Economic valuation of carbon storage and sequestration of tree species using i-Tree Eco in Deer Park, Hauz Khas

Dissertation Submitted by

Ankita Singh Marskole

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Economic valuation of carbon storage and sequestration of tree species using i-Tree Eco in Deer Park, Hauz Khas

(Photograph taken during field work)

INTERNAL SUPERVISOR

Dr. Ajay Maletha

Assistant Professor

Amity Institute of Forestry & Wildlife

Amity University, Noida (Uttar Pradesh)

EXTERNAL SUPERVISOR

Dr. Anand Kumar

i-Tree Expert

Give Me Trees Trust

Ghaziabad, U.P.- 201007, India

AMITY UNIVERSITY

UTTAR PRADESH

AMITY INSTITUTE OF FORESTRY & WILDLIFE

Ajay Maletha, Ph.D
Assistant Professor-II

Email: amaletha@amity.edu
Phone 01204392869
Mob: +91-9410528026
Website:amity.edu/aifw/

Commission Member - IUCN/CEM/Commission on Ecosystem Management
Commission Member - IUCN/WCPA/World Commission on Protected Areas
Specialist Group Member-IUCN/ CEM/ Forest Ecosystems Specialist Group
Specialist Group Member-IUCN/ CEM/ Mountain Ecosystems Specialist Group

Dated: 13/05/2025

COMPLETION CERTIFICATE

This is to certify that Ms ANKITA SINGH MARSKOLE with Enrollment Number A137120321004, a student of Programme B.Sc. (Hons) - Forestry Batch 2021-2025 Semester at Amity Institute of Forestry and Wildlife has pursued Dissertation NRESDS100 on topic Assessment of ecosystem services of some selected residential green spaces based on itree eco model under my guidance from 17/12/2024 to 13/05/2025. The Student has submitted 15 out of total 16 Weekly Progress Reports.Ms ANKITA SINGH MARSKOLE has completed the project-related work and the work done is satisfactory.

(Dr. Ajay Maletha)

Amity Institute of Forestry & Wildlife
J1 Block, Room No-G14, Ground Floor, Amity University Noida Campus, Sector-125, Noida – 201 303,
Gautam Buddha Nagar U.P. (INDIA)

GIVE ME TREES TRUST

(Registration No. 9377-Delhi)
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Contact : +91-9873180253, 8800326033
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<u>TO WHOM SO EVER IT MAY CONCERN</u>

This is to certify that **Ms. Ankita Singh Marskole** from Amity University, has successfully completed her **internship** as an **Intern** with **Give Me Trees Trust** under the mentorship of **Dr. Anand Kumar**. Her internship tenure was from **Feb 3, 2025 to May 28, 2025**.

During the internship, she majorly worked on field and participated in the plantation activities at our plantation sites. Her role involved assisting with plantation activities, sapling care, and community engagement.

She has shown a keen interest in learning and gaining knowledge and experience while working here, which is really commendable. We found her extremely inquisitive, sincere and hardworking during her tenure at Give Me Trees Trust.

We wish her all the best for her future endeavors.

Dr Anand Kumar
External Mentor

Yours Sincerely,

For Give Me Trees Trust

Swami Prem Parivartan
(Peepal Baba)
Managing Trustee

E-mail : peepalbaba@gmail.com, givemetrees@gmail.com
Web: www.givemetrees.org | https:/www.facebook.com/givemetreestrust

SELF DECLARATION

I, Ankita Singh Marskole, student of B.Sc. (Hons.) Forestry, hereby declare that the project titled "**Economic valuation of carbon storage and sequestration of tree species using i-Tree Eco in Deer Park, Hauz Khas**" which is submitted by me to the Amity Institute of Forestry & Wildlife, Amity University, Noida, Uttar Pradesh in partial fulfilment of the degree of B.Sc. (Hons.) Forestry has not been previously formed the basis for the award of my degree, diploma, or any similar title of recognition.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTO PLATE

1. Abstract:

Urban green spaces serve as vital carbon sinks that contribute to climate change mitigation through the sequestration and long-term storage of atmospheric carbon dioxide. This study assesses the carbon storage and sequestration potential of tree species in Deer Park, Hauz Khas, New Delhi, using the i-Tree Eco model. A total of 415 individual trees, representing 61 species, were recorded for biometric parameters including diameter at breast height (DBH), tree height, and crown width to measure carbon storage and sequestration. The analysis revealed a total carbon storage of approximately 1,545 tons and an annual carbon sequestration of 91.69 tons. Among the species, *Azadirachta indica* showed the highest storage of carbon (604.4 tons) and sequestration rate (30.59 tons) annually. The findings demonstrate that native (1329.94 tons) and evergreen (1036.2 tons) species sequester and store significantly more carbon than introduced and deciduous ones. The study concludes that native, climate-resilient species such as *Azadirachta indica*, *Putranjiva roxburghii*, and *Cassia fistula* should be prioritized in urban green spaces . The study further advocates for leveraging carbon credit frameworks to monetise ecosystem services, incentivise conservation, and integrate urban forestry into Delhi's broader climate action and carbon finance strategies.

Keywords:

Urban Green space, , carbon storage, carbon sequestration, i-Tree Eco, carbon credits, economic valuation, climate change mitigation, Delhi NCR.

2. Introduction:

Urban forests have emerged as vital components of sustainable cities, offering not just aesthetic value but also tangible environmental, social, and economic benefits. As more than half of the world's population currently resides in urban areas—and with projections suggesting this will rise to 68% by 2050 (United Nations, 2018)— cities are grappling with intensifying challenges such as air pollution, urban heat islands, biodiversity loss, and deteriorating public health. Amidst this rapid urban expansion, the importance of trees and green spaces cannot be overstated. They act as natural air filters, carbon sinks, climate regulators, and stormwater buffers, while also improving mental and physical well-being (Alvarado, 2025).

Yet, despite their significance, ecosystem services provided by urban green spaces are often over looked or undervalued in city planning. This result helps in fragmented, poorly managed landscapes that fail to unlock the full potential of nature in cities (Kabisch et al., 2016). A more integrated, science-based approach is needed one that considers urban greenery as essential infrastructure rather than ornamental add-ons.

One promising pathway is the adoption of Nature-based Solutions (NbS) a concept gaining global traction in urban environmental strategies. NbS harness is the power of natural systems, including green roofs, permeable surfaces, and urban forests, to make cities more climate-resilient and sustainable (European Commission, 2015). Among these, urban forests stand out for their capacity to tackle multiple challenges simultaneously: reducing air pollutants, storing carbon, cooling urban microclimates, and creating biodiversity corridors (Lin et al., 2020). However, understanding and quantifying these benefits remains a complex task, as existing tools and frameworks often struggle with inconsistencies and lack of contextual adaptability.

To address this gap, i-Tree tools have been developed to systematically evaluate urban forest structure, function, and associated ecosystem services. i-Tree Eco employs field measurements and meteorological data to estimate key indicators such as carbon sequestration, air pollution removal, and stormwater interception (Nowak et al., 2008). The recent studies indicate that the precision and applicability of these models depend on factors such as plot size, sampling methodology, and local environmental conditions (Nowak et al., 2008; Lin et al., 2 2020). The effectiveness of urban forest assessments is influenced by methodological choices, highlighting the need for refined approaches that balance the accuracy, efficiency, and scalability (Nowak et al., 2008).

This dissertation is contribute the growing field of urban forestry research by evaluating the ecosystem services of urban trees by using a quantitative approach. By applying i-Tree and integrating empirical field data, the study will assess the multiple benefits provided by urban forests and explore strategies to enhance their role in sustainable urban development. The findings will offer valuable insights for urban planners, policymakers, and conservationists seeking to optimize urban green spaces for climate resilience and human well-being.

This is particularly relevant for cities like Delhi, which are experiencing intense urbanization, accompanied by escalating pollution levels, rising temperatures, and shrinking the green cover. Delhi's transformation from expansive farmlands and forest patches to a concrete-dominated megacity that has placed enormous pressure on its natural ecosystems.

Between 1989 and 2018, the city's built-up area surged from 11% to over 36%, largely at the cost of agricultural lands, forests, and ecologically sensitive zones like the Delhi Ridge and Yamuna floodplains (Joshi et al., 2022). These shifts have a significant contribution in the loss of native vegetation, increased urban heat island effects, and deteriorating air quality.

Delhi's remaining green spaces are unevenly distributed, with high income areas often enjoying leafy neighbourhoods and biodiversity parks, while many low-income settlements that lack access to well-maintained urban greenery. This inequitable access reinforces patterns of environmental injustice. The spread of invasive species like Prosopis juliflora has further reduced biodiversity in the city's green spaces, displacing native species and altering ecosystem functions (Kalpavriksh and DDA, 2009). Native wildlife such as jackals, civets, and peafowl, once commonly spotted in city parks, are now rare sightings.

Despite these challenges, various encouraging initiatives have emerged. Delhi's Biodiversity Parks, have successfully restored native flora and improved local ecosystem services such as groundwater recharge and wildlife habitats. The tool, i-Tree Eco have been instrumental in quantifying and communicating the value of urban trees. A Delhi-specific assessment using i-Tree Eco by Prasad et al. (2020) estimated that the city's urban forests remove about 1,300 tonnes of air pollutants annually and store roughly 77,000 tonnes of carbon. Dominant species like *Prosopis juliflora* and *Azadirachta indica* played significant roles in delivering these benefits.

As highlighted by Begum et al. (2020), there remains a need for more localized, data-driven management strategies. Their study across institutional campuses in Delhi demonstrated wide variability in ecosystem services depending 3 on tree species, canopy size, and site characteristics. They emphasize prioritizing native, resilient species and incorporating i-Tree Eco into routine of urban forestry planning.

That said, such tools are not without limitations. Small sample sizes, species misidentification, and insufficient integration of biodiversity and soil quality data can compromise accuracy. For robust urban forestry strategies, a more comprehensive approach is needed one that includes ecological fieldwork, spatial mapping using GIS, and active community involvement. Sharma et al. (2019) stress the importance of connecting green patches and maintaining native species diversity as core principles for sustainable urban development.

In light of this, the proposed study will focus on Deer Park, Hauz Khas, New Delhi, as a representative urban forest. Using the i-Tree tools, the research will evaluate the park's tree species in terms of carbon sequestration, air quality improvement, and biomass storage. The goal is to identify high-performing species and generate evidence-based recommendations for enhancing urban forest management. This work aims to support more inclusive, resilient, and scientifically informed urban green infrastructure planning in Indian cities.

3. Aim:

To quantify carbon storage and sequestration potential and economic valuation of tree species in Deer Park, Hauz Khas using i-Tree Eco

Objectives:

1. To assess the carbon storage and sequestration of tree species using i-Tree Eco.
2. Quantification and economic valuation of tree species utilize for carbon storage and sequestration for sustainable management.
3. To develop a framework for selecting tree species for optimise carbon storage and sequestration rate.

4. Literature Review:

Urban forests have long been recognized as vital components of urban ecosystems, providing a suite of services that include climate regulation through carbon storage and sequestration. In North America, rigorous ground-based protocols for quantifying urban forest structure and associated ecosystem services using systematic plot inventories and locally calibrated allometric equations were established (Nowak et al., 2006). This methodological framework laid the groundwork for the development of the i-Tree Eco model, which integrates field measurements with urban forest databases to estimate carbon pools and fluxes quantitatively. Shortly thereafter, a national assessment applied these methods across diverse U.S. cities to benchmark carbon stocks and flows at a continental scale (Nowak et al., 2013). Collectively, these studies provided both the scientific rigor and the economic valuation approaches—translating biophysical measurements into monetary units—that underpin much of today's urban carbon accounting initiatives.

Moving to South America, the i-Tree Eco framework to subtropical urban contexts by examining growth dynamics and carbon storage potential in Sibipiruna (Cenostigma pluviosum) within São Paulo, Brazil (Rodrigues-Leite et al., 2024). Their detailed case study emphasized the importance of calibrating allometric models and site-specific parameters to account for regional species traits and climatic conditions. Although focused on a limited number of specimens, this work underscored the need for comprehensive inventories across Latin American cities to capture the heterogeneity of urban tree communities.

In Europe, the use of i-Tree Eco to Barcelona's municipal forests to assess the contribution of urban trees to climate regulation and air quality improvement (Baró et al., 2014). By framing carbon storage and sequestration alongside pollutant removal in both biophysical and economic terms, this study provided critical insights for policymakers seeking to integrate green infrastructure into urban climate action plans. Similarly, the carbon sequestration and air pollutant removal by street and park trees in Szeged, Hungary, demonstrating the versatility of the i-Tree Eco model across temperate European climates by (Kiss et al., 2015). These European applications reinforced the model's capacity to inform local management decisions while highlighting the modest relative contribution of urban forests to total city emissions.

African urban carbon initiatives have often intertwined community development with carbon offset projects. A prominent example is the Buffelsdraai Landfill Site Community Reforestation Project in Durban, South Africa, which planted over 500,000 indigenous trees to generate carbon credits for major events, including the 2010 FIFA World Cup (Douwes et al., 2015). This FAO-endorsed initiative exemplifies how carbon accounting frameworks originally developed in temperate regions can be adapted to support ecosystem restoration, community livelihoods, and urban resilience in African contexts.

In the Southern Hemisphere, some empirical findings from urban forest studies across five continents—including many employing i-Tree Eco—to evaluate the broader impacts of urban trees on hydrological, thermal, pollution, and carbon cycles (Livesley et al., 2016). Their global review stressed that species selection, landscape configuration, and local climate significantly mediate the magnitude of carbon storage and sequestration services.

By comparing diverse biomes and management regimes, this work provided a forward-looking perspective on optimizing urban forest design for multiple ecosystem services.

Together, these global studies demonstrate the adaptability and robustness of the i-Tree Eco model and related methodologies for quantifying and valuing carbon storage and sequestration in urban green spaces. From temperate cities in North America and Europe to subtropical Latin American metropolises, African community reforestation efforts, and multi-continental syntheses initiated in Australia, researchers have built a cohesive body of evidence that informs urban climate policy, carbon credit mechanisms, and green infrastructure planning. As cities worldwide confront rising greenhouse gas emissions, the continued refinement of regionally appropriate allometric models, alongside economic valuation frameworks, will be crucial for scaling up urban forest carbon services in a scientifically rigorous and policy-relevant manner.

In many parts of Asia, scholars have explored various methods to quantify and economically value these ecosystem services by i-Tree Eco. In Shanghai, a multidisciplinary study employed both i-Tree and Pathfinder to evaluate carbon sequestration, storage, and emissions in various types of urban green spaces(Jinjin et al., 2022). This hybrid approach combined the spatial precision of Pathfinder with the biomass quantification of i-Tree Eco, offering a dual-layered understanding of urban forest dynamics. The study highlighted how landscape facility structures, urban microclimates, and anthropogenic interference influence carbon storage potential. This is particularly useful for regions looking to integrate green space management with broader climate policy agendas.

South Korea has also utilized i-Tree Eco in national studies focusing on ecosystem service modeling in urban parks. One such study investigated Daejeon's Yurim Park and adopted a grid-based spatial analysis to calculate carbon sequestration rates across different park zones(Kim et al., 2024). The analysis demonstrated how variation in species diversity, land cover types, and age distribution of tree populations can alter overall carbon dynamics. The study underlined the potential of i-Tree Eco as a decision-support system in policy implementation, especially for selecting tree species with long-term sequestration capacity.

In Bangladesh, the issue of carbon sequestration in urban spaces has been explored through localized studies of city parks. A recent investigation of Shaheed Zayan Chowdhury Playground in Dhaka measured carbon storage across diverse urban trees using field-based allometric equations, given the limited local application of i-Tree Eco (Shadman et al., 2022). While the study didn't use i-Tree directly, its methodological framework was compatible with i-Tree modelling principles and highlighted similar indicators, such as tree height, DBH, and species-specific growth rates. The study serves as a foundational reference for integrating i-Tree into future carbon quantification projects in South Asia.

In Thailand, (Singkran, 2023) assessed the role of greening management in enhancing ecosystem services in 25 urban parks using i-Tree Eco. The study examined services including carbon storage, air pollution removal, and runoff reduction. By comparing managed and unmanaged parks, the authors developed performance benchmarks for ecosystem services. The policy implications of this study are significant, as they align with Thailand's national agenda for achieving climate resilience through nature-based solutions and can guide future carbon credit schemes based on green infrastructure investments.

In Zhengzhou, China, remote sensing data were coupled with field-based measurements and i-Tree Eco to analyze carbon sequestration and storage potentials across multiple parks(Du et al., n.d.). The study aimed to map carbon density at both macro and micro spatial scales, utilizing normalized difference vegetation index (NDVI) values to identify tree canopy density. One of the notable contributions of this study was its methodological innovation, integrating geospatial and ecological modeling for high-accuracy carbon accounting. Such approaches are valuable for urban governments and planners seeking precision in quantifying urban green contributions toward emission offsetting.

The synergy across these studies lies in their commitment to quantifying ecosystem services, particularly carbon storage and sequestration, with an eye toward monetization and policy integration. Tools like i-Tree Eco have emerged as indispensable for this purpose, especially in urban contexts where environmental degradation and land-use pressures are severe. The economic valuation of carbon stocks through shadow pricing, social cost of carbon (SCC), or voluntary carbon market rates allows municipalities and planners to justify investments in green spaces not just on ecological grounds but also through fiscal rationale.

Moreover, as the global carbon market expands, the data generated through tools like i-Tree Eco can support the creation of carbon credits from urban forestry projects. These credits can be traded or used to meet local emissions targets under schemes such as CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) or regional voluntary carbon markets. As evidenced by studies across Asia, quantifying urban carbon sinks is no longer just an academic exercise—it's a foundational requirement for integrating cities into climate finance systems.

Now coming to Indian context, numerous cities beyond the capital have initiated scientific studies to explore the economic and environmental benefits of urban green spaces through carbon sequestration and storage assessment. These studies often integrate field data with tools like i-Tree Eco, allometric models, and GIS, reflecting an emerging trend in ecosystem service evaluation to support climate adaptation planning. In Mumbai, the Mumbai Climate Action Plan (MCAP) was established in 2021 to address climate change challenges. The plan emphasizes urban greening and biodiversity, aiming to increase green cover and biodiversity in a planned and inclusive manner. The MCAP serves as a 30-year roadmap to guide the city towards climate resilience through mitigation and adaptation strategies, including low-carbon, resilient, and inclusive development pathways.

In Bhopal, the Kerwa Forest Area (KFA) has been identified as a critical urban forest providing essential ecosystem services. Highlighted the ecological benefits of urban forestry in the KFA, emphasizing its role in carbon sequestration and the health and wellbeing of Bhopal residents. The study underscores the importance of preserving such urban forests to maintain ecological balance and provide ecosystem services necessary for urban populations (Dwivedi et al., 2009).

Furthermore, (Behera et al. 2022) assessed the carbon sequestration potential of tropical tree species for urban forestry in India. The study found that native tree species, such as Teak (*Tectona grandis*), have a high potential for carbon sequestration in urban areas with high greenhouse gas concentrations. The research suggests that planting a mix of native species can provide more ecosystem services and act as effective carbon sinks in rapidly urbanizing areas.

These studies collectively demonstrate the critical role of urban green spaces in carbon sequestration and the utility of tools like i-Tree Eco in quantifying and optimizing these ecosystem services. The research highlights the importance of species selection, spatial planning, and management practices in enhancing the carbon storage capacities of urban forests. By providing empirical data and practical guidelines, these studies contribute to the development of sustainable urban environments capable of mitigating climate change impacts through effective green space management.

Urban green spaces in Delhi have garnered significant attention for their role in carbon sequestration and storage, particularly in the context of rapid urbanization and environmental degradation. The application of tools like i-Tree Eco has facilitated the quantification and economic valuation of these ecosystem services, providing valuable insights for urban planning and policy development.

A study conducted by (Bhalla & Bhattacharya, 2015)presents a comparative analysis of green space planning in Lutyens' Delhi and the Dwarka sub-city. Utilizing field-based surveys and questionnaires, the research examines urban tree species distribution, planning, management practices, and public perception regarding urban forestry. The findings highlight the diversity of urban trees in Lutyens' Delhi, with 125 species identified, compared to 26 species in Dwarka. The study underscores the importance of species selection and public awareness in enhancing urban biodiversity and ecosystem services.

Explore the carbon flow in Delhi's urban forest ecosystems, emphasizing the significance of trees as carbon sinks due to their biomass composition. The research highlights the role of forested areas in carbon sequestration and the necessity of preserving and expanding urban green spaces to mitigate climate change impacts (Tripathi & Joshi, 2015).

The Municipal Corporation of Delhi (MCD) has initiated urban forestry projects using the Miyawaki technique to create dense, native forests in unauthorized settlements and industrial areas. These efforts aim to transform degraded lands into thriving urban forests, enhancing biodiversity and contributing to carbon sequestration. The Miyawaki method accelerates forest growth, enabling saplings to mature in just five years, thereby providing a rapid response to urban environmental challenges.

A study by (Bherwani et al., 2024) reviews the role and value of urban forests in carbon sequestration within the Indian context, including Delhi. The research employs normalized difference vegetation index (NDVI) and allometric relationships to evaluate the economic importance of urban green spaces in sequestering carbon emissions and mitigating climatic impacts. The study emphasizes the potential of urban forests in contributing to climate change mitigation strategies and the need for integrating green infrastructure into urban planning.

The Okhla Bird Sanctuary in Delhi serves as a case study for examining carbon mitigation and sequestration by urban forests. The research highlights the sanctuary's role in providing ecosystem services, including carbon offsetting, and underscores the importance of preserving such green spaces amidst urban expansion. The study advocates for prioritizing slow-growing tree species for long-term carbon storage and emphasizes the need for strategic planning to enhance the ecological balance between urban development and environmental sustainability (Tripathi & Joshi, n.d.).

The i-Tree Eco model, developed by the U.S. Forest Service, has been instrumental in quantifying ecosystem services provided by urban trees, including carbon storage and sequestration. The model estimates carbon storage in trees, annual carbon sequestration, and emissions via tree decomposition. It requires inputs such as tree species, diameter at breast height (DBH), total tree height, and crown characteristics. The model's application in Delhi has facilitated the assessment of urban forest structure and the valuation of ecosystem services, informing sustainable urban forestry practices.

In conclusion, the integration of tools like i-Tree Eco and the implementation of urban forestry initiatives in Delhi underscore the city's commitment to enhancing carbon sequestration and storage through green infrastructure. These efforts contribute to climate change mitigation, improve urban biodiversity, and provide economic valuation of ecosystem services, aligning with sustainable urban development goals.

The i-Tree Eco model, developed by the U.S. Forest Service, has been instrumental in operationalizing urban forest assessments. At its core, i-Tree Eco integrates field-based measurements of tree attributes—such as species, DBH (diameter at breast height), tree height, and crown dimensions—with localized environmental data and allometric equations to estimate numerous ecosystem services. These include carbon storage, annual carbon sequestration, air pollution removal, avoided runoff, and structural value. Importantly, the tool supports the monetary valuation of these services, allowing cities and stakeholders to assess the cost-effectiveness of investing in green infrastructure (Nowak et al., 2006; Nowak et al., 2013).

International studies have shown that i-Tree Eco can adapt to regional data by using localized allometric models and environmental variables. For instance, in Barcelona, the tool was used not only to calculate carbon storage but also to evaluate its co-benefits like air purification (Baró et al., 2014). Similarly, studies in São Paulo, Brazil (Rodrigues-Leite et al., 2024), and in Szeged, Hungary (Kiss et al., 2015), emphasized the importance of regional calibration and ecosystem-specific modifications for more accurate outputs. These experiences underscore the potential for tailoring i-Tree Eco’s structure to reflect Delhi’s urban forestry characteristics and species composition.

In Asia, particularly in South Korea, China, and Thailand, the i-Tree Eco model has been applied to grid-based analysis, urban park planning, and climate resilience modeling (Kim et al., 2024; Du et al., 2025). These studies emphasize its decision-support utility—using outputs from i-Tree Eco to not only quantify services but also simulate different planting or management scenarios. Such simulation capabilities could be directly applicable to the objective of developing a framework for selecting tree species to optimize carbon sequestration.

In the Indian context, while the application of i-Tree Eco is still emerging, its utility has been recognized in urban planning frameworks and state climate action strategies. The model’s value lies in its standardized and replicable protocol, which is especially useful in cities like Delhi that are characterized by complex land-use patterns, diverse species, and varying degrees of ecological degradation. The Municipal Corporation of Delhi’s urban forestry efforts, especially those adopting the Miyawaki technique, could benefit from i-Tree Eco's capacity to measure rapid-growth carbon sequestration and compare it with longer-term slow-growing native species (Tripathi & Joshi, 2015).

The model has also proven effective in identifying carbon hotspots within urban parks, which can help prioritize planting and conservation efforts. For example, the application of i-Tree Eco in parks like the Okhla Bird Sanctuary can yield insights into spatial carbon storage patterns, tree health, and species-level contributions (Tripathi & Joshi, 2015). These insights are not only scientifically valuable but also have direct implications for carbon credit mechanisms—an emerging field in Indian environmental policy. Urban forests quantified using i-Tree Eco could eventually feed into voluntary carbon markets or state-level offset programs, offering financial incentives for conservation and afforestation.

Furthermore, as climate change mitigation increasingly intersects with economic policy, the value of i-Tree Eco lies in its forward-looking potential. With global and national carbon pricing mechanisms gaining traction, tools that quantify and value carbon sequestration will play an essential role in enabling urban forests to participate in carbon finance. The robust data provided by i-Tree Eco could be used to support project registration under platforms such as Verra's Verified Carbon Standard or India's emerging national carbon market.

Thus, concluding this literature review, it is evident that i-Tree Eco is not merely a tool for measurement but a comprehensive framework for strategic urban forestry management. Its widespread international application, adaptability to local contexts, and capacity to translate biophysical data into actionable economic metrics make it ideally suited for the study. By deploying i-Tree Eco in Deer Park, the research with global best practices while addressing localized sustainability goals. This not only enhances the scientific validity of the findings but also strengthens their relevance for policy application, urban climate strategy, and potential monetization through carbon markets.

5. Material & Methods:

5.1. Study Area

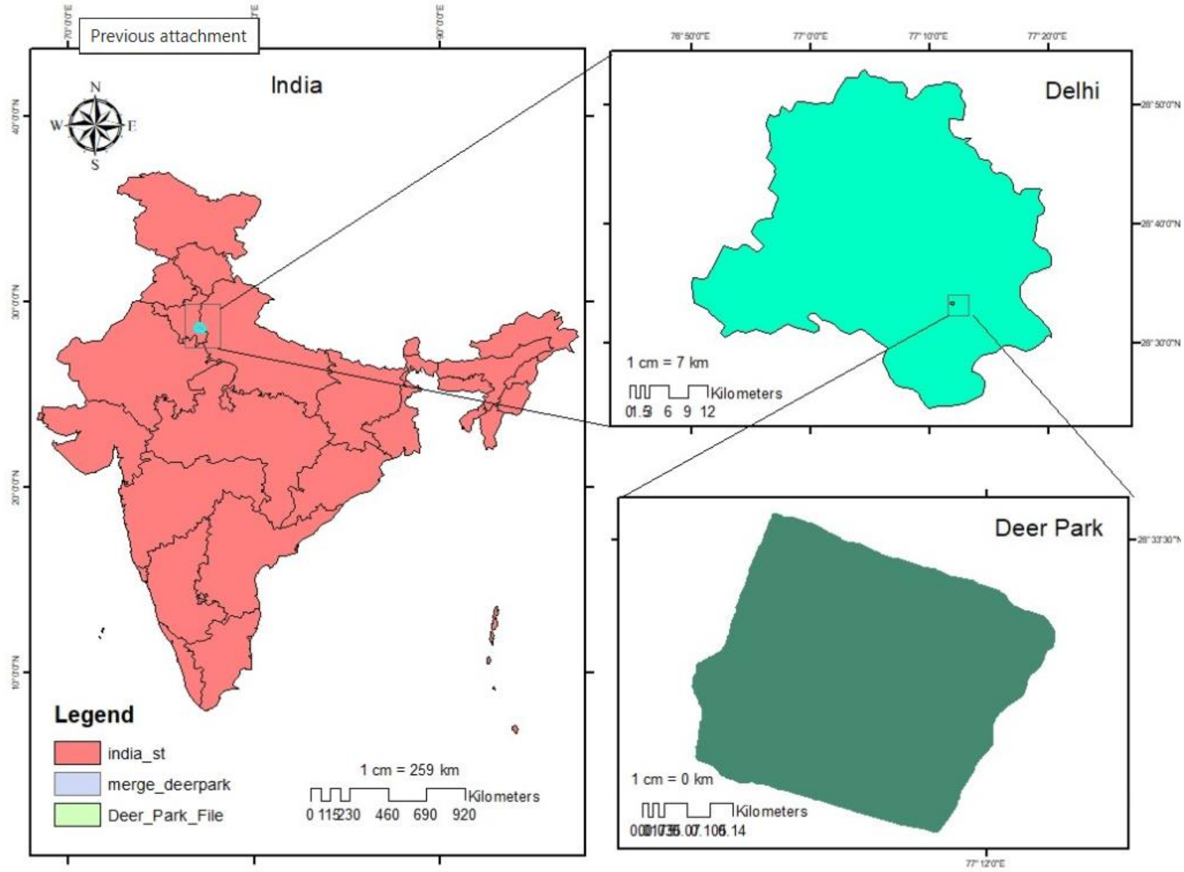
The present study focuses on Deer Park, Hauz Khas, located in the National Capital Territory (NCT) of Delhi, one of India's most urbanized and rapidly expanding metropolitan regions (Fig.1). Delhi, the capital of India, is not only the administrative heart of the country but also a key economic, cultural, 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).

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.

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 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.



(Fig 1: Location map of Deer Park, Hauz Khas.)

5.2. Methodology

The methodology for this study integrates spatial, ecological, and computational techniques to assess the ecosystem services provided by urban green spaces, with a focus on Deer Park, Hauz Khas, Delhi. The core of this analysis is based on the use of the i-Tree tools, developed by the United States Department of Agriculture (USDA) Forest Service in partnership with local NGOs.

The i-Tree Eco method and software (6.1.53) will be used to assess the structure and ecosystem services provided by, the tree in Deer Park, Hauz Khas. i-Tree Eco is an adaptation of the Urban Forest Effects (UFORE) model, which was cooperatively developed by the U.S. Forest Service Northern Research Station (NRS), USDA State and Private Forestry's Urban and Community Forestry Program and Northeastern Area, Davey Tree Expert Company, and SUNY College of Environmental Science and Forestry (Photo plate 1).

5.2.1 Sampling Design and Plot Distribution

A plot-based inventory approach will be chosen as the sampling method to estimate tree-based ecosystem services. To achieve statistically valid results, a random sampling method will be employed. The plots will be randomly distributed across the park. Each plot will have a standard size of 0.04 hectares (400 m2 or 12 m radius), as recommended by i-Tree Eco. The number of plots to be surveyed will be determined based on the park’s size and vegetation density to ensure an optimal balance between accuracy and efficiency.

5.2.2 Field Data Collection

It was conducted using standardized i-Tree Eco protocols from February to May (annexture 1). The following parameters were recorded for each randomly selected plot:

Tree-Level Attributes:

- Tree species identification
- Diameter at Breast Height (DBH) at 1.37 m (4.5 feet)
- Total Tree Height
- Total Crown Height
- Crown width (measured in two perpendicular directions)
- Crown Dieback percentage
- Crown Missing percentage

Plot-Level Attributes:

- GPS Coordinates of Plot Centres
- Land-Use Classifications

5.2.3. Data Processing and Model Execution in i-Tree Eco

Once the field data was collected, it was uploaded and processed in the i-Tree Eco software during the month of May. After processing the data, the outcomes were examined to assess species distribution, carbon sequestration rates, and to determine the most efficient species for future planting initiatives. The findings from the i-Tree Eco model facilitated the creation of suggestions to improve carbon capture and the park's overall sustainability. The information was likewise analysed alongside national and global benchmarks to contextualize the park's role in efforts to mitigate climate change. This detailed data processing phase was vital for guaranteeing the precision and dependability of the carbon sequestration estimates, which are important for guiding urban forestry management and climate policy choices.

(Photo Plate 1 : Instruments used for data collection)

6. Results:

Objective 1 :

6.1. Species Composition :

The species composition of District Park, Hauz Khas, reveals a notable dominance of *Putranjiva roxburghii* (Putranjivaceae) with 271 individuals, significantly surpassing other species in abundance. *Azadirachta indica* (Meliaceae), commonly known as Neem, ranks second with 122 individuals, followed by *Cassia fistula* (Caesalpinioideae) with 102 trees. These three species together constitute the bulk of the total tree population, indicating a strong preference or natural proliferation in the park. Other notably represented species include *Pongamia pinnata* (Fabaceae) with 68 individuals and *Delonix regia* (Caesalpinioideae) with 41 individuals, both known for their ecological resilience and aesthetic value. Lesser but still relatively common trees include *Morus alba* (30), *Ficus virens* (28), *Syzygium cumini* (27), and *Ehretia laevis* (24), reflecting a mixture of functional types including fruit-bearing and shade-providing trees. The park also hosts a large diversity of species represented by lower numbers, such as *Terminalia arjuna* (18), *Tectona grandis* (18), *Bombax ceiba* (16), and *Mimusops elengi* (15), which are valued for their ecological roles and traditional uses. A wide tail of rare species such as *Ailanthus excelsa*, *Spathodea campanulata*, *Bauhinia purpurea*, *Kigelia africana*, and *Moringa oleifera* are represented by only one individual each, emphasizing species richness but with a skewed distribution.

The family Moraceae leads with the highest species richness, contributing 8 species to the park's overall tree diversity. Following closely are Caesalpiniaceae and Mimosaceae, each with 6 species. These families belong to the larger legume group and are especially valuable in urban forestry due to their nitrogen-fixing capabilities and fast growth. The next tier of families includes Bignoniaceae, Fabaceae, and Myrtaceae, each represented by 4 species. Malvaceae and Meliaceae follow with 3 species each. The families Ebenaceae, Ulmaceae, Apocynaceae, and Proteaceae are each represented by 2 species. Finally, there is a broad list of families represented by only 1 species each, highlighting a long tail of taxonomic diversity. These include Anacardiaceae, Annonaceae, Boraginaceae, Capparaceae, Casuarinaceae, Citrus, Combretaceae, Lythraceae, Moringaceae, Myrpaceae, Putranjivaceae, Rubiaceae, and Sapotaceae

Accounting for 40 species, which highlights a strong preference for indigenous flora likely due to their ecological adaptability and environmental benefits. Introduced species make up a significant portion as well, with 20 species, reflecting efforts to diversify the landscape or include aesthetically appealing and fast-growing trees. Only 1 species is listed as naturalized, indicating that it is non-native but has successfully adapted and integrated into the local ecosystem.

Out of 61 tree species, 30 tree species was identified as evergreen tree species, followed by deciduous tree species (24). and perennial tree species (7) (Table 1). Their dominance reflects a strategic emphasis on maintaining year-round canopy cover, which supports continuous carbon sequestration, shade, and microclimate regulation, seasonal biodiversity and aiding in nutrient cycling through leaf litter. This distribution suggests a balanced plantation strategy that favors ecological stability while also ensuring seasonal variation and visual appeal.

Table 1: Species composition recorded in Deer Park, Hauz Khas

Tree species name	Common name	No. of individuals	Family	Status	Habit
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	Caesalpiniaceae	native	Evergreen
Cassia fistula	Canafistula	102	Caesalpiniaceae	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

The carbon storage and sequestration of tree species using i-Tree Eco.

6.2 . Carbon storage and sequestration rate of tree species:

Among all the species (referring to table 2), *Azadirachta indica* (Neem) stores the highest amount of carbon, totaling **604.40 tons**, reflecting both its high abundance and mature biomass. This is followed by *Putranjiva roxburghii* with **141.50 tons**, which is also the most abundant species in the park, indicating that population size significantly impact on storage capacity. *Cassia fistula* and *Bombax ceiba* also contribute substantially to carbon storage with **82.40 tons** and **68.00 tons** respectively, highlighting their sizeable canopy and wood density. *Terminalia arjuna* (61.60 tons), *Syzygium cumini* (55.50 tons), and *Ficus religiosa* (56.40 tons) also demonstrate high storage potential, indicating the value of native species in long-term carbon accumulation. Other notable contributors include *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), all contributing between 25–50 tons each, depending on size, density, and individual count. Moderate carbon storage values are observed in species such as *Ulmus laevis* (33.80 tons), *Ficus virens* (34.70 tons), and *Dalbergia sissoo* (12.40 tons), while smaller-sized or less dense species like *Grevillea parallela* (5.40 tons), *Artocarpus heterophyllus* (0.20 tons), and *Acacia senegal* (0.10 tons) store much lower amounts of carbon.

In terms of gross carbon sequestration, *Azadirachta indica* again leads with 30.59 tons per year, showcasing its significant role in dynamic carbon uptake. This is followed by *Putranjiva roxburghii* at 9.88 tons/year, *Cassia fistula* at 7.79 tons/year, and *Bombax ceiba* at 4.16 tons/year, all indicating strong annual performance in carbon assimilation. *Albizia lebbeck* follows with 3.10 tons/year, while *Delonix regia* and *Terminalia arjuna* show rates of 2.66 and 2.30 tons/year, respectively. *Syzygium cumini* and *Ficus religiosa* also perform well, with 2.30 and 2.14 tons/year, making them valuable assets for long-term carbon management. Other mid-range performers include *Morus alba* (1.93), *Ceiba speciosa* (1.89), *Pterospermum acerifolium* (1.83), and *Ficus virens* (1.73), showing that several native and ornamental species play a vital role in ongoing sequestration. Lower annual sequestration rates are observed in smaller species or those with lower biomass turnover, such as *Acacia senegal* (0.01), *Plumeria obtusa* (0.06), and *Artocarpus heterophyllus* (0.03), which, while offering other ecosystem services, contribute less significantly to carbon dynamics. Interestingly, *Prosopis juliflora* records zero gross sequestration, possibly indicating maturity or stagnant growth.

Table 2 : Carbon storage and sequestration rate of tree species recorded in Deer Park, Hauz Khas.

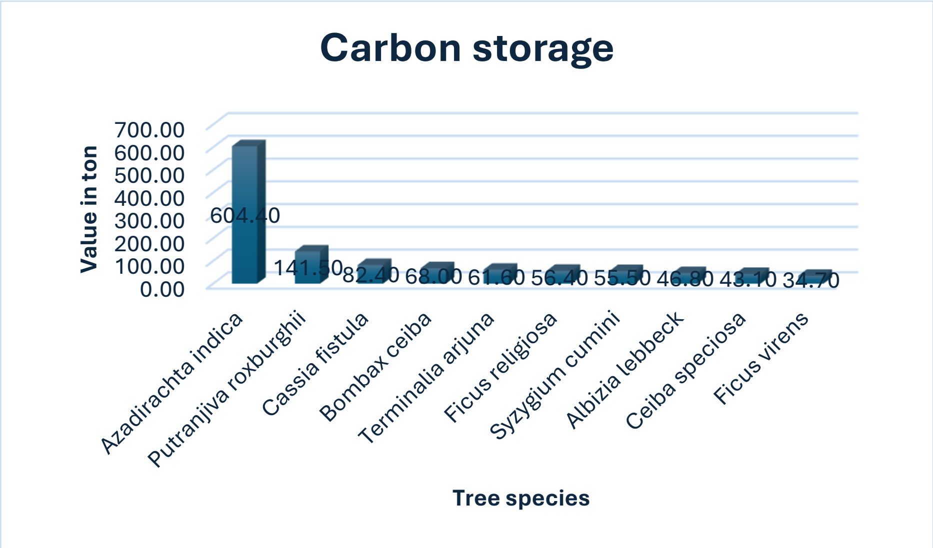
Species	Carbon Storage (ton)	Gross Carbon Sequestration (ton/yr)
Acacia auriculiformis	1.50	0.03
Vachellia nilotica	1.10	0.08
Acacia senegal	0.10	0.01
Albizia lebbeck	46.80	3.10
Alstonia scholaris	1.30	0.08
Artocarpus heterophyllus	0.20	0.03
Azadirachta indica	604.40	30.59
Bauhinia forficata	0.10	0.01
Bauhinia racemosa	3.80	0.18
Bauhinia variegata	0.90	0.12
Bombax ceiba	68.00	4.16
Callistemon citrinus	0.10	0.01
Casuarina equisetifolia	4.50	0.49
Cassia fistula	82.40	7.79
Callistemon pendula	15.60	0.61
Senna siamea	10.80	0.81
Ceiba speciosa	43.10	1.89
Citrus	1.90	0.21
Crateva religiosa	0.40	0.03

Dalbergia sissoo	12.40	0.75
Delonix regia	31.30	2.66
Diospyros montana	2.80	0.22
Diospyros melanoxylon	2.50	0.18
Ehretia laevis	9.20	0.94
Erythrina variegata	0.10	0.00
Eucalyptus globulus	8.20	0.76
Ficus benjamina	0.30	0.05
Ficus benghalensis	0.40	0.10
Ficus elastica	0.90	0.13
Ficus racemosa	8.20	0.55
Ficus religiosa	56.40	2.14
Ficus virens	34.70	1.73
Grevillea parallela	5.40	0.35
Grevillea robusta	6.50	0.80
Jacaranda mimosifolia	1.70	0.10
Kigelia africana	2.80	0.08
Lagerstroemia speciosa	0.00	0.01
Leucaena leucocephala	3.80	0.48
Mangifera indica	0.70	0.07
Melia azedarach	24.80	1.98
Mimusops elengi	2.80	0.36
Millingtonia hortensis	1.20	0.14
Morus alba	27.80	1.93
Morinda citrifolia	0.60	0.09
Moringa oleifera	0.30	0.03
Peltophorum pterocarpum	10.20	0.58
Plumeria obtusa	0.70	0.06
Pongamia	31.40	2.49
Polyalthia longifolia v. pendula	8.20	0.74
Prosopis juliflora	9.00	0.00
Psidium guajava	3.00	0.27
Pterospermum acerifolium	20.30	1.83
Putranjiva roxburghii	141.50	9.88
Saraca asoca	5.50	0.18
Spathodea campanulata	0.40	0.05
Syzygium cumini	55.50	2.97
Terminalia arjuna	61.60	2.30
Tectona grandis	13.60	1.42
Toona ciliata	9.30	0.63

Ulmus laevis	33.80	1.41
Ulmus minor ssp. angustifolia	8.30	0.01
Total	**1545.00**	**91.69**

6.3. Species with a high rate of carbon storage:

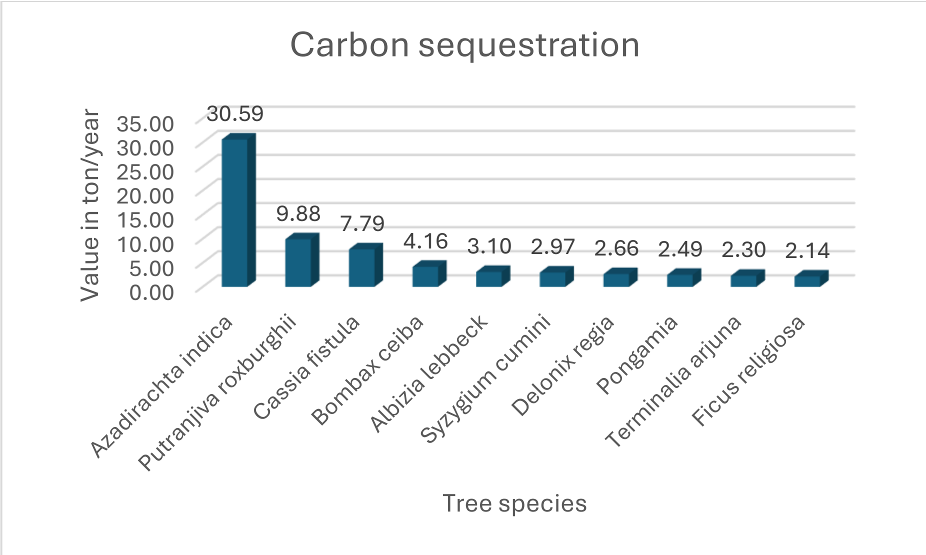
With a total of 604.4 tonnes, *Azadirachta* indica is the most abundant species in terms of carbon storage, greatly surpassing all other species. *Putranjiva roxburghii* comes next, storing 141.5 tonnes of carbon. Additional species that make significant contributions to the ecosystem's carbon storage include *Terminalia arjuna* (61.6 tonnes), *Cassia fistula* (82.4 tonnes), and *Bombax ceiba* (68.0 tonnes). Other species' storage capacities, however, show a sharp reduction; *Ficus viren*s can only store 34.7 tonnes. The significance of a few key species in carbon sequestration—which is necessary for long-term carbon storage and climate mitigation strategies—is highlighted by this distribution (Fig. 2).



(Fig 2 : Species with a high rate of carbon storage)

6.4. Species with high rate of carbon sequestration:

With an annual carbon sequestration rate of 30.59 tonnes, *Azadirachta indica* outperforms all other species in terms of carbon sequestration. The next highest sequestration rate is 9.88 tonnes per year for *Putranjiva roxburghii* and 7.79 tonnes per year for *Cassia fistula*. Though at far lesser rates, other plants including *Syzygium cumini* (2.97 tonnes), *Albizia lebbeck* (3.10 tonnes), and *Bombax ceiba* (4.16 tonnes) also aid in carbon sequestration. *Ficus religiosa* (2.14 tonnes), *Terminalia arjuna* (2.30 tonnes), *Pongamia* (2.49 tonnes), and *Delonix regia* (2.66 tonnes) all further highlight the varied roles that different tree species play in reducing carbon emissions. The information highlights how important a few essential species are to carbon sequestration efforts, especially *Azadirachta indica* (Fig.3).

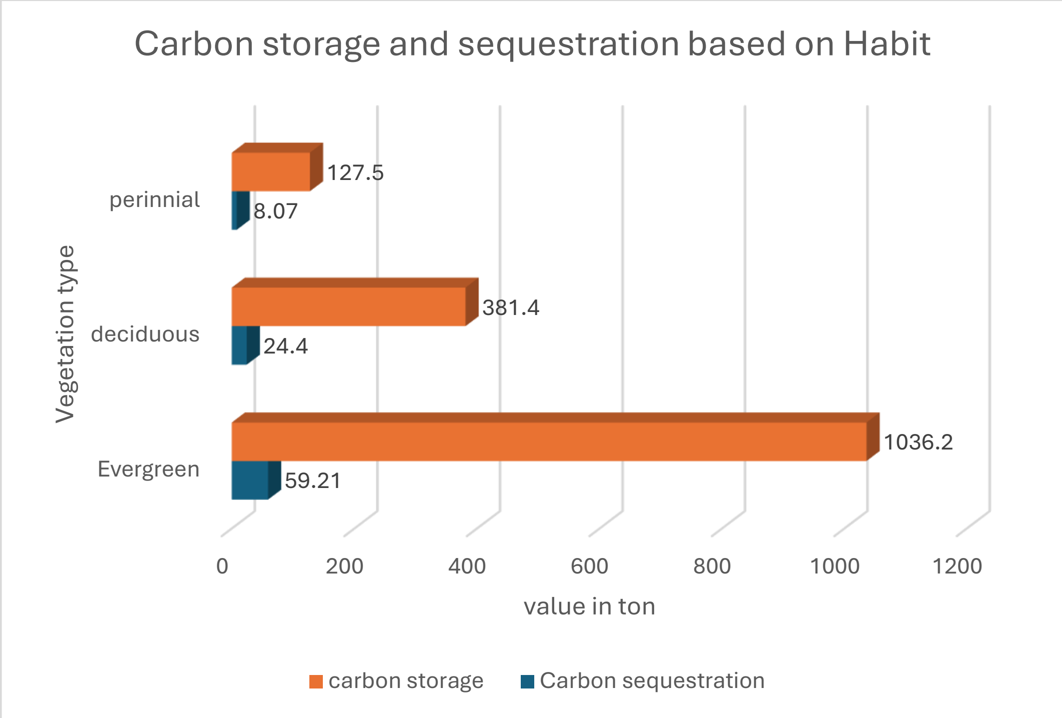


(Fig. 3 : Species with high rate of carbon sequestration)

6.5. Carbon storage and sequestration based on Habit :

The data indicates the carbon storage and sequestration values based on the type of vegetation. Evergreen species significantly outperform both deciduous and perennial species when it comes to carbon storage and sequestration. Evergreen species sequester a total of 1,036.2 tons of carbon and take in 59.21 tons annually. Deciduous species store 381.4 tons of carbon, sequestering 24.4 tons annually, while perennial species store 127.5 tons and sequester only 8.07 tons each year.

This distribution indicates that evergreen species are superior in both prolonged carbon storage and ongoing carbon sequestration, highlighting their crucial role in carbon mitigation efforts. In contrast, while perennial and deciduous plants contribute to carbon storage and sequestration, their effectiveness is notably diminished, underscoring the necessity to focus on evergreen species for improved carbon capture and storage (Fig.4).

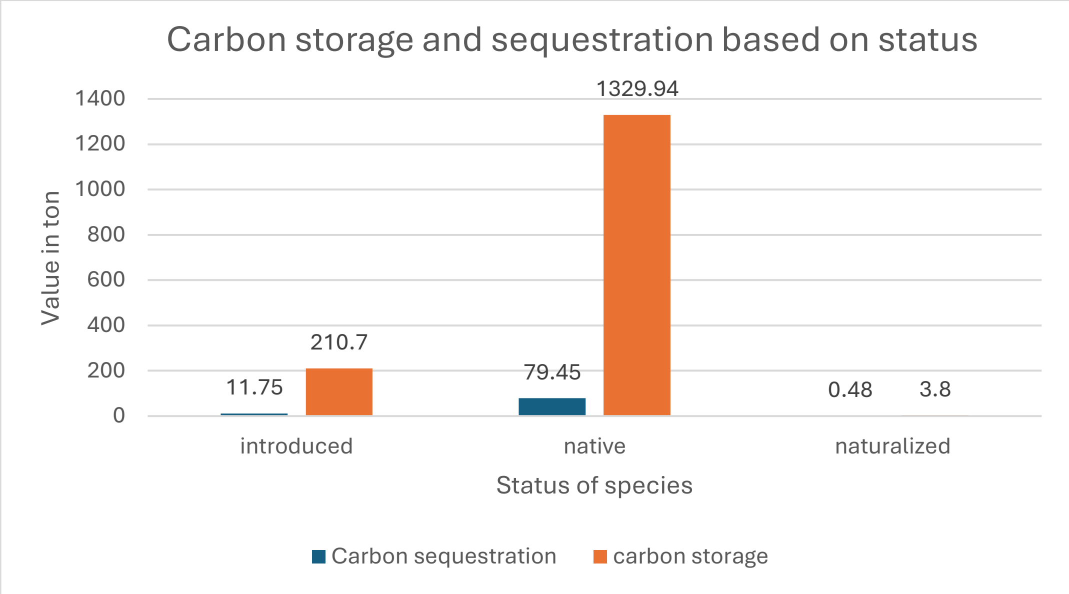


(Fig. 4 : Carbon storage and sequestration based on Habit)

6.6. Carbon storage and sequestration based on tree species status:

The information emphasizes the carbon storage and sequestration abilities depending on the status of different species. Indigenous species have a significant impact on carbon storage, accumulating a total of 1,329.94 tons and sequestering 79.45 tons each year (Fig.5.). This sharply contrasts with introduced species, which capture merely 210.7 tons of carbon, exhibiting a significantly lower sequestration rate of 11.75 tons. Naturalized species hold a minimal amount of carbon, featuring just 3.8 tons in storage and 0.48 tons sequestered annually.

This distribution highlights the essential role of native species in carbon sequestration and storage, emphasizing their significance in sustainable carbon capture initiatives. In contrast, introduced and naturalized species provide significantly lower contributions, underscoring the ecological and carbon storage importance of native species within the examined ecosystem.



(Fig.5 : Carbon storage and sequestration based on tree species status)

Objective 2 :

Economic valuation of tree species utilized for carbon storage and sequestration

6.7. Carbon credit based on carbon storage:

The carbon credit valuation of various tree species based on a cumulative 130 metric tons of CO_2 equivalent emissions offset, calculated using a conversion rate of 1 US dollar = ₹85.50 INR (Table 3). The values reflect how much CO_2 equivalent each species sequesters, alongside the corresponding market value of that sequestration in both USD and INR. This analysis plays a pivotal role in monetizing ecosystem services rendered by urban trees and evaluating their performance in the voluntary carbon market through the lens of carbon credits.

At the top of the list is *Azadirachta indica*, which overwhelmingly dominates with a CO_2 equivalent of 2216.30 tons, generating a carbon credit value of $288,119, equating to ₹24,588,075.46. This is a striking figure, suggesting the species' massive potential in climate mitigation strategies and justifying its use in carbon finance projects. Following this is *Putranjiva roxburghii*, contributing 518.90 tons CO_2, worth $67,457 or ₹5,756,780.87, which is also a substantial amount. In third place is *Cassia fistula* with 302.20 tons, valued at $39,286 or ₹3,356,267.44, further confirming its role as a high-value sequestrator.

Bombax ceiba comes next with 249.40 tons, equating to $32,422 or ₹2,766,893.48, while *Terminalia arjuna* closely follows at 225.80 tons, valued at $29,354 (₹2,505,070.36). *Ficus religiosa*, a culturally and ecologically significant species, stores 206.90 tons, which translates into $26,897 or ₹2,259,389.98. Another high-performing species, *Syzygium cumini*, contributes 203.50 tons, valued at $26,465 or ₹2,257,669.70.

Continuing down the hierarchy, *Albizia lebbeck* stores 171.50 tons, valued at $22,295 (₹1,902,655.30), while *Ceiba speciosa* stores 158.10 tons, equating to $20,553 or

₹1,753,993.02. Other notable 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). *Pongamia* and *Delonix regia* contribute nearly equally, each with values exceeding $14,000 or ₹1.27 million INR.

On the moderate contribution spectrum, species like *Melia azedarach* (90.90 tons, $11,817, ₹1,008,462.78) and *Pterospermum acerifolium* (74.30 tons, $9,659, ₹824,299.06) also hold substantial carbon value. The middle range includes species such as *Callistemon pendula*, *Tectona grandis*, *Dalbergia sissoo*, and *Senna siamea*, each ranging between 30–60 tons of CO_2, contributing between $4,000–7,400, or ₹350,000–630,000 INR.

At the lower end, yet still notable, are species such as *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). These values reflect the diminishing financial returns for smaller or slower-growing species but highlight their ongoing contribution to biodiversity and ecosystem function.

The least economically contributing species include *Ficus benjamina* (1.00 tons, $130, ₹11,094.20), *Artocarpus heterophyllus* (0.70 tons, $91, ₹7,765.94), and species like *Callistemon citrinus* and *Lagerstroemia speciosa*, each under 0.50 tons CO_2 equivalent, valued below $65 (₹5,000 INR).

Table 3 : Carbon credit based on carbon storage

Species	CO_2 Equivalent	US $	INR
Acacia auriculiformis	5.30	689	58799.26
Vachellia nilotica	4.10	533	45486.22
Acacia senegal	0.40	52	4437.68
Albizia lebbeck	171.50	22295	1902655.3
Alstonia scholaris	4.80	624	53252.16
Artocarpus heterophyllus	0.70	91	7765.94
Azadirachta indica	2216.30	288119	24588075.46
Bauhinia forficata	0.40	52	4437.68
Bauhinia racemosa	13.80	1794	153099.96
Bauhinia variegata	3.40	442	37720.28
Bombax ceiba	249.40	32422	2766893.48
Callistemon citrinus	0.30	39	3328.26
Casuarina equisetifolia	16.70	2171	185273.14
Cassia fistula	302.20	39286	3352667.24
Callistemon pendula	57.20	7436	634588.24

Senna siamea	39.60	5148	439330.32
Ceiba speciosa	158.10	20553	1753993.02
Citrus	7.10	923	78768.82
Crateva religiosa	1.30	169	14422.46
Dalbergia sissoo	45.40	5902	503676.68
Delonix regia	114.80	14924	1273614.16
Diospyros montana	10.20	1326	113160.84
Diospyros melanoxylon	9.00	1170	99847.8
Ehretia laevis	33.70	4381	373874.54
Erythrina variegata	0.50	65	5547.1
Eucalyptus globulus	29.90	3887	331716.58
Ficus benjamina	1.00	130	11094.2
Ficus benghalensis	1.60	208	17750.72
Ficus elastica	3.10	403	34392.02
Ficus racemosa	30.20	3926	335044.84
Ficus religiosa	206.90	26897	2295389.98
Ficus virens	127.30	16549	1412291.66
Grevillea parallela	19.90	2587	220774.58
Grevillea robusta	23.80	3094	264041.96
Jacaranda mimosifolia	6.10	793	67674.62
Kigelia africana	10.30	1339	114270.26
Lagerstroemia speciosa	0.10	13	1109.42
Leucaena leucocephala	13.90	1807	154209.38
Mangifera indica	2.50	325	27735.5
Melia azedarach	90.90	11817	1008462.78
Mimusops elengi	10.30	1339	114270.26
Millingtonia hortensis	4.30	559	47705.06
Morus alba	102.10	13273	1132717.82
Morinda citrifolia	2.20	286	24407.24
Moringa oleifera	1.10	143	12203.62
Peltophorum pterocarpum	37.30	4849	413813.66
Plumeria obtusa	2.60	338	28844.92

Pongamia	115.00	14950	1275833
Polyalthia longifolia v. pendula	29.90	3887	331716.58
Prosopis juliflora	33.10	4303	367218.02
Psidium guajava	11.10	1443	123145.62
Pterospermum acerifolium	74.30	9659	824299.06
Putranjiva roxburghii	518.90	67457	5756780.38
Saraca asoca	20.00	2600	221884
Spathodea campanulata	1.50	195	16641.3
Syzygium cumini	203.50	26455	2257669.7
Terminalia arjuna	225.80	29354	2505070.36
Tectona grandis	49.80	6474	552491.16
Toona ciliata	34.10	4433	378312.22
Ulmus laevis	124.10	16133	1376790.22
Ulmus minor ssp. angustifolia	30.60	3978	339482.52
	5665.50	**736489**	**62851971.26**

Objective 3:

A framework for selecting tree species to optimize carbon storage, and sequestration rate

The carbon storage data reveal that the majority of tree species fall within the 0–1 ton category, with 16 species storing the least amount of carbon (Table 4). These are likely young, small-sized trees or species with lower wood density and biomass. The next most common category is 2–5 ton, with 14 species, indicating a slightly higher contribution to carbon stock. 10 species each fall into the 6–10 ton and 11–20 ton ranges, suggesting a moderate number of species providing medium-level carbon storage. A notable 9 species fall into the 21–50 ton category, and 5 species each contribute between 51–100 ton, showing a small group of mature or large-canopied trees that offer substantial carbon storage. Remarkably, only 3 species exceed 101 tons in carbon storage, which reflects the high carbon accumulation potential of a few dominant trees, such as *Azadirachta indica*, *Putranjiva roxburghii*, and *Cassia fistula*.

In terms of gross carbon sequestration, 13 species sequester between 0–0.05 ton/year, indicating minimal annual carbon uptake. These are likely slower-growing or less photosynthetically active species. Similarly, another 13 species fall within the 0.11–0.5 ton/year range, reflecting a moderate carbon assimilation rate. 8 species sequester between 0.06–0.1 ton/year, which slightly overlaps the lower range. Moving to higher-performing species, 10 trees sequester between 0.51–1 ton/year, and 7 species each fall into both the 1.1–2 ton/year and 2.1–5 ton/year categories, showing a consistent mid-range group of species making meaningful contributions to carbon offsetting. Only 4 species surpass 5 ton/year, which are *Azadirachta indica, Putranjiva roxburghii, Cassia fistula, Bombax ceiba, and Albizia lebbeck* suggesting that very few trees have exceptionally high sequestration potential, usually correlated with their size, canopy spread, and active growth rates.

Looking at the species status, the park's vegetation is dominated by native species, which account for 40 out of the total tree species studied. This supports ecological stability and biodiversity conservation in urban environments. Introduced species number 20, reflecting an intention to diversify the flora and perhaps meet ornamental or functional goals in landscape design. Only 1 species is categorized as naturalized, meaning it is not native but has adapted well enough to become part of the local ecosystem. This balance suggests a careful planting strategy that emphasizes native dominance while incorporating select non-native species for specific benefits.

Regarding tree habits, evergreen species dominate the landscape, with 30 species present. Their year-round foliage provides continuous carbon sequestration, shade, and microclimate regulation, making them a core component of sustainable urban forestry. Deciduous trees account for 24 species, offering seasonal variation and contributing to nutrient cycling through leaf fall. Perennial species are the least common, with 7 species, which may include some semi-evergreen or irregularly shedding trees. This habit diversity ensures that the park maintains ecological functions throughout the year, balancing carbon dynamics with biodiversity and visual variety. Overall, the table highlights a well-structured and balanced urban forest composition that maximizes ecosystem services through a mix of species functionality, growth traits, and conservation value.

Table 4 : Framework for selecting tree species to optimize carbon storage, and sequestration rate

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)				

7. Discussion:

The results derived from the i-Tree Eco assessment of Deer Park, Hauz Khas, provide a substantial and layered understanding of the carbon storage and sequestration capabilities of urban tree species in a highly urbanized context like New Delhi. The first objective, which aimed to assess carbon storage and sequestration of tree species, has produced several insightful outcomes. The most critical among them is the revelation that the total carbon storage within Deer Park stands at approximately 1,545 tons, while the total annual carbon sequestration is 91.69 tons. These figures are significant in understanding the ecological capacity of urban forests to mitigate climate change.

Among individual species, *Azadirachta indica* (Neem) emerges as the most impactful contributor with a carbon storage of 604.4 tons and annual sequestration of 30.59 tons. This single species accounts for nearly 39% of the park's total carbon storage. The second most effective species, *Putranjiva roxburghii*, stores 141.5 tons and sequesters 9.88 tons annually. These figures reflect not only the physiological robustness of these species but also their population density in the park. In comparison, (Prasad et al., 2020) estimated that across the city of Delhi, urban trees cumulatively stored about 77,000 tons of carbon, with species like *Prosopis juliflora* and *Azadirachta indica* playing major roles. However, it is notable that in my study, *Prosopis juliflora* contributes a mere 9 tons in storage and shows no gross sequestration, possibly indicating senescence or stagnation in growth, which aligns with (Begum et al., 2020), who found wide variability in carbon performance among Delhi's institutional green spaces.

It is important to note that while (Prasad et al. 2020) dealt with macro-level estimations across multiple green spaces in Delhi, the study offers a more micro-level, high-resolution analysis focused on a single park. This allows for a granular understanding of species-level contributions and provides a refined basis for urban forestry planning. The methodology of employing 0.04-hectare plots and integrating precise tree-specific parameters (DBH, crown size, and height) aligns with best practices as outlined (Nowak et al., 2008) in their development of the UFORE model, the foundation of i-Tree Eco.

Beyond the dominant species, others such as *Cassia fistula* (82.4 tons storage, 7.79 tons sequestration), *Bombax ceiba* (68 tons, 4.16 tons/year), and *Terminalia arjuna* (61.6 tons, 2.3 tons/year) also contribute substantially. These findings underscore the importance of tree biomass, maturity, and species-specific growth patterns in urban carbon accounting. The robust carbon sequestration by native species corroborates the emphasis (Behera et al., 2022), who found that tropical natives like *Tectona grandis* and *Azadirachta indica* possess high sequestration capacity under Indian urban conditions.

A compelling dimension of this analysis is the differentiation based on species status. Native species dominate with 1,329.94 tons of stored carbon and 79.45 tons annually sequestered, sharply contrasting with introduced species, which collectively store 210.7 tons and sequester only 11.75 tons per year. This finding is consistent with (Sharma et al., 2019), who advocated for prioritizing native species in Delhi's green planning to ensure ecological integrity and resilience. Moreover, naturalized species make a negligible contribution (3.8 tons storage and 0.48 tons sequestration), reinforcing the principle that adaptation to local conditions does not necessarily equate to ecological efficacy.

Furthermore, categorizing the data by vegetative habit reveals that evergreen trees outperform others in both metrics, storing 1,036.2 tons and sequestering 59.21 tons annually. In contrast, deciduous species store 381.4 tons and sequester 24.4 tons, while perennials contribute a modest 127.5 tons in storage and 8.07 tons annually in sequestration. These trends support the case for planting evergreens in urban zones, as their year-round photosynthetic activity translates to uninterrupted carbon assimilation, aligning with insights from global studies like those by (Baró et al., 2014) in Barcelona and (Kim et al., 2024) in South Korea.

Coming to the next objective it involved creating a framework for species selection based on storage and sequestration capacity, further deepens the practical utility of the findings. The distribution shows that only three species—*Azadirachta indica, Putranjiva roxburghii, and Cassia fistula* cross the 100-ton mark for carbon storage. Similarly, only four species surpass 5 tons/year in gross sequestration. These elite contributors should form the core of species selection for urban forest planning under climate mitigation frameworks. The findings align with the conceptual model proposed by (Livesley et al., 2016), who emphasized targeting 'high-yielding' species in heterogeneous urban matrices.

Importantly, (Prasad et al., 2020) found Delhi-wide sequestration rates approaching 1,300 tons per year. However, the site-specific sequestration rate of 91.69 tons/year for a single park reflects the potential for scaling such findings to city-wide levels, particularly if species selection is optimized. Moreover, while their work focused on dominant species like *Prosopis juliflora* which in this study contributed minimally, highlights the long-term inefficiency of over-relying on invasive or naturalized species. This discrepancy underscores the importance of context-specific assessments using standardized models like i-Tree Eco.

The presence of a large number of species storing less than 1 ton of carbon (16 species) and sequestering less than 0.05 tons/year (13 species) raises questions about the role of these trees. While their carbon contribution is limited, they may support biodiversity, aesthetics, and resilience. This nuanced understanding complements the arguments by (Tripathi & Joshi, 2015), who urged maintaining functional diversity in urban parks even when some species offer limited carbon services.

Taken together, the findings advocate for a strategic, data-driven approach to urban forestry that emphasizes native, evergreen, high-performing species for carbon services while maintaining a mosaic of other trees for ancillary ecosystem benefits. The economic justification provided by the valuation results also gives this strategy fiscal credibility. As carbon markets evolve, cities like Delhi can leverage tools like i-Tree Eco not only for planning but also to unlock revenue streams through carbon credits—a direction supported by emerging global frameworks (Du et al., 2025; Kim et al., 2024).

8. Conclusion:

The current study has provided a detailed, data-driven assessment of the carbon storage and sequestration potential of tree species in Deer Park, Hauz Khas, using the internationally recognized i-Tree Eco tool. The core outcomes not only quantify the ecological contributions of urban green spaces but also provide a robust framework for economic valuation and species-level prioritization. This allows urban planners, forestry professionals, ecologists, and policymakers to anchor urban greening efforts within a scientifically validated and economically defensible strategy.

At the most fundamental level, this research confirms that urban forests in dense metropolitan contexts like Delhi can offer significant contributions toward climate change mitigation through carbon sequestration and long-term carbon storage. The park, with 415 trees across 61 species, stores an estimated 1,545 tons of carbon and sequesters about 91.69 tons of carbon annually. While these numbers may seem modest in the larger context of city-wide emissions, they are quite substantial when scaled proportionately and replicated across Delhi's numerous parks and green belts. In a city struggling with air pollution, urban heat islands, and ecological degradation, every pocket of carbon-sequestering vegetation matters.

Importantly, the results reveal a highly skewed pattern of carbon contribution. Just a handful of species are responsible for the majority of the park's carbon storage and sequestration. For instance, *Azadirachta indica* (Neem), with 122 individuals, accounts for 604.4 tons of stored carbon—nearly 39% of the total—while also sequestering 30.59 tons annually. This affirms Neem's status as a cornerstone species for urban ecological planning in North India. Its high leaf area index, long lifespan, fast growth in semi-arid conditions, and resistance to pollution make it exceptionally well-suited to Delhi's challenging environment. Similarly, *Putranjiva roxburghii*, the most abundant species in the park (271 individuals), also emerged as a carbon storage and sequestration leader, storing 141.5 tons and sequestering 9.88 tons/year. These values strongly support the continued propagation of these species in urban green areas.

Other significant contributors included *Cassia fistula* (82.4 tons, 7.79 tons/year), *Bombax ceiba* (68 tons, 4.16 tons/year), and *Terminalia arjuna* (61.6 tons, 2.3 tons/year), all of which are native, deep-rooted species adapted to tropical and sub-tropical climates. This result is particularly important because it validates the ecological argument that native species often outperform exotic or ornamental species in long-term carbon assimilation due to their natural adaptation to local soil and climate conditions.

Beyond individual species, the study also revealed a striking dominance of evergreen trees in carbon dynamics. Evergreen species account for 1,036.2 tons of the total carbon storage and sequester 59.21 tons annually—far exceeding the contributions of deciduous (381.4 tons; 24.4 tons/year) and perennial species (127.5 tons; 8.07 tons/year). Given their continuous canopy cover and photosynthetic activity, evergreens provide year-round carbon capture, regulate microclimates, and offer shade—an invaluable asset in heat-stressed urban regions. Their superiority in mitigating atmospheric carbon makes them an essential category for future plantation drives.

Moreover, the study found that native species outperformed introduced and naturalized species by a wide margin. Native trees stored 1,329.94 tons of carbon and sequestered 79.45 tons/year, while introduced species contributed only 210.7 tons and 11.75 tons/year respectively. The lone naturalized species stored just 3.8 tons and sequestered 0.48 tons/year. This reinforces ecological theories of niche adaptation, where native species, having evolved in local bioclimatic conditions, are more efficient in ecosystem service provisioning. It also underlines the ecological risks of relying on introduced species, which, while aesthetically appealing or fast-growing, may offer limited environmental utility and could potentially disrupt native biodiversity.

From a future-oriented perspective, this study yields several actionable insights. Firstly, *Azadirachta indica*, *Putranjiva roxburghii*, and *Cassia fistula* should be considered primary species for urban afforestation and reforestation in Delhi and similar agro-climatic zones. Their superior performance in both static (storage) and dynamic (sequestration) carbon metrics makes them ideal candidates for carbon-centric tree planting programs. In fact, Delhi's municipal bodies could prioritize these species in the ongoing Miyawaki forest initiatives and institutional campus greening projects. Not only do they offer high carbon returns, but they also align with native biodiversity restoration goals.

Secondly, *Terminalia arjuna* and *Syzygium cumini* also show strong sequestration potential and bring the added advantage of improving hydrology and soil quality. These trees are traditionally associated with riparian zones and could be strategically used in green belts along urban water bodies like the Yamuna floodplains. Their integration into riverfront development and wetland rejuvenation projects could amplify ecological resilience while contributing to carbon neutrality targets.

Third, evergreen species like *Ficus virens*, *Polyalthia longifolia*, and *Pterospermum acerifolium* should be prioritized for high-traffic urban corridors, road medians, and institutional campuses. Their continuous foliage offers not just carbon capture but also noise attenuation, dust interception, and temperature regulation—services that are vital in Delhi's congested and heat-prone micro-environments. Given their moderate to high carbon values and low maintenance requirements, these species provide excellent cost-benefit ratios in long-term urban planning.

While the findings point strongly toward native and evergreen trees, the role of functional diversity cannot be ignored. Though certain species sequester or store less carbon, they contribute to overall park aesthetics, soil microbial health, urban fauna support, and educational or recreational values. A small number of ornamental or seasonal trees may therefore still be necessary for enhancing biodiversity and human engagement, provided they are chosen judiciously and do not outcompete native vegetation.

The findings also suggest a need for periodic monitoring of tree performance over time, especially under changing climatic conditions. Delhi's urban ecosystem is subject to frequent stressors—heat waves, dust storms, pollution episodes, and erratic rainfall—all of which can alter tree physiology. Future research could build on the current dataset by incorporating temporal analysis, soil carbon fluxes, and species-level growth modeling. Additionally, integrating remote sensing tools with ground-based i-Tree Eco surveys could facilitate larger-scale, real-time monitoring, as demonstrated by studies in China and South Korea.

In the broader context of climate policy, the results underscore the potential for cities to integrate urban forestry into climate mitigation agendas. India's push for developing voluntary carbon markets and creating tradable urban carbon credits could find a credible foundation in studies like this one. As carbon finance becomes more decentralized and accessible, data-driven inventories like the one conducted here could be registered under recognized carbon credit standards such as Verra's Verified Carbon Standard or India's proposed domestic registry.

Finally, the policy implications of the study are significant. Urban forestry must be recognized not merely as a beautification effort but as a form of critical infrastructure on par with roads, drainage systems, and water supply networks. Legislative mandates, such as mandatory green cover percentages for urban planning zones or carbon budget allocations for municipal corporations, could institutionalize tree planting based on scientifically derived metrics. Furthermore, public-private partnerships (PPPs) in green space development, linked to carbon offsetting obligations for construction or transportation companies, could turn ecosystem service provisioning into an economically sustainable enterprise.

In conclusion, this study provides a vital template for future urban forest planning, one that is ecologically sound, economically justified, and climatically urgent. It demonstrates that small urban forests, if planned and managed well, can serve as effective carbon sinks and socio-environmental assets. The case of Deer Park, Hauz Khas, while spatially limited, exemplifies how detailed, species-specific inventories can support national and global goals—be it the Paris Agreement, India's State Action Plans on Climate Change, or the Sustainable Development Goals (SDGs), particularly SDG 13 (Climate Action) and SDG 11 (Sustainable Cities and Communities).

As Delhi and other Indian cities confront the dual pressures of urban expansion and ecological degradation, adopting an evidence-based, locally adapted, and economically rational urban forestry model becomes not just beneficial but imperative. The insights and recommendations presented through this study aim to serve as a blueprint for such a transformation—rooted in science, sustained by community, and driven by a vision of greener, healthier, and more resilient cities.

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10.Appendix I :

i-tree Eco Data Collection Sheet				
Date			Place	
Surveyor:				

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

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

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

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

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

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