2014). While policy interventions such as vehicular restrictions and cleaner fuel adoption have been implemented, their effectiveness is often limited by enforcement challenges and the scale of the problem (Kumar et al., 2019).

Urban forests mitigate air pollution through dry deposition, where tree leaves and other plant surfaces capture airborne pollutants, and through evapotranspiration, which reduces urban heat island (UHI) effects (Nowak et al., 2006). Delhi's UHI intensity, ranging from 3.8°C to 7.6°C in the afternoon and 2.8°C to 8.3°C at night, exacerbates heat stress and energy demands, making urban greenery essential for temperature regulation (Mohan et al., 2012). Additionally, urban trees act as carbon sinks, sequestering carbon dioxide in their woody biomass and reducing emissions associated with energy consumption in buildings and transportation (Nowak & Crane, 2002). In the United States, urban trees are estimated to capture 25.6 million tons of carbon annually, equivalent to 643 million tons of carbon storage, demonstrating their global ecological significance (Nowak et al., 2013). In Delhi, a study by Prasad et al. (2020) estimated that urban forests remove approximately 1,300 tonnes of air pollutants and store 77,000 tonnes of carbon annually, with species like *Azadirachta indica* and *Prosopis juliflora* playing significant roles.

The i-Tree Eco tool, developed by the USDA Forest Service, provides a robust framework for quantifying urban forest ecosystem services, including air pollution removal, carbon sequestration, and stormwater interception (Nowak et al., 2008). By integrating field measurements—such as tree species, diameter at breast height (DBH), height, crown dimensions, and health—with local meteorological and pollution data, i-Tree Eco generates site-specific estimates of ecosystem services and their economic value (Hirabayashi et al., 2012). While widely applied in North America, Europe, and East Asia, its use in Indian cities is limited due to data scarcity, particularly the lack of high-resolution tree inventories (Gopalakrishnan et al., 2022). Recent studies have adapted i-Tree Eco for Indian contexts by incorporating low-resolution satellite imagery, such as Landsat, to overcome these limitations, demonstrating its potential for sites like Deer Park (Gopalakrishnan et al., 2022; Venter & Piana, 2023). For instance, Gopalakrishnan et al. (2022) applied i-Tree Eco in South Delhi, estimating significant carbon sequestration and pollution mitigation, while Prasad et al. (2020) highlighted the tool's utility in quantifying Delhi's urban forest benefits.

Deer Park's ecological diversity, with 125 tree species in older areas like Lutyens' Delhi compared to 26 in newer sub-cities like Dwarka, reflects the varied urban forestry landscape of Delhi (Bhalla & Bhattacharya, 2015). However, the park faces challenges from invasive species like *Prosopis juliflora*, which negatively impact avian biodiversity, and from urban encroachment, which fragments green spaces (Bhattacharya, 2009; Randhawa & Bhattacharya, 2023). These issues are compounded by Delhi's environmental conditions, including extreme heat and high post-monsoon air pollution, which necessitate strategic species selection and long-term maintenance to ensure urban forest sustainability (Chaudhry et al., 2011; Babu & Singh, 2024). The absence of comprehensive planning and monitoring, coupled with adverse soil conditions and limited root zones, contributes to high sapling mortality rates, undermining tree planting initiatives (Menon & Kohli, 2022).

Globally, urban forests are recognized as critical components of nature-based solutions (NbS), which leverage natural systems to enhance climate resilience and sustainability (European Commission, 2015). Studies like Lin et al. (2020) and Doick et al. (2018) emphasize i-Tree Eco's role in providing tangible data to inform stakeholders and policymakers, a model that could enhance Deer Park's management. By integrating field data with advanced modeling, this study aims to assess Deer Park's ecosystem services, focusing on air pollutant removal (PM2.5, CO, NO_2, SO_2, O_3), carbon storage, and species-specific contributions. The research builds on methodologies from Venter and Piana (2023), who advocate combining remote sensing with i-Tree Eco for data-scarce regions, and Begum et al. (2020), who highlight the variability of ecosystem services based on tree species and site characteristics.

This study also addresses the broader context of Delhi's urban transformation, where the built-up area surged from 11% to over 36% between 1989 and 2018, reducing agricultural lands, forests, and ecologically sensitive zones like the Delhi Ridge and Yamuna floodplains (Joshi et al., 2022). This expansion has led to biodiversity loss, with native wildlife like jackals and peafowl becoming rare in city parks (Kalpavriksh & DDA, 2009). Moreover, inequitable access to green spaces, with high-income areas enjoying better-maintained parks than low-income settlements, reinforces environmental injustice (Anand & Bhattacharya, 2023). Initiatives like Delhi's Biodiversity Parks demonstrate the potential for restoring native flora and improving ecosystem services, such as groundwater recharge and wildlife habitats, but localized, data-driven strategies remain underutilized (Begum et al., 2020).

By applying i-Tree Eco to Deer Park, this research seeks to quantify the park's contributions to air quality improvement, carbon sequestration, and biodiversity conservation, identifying high-performing tree species for future afforestation efforts. The findings will provide actionable insights for policymakers, urban planners, and environmental managers, supporting evidence-based strategies to enhance Delhi's urban forestry. This work contributes to the growing body of literature on urban ecosystem services in India, addressing gaps in species-specific research and policy integration highlighted by Chaudhry et al. (2011) and Anand and Bhattacharya (2023). Ultimately, this study underscores the ecological and social value of urban green spaces like Deer Park, offering a model for sustainable urban forest management in the face of rapid urbanization and environmental challenges.

2. AIM AND OBJECTIVES

Aim

To quantify ecosystem services of Deer Park's urban forest in New Delhi using i-Tree Eco, focusing on tree diversity, carbon storage, air pollution removal, and stormwater reduction, to guide sustainable urban forestry.

Objectives

1. To assess tree species composition and structure to inform biodiversity conservation.
2. To measure carbon storage/sequestration and its monetary value for urban planning.

3. To quantify removal of pollutants (PM2.5, PM10, CO, NO_2, SO_2, O_3) to improve air quality strategies.
4. To evaluate tree canopy in reducing stormwater runoff to support water management.

3. LITERATURE REVIEW:

Urban forests encompass trees and associated vegetation in urban environments, including public parks, street trees, private gardens, and green roofs, managed to provide ecological, social, and economic benefits (Nowak & Dwyer, 2007). These forests consist of diverse components such as tree species (native and exotic), shrubs, and understory vegetation, integrated into urban landscapes to enhance ecosystem functionality (Borelli et al., 2023). Urban forests deliver critical ecosystem services, including air pollution removal, carbon sequestration, temperature regulation, stormwater interception, and biodiversity conservation (Nowak et al., 2014; Escobedo et al., 2011). For instance, Nowak et al., (2013) estimated that urban trees in the United States sequester 25.6 million tons of carbon annually, equivalent to 643 million tons of carbon storage. Additionally, urban forests mitigate urban heat islands (UHI), with studies showing temperature reductions of 3.8-7.6°C in urban areas (Mohan et al., 2012; Armson et al., 2012). Health benefits include reduced respiratory and cardiovascular diseases due to improved air quality and stress reduction through exposure to green spaces (Mitchell & Popham, 2008; Ulrich et al., 1991). Economically, urban forests lower energy costs by reducing air conditioning needs and enhance property values (Akbari et al., 2001; McPherson et al., 2011). However, challenges such as invasive species, urban encroachment, and poor maintenance can diminish these benefits (Esperon-Rodrigue et al., 2025).

The mechanisms underlying these benefits involve complex ecological processes. Dry depositions, where tree leaves capture pollutants like PM2.5, CO, NO_2, SO_2, and O_3, are a primary mechanism for air quality improvement (Nowak et al., 2006; Hirabayashi et al., 2011). Carbon sequestration occurs through photosynthesis, storing carbon in woody biomass (Nowak & Crane, 2002), while evapotranspiration and shade reduce urban temperatures (Zhou et al., 2011). Stormwater interception by tree canopies minimizes runoff, reducing urban flooding risks (Xiao & McPherson, 2002). Biodiversity conservation is supported by diverse tree species, which provide habitats for wildlife, though invasive species like Prosopis juliflora can disrupt ecosystems (Bhalla & Bhattacharya, 2015). Socially, urban forests enhance community well-being by providing recreational spaces and fostering environmental stewardship (Tzoulas et al., 2007).

Globally, urban forest assessment has advanced through tools like i-Tree Eco, developed by the USDA Forest Service, to quantify ecosystem services such as air pollution removal, carbon sequestration, and stormwater interception (Nowak et al., 2008; USDA Forest Service, 2023). The i-Tree Eco model integrates field data (e.g., tree species, diameter at breast height (DBH), crown dimensions) with meteorological and pollution data to provide site-specific estimates (Hirabayashi et al., 2012). For example, Nowak et al., (2014) used i-Tree Eco to estimate that U.S. urban forests remove 17.4 million tons of pollutants annually, with significant health and economic benefits. In Beijing, Yang et al., (2005) applied similar methodologies, finding that urban trees reduced PM10 by 772 tons annually. In Latin America, Arroyave-Maya et al., (2019) demonstrated i-tree Eco's utility in Colombia's Aburra Valley, estimating substantial pollutant removal despite data limitations.

Other global approaches include micrometeorological methods to measure gas exchanges (Baldocchi et al., 1988) and canopy stomatal resistance models for pollutant deposition (Baldocchi et al., 1987). These methods complement i-Tree Eco by providing detailed insights into pollutant uptake processes. For instance, Lovett (1994) highlighted the role of atmospheric deposition in nutrient and pollutant cycling, emphasizing tree canopies' interception capabilities. Recent advancements integrate remote sensing and GIS for spatial analysis, as seen in Ma et al., (2021), who used Kriging interpolation to map carbon storage in Beijing's urban forests. In Singapore, Tan et al., (2013) combined field inventories with GIS to assess urban greening impacts, informing policy. However, challenges such as small sample sizes, species misidentification, and inconsistent methodologies can compromise assessment accuracy (Morgenroth et al., 2020). Studies like Mosyaftiani et al., (2022) advocate for standardized protocols to enhance urban forest management scalability.

Urban forests in India provide critical ecosystem services, but their management is hindered by fragmented governance, inadequate species selection, and high sapling mortality due to poor soil conditions and limited maintenance (Chaudhry & Tewari, 2011; Menon & Kohli, 2022). For instance, exotic species like *Prosopis juliflora* have displaced native flora, reducing biodiversity (Bhalla and Bhattacharya, 2015).

Research on Indian urban forestry is limited, with most studies focusing on qualitative assessments or broad vegetation cover rather than species-specific ecosystem services (Singh et al., 2021). However, recent studies have applied i-Tree Eco to quantify benefits. Prasad et al., (2022) estimated that Delhi's urban forests remove 1,300 tonnes of pollutants and store 77,000 tonnes of carbon annually, with species like *Azadirachta indica* being significant contributors. Similarly, Som et al., (2021) assessed carbon sequestration in Delhi's Guru Gobind Singh Indraprastha University campus, highlighting the potential of institutional green spaces. In Bhopal, Dugaya et al., (2020) found that roadside trees sequester substantial carbon, emphasizing the role of linear urban forests. Other studies, such as Bhatnagar et al., (2024) in Katni and Vasagadegar et al., (2023) in Kolhapur, underscore the carbon storage potential of urban parks but note data gaps in species specific assessments.

Air pollution is a critical driver for urban forestry in India, with Delhi's PM2.5 levels far exceeding WHO guidelines (IQAir, 2025). Gupta et al., (2018) demonstrated that Delhi's urban vegetation mitigate PM2.5 through dry deposition, though species composition and canopy structure influence effectiveness. The urban heat island effect, intensified by Delhi's 36% built-up area increase from 1989 to 2018, further underscores the need for urban forests (Joshi et al., 2022; Mallick et al., 2024). Policy frameworks, such as the Town and Country Planning Organization's Urban Green Guidelines (2014), advocate for green infrastructure, but implementation is inconsistent. Initiatives like Delhi's Biodiversity Parks show promise in restoring native flora and enhancing ecosystem services, yet challenges like public awareness and equitable access to green spaces persist (Begam et al., 2024; Anand & Bhattacharya, 2023). Integrating tools like i-Tree Eco with GIS and community engagement, as suggested by Lahoti et al., (2019), could bride these gaps, fostering sustainable urban forestry in India.

Urban forestry has increasingly utilized technological innovations to analyze and manage the urban green infrastructure. One of the major innovations in this context is embodied in the i-Tree suite of tools that were developed through collaborative research among the USDA Forest Service, the Davey Tree Expert Company, and other collaborators. According to Nowak et al. (2011) and the Tree City USA bulletin (2020), i-Tree provides a suite of scientifically tested applications made available to the public for the purpose of analyzing the structure, function, and ecosystem services of urban trees. These applications, i.e., i-Tree Eco, Canopy, Design, and Landscape, provide combined capabilities to analyze factors such as carbon sequestration, stormwater management, air quality improvement, and energy conservation. Among these, i-Tree Eco is a core tool developed from the Urban Forest Effects (UFORE) model. It makes use of extensive field data and environmental conditions to simulate ecological services of urban forests at various spatial scales, ranging from a single tree to an entire city.

A large number of global case studies has confirmed the adaptability and scientific value of i-Tree Eco, which has been applied in more than 100 countries to date. Such case studies often underpin regional policy development, assess tree planting opportunities, and predict future environmental effects. Urban cities in Asia, Europe, and North America, for instance, have shown that the application of i-Tree tools raises awareness and increases climate resilience interventions. However, studies relating to urban forestry in Delhi, India, are not well documented. Current research on Delhi's green infrastructure is largely focused on land cover change satellite-based analysis and socio-ecological contrasts in the provision of open space, but not on direct applications of i-Tree models. Such is a significant research gap, especially in the application of advanced tools like i-Tree Eco in conjunction with regional field data to assess ecosystem services in the city's unique urban-rural interface and semi-arid terrain.

Additionally, literature exists to suggest that i-Tree tools need further adaptation to suit the conditions prevailing in developing countries, where field data availability, trained staff, and stable policy environments might be scarce. Finally, there is also potential for the capacity of i-Tree to better capture biodiversity, soil health, and native species indicators, all of which are essential elements of an integrated strategy for managing urban forests. Overall, therefore, while the i-Tree system is a revolutionary strategy for urban forest assessment and promotion, its use in cities like Delhi is second-best—highlighting the need for local research, pilot projects, and capacity building.

Urban forestry has become a critical strategy for both climate change mitigation and improving urban environmental quality. The i-Tree Eco model, created by the USDA Forest Service and numerous collaborators, paves the way by enabling a holistic analysis of urban tree species and the related ecosystem services. i-Tree Eco measures the services that trees offer, such as carbon sequestration, air pollution reduction, energy conservation, and stormwater management, as argued by Nowak et al. (2011), thus offering evidence-based support for urban green infrastructure planning.

Recent advances have greatly expanded the scope of applicability of the model to a large range of geographic conditions and have enabled it to be adapted to include spatial, vertical, and temporal variation in vegetation cover.

A study confirmed the ability of the i-Tree Eco model to estimate the removal of fine particulate matter (PM2.5) by urban vegetation. Wu et al. (2019) applied an enhanced version of the i-Tree Eco model in Shenzhen, China, to analyze vertical spatial heterogeneity—a factor frequently overlooked in previous studies. The results presented evidence that PM2.5 removal was mainly governed by the leaf area index (LAI) and was heavily dependent on elevation, indicating that vegetation types and topography are both important in improving urban air quality. Specifically, evergreen shrubs were very effective in highly developed low-elevation areas, while evergreen forests were better in high-elevation areas.

For carbon sequestration, Kim et al. (2024) carried out a comprehensive study in Yulim Park in South Korea involving the use of i-Tree Eco coupled with drone-supported data acquisition and spatial grid modeling techniques. The findings of the study indicated considerable sequestration potential variations between vegetation types and spatial distributions, with broad-leaved trees growing in closed canopies having the highest carbon storage capacity per unit area as the most salient observation. Such precise spatial analysis is central to guiding planting plans to optimize carbon storage capacity in the urban park ecosystem context.

Global application of i-Tree Eco is increasing; however, studies on urban forestry in Delhi, India, are limited. Existing research in Delhi is mainly focused on land cover change and inequality in greenspace, with limited evidence of application of ecological modeling tools like i-Tree Eco. This reflects a significant research shortfall in studies to verify the environmental relevance of Delhi's urban trees using standardized methods. Existing i-Tree models would also need to be adapted to effectively assist subtropical, semi-arid climates like Delhi's, with incorporation of locally native tree species and region-specific air quality data. Literature still verifies the value of improving urban forest planning with high-resolution spatial analysis, elevation-informed modeling, and species-specific analysis. However, concerns about vertical modeling in mountain cities, incorporation of socio-economic variables, and region-standardized monitoring protocols persist. Resolution of these through contextually appropriate applications of tools like i-Tree Eco can improve the ecological and the public health value of urban forests, especially for rapidly expanding cities of the Global South.

Urban forestry is pivotal to attaining ecological sustainability in fast-developing regions like Delhi. Studies have proven that the potential capital has various patches of forests, mainly the Ridge forests, that act as ecological buffers and sites of reservoirs of biodiversity in the wake of rising anthropogenic pressures. Randhawa and Shimrah (2023) carried out an exhaustive investigation of the community structure and regeneration status of tree species at three Ridge sites of Kamla Nehru Ridge, Central Ridge, and Southern Ridge. The results indicated dominance by alien species like Prosopis juliflora, which jeopardizes the regeneration of native species. Despite a total of 51 species belonging to 21 families having been reported, regeneration at all the sites was extremely poor, with most species exhibiting poor or no recruitment of seedlings. This indicates extensive ecological distress, which could be due to the expansion of the city, overgrazing, and release of invasive species.

Tripathi and Joshi (2015) outlined the carbon sequestration potential of urban parks in East Delhi. Estimating the biomass and carbon stock of 36 parks with a total area of 4.48 hectares, they estimated the total value of carbon storage at 255.49 tons in 2,688 trees. Among the species examined, Ficus benghalensis and Azadirachta indica were two dominant species and major contributors to above- and below-ground biomass. The results of their study underscored the imperative for systematic carbon accounting in urban settings, especially in the context of climate change mitigation and international environmental governance such as the Kyoto Protocol and the reporting framework mandated by the UNFCCC.

Overall, the study underscores the ecological and functional importance of Delhi's urban forests. Certain specific locations possess high carbon sequestration capacity; however, there are other locations that are burdened with serious regeneration problems that are the outcomes of anthropogenic activities and poor biodiversity management. These findings call for an integrated strategy that brings together biodiversity conservation, ecological restoration, and climate-resilient urban planning in an attempt to increase the resilience of green infrastructure in Delhi's urban ecosystem.

Despite the increasing awareness of the ecological, social, and economic value conferred by urban forests, several important research gaps still exist. To start with, even though global models such as i-Tree Eco have progressed to quantify ecosystem services, the use and calibration of the same for the urban ecosystem in India, and more specifically in Delhi, still fall short. Integrating species-specific local ecological features, air quality parameters, and climatic variables into such models is necessary to enhance the accuracy of estimates.

Second, existing research work in India is mostly confined to city-scale or landscape-scale appraisal with the aid of satellite imagery. There are virtually none that go down to species-level analysis, which is critical in the determination of the ecological functionality and service provision by indigenous versus alien species. This absence of species-specific data limits evidence-based tree species choice and management.

Third, temporal observation of urban forests is weak. The majority of studies offer cross-sectional measurements instead of longitudinal data on forest development, species regeneration, or seasonal trends in ecosystem service provision. Without ongoing monitoring, it is hard to monitor the effect of urban forestry interventions or climate variability over time.

Fourth, there is a disjointed methodological approach between studies. Variability in sampling techniques, measurement regimes of trees, and approaches to ecosystem service valuation complicate comparisons. Standardized protocols for measuring urban forest inventory and ecosystem services across cities and research centers are called for.

Fifth, although instruments such as i-Tree Eco measure the avoidance of pollutants and carbon sequestration, ancillary values such as soil health, hydrology, and socio-cultural values are not considered. Urban forests need to be evaluated in their total context, including their contribution to mental well-being, cultural significance, and urban justice, especially in the Indian context where people's participation and self-managed green spaces are prominent.

Sixth, scientific evidence documents the invasion of species like Prosopis juliflora in Delhi's Ridge forests but not thorough studies on the mechanisms through which such species inhibit native regeneration and affect ecosystem resilience. There is no empirical data for long-term ecological consequences of the composition of urban tree species. Seventh, despite the existence of many policy documents (e.g., Urban Greening Guidelines and Biodiversity Parks initiatives), their implementation is uneven, and empirical evaluation of such interventions is lacking. There is limited evidence regarding governance frameworks, stakeholder involvement, and public awareness as determinants or barriers of effective urban forest management. Last but not least, there is limited integration of remote sensing, GIS, and ground data into a comprehensive framework. Although remote sensing facilitates macro-scale mapping, integration with ground tools such as i-Tree Eco and participatory mapping would enable more spatial and functional resolution.

4. MATERIALS AND METHODS:

4.1 STUDY AREA:

The present study focuses on Deer Park, Hauz Khas, located in the National Capital Territory (NCT) of Delhi, one of India's most urbanized and rapidly expanding metropolitan regions. Delhi, the capital of India, is not only the administrative heart of the country but also a key economic, cultural, and political center. It is classified as a Union Territory with special status and is officially known as the National Capital Territory of Delhi (NCT Delhi).

Geographical Location

Delhi is situated between 28°24′17″ N and 28°53′00″ N latitude, and 76°50′24″ E and 77°20′37″ E longitude, occupying a total area of about 1,483 square kilometers. It is bounded by Haryana on three sides and by Uttar Pradesh to the east. The city lies in the Indo-Gangetic alluvial plains and is flanked by the Aravalli Hills to the south and southwest, with the Yamuna River flowing along its eastern edge. Delhi experiences a semi-arid subtropical climate (BSh, Köppen-Geiger classification) characterized by extreme seasonal variation. The summer months (April to June) are intensely hot, with temperatures often exceeding 45°C, while winter (December to January) can see temperatures drop below 5°C. The monsoon season, from July to September, brings the majority of the city's annual rainfall, averaging around 800 mm to 1,200 mm. The city frequently experiences urban heat island effects, dust storms, and high air pollution levels, particularly in the post-monsoon months.

Table 1: District Wise Population (Source: Delhi Heat Action Plan, 2024-25)

Districts	Population (2011)
North-East	22,40,749

East	17,07,725
Central	14,27,910
West	25,31,583
North	8,87,978
North-West	22,46,311
South	12,33,401
New Delhi	11,73,902
South-West	17,49,492
South-East	15,00,351
Shahdara	22,40,749

Forest Types found in Delhi: The distribution of different forest types in Delhi, classified according to the Champion & Seth Forest Classification (1968) and based on the Forest Cover Map (FCM) from ISFR-2023, is shown in the table below.

Table 2: Area Statistics of the Forest Types Found in Delhi (Source: India State of Forest

Report, 2023)

SL. No.	**Forest type**	**Area**	**% of the total mapped area**
1	5B/C2 Northern dry mixed deciduous forest	20.41	10.33
2	6B/C2 Ravine thorn forest	64.48	32.62
	Sub Total	**84.89**	**42.95**
3	TOF/Plantation	112.78	57.05
	Total (Forest Cover and Scrub)	**197.67**	**100.00**

Source: India State of Forest Report 2023 (Volume II), Forest Survey of India, Ministry of Environment, Forest and Climate Change.

Delhi has 8% forest area and 20% green cover, with over 18,000 parks and gardens spread across 8,000 ha, along with roadsides and central verges. These areas are managed by agencies like MCD, DDA, NDMC, PWD, and CPWD, with varying levels of upkeep. The Delhi Parks and Garden Society was formed under the Societies Registration Act, 1860, to improve coordination and management. Each district is governed by its district magistrate and contributes to the overall urban dynamics of Delhi. The study area, Deer Park, is situated in the South Delhi district, which is known for its mix of residential neighborhoods, green areas, and institutional campuses.

Deer Park, Hauz Khas

Deer Park is one of Delhi's prominent urban green spaces, often referred to as the "lungs of South Delhi." Spread across approximately 95.30 acres, the park is part of a larger green complex that includes the Hauz Khas Lake and District Park, and it connects to the Rose Garden and Sanjay Van via green corridors. The park hosts a variety of tree species, shrubs, and grasslands and is home to spotted deer, peacocks, rabbits, and numerous bird species.

Strategically located near educational institutions, residential zones, and tourist attractions, Deer Park serves as a crucial recreational and ecological space. It plays an important role in microclimate regulation, biodiversity conservation, and carbon sequestration. The park's location within a densely populated urban area makes it an ideal site for applying tools like i-Tree Eco to assess ecosystem services and inform urban forest management strategies.

Delhi's natural beauty is enriched by a diverse mix of native and exotic trees, including vibrant species like Cassia fistula, Nyctanthes arbor-tristis, Ehretia laevis, Neolamarckia cadamba, Acacia auriculiformis, and Mimusops elengi, as noted by the Delhi Forest Department (2025). The city's parks further enhance this biodiversity, featuring a lush blend of trees, shrubs, and grasslands that provide a haven for wildlife such as spotted deer, colorful peacocks, rabbits, and a variety of birds, creating a lively and thriving ecological environment.

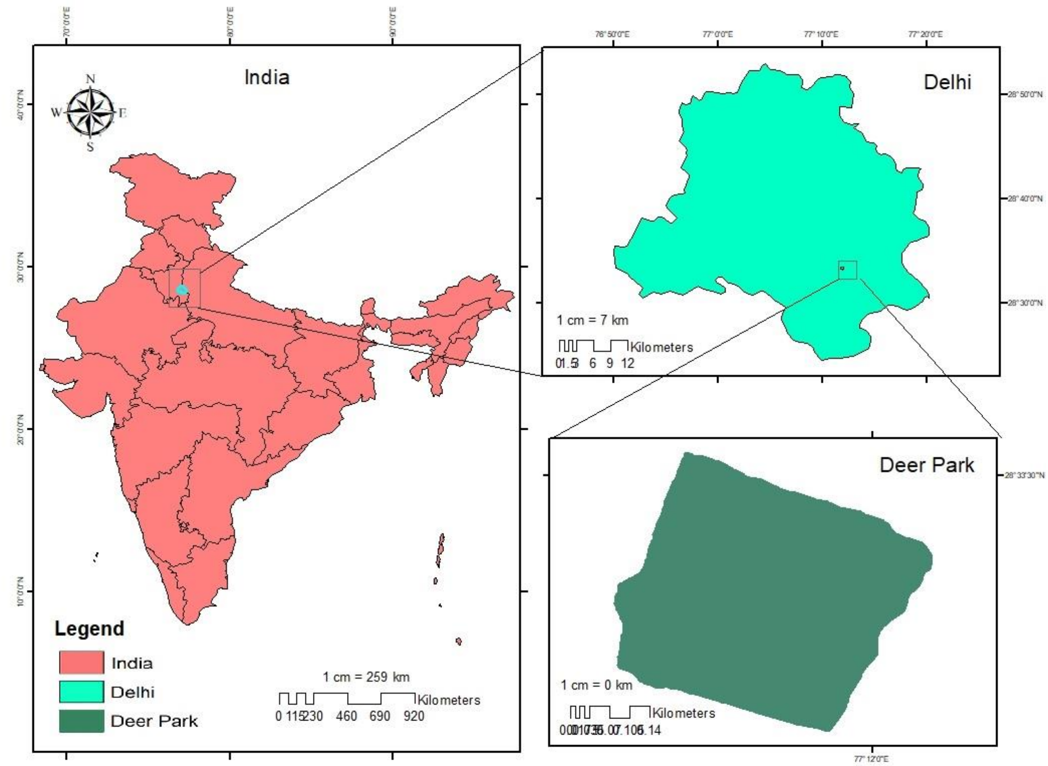

Figure 1: Map of Deer Park, Hauz Khas

4.2 METHODOLOGY:

The i-Tree Eco software (version 6.1.53) was utilized to evaluate the ecosystem services and structure of a tree located in Deer Park, Hauz Khas, Delhi. The i-Tree Eco model is based on the Urban Forest Effects (UFORE) framework, which was collaboratively developed by the U.S. Forest Service Northern Research Station (NRS), the USDA State and Private Forestry's Urban and Community Forestry Program and Northeastern Area, the Davey Tree Expert Company, and the SUNY College of Environmental Science and Forestry.

4.2.1 Sampling Design and Plot Distribution:

To estimate the potential for carbon sequestration and air pollution mitigation by trees in Deer Park, Hauz Khas, Delhi, a plot-based inventory approach was employed as the sampling strategy. A random sampling technique was utilized to ensure statistically significant results, with plots distributed randomly across the park. Following the i-Tree Eco manual's recommendations, each plot was standardized at 0.04 hectares (400 m^2 or 12 m radius). The number of plots surveyed was determined based on the park's size and vegetation density to optimize the balance between accuracy and efficiency. A total of 100 plots were selected, adhering to i-Tree Eco guidelines, which emphasize sufficient plot numbers to represent the park's overall tree population (USFS, 2021b). This sample size was chosen to provide robust, statistically significant estimates of carbon sequestration and air pollution removal potential while maintaining efficiency in time and resources (USFS, 2021a). The 100 plots ensured adequate capture of variability in tree species, sizes, and conditions within Deer Park, delivering accurate and reliable data for the study's objectives of assessing both carbon storage and air pollution mitigation.

Field Data Collection

Field data collection was conducted using standardized i-Tree Eco protocols in the months of February to May. The following parameters will be recorded for each randomly selected plot:

1. Tree-Level Attributes	**2. Plot-Level Attributes**	**3. Environmental Data**
Tree species identification	GPS Coordinates of plot centers	Meteorological data
Diameter at Breast Height (DBH) at 1.37m (4.5 feet)	Land-use classifications	Pollution data
Total tree height	Soil conditions	
Total crown height	Ground cover composition	
Crown width (measured in two perpendicular directions)		
Crown dieback		
Crown missing percentage		

Tools and Equipment Used for Data Collection:

- **30m Measuring Tape**: Used to measure crown width in two perpendicular directions and to gauge tree spacing within plots. It was also employed to measure the diameter at breast height (DBH) at 1.37 meters above ground level.
- **GPS Device (e.g., Garmin eTrex 20)**: Utilized to capture the geographic coordinates of each plot's center, ensuring precise mapping and enabling future revisits.
- **Clinometer**: Employed to determine tree height accurately.
- **Compass**: Helped locate plots with precision.
- **Field Datasheets and Clipboard**: Used for manually recording data during fieldwork.
- **Smartphone**: Served as a tool for inputting data directly into the i-Tree Eco software.
- **Species Identification Resources**: Included the "Trees of Delhi" field guide by Pradip Krishen and mobile apps like Google Lens, Seek and iNatClassic to confirm tree species when identification was uncertain.

4.2.2 Data Processing and Model Execution in i-Tree Eco:

After collecting field data from Deer Park, Hauz Khas, Delhi, it was entered and analyzed using the i-Tree Eco software in May. The results were studied to understand species distribution, evaluate carbon sequestration and air pollution removal rates, and identify the most effective tree species for future planting efforts. The insights from the i-Tree Eco model helped develop recommendations to enhance carbon storage, improve air quality, and boost the park's overall sustainability. The data was also compared with national and global standards to highlight Deer Park's contribution to climate change mitigation. This thorough data processing step was crucial for ensuring the accuracy and reliability of the estimates for carbon sequestration and air pollution benefits, which are essential for informing urban forestry management and shaping climate policy decisions.

5. RESULT:

5.1 Tree Species Diversity and Structure:

The tree population in Deer Park, Hauz Khas, is predominantly composed of *Putranjiva roxburghii* (Putranjivaceae), with 271 individuals, far outnumbering other species. Following it is *Azadirachta indica* (Meliaceae), known as Neem, with 122 trees, and *Cassia fistula* (Caesalpinioideae) with 102 trees. These three species form the majority of the park's tree population, suggesting either preferential planting or favorable natural growth. Other significant species include *Pongamia pinnata* (Fabaceae) with 68 trees and *Delonix regia* (Caesalpinioideae) with 41, both valued for their ecological adaptability and ornamental appeal. Less abundant but still notable species include *Morus alba* (30 trees), *Ficus virens*(28), *Syzygium cumini* (27), and *Ehretia laevis* (24), representing a mix of fruit-producing and shade-giving trees. The park also contains a diverse array of less common species, such as *Terminalia arjuna* (18), *Tectona grandis* (18), *Bombax ceiba* (16), and *Mimusops elengi* (15), appreciated for their ecological contributions and cultural significance. Several rare species, including *Ailanthus excelsa*, *Spathodea campanulata*, *Bauhinia purpurea*, *Kigelia africana*, and *Moringa oleifera*, are represented by only one individual each, indicating high species richness but uneven distribution.

In terms of taxonomic diversity, the Moraceae family leads with 8 species, followed by Caesalpiniaceae and Mimosaceae, each contributing 6 species. These legume-related families are prized in urban forestry for their nitrogen-fixing properties and rapid growth. Families like Bignoniaceae, Fabaceae, and Myrtaceae each have 4 species, while Malvaceae and Meliaceae contribute 3 species each. Families such as Ebenaceae, Ulmaceae, Apocynaceae, and Proteaceae are represented by 2 species each, and a wide range of families, including Anacardiaceae, Annonaceae, Boraginaceae, Capparaceae, Casuarinaceae, Citrus, Combretaceae, Lythraceae, Moringaceae, Myrpaceae, Putranjivaceae, Rubiaceae, and Sapotaceae, have just one species each, underscoring the park's extensive taxonomic variety.

Of the 61 tree species, 40 are native, reflecting a focus on indigenous flora for their ecological suitability and benefits. Additionally, 20 introduced species are present, likely included to enhance landscape diversity or for their aesthetic and fast-growing traits. Only one species is classified as naturalized, indicating a non-native species that has successfully adapted to the local environment.

Among the 61 species, 30 are evergreen, 24 are deciduous, and 7 are perennial. The prevalence of evergreen species highlights a deliberate strategy to ensure year-round canopy cover, aiding in consistent carbon sequestration, shade provision, and microclimate regulation. Deciduous and perennial species contribute to seasonal biodiversity and nutrient cycling through leaf litter, supporting ecological balance while adding visual diversity to the park.

Table 3: Species composition recorded in Deer Park, Hauz Khas

Tree species name	**Common name**	**No. of individuals**	**Family**	**Status**	**Evergreen /Deciduous**
Albizia lebbeck	Acacia amarilla	19	Mimosaceae	native	perinnial
Spathodea campanulata	African tulip tree	1	Bignoniaceae	introduced	Evergreen
Terminalia arjuna	Arjun	15	Combretaceae	native	Evergreen
Saraca asoca	Asoka-tree	5	Caesalpiniaceae	native	Evergreen
Casuarina equisetifolia	Australian pine	4	Casuarinaceae	native	perinnial

Toona ciliata	Australian redcedar	4	Meliaceae	native	deciduous
Bauhinia forficata	Bauhinia	1	Fabaceae	introduced	deciduous
Ficus benjamina	Benjamin fig	3	Moraceae	native	Evergreen
Eucalyptus globulus	Blue gum eucalyptus	2	Myrpaceae	introduced	Evergreen
Jacaranda mimosifolia	Blue jacaranda	1	Bignoniaceae	introduced	deciduous
Callistemon pendula	Bottlebrush	6	Myrtaceae	introduced	Evergreen
Bauhinia racemosa	Burmese Silk Orchid	6	Caesalpiniace ae	native	Evergreen
Cassia fistula	Canafistula	102	Caesalpiniace ae	native	deciduous
Melia azedarach	Chinaberry	15	Meliaceae	native	Evergreen
Citrus	Citrus spp	5	Citrus	native	perinnial
Ficus racemosa	Cluster Fig	5	Moraceae	native	Evergreen
Psidium guajava	Common guava	5	Myrtaceae	introduced	Evergreen

Callistemon citrinus	Crimson bottlebrush	1	Myrtaceae	introduced	Evergreen
Diospyros melanoxylon	Diospyros melanoxylon	5	Ebenaceae	native	deciduous
Ehretia laevis	Ehretia laevis	24	Boraginaceae	native	deciduous
Ulmus laevis	European white elm	23	Ulmaceae	introduced	deciduous
Gum arabic tree (Vachellia nilotica)	Gum arabic tree	3	Mimosaceae	native	Evergreen
Moringa oleifera	Horseradishtree	1	Moringaceae	native	deciduous
Ficus benghalensis	Indian banyan	1	Moraceae	native	Evergreen
Millingtonia hortensis	Indian cork tree	1	Bignoniaceae	introduced	deciduous
Morinda citrifolia	Indian mulberry	3	Rubiaceae	native	perinnial
Dalbergia sissoo	Indian rosewood	15	Fabaceae	native	deciduous
Artocarpus heterophyllus	Jackfruit	1	Moraceae	native	Evergreen

Syzygium cumini	Jambolan plum	27	Myrtaceae	native	Evergreen
Pterospermum acerifolium	Kanack champa	7	Malvaceae	native	Evergreen
Putranjiva roxburghii	Lucky bean tree	271	Putranjivaceae	native	Evergreen
Mangifera indica	Mango	3	Anacardiaceae	native	Evergreen
Prosopis juliflora	Mesquite	2	Mimosaceae	introduced	deciduous
Mimusops elengi	Mimusop	16	Sapotaceae	native	perinnial
Bauhinia variegata	Mountain ebony	2	Caesalpiniaceae	native	deciduous
Azadirachta indica	Neem Tree	122	Meliaceae	native	Evergreen
Acacia auriculiformis	Northern black wattle	1	Mimosaceae	introduced	Evergreen
Ficus religiosa	Peepul tree	13	Moraceae	native	deciduous
Pongamia pinnata	Indian beech tree	68	Fabaceae	native	deciduous

Lagerstroemia speciosa	Queen's crapemyrtle	1	Lythraceae	native	deciduous
Bombax ceiba	Red-silk cotton	18	Malvaceae	native	deciduous
Delonix regia	Royal poinciana	41	Caesalpiniaceae	introduced	Evergreen
Ficus elastica	Rubber plant	2	Moraceae	native	Evergreen
Crateva religiosa	sacred garlic pear	1	Capparaceae	native	deciduous
Kigelia africana	Sausage tree	1	Bignoniaceae	introduced	deciduous
Cassia siamea	Siamese cassia	5	caesalpiniaceae	native	Evergreen
Ceiba speciosa	Silk floss tree	12	Malvaceae	introduced	perinnial
Grevillea robusta	Silk oak	19	proteaceae	introduced	Evergreen
Grevillea parallela	Silver Oak	4	proteaceae	introduced	Evergreen
Plumeria obtusa	Singapore graveyard flower	3	apocynaceae	introduced	Evergreen

Tectona grandis	Teak	19	verbenaceae	native	deciduous
Erythrina variegata	Tiger's claw	3	Fabaceae	native	deciduous
Diospyros montana	Tomal	1	Ebenaceae	native	deciduous
Ulmus minor ssp. angustifolia	Ulmus minor angustifolia	1	Ulmaceae	introduced	deciduous
Polyalthia longifolia v. pendula	Weeping Mast Tree	7	Annonaceae	native	Evergreen
Acacia senegal	werek	1	Mimosaceae	native	deciduous
Alstonia scholaris	White Cheesewood	1	apocynaceae	native	Evergreen
Ficus virens	White fig	28	Moraceae	native	deciduous
Leucaena leucocephala	White lead tree	10	Mimosaceae	naturalized	Evergreen
Morus alba	White mulberry	30	Moraceae	introduced	perinnial
Peltophorum pterocarpum	Yellow flametree	4	Caesalpiniaceae	introduced	Evergreen
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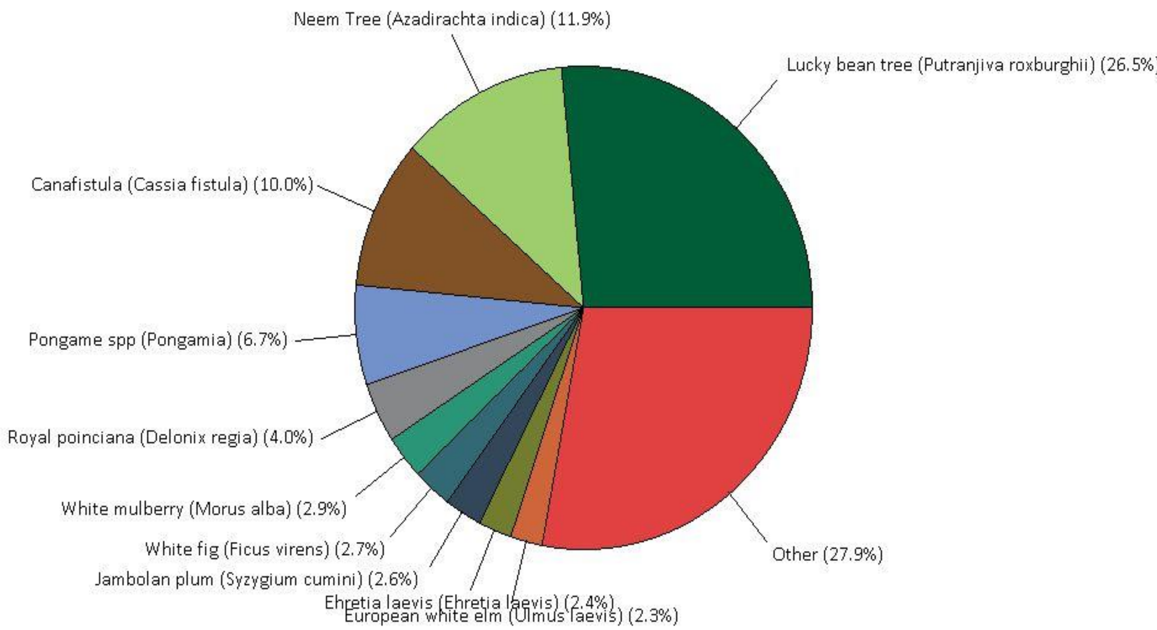

Figure 2: Tree species composition in Deer Park, Hauz Khas

5.2 Carbon storage and sequestration:

Among the species listed in Table 2, *Azadirachta indica* (Neem) stands out as the top carbon storage species, amassing 604.40 tons due to its high prevalence and substantial mature biomass. Following it is *Putranjiva roxburghii*, which stores 141.50 tons and is the most abundant species in the park, underscoring the influence of population size on carbon storage capacity. *Cassia fistula* and *Bombax ceiba* also make significant contributions, storing 82.40 tons and 68.00 tons, respectively, owing to their large canopies and dense wood. Other notable species, including *Terminalia arjuna* (61.60 tons), *Syzygium cumini* (55.50 tons), and *Ficus religiosa* (56.40 tons), demonstrate strong potential for long-term carbon accumulation, emphasizing the importance of native species. Additional contributors such as *Delonix regia* (31.30 tons), *Pongamia pinnata* (31.40 tons), Morus alba (27.80 tons), Melia azedarach (24.80 tons), and Albizia lebbeck (46.80 tons) store between 25 and 50 tons each, depending on their size, density, and population. Species with moderate storage include *Ulmus laevis* (33.80 tons), *Ficus virens* (34.70 tons), and *Dalbergia sissoo* (12.40 tons), while smaller or less dense species like *Grevillea parallela* (5.40 tons), *Artocarpus heterophyllus* (0.20 tons), and *Acacia senegal* (0.10 tons) contribute minimal carbon storage.

In terms of annual gross carbon sequestration, *Azadirachta indica* leads with 30.59 tons per year, highlighting its critical role in active carbon uptake. *Putranjiva roxburghii* follows with 9.88 tons/year, *Cassia fistula* with 7.79 tons/year, and *Bombax ceiba* with 4.16 tons/year, all showing robust annual carbon assimilation. *Albizia lebbeck* sequesters 3.10 tons/year, while *Delonix regia* and *Terminalia arjuna* record 2.66 and 2.30 tons/year, respectively. *Syzygium cumini* and *Ficus religiosa* also perform strongly, with 2.30 and 2.14 tons/year, making them valuable for sustained carbon management. Mid-range sequestration rates are observed in species like *Morus alba* (1.93 tons/year), *Ceiba speciosa* (1.89 tons/year), *Pterospermum acerifolium* (1.83 tons/year), and *Ficus virens* (1.73 tons/year), indicating the importance of both native and ornamental species in ongoing carbon capture. Smaller or less dynamic species, such as *Acacia senegal* (0.01 tons/year), *Plumeria obtusa* (0.06 tons/year), and *Artocarpus heterophyllus* (0.03 tons/year), show lower sequestration rates but provide other ecological benefits. Notably, *Prosopis juliflora* exhibits no gross sequestration, likely due to its mature or dormant growth phase.

Species	Carbon Storage (ton)	Gross Carbon Sequestration (ton/yr)
Acacia auriculiformis	1.5	0.03
Vachellia nilotica	1.1	0.08
Acacia senegal	0.1	0.01
Albizia lebbeck	46.8	3.1
Alstonia scholaris	1.3	0.08
Artocarpus heterophyllus	0.2	0.03

Azadirachta indica	604.4	30.59
Bauhinia forficata	0.1	0.01
Bauhinia racemosa	3.8	0.18
Bauhinia variegata	0.9	0.12
Bombax ceiba	68	4.16
Callistemon citrinus	0.1	0.01
Casuarina equisetifolia	4.5	0.49
Cassia fistula	82.4	7.79
Callistemon pendula	15.6	0.61
Senna siamea	10.8	0.81
Ceiba speciosa	43.1	1.89
Citrus	1.9	0.21
Crateva religiosa	0.4	0.03
Dalbergia sissoo	12.4	0.75
Delonix regia	31.3	2.66
Diospyros montana	2.8	0.22
Diospyros melanoxylon	2.5	0.18
Ehretia laevis	9.2	0.94
Erythrina variegata	0.1	0
Eucalyptus globulus	8.2	0.76
Ficus benjamina	0.3	0.05
Ficus benghalensis	0.4	0.1
Ficus elastica	0.9	0.13
Ficus racemosa	8.2	0.55
Ficus religiosa	56.4	2.14
Ficus virens	34.7	1.73
Grevillea parallela	5.4	0.35
Grevillea robusta	6.5	0.8
Jacaranda mimosifolia	1.7	0.1
Kigelia africana	2.8	0.08
Lagerstroemia speciosa	0	0.01
Leucaena leucocephala	3.8	0.48

Mangifera indica	0.7	0.07
Melia azedarach	24.8	1.98
Mimusops elengi	2.8	0.36
Millingtonia hortensis	1.2	0.14
Morus alba	27.8	1.93
Morinda citrifolia	0.6	0.09
Moringa oleifera	0.3	0.03
Peltophorum pterocarpum	10.2	0.58
Plumeria obtusa	0.7	0.06
Pongamia	31.4	2.49
Polyalthia longifolia v. pendula	8.2	0.74
Prosopis juliflora	9	0
Psidium guajava	3	0.27
Pterospermum acerifolium	20.3	1.83
Putranjiva roxburghii	141.5	9.88
Saraca asoca	5.5	0.18
Spathodea campanulata	0.4	0.05
Syzygium cumini	55.5	2.97
Terminalia arjuna	61.6	2.3
Tectona grandis	13.6	1.42
Toona ciliata	9.3	0.63
Ulmus laevis	33.8	1.41
Ulmus minor ssp. angustifolia	8.3	0.01
Total	**1545**	**91.69**

5.3 Species with High Carbon Storage Capacity:

Azadirachta indica leads in carbon storage, accumulating 604.4 tons, far exceeding other species due to its high abundance. Following it, *Putranjiva roxburghii* stores 141.5 tons, with notable contributions from *Cassia fistula* (82.4 tons), *Bombax ceiba* (68.0 tons), and *Terminalia arjuna* (61.6 tons). Other species, such as *Ficus virens*, store significantly less, with only 34.7 tons. This distribution underscores the critical role of a few dominant species in carbon storage, essential for long-term climate mitigation strategies.

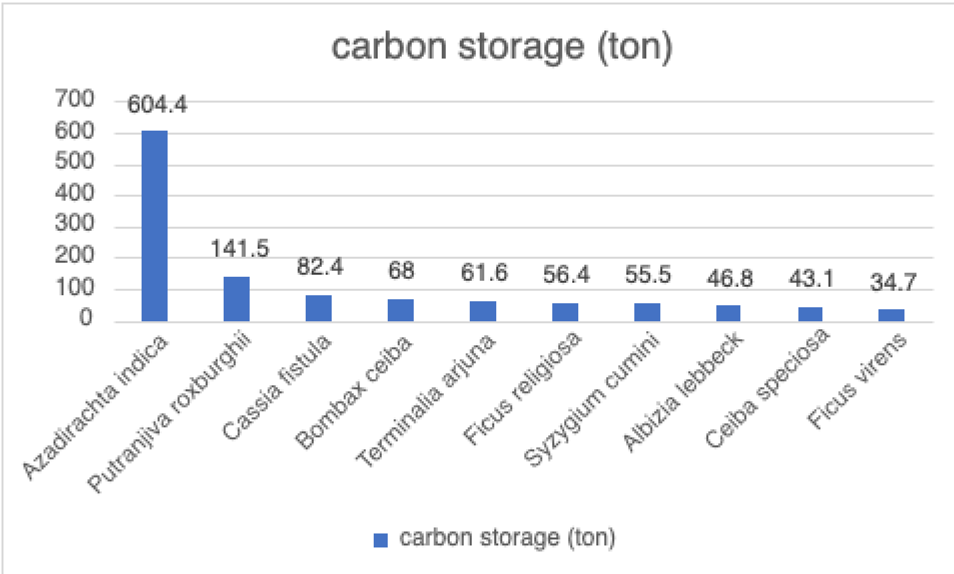

Figure 3: Graph showing top 10 species for carbon storage

5.4 Species with High Carbon Sequestration Rates:

Azadirachta indica excels in annual carbon sequestration, capturing 30.59 tons per year, outpacing all other species. *Putranjiva roxburghii* follows with 9.88 tons per year, and *Cassia fistula* sequesters 7.79 tons annually. Other contributors include *Bombax ceiba* (4.16 tons), *Albizia lebbeck* (3.10 tons), *Syzygium cumini* (2.97 tons), *Delonix regia* (2.66 tons), *Pongamia* (2.49 tons), *Terminalia arjuna* (2.30 tons), and *Ficus religiosa* (2.14 tons). These figures highlight the diverse contributions of tree species to carbon sequestration, with *Azadirachta indica* playing a pivotal role in reducing atmospheric carbon.

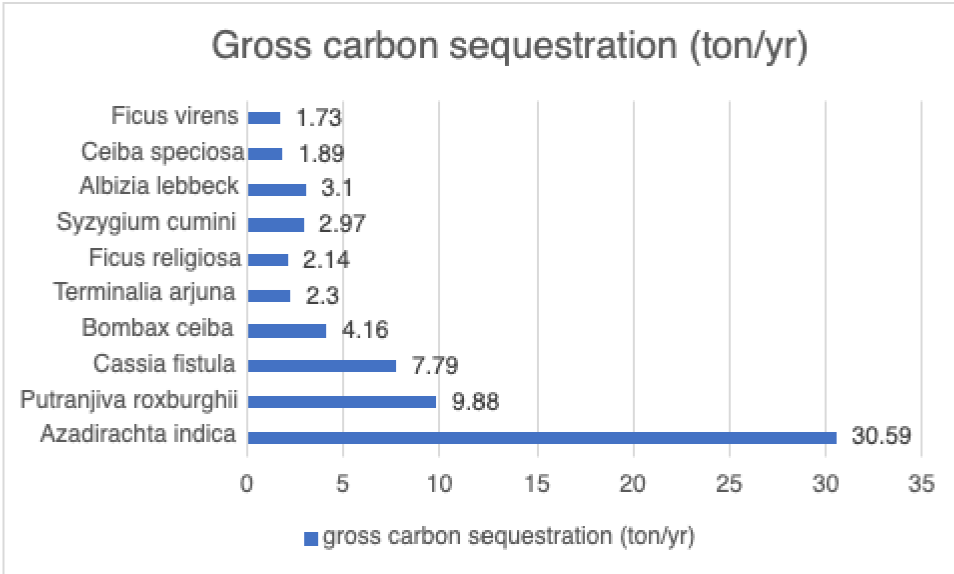

Figure 4: Graph depicting Gross Carbon Sequestration for top 10 species

5.5 Carbon Storage and Sequestration by Vegetation Type:

The data reveals variations in carbon storage and sequestration across different vegetation types. Evergreen species demonstrate superior performance, storing a total of 1,036.2 tons of carbon and sequestering 59.21 tons annually. In comparison, deciduous species store 381.4 tons and sequester 24.4 tons per year, while perennial species contribute 127.5 tons of storage and 8.07 tons of annual sequestration.

This pattern highlights the exceptional capacity of evergreen species for both long-term carbon storage and continuous sequestration, emphasizing their vital role in carbon mitigation strategies. Although deciduous and perennial species also contribute, their lower effectiveness suggests a need to prioritize evergreen species for enhanced carbon capture and retention.

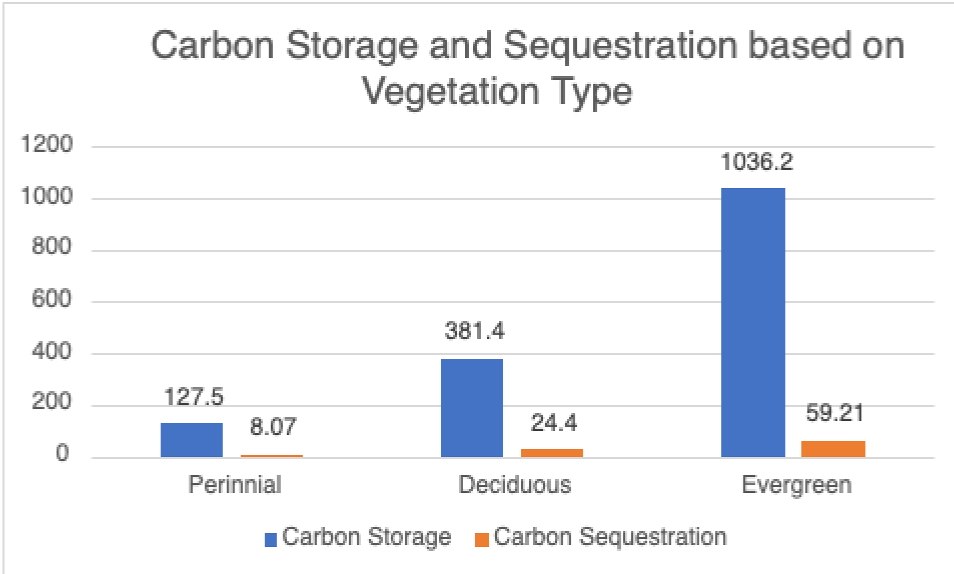

Figure 5: Carbon Storage and Sequestration based on Vegetation Type

5.6 Carbon Storage and Sequestration by Tree Species Status:

The data highlights the carbon storage and sequestration capacities based on the status of tree species. Native species dominate, storing a total of 1,329.94 tons of carbon and sequestering 79.45 tons annually (Fig. 5). In contrast, introduced species store only 210.7 tons and sequester 11.75 tons per year, while naturalized species contribute minimally, with just 3.8 tons stored and 0.48 tons sequestered annually.

This distribution underscores the critical role of indigenous species in both carbon storage and sequestration, highlighting their importance for effective carbon management strategies. Conversely, introduced and naturalized species show significantly lower contributions, reinforcing the ecological and carbon storage value of native species in the studied ecosystem.

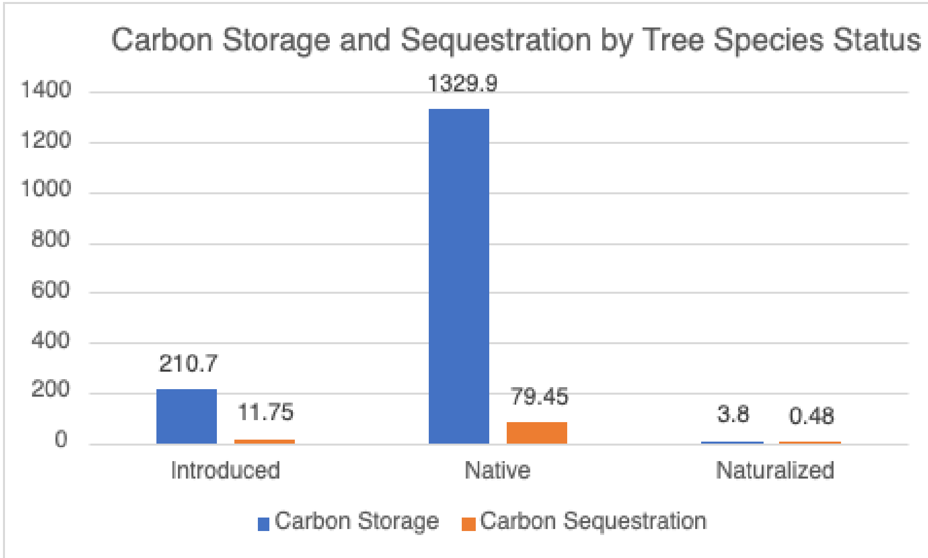

Figure 6: Carbon Sequestration and Storage by Tree Species Status

5.7 Carbon credit based on carbon storage:

The carbon credit valuation for various tree species is based on a cumulative offset of 130 metric tons of CO_2 equivalent, using a conversion rate of 1 USD = ₹85.50 INR (Table 3). These figures represent the CO_2 equivalent sequestered by each species and their corresponding market value in USD and INR, highlighting the economic potential of urban trees in the voluntary carbon market and their role in monetizing ecosystem services.

Leading the list, Azadirachta indica sequesters an impressive 2216.30 tons of CO_2, yielding a carbon credit value of $288,119 (₹24,588,075.46), underscoring its immense potential for climate mitigation and carbon finance initiatives. Putranjiva roxburghii follows, capturing 518.90 tons, valued at $67,457 (₹5,756,780.87), a significant contribution. Cassia fistula ranks third, sequestering 302.20 tons, worth $39,286 (₹3,356,267.44), affirming its importance as a high-value species.

Bombax ceiba sequesters 249.40 tons, valued at $32,422 (₹2,766,893.48), while *Terminalia arjuna* stores 225.80 tons, equating to $29,354 (₹2,505,070.36). Ficus religiosa, notable for its ecological and cultural significance, captures 206.90 tons, translating to $26,897 (₹2,259,389.98). *Syzygium cumini* contributes 203.50 tons, valued at $26,465 (₹2,257,669.70).

Further down, *Albizia lebbeck* stores 171.50 tons, worth $22,295 (₹1,902,655.30), and *Ceiba speciosa* sequesters 158.10 tons, valued at $20,553 (₹1,753,993.02). Other key species include *Ficus virens* (127.30 tons, $16,549, ₹1,412,291.66) and *Ulmus laevis* (124.10 tons, $16,133, ₹1,376,790.22). Both *Pongamia* and *Delonix regia* contribute over $14,000 (₹1.27 million INR) each.

Moderately contributing species include *Melia azedarach* (90.90 tons, $11,817, ₹1,008,462.78) and *Pterospermum acerifolium* (74.30 tons, $9,659, ₹824,299.06). Mid-range species such as *Callistemon pendula*, *Tectona grandis*, *Dalbergia sissoo*, and *Senna siamea* sequester 30–60 tons, valued between $4,000–$7,400 (₹350,000–₹630,000 INR).

At the lower end, species like *Saraca asoca* (20.00 tons, $2,360, ₹221,884), *Casuarina equisetifolia* (16.70 tons, $2,171, ₹185,273.14), and *Leucaena leucocephala* (13.90 tons, $1,807, ₹154,209.38) still contribute to ecosystem services despite lower financial returns. The least impactful species, such as *Ficus benjamina* (1.00 ton, $130, ₹11,094.20), *Artocarpus heterophyllus* (0.70 tons, $91, ₹7,765.94), and species like *Callistemon citrinus* and *Lagerstroemia speciosa* (below 0.50 tons, under $65 or ₹5,000 INR), reflect minimal economic contributions but support biodiversity and ecosystem functionality.

Species	CO_2 Equivalent (tons)	Carbon Credit Value (USD)	Carbon Credit Value (INR)
Acacia auriculiformis	5.3	689	58,799.26
Vachellia nilotica	4.1	533	45,486.22
Acacia senegal	0.4	52	4,437.68
Albizia lebbeck	171.5	22,295	1,902,655.30
Alstonia scholaris	4.8	624	53,252.16
Artocarpus heterophyllus	0.7	91	7,765.94

Azadirachta indica	2216.3	288,119	24,588,075.46
Bauhinia forficata	0.4	52	4,437.68
Bauhinia racemosa	13.8	1,794	153,099.96
Bauhinia variegata	3.4	442	37,720.28
Bombax ceiba	249.4	32,422	2,766,893.48
Callistemon citrinus	0.3	39	3,328.26
Casuarina equisetifolia	16.7	2,171	185,273.14
Cassia fistula	302.2	39,286	3,352,667.24
Callistemon pendula	57.2	7,436	634,588.24
Senna siamea	39.6	5,148	439,330.32
Ceiba speciosa	158.1	20,553	1,753,993.02
Citrus	7.1	923	78,768.82
Crateva religiosa	1.3	169	14,422.46
Dalbergia sissoo	45.4	5,902	503,676.68
Delonix regia	114.8	14,924	1,273,614.16
Diospyros montana	10.2	1,326	113,160.84
Diospyros melanoxylon	9	1,170	99,847.80
Ehretia laevis	33.7	4,381	373,874.54
Erythrina variegata	0.5	65	5,547.10
Eucalyptus globulus	29.9	3,887	331,716.58
Ficus benjamina	1	130	11,094.20
Ficus benghalensis	1.6	208	17,750.72
Ficus elastica	3.1	403	34,392.02
Ficus racemosa	30.2	3,926	335,044.84
Ficus religiosa	206.9	26,897	2,295,389.98
Ficus virens	127.3	16,549	1,412,291.66
Grevillea parallela	19.9	2,587	220,774.58
Grevillea robusta	23.8	3,094	264,041.96

Jacaranda mimosifolia	6.1	793	67,674.62
Kigelia africana	10.3	1,339	114,270.26
Lagerstroemia speciosa	0.1	13	1,109.42
Leucaena leucocephala	13.9	1,807	154,209.38
Mangifera indica	2.5	325	27,735.50
Melia azedarach	90.9	11,817	1,008,462.78
Mimusops elengi	10.3	1,339	114,270.26
Millingtonia hortensis	4.3	559	47,705.06
Morus alba	102.1	13,273	1,132,717.82
Morinda citrifolia	2.2	286	24,407.24
Moringa oleifera	1.1	143	12,203.62
Peltophorum pterocarpum	37.3	4,849	413,813.66
Plumeria obtusa	2.6	338	28,844.92
Pongamia	115	14,950	1,275,833.00
Polyalthia longifolia v. pendula	29.9	3,887	331,716.58
Prosopis juliflora	33.1	4,303	367,218.02
Psidium guajava	11.1	1,443	123,145.62
Pterospermum acerifolium	74.3	9,659	824,299.06
Putranjiva roxburghii	518.9	67,457	5,756,780.38
Saraca asoca	20	2,600	221,884.00
Spathodea campanulata	1.5	195	16,641.30
Syzygium cumini	203.5	26,455	2,257,669.70
Terminalia arjuna	225.8	29,354	2,505,070.36
Tectona grandis	49.8	6,474	552,491.16

Toona ciliata	34.1	4,433	378,312.22
Ulmus laevis	124.1	16,133	1,376,790.22
Ulmus minor ssp. angustifolia	30.6	3,978	339,482.52
Total	5665.50	736489	62851971.26

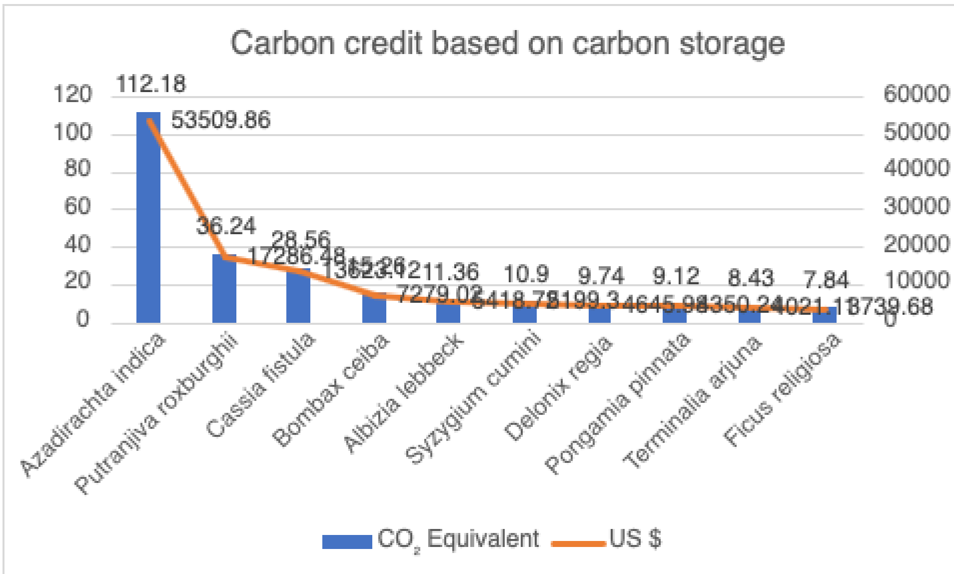

Figure 7: Carbon Credit based on Carbon Storage

5.8 Framework for Selecting Tree Species to Maximize Carbon Storage and Sequestration

The carbon storage data indicate that most tree species, specifically 16, fall within the 0–1 ton range, likely comprising young, smaller trees or those with lower wood density and biomass (Table 4). The next prevalent group includes 14 species storing 2–5 tons, contributing modestly to carbon stocks. Ten species each are found in the 6–10 ton and 11–20 ton categories, reflecting moderate carbon storage capacity. Nine species store 21–50 tons, and five species store 51–100 tons, indicating a select group of mature or large-canopied trees with significant carbon storage potential. Notably, only three species—Azadirachta indica, Putranjiva roxburghii, and Cassia fistula—exceed 101 tons, highlighting the exceptional carbon accumulation of these dominant trees.

For gross carbon sequestration, 13 species fall within the 0–0.05 ton/year range, suggesting limited annual carbon uptake, likely due to slower growth or lower photosynthetic activity. Another 13 species sequester 0.11–0.5 ton/year, indicating moderate carbon assimilation. Eight species fall in the 0.06–0.1 ton/year range, slightly overlapping the lower tier. Ten species sequester 0.51–1 ton/year, while seven species each fall into the 1.1–2 ton/year and 2.1–5 ton/year ranges, demonstrating consistent contributions to carbon offsetting. Only four species—Azadirachta indica, Putranjiva roxburghii, Cassia fistula, Bombax ceiba, and Albizia lebbeck—exceed 5 tons/year, reflecting their high sequestration potential, driven by large size, expansive canopies, and robust growth rates.

Regarding species status, native species dominate, with 40 of the studied tree species, promoting ecological stability and biodiversity in urban settings. Introduced species, totaling 20, suggest intentional diversification for ornamental or functional purposes in landscape design. Only one naturalized species is present, indicating a non-native species that has successfully integrated into the local ecosystem. This composition reflects a strategic planting approach prioritizing native species while incorporating select non-native ones for specific benefits.

In terms of tree habits, evergreen species, numbering 30, dominate the landscape, offering continuous carbon sequestration, shade, and microclimate regulation due to their year-round foliage. Deciduous species, with 24 types, provide seasonal variation and support nutrient cycling through leaf litter. Perennial species, the least common with seven types, may include semi-evergreen or irregularly shedding trees. This diversity in habits ensures year-round ecological functionality, balancing carbon dynamics with biodiversity and aesthetic variety. Overall, the data reflect a thoughtfully designed urban forest that optimizes ecosystem services through diverse species traits, growth characteristics, and conservation value.

Criteria	**Indicators**						
Carbon storage	0-1 ton (16)	2-5 tons (14)	6-10 tons (10)	11-20 tons (5)	21-50 tons (9)	51-100 tons (5)	101+tons (3)

Carbon sequestration	0-0.05 (13)	0.06-0.1 (8)	0.11-0.5 (13)	0.51-1 (10)	1-1.2 (7)	2.1-5 (7)	5+ (4)
Status	Introduced (20)	Native (40)	Naturalized (1)				
Habit	Evergreen (30)	Deciduous (24)	Perennial (7)				

5.9 Tree Species Composition and Their Pollution Removal Capacity

The dataset from Deer Park, Hauz Khas provides detailed insights into the air pollution removal capabilities of various tree species. The analysis focuses on six major air pollutants: Carbon Monoxide (CO), Ozone (O_3), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Particulate Matter less than 10 microns (PM10), and Particulate Matter less than 2.5 microns (PM2.5). The total pollution removal across all species, converted from ounces per year (oz/yr) to grams per year (g/yr) using the conversion factor 1 oz = 28.3495 g, is as follows:

- **PM10**: 257,368.8 g/yr
- **PM2.5**: 20,833.9 g/yr
- **NO_2**: 27,838.3 g/yr
- **SO_2**: 19,862.3 g/yr
- **O_3**: 7,649.0 g/yr
- **CO**: 7,862.6 g/yr

These figures indicate that trees are most effective at removing particulate matter, particularly PM10, followed by PM2.5, NO_2, SO_2, O_3, and CO. The species composition includes prominent trees such as Neem Tree, Lucky Bean Tree, Royal Poinciana, Canafistula, Pongame spp, and others, each contributing variably to pollutant removal based on their physiological characteristics and canopy structure.

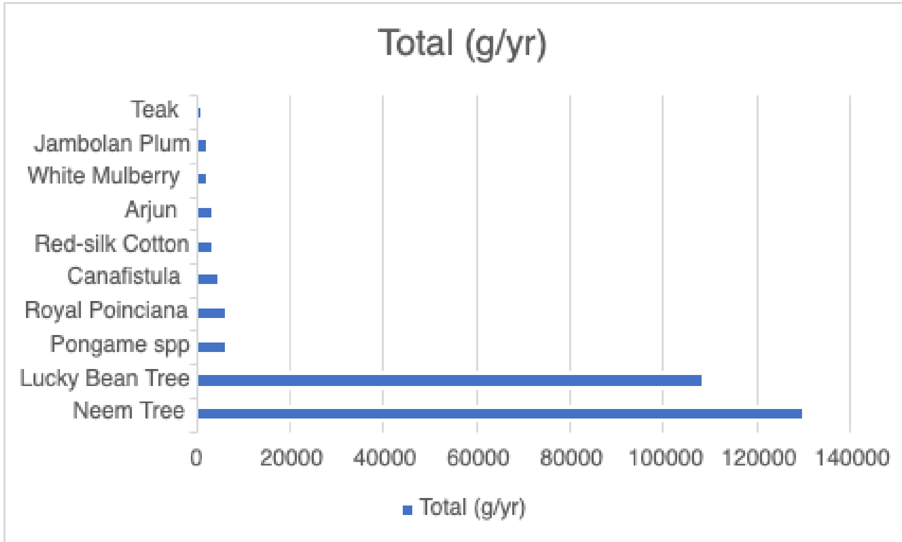

Figure 8: Tree Species Composition and Their Pollution Removal Capacity

5.9.1 Removal of CO

Total CO Removal: 7,862.6 g/yr

- **Neem Tree**: Contributes significantly with 3,714.4 g/yr across multiple plots, with notable individuals (e.g., Plot 86, Tree 6: 70.9 g/yr). Its high leaf surface area enhances CO absorption.
- **Lucky Bean Tree**: Removes 2,408.1 g/yr, with standout performers (e.g., Plot 86, Tree 7: 42.5 g/yr). Its prevalence in the dataset (multiple entries across plots) underscores its consistent contribution.
- **Other Species**: Species like Royal Poinciana (224.0 g/yr), Pongame spp (237.0 g/yr), and Canafistula (156.3 g/yr) contribute moderately. Less common species, such as Singapore Graveyard Flower and Queen's Crape myrtle, have minimal impact (<28.3 g/yr).

Neem and Lucky Bean Trees dominate CO removal due to their abundance and capacity to sequester gaseous pollutants.

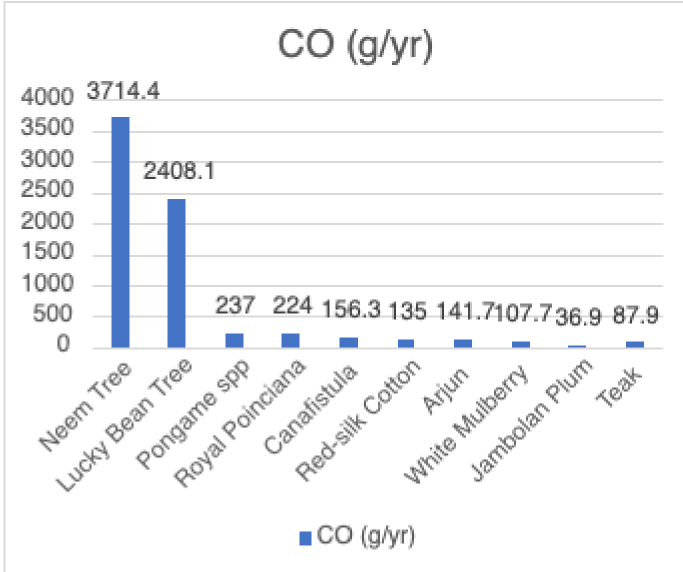

Figure 9: Removal of CO

5.9.2 Removal of O_3

Total O_3 Removal: 7,649.0 g/yr

- **Neem Tree**: Leads with 3,399.9 g/yr, with high performers like Plot 86, Tree 6 (805.1 g/yr) and Plot 4, Tree 3 (422.4 g/yr). Its broad canopy facilitates significant O_3 uptake.
- **Lucky Bean Tree**: Accounts for 2,254.7 g/yr, with key contributors like Plot 86, Tree 7 (496.1 g/yr). Its frequent occurrence amplifies its role.
- **Other Species**: Royal Poinciana (228.4 g/yr), Pongame spp (258.8 g/yr), and Canafistula (141.7 g/yr) provide moderate contributions. Species like White Mulberry and Benjamin Fig have lower impacts (<100 g/yr).

O_3 removal is driven by species with dense foliage, with Neem and Lucky Bean Trees being the most effective due to their extensive canopy coverage.

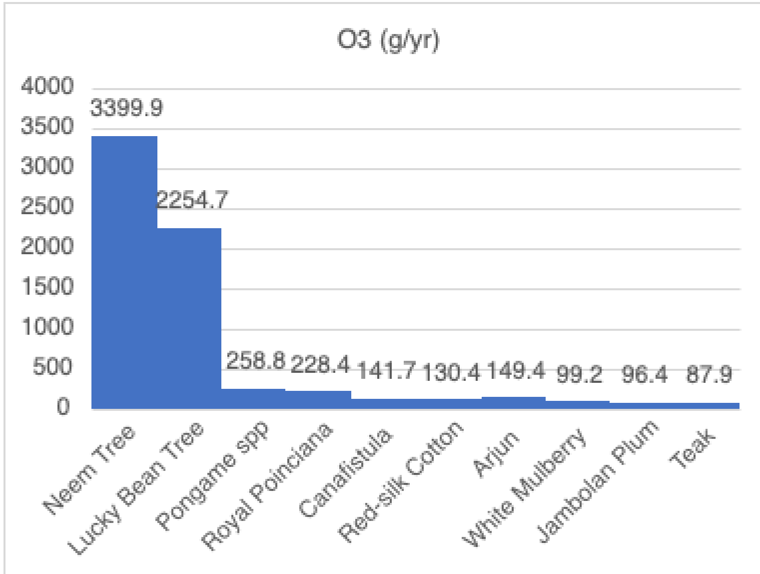

Figure 10: Removal of O_3

5.9.3 Removal of SO_2

Total SO_2 Removal: 19,862.3 g/yr

- **Neem Tree**: Removes 7,995.7 g/yr, with significant contributions from individuals like Plot 86, Tree 6 (206.9 g/yr). Its ability to filter SO_2 is enhanced by its leaf structure.
- **Lucky Bean Tree**: Contributes 5,466.9 g/yr, with notable trees like Plot 86, Tree 7 (127.6 g/yr). Its widespread presence ensures substantial SO_2 removal.
- **Other Species**: Royal Poinciana (623.7 g/yr), Pongame spp (566.9 g/yr), and Canafistula (396.9 g/yr) play moderate roles. Species like Singapore Graveyard Flower and Queen's Crapemyrtle contribute negligibly (<28.3 g/yr).

Neem and Lucky Bean Trees are the primary SO_2 removers, leveraging their canopy size and leaf surface area.

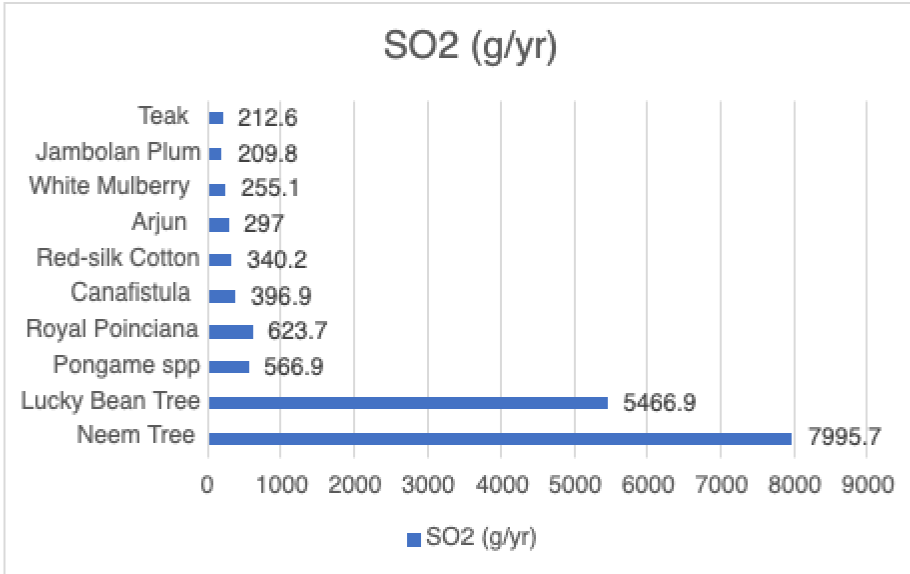

Figure 11: Total SO_2 Removal

5.9.4 Removal of NO_2

Total NO_2 Removal: 27,838.3 g/yr

- **Neem Tree**: Dominates with 12,708.7 g/yr, with top performers like Plot 86, Tree 6 (323.2 g/yr) and Plot 4, Tree 3 (170.1 g/yr). Its extensive foliage enhances NO_2 absorption.
- **Lucky Bean Tree**: Removes 8,441.9 g/yr, with significant contributions from Plot 86, Tree 7 (198.4 g/yr). Its abundance in the dataset boosts its impact.
- **Other Species**: Royal Poinciana (737.1 g/yr), Pongame spp (680.4 g/yr), and Canafistula (510.3 g/yr) contribute moderately. Less common species like White Mulberry and Benjamin Fig have minor roles (<200 g/yr).

Neem and Lucky Bean Trees excel in NO_2 removal due to their canopy density and prevalence across plots.

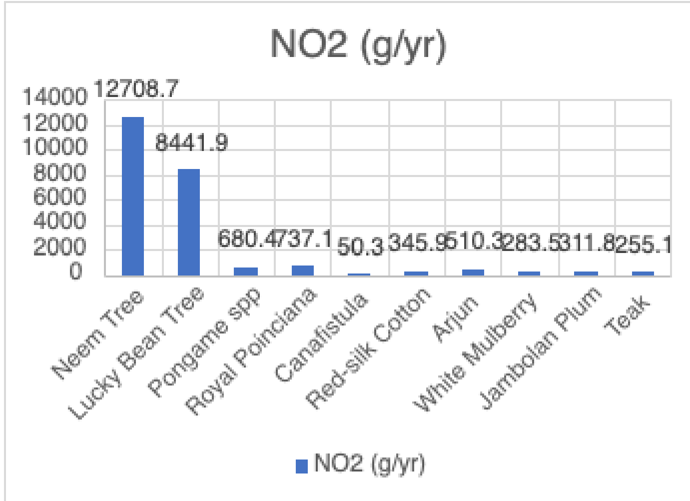

Figure 12: Total NO_2 Removal

5.9.5 Removal of PM10

Total PM10 Removal: 257,368.8 g/yr

- **Neem Tree**: Leads with 94,255.0 g/yr, with exceptional performers like Plot 86, Tree 6 (2,863.4 g/yr). Its large canopy and leaf surface area make it highly effective for PM10 capture.
- **Lucky Bean Tree**: Contributes 83,687.3 g/yr, with key individuals like Plot 86, Tree 7 (1,766.2 g/yr). Its widespread distribution enhances its role.
- **Other Species**: Royal Poinciana (4,105.9 g/yr), Pongame spp (4,278.7 g/yr), and Canafistula (3,486.9 g/yr) provide moderate contributions. Species like Singapore Graveyard Flower and Queen's Crapemyrtle have negligible impacts (<100 g/yr).

PM10 removal is dominated by Neem and Lucky Bean Trees, reflecting their ability to trap larger particulate matter through their foliage.

5.9.6 Removal of PM2.5

Total PM2.5 Removal: 20,833.9 g/yr

- **Neem Tree**: Removes 8,277.8 g/yr, with significant contributions from Plot 86, Tree 6 (249.5 g/yr) and Plot 4, Tree 3 (96.6 g/yr). Its dense canopy effectively captures fine particles.
- **Lucky Bean Tree**: Contributes 6,587.7 g/yr, with notable trees like Plot 86, Tree 7 (156.0 g/yr). Its prevalence ensures substantial PM2.5 removal.
- **Other Species**: Royal Poinciana (510.3 g/yr), Pongame spp (510.3 g/yr), and Canafistula (368.5 g/yr) have moderate impacts. Species like White Mulberry and Benjamin Fig contribute minimally (<100 g/yr).

Neem and Lucky Bean Trees are the most effective at PM2.5 removal, leveraging their canopy structure to filter fine particulate matter.

The tree species in Deer Park, particularly Neem and Lucky Bean Trees, demonstrate significant pollution removal capabilities, with PM10 and PM2.5 being the most effectively removed pollutants. Neem Trees consistently lead across all pollutant categories due to their abundance and large canopy size, followed closely by Lucky Bean Trees. Other species like Royal Poinciana, Pongame spp, and Canafistula contribute moderately, while less common species have minimal impact. These findings highlight the importance of strategic tree planting, prioritizing species like Neem for urban air quality improvement.

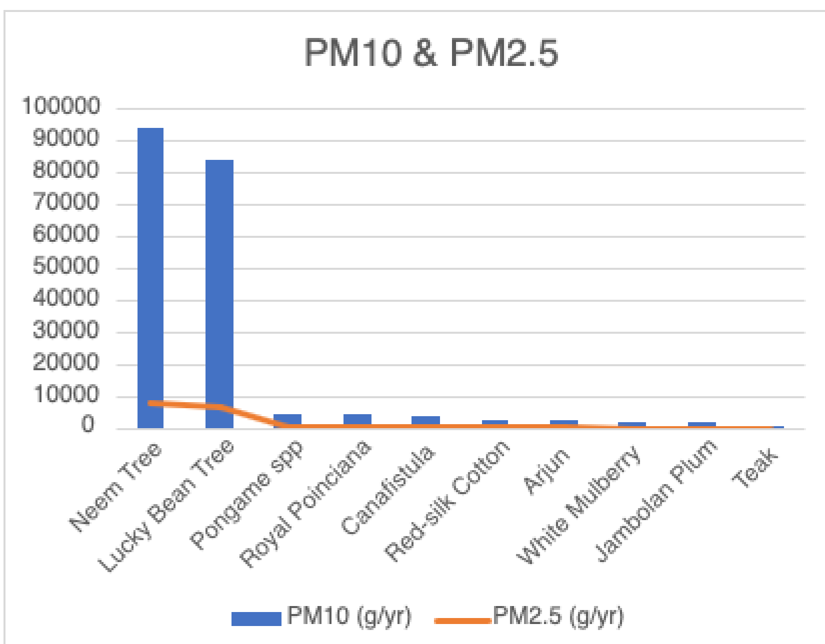

Figure 13: Pollution removal by tree species – PM2.5 & PM10

Species Name	CO (g/yr)	O_3 (g/yr)	NO_2 (g/yr)	SO_2 (g/yr)	PM10 (g/yr)	PM2.5 (g/yr)	Total (g/yr)
Neem Tree	3714.4	3399.9	12708.7	7995.7	94255	8277.8	130351.5
Lucky Bean Tree	2408.1	2254.7	8441.9	5466.9	83687.3	6587.7	108846.6
Pongame spp	237	258.8	680.4	566.9	4278.7	510.3	6532.1
Royal Poinciana	224	228.4	737.1	623.7	4105.9	510.3	6429.4
Canafistula	156.3	141.7	510.3	396.9	3486.9	368.5	5060.6
Red-silk cotton	135	130.4	345.9	340.2	2463.2	439.4	3854.1
Arjun	141.7	149.4	510.3	297	2463.2	260.8	3822.4
White mulberry	107.7	99.2	283.5	255.1	1643.7	192.8	2582
Jambolan plum	36.9	96.4	311.8	209.8	1586.9	170.1	2411.9
Teak	87.9	87.9	255.1	212.6	652.7	113.4	1409.6
Acacia amarilla	22.7	22.7	113.4	99.2	1020.6	56.7	1335.3
Cluster Fig	36.9	425.2	170.1	110.6	453.6	96.4	1292.8
Asoka-tree	107.7	124.7	324.5	280.6	113.4	113.4	1064.3

Chinaberry	85	85	226.8	198.4	368.5	141.7	1105.4
Indian rosewood	25.5	85	141.7	85	368.5	85	790.7
Ehretia laevis	28.3	28.3	113.4	99.2	368.5	99.2	736.9
Benjamin fig	5.7	14.2	56.7	45.3	283.5	28.3	433.7
Kanack champa	22.7	22.7	113.4	99.2	76.5	76.5	411
Indian cork tree	11.3	11.3	56.7	36.9	141.7	28.3	286.2
Peepul tree	2.8	28.3	56.7	56.7	62.4	0	206.9
Citrus spp	2.8	2.8	56.7	56.7	62.4	0	181.4
Silk floss tree	0	0	28.3	28.3	59.6	28.3	144.5
Burmese Silk Orchid	2.8	2.8	28.3	28.3	62.4	0	124.6
Weeping Mast Tree	0	0	2.8	28.3	62.4	0	93.5
Diospyros melanoxylon	0	0	14.2	14.2	62.4	0	90.8
Siamese cassia	0	0	14.2	14.2	59.6	0	88
Jackfruit	2.8	2.8	5.7	5.7	22.7	25.5	65.2
Singapore graveyard flower	2.8	2.8	14.2	14.2	28.3	2.8	65.1
Mango	2.8	2.8	5.7	5.7	62.4	0	79.4
Common guava	2.8	28.3	28.3	28.3	62.4	0	150.1

Queen's crapemyrtle	0	0	0	0	0	0	0
Gum arabic tree	0	0	2.8	2.8	2.8	0	8.4
Total	7862.6	7649	27838.3	19862.3	257368.8	20833.9	341414.9

5.10 Avoided Runoff by Tree Species in Deer Park

Surface runoff poses a significant challenge in urban environments, contributing to pollution in streams, wetlands, rivers, lakes, and oceans. In urban areas like Deer Park, the prevalence of impervious surfaces exacerbates runoff by preventing water infiltration into the soil. However, trees and shrubs play a crucial role in mitigating this issue by intercepting precipitation and promoting infiltration through their root systems. At Deer Park, urban trees and shrubs collectively reduce runoff by an estimated 715 thousand gallons annually, with an associated value of Rs510 thousand, based on local weather data from 2021, which recorded a total annual precipitation of 42.2 inches.

The graph (Figure 10) illustrates the avoided runoff (in thousands of gallons) and its associated value (in Rs thousands) for the tree species with the greatest impact on runoff reduction in Deer Park. The data is presented in two forms: points represent the avoided runoff volume, while bars indicate the monetary value of this reduction.

Among the species analyzed, the Neem tree demonstrates the highest impact, avoiding approximately 160 thousand gallons of runoff annually, with a corresponding value of around Rs120 thousand. This significant contribution highlights the Neem tree's effectiveness in intercepting precipitation and enhancing soil infiltration. Following closely is the Lucky bean tree, which avoids about 130 thousand gallons of runoff, valued at roughly Rs90 thousand. The Red-silk cotton tree ranks third, with an avoided runoff of around 50 thousand gallons, translating to a value of approximately Rs35 thousand.

Other notable species include the Canafistula and White fig, each avoiding around 40 thousand gallons of runoff, with values of about Rs30 thousand. The Pongam spp., Arjun, Jamolan plum, Acacia auriculiformis, and European white elm contribute to lesser extents, with avoided runoff volumes ranging from 20 to 30 thousand gallons and values between Rs15 thousand and Rs20 thousand.

This analysis underscores the critical role of specific tree species in mitigating surface runoff in Deer Park. By prioritizing the planting and maintenance of high-performing species like the Neem and Lucky bean trees, urban planners can enhance runoff reduction efforts, thereby improving water quality and reducing pollution in surrounding water bodies. The monetary value of these ecosystem services further emphasizes the economic benefits of urban greenery, supporting the case for increased investment in tree planting and preservation initiatives.

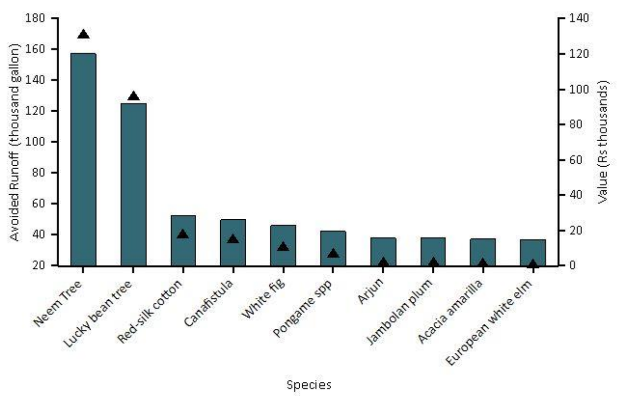

Figure 10. Avoided runoff (points) and value (bars) for species with greatest overall impact on runoff, Deer Park

Figure 14: Avoided Runoff by Tree Species in Deer Park

6. DISCUSSION:

The i-Tree Eco assessment conducted in Deer Park, Hauz Khas, New Delhi, provides a comprehensive analysis of the carbon storage, sequestration, and air pollution removal capacities of urban tree species in a highly urbanized environment. This discussion integrates the findings on carbon dynamics with the air pollution removal data previously analyzed, offering insights into the ecological contributions of urban trees and their implications for urban forestry planning in New Delhi. The results underscore the critical role of native, evergreen, high-performing species like *Azadirachta indica* (Neem) and *Putranjiva roxburghii* (Lucky Bean Tree) in mitigating climate change and improving air quality, while highlighting the need for strategic species selection to optimize ecosystem services.

The i-Tree Eco assessment reveals that Deer Park's urban forest stores approximately 1,545 tons of carbon and sequesters 91.69 tons annually. These figures position Deer Park as a significant carbon sink within New Delhi's urban landscape, contributing to climate change mitigation in a city grappling with high greenhouse gas emissions. *Azadirachta indica* dominates with 604.4 tons of carbon storage (39% of the total) and 30.59 tons of annual sequestration, followed by *Putranjiva roxburghii* with 141.5 tons stored and 9.88 tons sequestered annually. Other notable contributors include *Cassia fistula* (82.4 tons storage, 7.79 tons/year sequestration), *Bombax ceiba* (68 tons, 4.16 tons/year), and *Terminalia arjuna* (61.6 tons, 2.3 tons/year). These species' high performance is attributed to their physiological robustness, large canopy sizes, and population density within the park, aligning with findings by Behera et al. (2022), who noted the superior sequestration capacity of tropical natives like *Azadirachta indica* under Indian urban conditions.

Comparatively, *Prosopis juliflora*, a dominant species in city-wide studies by Prasad et al. (2020), contributes only 9 tons to storage and negligible sequestration in Deer Park, potentially due to senescence or limited growth, as suggested by Begum et al. (2020). This discrepancy highlights the variability in species performance across different urban green spaces and underscores the value of site-specific assessments. The micro-level focus of this study, using 0.04-hectare plots and precise tree-specific parameters (e.g., DBH, crown size, height) as per the UFORE model (Nowak et al., 2008), provides a granular understanding that complements macro-level estimations like those of Prasad et al. (2020), who reported Delhi's urban trees storing 77,000 tons of carbon city-wide.

The dominance of native species, contributing 1,329.94 tons of stored carbon and 79.45 tons of annual sequestration, compared to introduced species (210.7 tons storage, 11.75 tons/year sequestration) and naturalized species (3.8 tons storage, 0.48 tons/year sequestration), reinforces the ecological superiority of natives in Delhi's context. This aligns with Sharma et al. (2019), who advocate for prioritizing native species to enhance ecological resilience. Evergreen trees, storing 1,036.2 tons and sequestering 59.21 tons annually, outperform deciduous (381.4 tons storage, 24.4 tons/year sequestration) and perennial species (127.5 tons storage, 8.07 tons/year sequestration), supporting the case for evergreen planting in urban areas due to their year-round photosynthetic activity (Baró et al., 2014; Kim et al., 2024).

The air pollution removal data further enhances the understanding of Deer Park's urban forest as a multifunctional ecosystem. The total annual pollution removal includes 257,368.8 g/yr of PM10, 20,833.9 g/yr of PM2.5, 27,838.3 g/yr of NO_2, 19,862.3 g/yr of SO_2, 7,649.0 g/yr of O_3, and 7,862.6 g/yr of CO. *Azadirachta indica* and *Putranjiva roxburghii* again emerge as top performers, removing 94,255.0 g/yr and 83,687.3 g/yr of PM10, respectively, and significant amounts of PM2.5, NO_2, SO_2, O_3, and CO. Their large canopies and high leaf surface areas facilitate effective pollutant capture, particularly for particulate matter, which is critical in New Delhi, a city with severe air quality issues (WHO, 2018).

Other species, such as *Cassia fistula* (3,486.9 g/yr PM10, 368.5 g/yr PM2.5), *Pongamia pinnata* (4,278.7 g/yr PM10, 510.3 g/yr PM2.5), and *Bombax ceiba* (2,463.2 g/yr PM10, 439.4 g/yr PM2.5), contribute moderately but are less impactful due to lower population density or smaller canopies. Minor contributors, such as *Queen's Crapemyrtle* and *Gum Arabic Tree*, show negligible removal, likely due to limited abundance or canopy size, consistent with findings by Tripathi and Joshi (2015) that low-performing species may still offer biodiversity or aesthetic benefits.

The dominance of *Azadirachta indica* and *Putranjiva roxburghii* in both carbon and pollution metrics highlights their suitability for urban forestry in polluted, tropical cities. Their ability to remove PM10 and PM2.5, the most significant pollutants in terms of mass removed, aligns with global studies like Nowak et al. (2014), who quantified urban trees' capacity to mitigate particulate matter in U.S. cities. The evergreen nature of these species ensures consistent pollutant capture, complementing their carbon sequestration benefits and reinforcing the case for their prioritization, as supported by Baró et al. (2014).

The findings suggest a strategic framework for species selection that prioritizes high-performing, native, evergreen species like *Azadirachta indica*, *Putranjiva roxburghii*, and *Cassia fistula*, which exceed 100 tons in carbon storage or 5 tons/year in sequestration. This aligns with Livesley et al. (2016), who advocate targeting “high-yielding” species in urban settings. The minimal contribution of *Prosopis juliflora* in Deer Park, despite its city-wide prominence (Prasad et al., 2020), cautions against over-reliance on invasive or naturalized species, which may underperform in specific contexts due to senescence or environmental constraints.

The presence of 16 species storing less than 1 ton of carbon and 13 species sequestering less than 0.05 tons/year suggests that while these trees contribute minimally to carbon and pollution services, they may enhance biodiversity, aesthetics, or resilience (Tripathi & Joshi, 2015). A balanced urban forestry approach should thus maintain functional diversity while prioritizing high performers. The economic valuation of carbon storage and pollution removal, as facilitated by i-Tree Eco, supports fiscal justification for such strategies, potentially unlocking carbon credit revenue streams (Du et al., 2025; Kim et al., 2024).

Compared to city-wide estimates by Prasad et al. (2020), which report 1,300 tons/year of sequestration across Delhi, Deer Park’s 91.69 tons/year from a single park underscores its disproportionate contribution and the potential for scaling through optimized species selection. However, limitations include the dataset’s focus on a single park, which may not fully represent Delhi’s diverse urban forest. Additionally, the negligible performance of some species may reflect data gaps or measurement limitations, as noted in the i-Tree Eco methodology (Nowak et al., 2008). Future studies could expand plot coverage or incorporate long-term growth data to refine estimates.

The i-Tree Eco assessment of Deer Park demonstrates the critical role of native, evergreen species like *Azadirachta indica* and *Putranjiva roxburghii* in carbon storage, sequestration, and air pollution removal. These species’ dominance across both metrics highlights their suitability for urban forestry in New Delhi, supporting climate change mitigation and air quality improvement. Strategic planting of high-performing species, balanced with biodiversity considerations, can enhance urban ecosystem services while aligning with global frameworks for carbon markets and sustainable urban planning.

7. CONCLUSION:

The i-Tree Eco assessment of Deer Park, Hauz Khas, New Delhi, offers a comprehensive, scientifically grounded evaluation of urban tree species' contributions to carbon storage, sequestration, and air pollution removal. This study, encompassing 415 trees across 61 species, quantifies the park's ecological services, storing 1,545 tons of carbon, sequestering 91.69 tons annually, and removing significant pollutants: 257,368.8 g/yr of PM10, 20,833.9 g/yr of PM2.5, 27,838.3 g/yr of NO_2, 19,862.3 g/yr of SO_2, 7,649.0 g/yr of O_3, and 7,862.6 g/yr of CO. These findings provide a robust blueprint for urban planners, ecologists, and policymakers to develop evidence-based, economically viable urban greening strategies that address climate change and air quality challenges in Delhi's polluted, urbanized landscape.

The results highlight the disproportionate contributions of a few native, evergreen species. *Azadirachta indica* (Neem), with 122 individuals, accounts for 604.4 tons of carbon storage (39% of the total), 30.59 tons/yr of sequestration, and substantial pollution removal (94,255.0 g/yr PM10, 8,277.8 g/yr PM2.5). *Putranjiva roxburghii* (Lucky Bean Tree), with 271 individuals, contributes 141.5 tons of storage, 9.88 tons/yr of sequestration, and 83,687.3 g/yr of PM10 removal. Other key species, including *Cassia fistula* (82.4 tons storage, 7.79 tons/yr sequestration, 3,486.9 g/yr PM10), *Bombax ceiba* (68 tons, 4.16 tons/yr, 2,463.2 g/yr PM10), and *Terminalia arjuna* (61.6 tons, 2.3 tons/yr, 1,643.7 g/yr PM10), reinforce the ecological superiority of native species, which collectively store 1,329.94 tons and sequester 79.45 tons/yr, far surpassing introduced (210.7 tons, 11.75 tons/yr) and naturalized species (3.8 tons, 0.48 tons/yr) (Sharma et al., 2019). Their adaptability to Delhi's semi-arid conditions, high leaf area, and pollution resistance make them ideal for urban ecosystems (Behera et al., 2022).

Evergreen species, storing 1,036.2 tons and sequestering 59.21 tons/yr, outperform deciduous (381.4 tons, 24.4 tons/yr) and perennial species (127.5 tons, 8.07 tons/yr), offering year-round carbon capture, pollutant interception, and microclimate regulation—critical in Delhi's heat- and pollution-stressed environment (Baró et al., 2014). Their dominance in air pollutant removal, particularly PM10 and PM2.5, underscores their role in mitigating health risks in a city with severe air quality issues (WHO, 2018).

This study informs a strategic urban forestry framework. High-performing species like *Azadirachta indica*, *Putranjiva roxburghii*, and *Cassia fistula* should anchor afforestation efforts, such as Miyawaki forests and campus greening, due to their exceptional carbon and pollution mitigation capacities (Livesley et al., 2016). *Terminalia arjuna* and *Syzygium cumini*, with hydrological benefits, are recommended for green belts along water bodies like the Yamuna, enhancing ecological resilience. Evergreen species like *Ficus virens* and *Polyalthia longifolia* are ideal for high-traffic corridors, providing noise reduction, dust capture, and temperature moderation alongside carbon and pollution benefits (Kim et al., 2024). While low-performing species (e.g., *Queen's Crapemyrtle*, negligible contributions) offer limited carbon and pollution services, their role in biodiversity, aesthetics, and ecosystem resilience justifies a balanced approach to species diversity (Tripathi & Joshi, 2015).

The economic valuation of these services, enabled by i-Tree Eco, positions urban forests as critical infrastructure, comparable to urban utilities. Integration into carbon markets, such as Verra's Verified Carbon Standard or India's proposed domestic registry, can generate revenue, supporting India's commitments to the Paris Agreement and SDGs 11 (Sustainable Cities) and 13 (Climate Action) (Du et al., 2025). Policy recommendations include mandating green cover percentages, establishing carbon budgets for municipalities, and fostering public-private partnerships to link tree planting with carbon offsetting, ensuring economic sustainability.

Future research should incorporate temporal monitoring, soil carbon analysis, and remote sensing to track tree performance under Delhi's climatic stressors—heat waves, pollution, and erratic rainfall (Kim et al., 2024). Despite its focus on a single park, Deer Park's contributions, compared to Delhi's 1,300 tons/yr city-wide sequestration (Prasad et al., 2020), highlight the potential for scaling through optimized species selection. This study offers a scalable, science-driven model for urban forestry, fostering resilient, healthier cities amid urban expansion and environmental degradation.

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ANNEXURE- 1:

i-tree Eco Data Collection Sheet				
Date			Place	
Surveyor:				

Name		**Name**	
Height of observer		Height of observer	
Distance b/w tree & Observer		Distance b/w tree & Observer	
CBH (cm)		CBH (cm)	
Diameter (cm)		Diameter (cm)	
Tree Total Height (m)		Tree Total Height (m)	
Canopy Top Height (m)		Canopy Top Height (m)	
Canopy Base Height (m)		Canopy Base Height (m)	
Canopy dimension (N/S)		Canopy dimension (N/S)	
Canopy dimension (E/W)		Canopy dimension (E/W)	
Canopy Missing (%)		Canopy Missing (%)	
Crown Dieback (%)		Crown Dieback (%)	
Crown Light Exposure		Crown Light Exposure	

Name		**Name**	
Height of observer		Height of observer	
Distance b/w tree & Observer		Distance b/w tree & Observer	
CBH (cm)		CBH (cm)	
Diameter (cm)		Diameter (cm)	
Tree Total Height (m)		Tree Total Height (m)	
Canopy Top Height (m)		Canopy Top Height (m)	
Canopy Base Height (m)		Canopy Base Height (m)	
Canopy dimension (N/S)		Canopy dimension (N/S)	
Canopy dimension (E/W)		Canopy dimension (E/W)	
Canopy Missing (%)		Canopy Missing (%)	
Crown Dieback (%)		Crown Dieback (%)	
Crown Light Exposure		Crown Light Exposure	

Name		**Name**	
Height of observer		Height of observer	
Distance b/w tree & Observer		Distance b/w tree & Observer	
CBH (cm)		CBH (cm)	
Diameter (cm)		Diameter (cm)	
Tree Total Height (m)		Tree Total Height (m)	
Canopy Top Height (m)		Canopy Top Height (m)	
Canopy Base Height (m)		Canopy Base Height (m)	
Canopy dimension (N/S)		Canopy dimension (N/S)	
Canopy dimension (E/W)		Canopy dimension (E/W)	
Canopy Missing (%)		Canopy Missing (%)	
Crown Dieback (%)		Crown Dieback (%)	
Crown Light Exposure		Crown Light Exposure	