ANALYZING PLANT SPECIES DISTRIBUTION IN SACRED GROVES THROUGH SPATIAL CLUSTERING

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ABSTRACT

Sacred groves are patches of natural vegetation preserved through local taboos and sanctions that entail spiritual and ecological values. Sacred Groves play a vital role in preserving the ecological balance and biodiversity. They offer crucial ecosystem services like carbon sequestration, soil conservation, and habitat preservation. Preserving them is key to mitigating the impacts of climate change and maintaining ecosystem resilience. This study involved the design and development of technology tools such as a mobile app for field data collection and a Web-based analytical Dashboard. A detailed field data collection was carried out to identify the plant species across 108 sacred groves in the *Pathanamthitta* district. Among 479 plant species found in these groves, 146 were trees and 333 were non-trees, including shrubs, lianas, and herbs. The dominant tree species, *Caryota urens L*, was found with a total count of 427 individuals in the 90 sacred groves. Furthermore, 41 species were listed in the IUCN status, with 17 being trees and 24 being non-trees, highlighting the conservation significance of these groves and emphasizing the necessity of their protection. Nearest neighbour analysis revealed species clustering with low index values, while hotspot analysis identified clusters of species characterized by high and low species richness. The identified low species richness patches potentially indicated a risk of extinction of species that need immediate intervention for conservation.

Keywords: Sacred groves, Spatial analysis, Geo-computational modelling

1. INTRODUCTION

Sacred groves act as natural carbon sinks, and their dense canopies play a crucial role in sequestering carbon dioxide and mitigating climate change. These groves provide essential ecosystem services, such as soil conservation, habitat preservation, and microhabitats for numerous endemic and rare species of flora and fauna. Many plant species found in sacred groves hold medicinal value, serving as sources of traditional knowledge and remedies for local communities. Moreover, the presence of plant species listed on the International Union for Conservation of Nature (IUCN) Red List underscores the significance of sacred groves, highlighting their role in providing shelter for endangered and vulnerable species. Understanding the distribution patterns of plant species within sacred groves is essential for formulating effective conservation strategies and ensuring the long-term viability of these unique ecosystems.

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Spatial analysis and geocomputational modeling offer powerful tools for studying plant species distribution patterns and ecological dynamics within sacred groves. Using advanced spatial analysis techniques such as hotspot analysis, nearest neighbour analysis, and spatial density estimation, it can solve the complex spatial relationships among plant species and their environments. The spatial distribution of medicinal and herbal plants in semi-arid and arid zones is influenced by anthropogenic activities and land use patterns, with a notable decline in plant species diversity as altitude increases [1]. Similarly, in sacred groves, the conservation status of plant species is influenced by both natural and anthropogenic factors. Integrating GIS and spatial analysis techniques can facilitate the identification of critical conservation areas, promoting more effective preservation strategies. Spatial clustering techniques have been advanced through the integration of the Getis–Ord Gi* statistic with k-means clustering, offering a novel method for identifying spatial clusters of orchard trees and improving agricultural landscape management [2]. In sacred groves, similar clustering techniques can be applied to analyze the spatial distribution of various plant species, ensuring the sustainable management of these ecologically significant areas. To address challenges in handling high-dimensional datasets, modifications to the density peaks clustering (DPC) algorithm have been proposed, enhancing its accuracy in cluster identification [3]. By incorporating k-nearest neighbors (KNN) and principal component analysis (PCA), the enhanced DPC-KNN-PCA algorithm demonstrates improved performance in cluster detection and data preprocessing, offering a promising tool for cluster analysis in various domains. Effective geospatial data analysis relies on optimal geo-clustering approaches, with recent innovations focusing on clustering geodata for online maps to improve visual analysis and situational awareness [4]. The analysis of point-event data, ranging from individual location data to spatial epidemiology datasets, presents diverse challenges and methodological considerations, necessitating careful selection of spatial cluster analysis techniques to address thematic issues [5].

The objective of the study is to explore the application of advanced spatial analysis and geocomputational modeling techniques to understand the distribution patterns and conservation status of plant species within sacred groves. Integrating methods such as hotspot analysis, and nearest neighbour analysis, can uncover the complex relationships between plant species and their environments.

2. MATERIAL AND METHODS

2.1 Study area and data collection

To facilitate field data collection and analysis, developed technology tools including a mobile app and a web-based analytical dashboard. The mobile app was used for collecting field data on plant species within the sacred groves. The web-based dashboard provided a comprehensive platform for data visualization and analysis. Investigated the distribution patterns of plant species across 108 sacred groves in the *Pathanamthitta* district as shown in Figure 1.

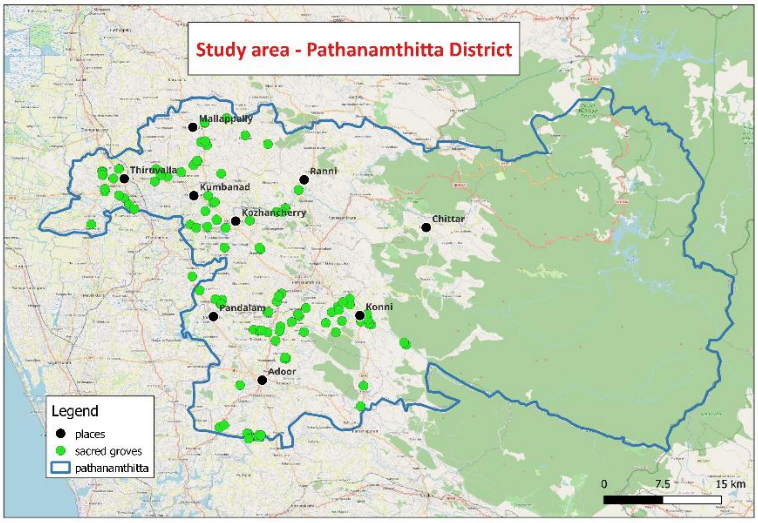

Figure 1. Study area map of the Pathanamthitta district.

A total of 479 plant species were identified, including 146 tree species and 333 non-tree species such as shrubs, lianas, and herbs. The dominant tree species, Caryota urens L., was found with a total count of 427 individuals in the sacred groves, while Chassalia curviflora ophioxyloides (Wall.), the dominant non-tree species, was found across 85 groves with a total of 228 individuals. Additionally, 41 species were listed in the IUCN Red List, with 17 being trees and 24 being non-trees, emphasizing the conservation significance of these groves. The collected data were analyzed using spatial analysis techniques.

2.2 Hotspot Analysis

A hotspot is a place or a small area with a concentration of species inside a designated boundary. To locate the hotspots of various species, used the Getis-Ord Gi* method which identifies clusters produced by features with high or low values by analyzing both the local and global situations. It assesses each feature along with its neighbouring features within the same dataset. A statistically significant Z score results when the local sum of a feature and its neighbours is significantly different from the sum of all features or is too large to be the result of random chance. This analysis is visualized through hotspot maps, which highlight areas of interest for further investigation.

Additionally, the use of spatial weights and autocorrelation measures is consistent with the principles of spatial point pattern analysis to geographical epidemiology [6]. Spatial weights are generated using the K-nearest neighbour method, and these weights are standardized. Local spatial autocorrelation is calculated using the Getis-Ord Gi* statistic, identified hotspots (high values) and cold spots (low values) of plant counts. P-values and z-scores are used to determine the significance of these spots. A map with red and blue markers for hotspots and cold spots, respectively, integrates seamlessly with a WebGIS platform. The hotspot analysis of *Caryota urens L* and *Chassalia curviflora ophioxyloides (Wall.)* is shown in Figure 2 and 3.

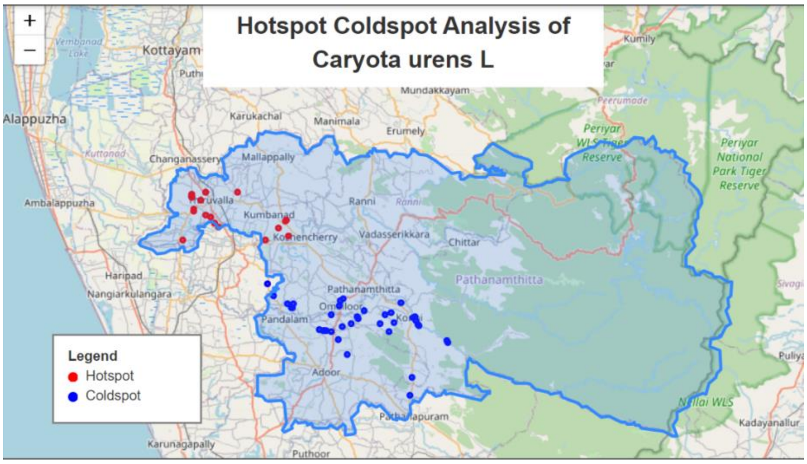

Figure 2. Hotspot analysis of Caryota urens L.

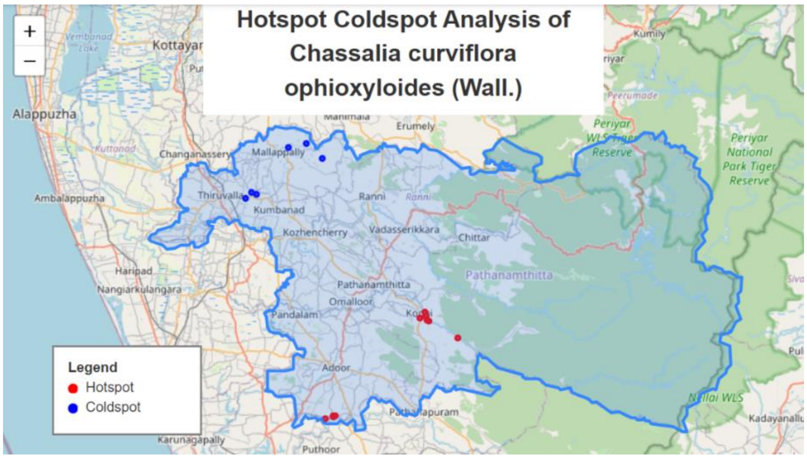

Figure 3. Hotspot analysis of Chassalia curviflora ophioxyloides (Wall.).

2.3 Nearest Neighbour Analysis

Nearest-neighbour analysis (NNA) is a technique used to evaluate the deviation of a spatial point pattern from randomness, indicating whether it exhibits clustering or regularity. In this analysis, Python's SciPy library is employed, and users can select a species through a spatial query in PostGIS. During NNA, a popup displays key metrics such as observed mean distance, expected mean distance, nearest neighbour index, number of points, and Z-Score. By examining the nearest neighbour index value in the popup, users can easily determine whether a species is clustered or not. This method builds a refined nearest-neighbor approach to identify cluster features in overlaid spatial point processes [7].

3. RESULTS AND DISCUSSION

Significant hotspots and cold areas of various plant species inside the sacred groves were determined using the Getis-Ord Gi* technique. The analysis revealed clusters characterized by high and low species richness. High-value clusters (hotspots) indicated areas with a high concentration of species, while low-value clusters (cold spots) suggested areas with lower species diversity. For *Caryota urens L*, the hotspot analysis revealed Z-scores as shown in Table 1, indicating 19 hotspots where species are densely clustered. Conversely, 37 coldspots, which indicated areas with significantly lower species density. Similiarly, *Chassalia curviflora ophioxyloides (Wall.)*, hotspots had Z-scores between 1.5075 and 2.8505 (10 hotspots), while

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coldspots ranged from -2.4256 to -1.5625 (6 coldspots). The identification of areas with high species richness (hotspots) underscores the need for protection to maintain biodiversity. Conservation efforts should focus on these hotspots to ensure the survival of species with high conservation value. Conversely, the identification of cold spots, which may be at risk of species extinction due to environmental stressors or anthropogenic activities, indicates that immediate conservation interventions are necessary in these low-rich patches. This approach is essential to prevent further biodiversity loss and ensure the sustainability of the ecosystem.

Table 1. Hotspot analysis for dominant tree and shrub.

Plant Species name	Hotspot/coldspot	count	Min Z-Score	Max Z-Score
Caryota Urens L	Hotspot	19	1.9024774	4.156341
	Coldspot	37	-2.130916	-1.589373
Chassalia curviflora ophioxyloides (Wall.)	Hotspot	10	1.507532	2.850489
	Coldspot	6	-2.425590	-1.562541

The spatial arrangement and linkages between plant species and sacred groves were revealed using the Nearest Neighbour Analysis (NNA). Through spatial queries, users can select dominant species for which the NNA is performed. Based on the index values, it becomes evident whether the species is clustered in the geographical area. The key metrics for Caryota urens L. and Chassalia curviflora ophioxyloides (Wall.) are provided in Table 2. For Caryota urens L., the low nearest neighbour index indicates a strong clustering pattern. Similarly, Chassalia curviflora ophioxyloides (Wall.) also shows a significant clustering pattern. These results highlight the dense clustering of these species within certain areas of the sacred groves, providing crucial information for developing targeted conservation strategies.

Table 2. Nearest neighbour analysis for dominant tree and shrub.

Plant sp. Name	Observed mean distance	Expected mean distance	Nearest neighbour index	Number of points	Z-Score	Cluster status
Caryota Urens L	0.009102	0.019360	0.470164	90	-9.615963	cluster
Chassalia curviflora ophioxyloides (Wall.)	0.008562	0.020052	0.426993	85	-10.106479	cluster

The integration of technology tools, including a mobile app for field data collection and a WebGIS platform for integration and dynamic visualization, significantly enhanced the efficiency and accuracy of our study. This approach is consistent with the geospatial analytical frameworks, which emphasize the role of technology in improving spatial data analysis and decision-making [8]. The findings of this study underscore the ecological importance of sacred groves as critical habitats for biodiversity conservation. The presence of IUCN-listed species within these groves further highlights their role in preserving endangered and vulnerable species. However, the identification of cold spots, which may be at risk of species extinction due to environmental degradation or human activities, calls for immediate conservation interventions. These results are consistent with the utility of spatial clustering techniques in identifying areas requiring urgent conservation action [9].

4. CONCLUSION

This study highlights the critical role of sacred groves in maintaining biodiversity and ecological balance, revealing significant patterns of species distribution through advanced spatial analysis techniques. For Caryota urens L., hotspot analysis identified 19 densely clustered areas and 37 cold spots with notably lower species density, while Chassalia curviflora ophioxyloides (Wall.) exhibited 10 hotspots and 6 cold spots, with both species demonstrating strong clustering patterns as confirmed by low nearest neighbor index values. These findings emphasize the importance of sacred groves as vital habitats for biodiversity conservation, particularly given the presence of high plant species diversity and IUCN-listed species, which underscore their role in sustaining ecosystem health and delivering essential services. The results call for targeted conservation strategies to protect these key areas and ensure their continued contribution to biodiversity. Integrating advanced spatial analysis techniques, such as machine learning and real-time geospatial monitoring, could further enhance our understanding and management of biodiversity in sacred groves and other critical habitats, paving the way for more effective conservation efforts globally.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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