Role of Sacred Groves in Climate Change Mitigation: A Carbon Storage Assessment in Puducherry

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Abstract - **Sacred groves are traditionally protected forest patches conserved by local communities through religious and cultural practices. While their ecological and cultural importance is well recognised, their role in climate change mitigation through carbon storage remains underexplored. This study assesses the carbon sequestration potential of selected sacred groves in and around the Union Territory of Puducherry, India. Three representative groves— Suriyanpet, Urani, and Kizhputhupet—were selected based on size, vegetation density, and disturbance levels. A non-destructive sampling approach using 20 m × 20 m quadrats was employed to estimate above- and below-ground biomass using standard allometric equations, followed by carbon stock estimation through established biomass-to-carbon conversion factors. The results indicate that sacred groves function as significant carbon sinks despite fragmentation and increasing anthropogenic pressures. The study underscores the need to conserve and restore sacred groves as effective nature-based solutions for climate change mitigation, while also supporting biodiversity conservation and cultural heritage preservation.**

Keywords: Sacred Groves, Carbon Storage, Non-Destructive Biomass Estimation, Cultural Heritage Conservation.

I. INTRODUCTION

Nature has long provided essential ecosystem services that support human survival and well-being. Traditional ecological knowledge systems, particularly those rooted in cultural and religious practices, have historically played a vital role in protecting natural resources and offer valuable responses to the most pressing global challenges today— namely, biodiversity conservation and the mitigation of climate change impacts.

In India, religious beliefs have often encouraged the protection of elements essential for life, such as land, water, trees, and wildlife. Sacred groves represent one such indigenous conservation practice, where patches of native vegetation are preserved due to spiritual beliefs associated with local deities. These groves are often strictly protected, with restrictions on resource extraction, allowing them to remain relatively undisturbed over long periods. There are still some notable, active instances of traditional and cultural forms of biodiversity conservation in use today, such as sacred groves and sacred landscapes [1].

Sacred groves have been developed as a means of conserving biodiversity since antiquity. The fundamental reason for such practices enduring over the ages is the belief system that surrounds them. It is forbidden to remove any material from these groves, not even dead wood or twigs, as the grove's ruling deity guards everything within. These groves, remnants of native vegetation that have been mostly left undisturbed, can still be found all over the world. Although rooted in religious belief systems, the preservation of these groves is crucial for safeguarding germplasm that would otherwise be threatened by human interventions [2].

Despite their ecological importance, sacred groves are increasingly threatened by urbanisation, land-use change, and declining traditional value systems. While several studies have documented their roles in biodiversity conservation and cultural heritage, little research has examined their contributions to climate change mitigation. This highlights the need for quantitative assessments of their carbon storage potential, particularly in rapidly urbanising regions such as Puducherry.

In this context, the present study assesses the carbon storage potential of selected sacred groves in Puducherry, highlighting their role as natural carbon sinks. By analysing their capacity for carbon storage and capture of atmospheric carbon, a major contributor to global warming, the study underscores how conserving sacred groves not only protects local biodiversity but also contributes to climate change mitigation through enhanced carbon sequestration.

II. SACRED GROVES OF PUDUCHERRY AND CARBON SEQUESTRATION

Puducherry has a long tradition of sacred groves, safeguarded by religious beliefs and cultural practices. A patch of Tropical Dry Evergreen Forest (TDEF) dedicated to Lord

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Manjiny and Ayyanar, covering more than 20 hectares, has been documented [3] [4]. This grove was reported to support 104 plant species belonging to 44 angiosperm families.

Puducherry and the surrounding regions within a 350 km² sector of Tamil Nadu contain approximately 180 sacred groves, of which nearly 50 possess significant biodiversity value [5]. These groves function as important ecological and cultural landscapes, serving as repositories of large and mature tree specimens, recreational and spiritual spaces, refugia for endemic and rare species, research and learning sites, bird and animal habitats, sources of medicinal plants, gene banks for economically important species, and watersheds contributing to groundwater recharge. Well-preserved sacred groves are often likened to mini biosphere reserves.

In recent times, there are increasing indications that many sacred groves are deteriorating, largely due to inadequate management practices. The decline of sacred groves has been attributed to shifting priorities from biodiversity conservation toward temple construction and changing worship practices, the conversion of forest land into plantations or agricultural fields, the spread of monotheistic religions, and the influence of Western culture and modernisation [6].Given their considerable biodiversity and botanical significance, there is an urgent need to reassess and strengthen conservation strategies to ensure the long-term survival of sacred groves.

Recent studies have increasingly examined the role of vegetation in carbon sequestration, particularly within forested ecosystems and urban green spaces. However, the carbon storage potential of sacred groves—especially in coastal tropical regions such as Puducherry—remains inadequately explored. Although carbon storage in sacred groves of Central India [7] and Kerala [8] has been analysed, comparable studies have not yet been conducted in the context of Puducherry. This study seeks to address this gap by quantifying carbon storage in selected sacred groves using non-destructive biomass estimation methods.

III. STUDY AREA

Puducherry is situated along the southeastern coast of India at approximately 11.9°–12.1° N latitude and 79.7°–79.9°

E longitude, bordering the Bay of Bengal (Figure 1). The region experiences a tropical humid climate, characterized by high temperatures and humidity throughout the year. The natural vegetation of the region is classified as tropical dry evergreen forest.
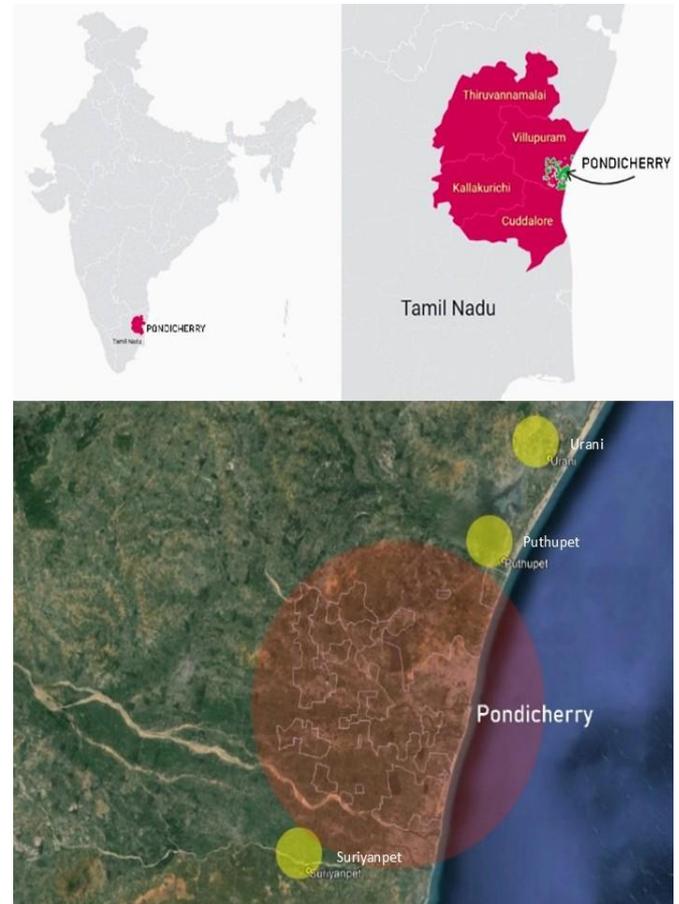

Figure 1: Site Location of Sacred Groves

The Auroville Botanical Gardens have conducted phytosociological studies of several sacred groves across the Puducherry, Villupuram, and Cuddalore regions, identifying them as biodiversity-rich remnants of tropical dry evergreen forest (Auroville Botanical Gardens, 2024). Three sacred groves located in and around Puducherry, India, were selected for the assessment of their carbon storage potential based on size, vegetation density, and representativeness—namely Suriyanpet, Urani, and Kizhputhupet (Table 1).

Table 1: Site Characteristics of Selected Sacred Groves

Sl No	Name of the Grove	Name of the Village	Area (Acre)	Remarks
1	Sri Ayyanar Thirukkovil	Suriyanpet	7.5	Low and Sparse Tree Cover
2	Sri Selliamman Thirukkovil	Urani	10	Dense and Tall Trees
3	Sri Ayyanarappan Thirukkovil	Kizhputhupet	20	Dense and Tall Trees

IV. METHODOLOGY

4.1 Sampling Method

Carbon storage in tree species can be estimated using both destructive and non-destructive methods, with the non-destructive approach being particularly suitable for protected and culturally significant forest patches, as it relies on allometric equations based on measurable parameters such as Diameter at Breast Height (DBH) and tree height, and avoids tree harvesting and physical disturbance [9][10]. Based on the initial field visit and observations of vegetation characteristics 20 m × 20 m quadrat was identified within each grove to represent the overall vegetation structure and density of the selected groves.

4.2 Biomass Estimation

The computation procedure for biomass estimation, [9][10]is as follows:

First, the tree morphological parameter, the Girth at Breast Height (GBH), which is a standard practice to measure at 1.32 m above ground surface was used to calculate the diameter (D), i.e. GBH was divided by π (3.14).

Biomass is computed for all 3 sacred groves using bio-statistics-based allometric equations. Above-ground biomass (AGB) is computed by multiplying the bio-volume by each tree species' wood density. Tree bio-volume (TBV) value was established by multiplying the diameter (D) and Height (H) of each tree species to the factor 0.40.[5&6]

Bio-volume (TBV) = 0.40x(D)^2xH   Equation:1

AGB = Wood Density x TBV   Equation:2

Where, D = (GBH/π), diameter (m) calculated from GBH, assuming the trunk to be cylindrical, H = Height (m), Wood Density oven-dry mass/fresh volume (gm/Cm^3) obtained from the Global Wood Density Database. The standard average density of 0.60 gm/Cm^3 is applied wherever the density value is not available for the tree species in the Wood Density database.[11]

Below Ground Biomass (BGB) is computed by multiplying the Above Ground Biomass (ABG) by 0.26 factors as the root: shoot ratio is established.

BGB = AGB x 0.26   Equation:3

Total biomass is the sum of Above Ground Biomass (AGB) and Below Ground Biomass (BGB).

Total Biomass (TB) = AGB + BGB   Equation:4

Carbon Estimation is generally for any tree species because 50 % of the Total Biomass (TB) is considered carbon [6&7].

Carbon Storage = Total Biomass x 50%   Equation:5

The non-destructive method was used to determine the carbon storage of individual trees and then extrapolate it to the entire grove using an empirical approach. This method most likely required monitoring crucial factors, including tree diameter, height, and species, to assess each tree's biomass and carbon content. The average values obtained from these individual tree measurements was extrapolated to the entire grove, yielding a non-invasive yet accurate estimate of the grove's carbon storage potential.

V. DATA COLLECTION

The extent and vegetation characteristics of the selected sacred groves, namely Suriyanpet, Urani and Kizhputhpet, were systematically observed and documented for identification of 20 m × 20 m quadrat. The observed characteristics of the sacred groves are described below.

5.1 Suriyanpet Sacred Grove

Figure 2: Aerial View of Suriyanpet Sacred Grove

Figure 3: Deities in Suriyanpet Sacred Grove

Suriyanpet Sacred Groves, located south of Puducherry, covers about 7.5 acres (Figure 2). It is home to several species from the same family, with the predominant species being *Aegle marmelos*. The trees exhibit an average height ranging between 6 and 8 m with girths varying from 0.25 to 0.75 meters (Figure 3).

5.2 Urani Sacred Grove

Urani is a 10-acre region north of Puducherry with a diverse range of tree types such as *Ficusreligiosa, Syzygiumcumini,* and *Garcinia spicata* (Figure 4). The trees in the region vary in height, and there is a recently constructed temple in the centre. The girth of the trees in Urani varies from 0.6 to 1.2 meters (Figure 5). The area is notable for its tall and dense foliage, which supports a variety of species.

Figure 4: Urani Sacred Grove

Figure 5: Deities in Urani Sacred Grove

5.3 Kizhputhupet Sacred Grove

Kizhputhupet sacred grove, located in Puducherry, contains only three types of species, namely Pterospermumsuberifolium, Madhucalongifolia and Azadirachtaindica (Figure 6 &7). The grove also contains a temple and is protected by local communities. The grove is accumulated with plastic waste due to increased anthropogenic intrusion. The 20m x 20m patch was selected for carbon storage study, which contains 7 trees.

Figure 6: Kizhputhupet Sacred Grove Site Map

Figure 7: Site Photo of Kizhputhupet Sacred Grove

Based on detailed field observations of the spatial extent, vegetation composition, and structural characteristics of all three selected sacred groves, a representative 20 m × 20 m quadrat was identified within each grove for detailed

investigation (Figure 8). The quadrats were carefully located to capture the overall vegetation structure, species composition, and tree density of each grove, while avoiding heavily disturbed edges, thereby ensuring that the sampled areas were representative of the respective groves.

Figure 8: 20m x 20m Study Area of Each Sacred Grove

VI. RESULTS AND DISCUSSION

Girth at Breast Height (GBH) in meters and overall height (m) of the trees and number of trees in the in the selected quadrat in all three sacred groves were measured through field study (Table 2).

Table 2: Structural Attributes of Trees in Sacred Groves

Sl No	Name of the Grove	No of Trees	Species Type	Average GBH (M)	Average Overall Height (M)	Dia-meter (m)
1	Suriyanpet	12	Singular	0.56	6.5	0.17
2	Urani	4	Multi	1.25	12	0.31
3	Kizhputhupet	7	Multi	0.75	10	0.23

Based on the data collected, diameter (m), wood density (g/cm³), bio-volume (TBV) (cu.m), above-ground biomass (AGB) (Kg), below-ground biomass (BGB) (Kg), total biomass (TB) (Kg) and total carbon (tC) (Kg) were calculated. The findings are given in Table 3.

Table 3: Tree Biomass and Carbon Stock Estimation in of selected sacred groves

SL NO	NAME OF THE GROVE	Wood density (gm/Cm^3), oven dry mass/fresh volume*	Diam eter (m)	Bio-Volume (TBV) Cu.m	AGB (Kg)	BGB (Kg)	TB (Kg)	tC (Kg)	No of Trees in the grid	Total tC (Kg) for the grid
1	Suriyanpet	0.6	0.17	0.09	0.05	0.01	0.07	0.03	12	0.39
2	Urani	0.9	0.31	0.46	0.42	0.11	0.52	0.26	4	1.05
3	Kizhputhupet	0.7	0.23	0.21	0.15	0.04	0.19	0.09	7	0.65

The overall carbon storage potential of the sacred groves can be calculated by summing the total carbon (tC) values for each grove. This calculation considers both the above-ground biomass (AGB) and below-ground biomass (BGB) of the trees in the groves. The total carbon storage potential of the sacred groves, computed by adding the individual grove values, provides an indication of the carbon sequestration capacity of these vital ecosystems.

Table 4: Area-Wise Carbon Storage Estimation in Selected Sacred Grove

Sl No	Name of the Grove	Area	tC (Kg) (20*20 M = 400 SQM)	tC (Kg) / Acre	Total Carbon Storage tC (tons)
1	Suriyanpet	7.5	0.39	3.9	0.03
2	Urani	10	1.05	10.5	0.11
3	Kizhputhupet	20	0.65	6.5	0.13

The structural attributes of trees, including wood density, GBH, height, biomass, and carbon content, were analysed for each sacred grove. The results indicate variations in carbon storage across the three sites, influenced by vegetation density, tree size, and species composition. Urani Sacred Grove exhibited the highest carbon storage potential due to dense and

mature tree cover, followed by Kizhputhupet and Suriyanpet. Although Suriyanpet had lower biomass values, it still contributed measurably to carbon sequestration.

Area-wise extrapolation revealed that even small patches of sacred groves can store significant amounts of carbon when preserved in their natural state.

VII. CONCLUSION

The findings of this study indicate that sacred groves function as effective carbon storage systems, contributing to climate change mitigation - one of the most pressing global challenges today. Approximately 0.25 tonnes of carbon were stored within the selected study patches alone, suggesting that substantially higher carbon stocks could be realized if sacred groves across the region are comprehensively documented and maintained. With appropriate policy support and community-based incentives, these groves can be better conserved, thereby sustaining both regional biodiversity and ecosystem services.

The carbon storage estimates, derived using non-destructive field-based methods highlight the significant role of sacred groves in sequestering carbon. Beyond their ecological value, sacred groves emerge as important nature-based solutions that integrate cultural heritage with climate action. This study reinforces the need to recognize, conserve, and restore sacred groves as valuable natural assets capable of delivering long-term environmental and climate mitigation benefits.

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