

MAPPING URBAN TREE CANOPY LOSS AS AN INDICATOR OF DEVELOPMENT PRESSURE IN THE COLOMBO METROPOLITAN AREA (2004–2024)

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Abstract: Urban tree canopy is essential to ecological resilience and liveability, yet increasingly threatened by urban growth. This study quantified canopy change in the Colombo Metropolitan Region from 2004 to 2024, using high-resolution Google Earth imagery and a 500m grid-based Tree Cover Mapping approach. Development pressure was modelled in ArcGIS through a composite index combining accessibility, population density, built-up intensity, and land use. Canopy cover declined from 31.45% (8,978 ha) to 23.19% (6,619 ha), with losses concentrated in high-pressure zones such as Pettah, Borella, and Battaramulla. Pearson and Spearman analyses show a moderate, statistically significant positive association between the Development Pressure and the Canopy Reduction (Pearson's $r = 0.36$; Spearman's $\rho = 0.34$; $p < 0.001$; $N = 947$), confirming that higher pressure is strongly linked to greater canopy loss. Spatial overlays revealed areas under high pressure show stronger canopy reduction and retain less canopy, whereas low-pressure areas particularly public and protected lands maintain or increase cover. A 30–40% canopy “transition range” in moderate-pressure areas signals a critical intervention point. These findings demonstrate that how nuanced spatial patterns, provide actionable evidence for integrating canopy targets, targeted greening, and systematic monitoring into Colombo's planning policies to balance urban development with ecological sustainability.

Keywords: tree cover loss, development pressure, urban green infrastructure, Tree Cover Mapping tool, GIS

1. Introduction

Urban tree canopy is a critical component of green infrastructure, enhancing ecological sustainability and urban liveability. Trees help regulate microclimates, reduce air pollution, mitigate stormwater runoff, and support human well-being (Nowak & Greenfield, 2012; Tzoulas et al., 2007). Yet, in many rapidly urbanizing cities of South and Southeast Asia, tree cover is steadily declining due to expanding built-up areas and competing land demands (Seto, Güneralp, & Hutyrá, 2012). In such contexts, green spaces are often undervalued in planning decisions, resulting in fragmented urban landscapes and reduced ecosystem services.

Colombo Metropolitan Region, Sri Lanka's commercial and administrative capital, has experienced profound urban transformation over the past two decades. Economic liberalization, infrastructure megaprojects, and population growth have driven the city's expansion from its historic core into surrounding areas, converting natural and semi-natural landscapes into built-up zones (UDA, 2020). This growth exerts pressure on remaining green spaces, particularly tree cover, across both public and private land. Although sustainable urban development is a stated policy goal, empirical evidence on the spatial and temporal dynamics of tree canopy loss in Colombo remains limited.

Advances in remote sensing and geospatial technologies now allow high-resolution monitoring of tree cover change, providing spatially explicit data that can serve as proxies for assessing development pressure (Weng, 2012). Such tools, especially the internationally recognised Tree Cover Mapping Tool developed by the U.S. Forest Service, enable quantification of canopy cover and associated ecosystem services with consistent accuracy (Nowak et al., 2021). When applied within a GIS framework, these methods can map and track canopy change over time, providing valuable insights for urban policy and green infrastructure planning.

This study analyses tree canopy change in the Colombo Metropolitan Area between 2004 and 2024 using satellite imagery, the Tree Cover Mapping tool, and spatial analysis techniques. By identifying where canopy loss overlaps with urban expansion, it seeks to produce evidence for targeted ecological interventions and planning decisions.

1.1 RESEARCH PROBLEM

Despite being a key element of urban green infrastructure, Colombo's tree canopy has significantly declined in the last two decades, particularly during periods of intense development (Atapattu et al., 2022; Fonseka et al., 2023). While studies have assessed overall green cover or impervious surface growth (Andrieu et al., 2024), few have isolated tree canopy loss as a distinct and measurable indicator of development pressure.

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Existing remote sensing studies (Fonseka et al., 2023; Jayaweera, 2021) map vegetation broadly but do not leverage tree-specific tools such as Tree Cover Mapping to quantify canopy loss at a citywide scale. As a result, planners lack precise, actionable insights to guide zoning, reforestation priorities, and climate resilience strategies. This gap is particularly critical in Colombo, where rapid infrastructure expansion, commercial intensification, and housing demand continue to reshape land use (UDA, 2020).

By applying a tree specific, GIS- integrated approach, this research generates empirical, spatially explicit evidence of canopy loss over two decades and correlates it with development trends. The findings can inform green infrastructure policy, environmental justice initiatives, and Sustainable Development Goals (SDG 11: Sustainable Cities and Communities; SDG 15: Life on Land).

1.2 RESEARCH QUESTIONS AND SUCCESS CRITERIA

To guide the study and ensure methodological clarity, the following research questions were formulated:

- I. What are the spatial and temporal patterns of tree canopy change in the Colombo Metropolitan Region between 2004 and 2024?
- II. How does the observed canopy change spatially correspond with varying levels of development pressure across the region?
- III. Can grid based analysis identify threshold conditions or “transition levels” of canopy cover that may signal heightened vulnerability to development pressure?

These questions were supported by a set of success criteria intended to ensure analytical rigor and policy relevance. The study aimed to (i) generate transparent and reproducible canopy estimates using a consistent Tree Cover Mapping sampling approach, (ii) establish meaningful statistical and spatial relationships between canopy change and development pressure, and (iii) identify actionable thresholds that can inform urban greening strategies, zoning amendments, and targeted interventions for canopy protection.

2. Literature Review

Urban tree cover is a cornerstone of green infrastructure, shaping the spatial, environmental, and social quality of cities. In planning theory and practice, trees are not merely ecological assets but integral components of urban form, public space design, and climate resilience strategies (Jim, 2004; Gill et al., 2007). They improve thermal comfort, enhance walkability, support biodiversity corridors, and contribute aesthetic and cultural value, thereby influencing both liveability and spatial equity (Tzoulas et al., 2007; Kabisch et al., 2016).

2.1 TREE COVER LOSS AND URBAN DEVELOPMENT PRESSURE

Globally, urban expansion, densification, and large scale infrastructure projects are among the main drivers of vegetation loss. In rapidly urbanizing South and Southeast Asian cities, weak enforcement of planning regulations and speculative land markets often result in the conversion of green spaces into impervious surfaces (Seto et al., 2012; Andrieu et al., 2024). In Colombo, remote sensing studies reveal a marked reduction in tree canopy since the early 2000s, with sharper declines after 2010 as large infrastructure projects accelerated (Atapattu et al., 2022). Fonseka et al. (2023) found that vegetation loss strongly correlates with rising land surface temperatures and built-up area growth, while Jayaweera (2021) linked canopy decline to intensified Surface Urban Heat Island (SUHI) effects. These studies underscore the ecological costs of unregulated urban expansion but tend to focus on overall vegetative cover rather than tree canopy as a discrete metric.

2.2 MAPPING TREE COVER

Remote sensing and GIS have transformed urban vegetation monitoring by enabling scalable, repeatable, and cost-effective analysis. Common approaches such as the Normalized Difference Vegetation Index (NDVI), supervised classification, and post classification change detection provide robust measures of vegetative change (Weng, 2012; Yang & Zeng, 2023). The increasing availability of high-resolution satellite imagery such as Planet, Scope and Sentinel-2 has further improved the accuracy of tree level mapping. In Sri Lanka, most remote sensing research has emphasized broad land cover categories (e.g., forest, grassland, built-up), which limits the capacity to detect canopy-specific changes (Fonseka et al., 2023). This constrains the ability to measure development pressure precisely and to value the structural role of tree canopies in urban ecosystems.

2.3 THE TREE COVER MAPPING APPROACH IN URBAN CANOPY STUDIES

The Tree Cover Mapping Tool, developed by the U.S. Forest Service, has become a global standard for urban forest assessment. The Tree Cover Mapping tool estimates percent tree cover through random sampling of high-resolution imagery, making it especially valuable in data-limited contexts (Nowak et al., 2018). While widely applied in North America, Europe, and East Asia, its application in South Asia especially in integration with GIS workflows remains rare.

Studies that combine Tree Cover Mapping outputs with spatial analysis demonstrate its potential for policy relevant insights. For example, Zardo et al. (2022) used Tree Cover Mapping data in Sao Paulo to uncover inequities in green resource

distribution, highlighting the tool’s ability to inform environmental justice debates. Embedding Tree Cover Mapping within GIS platforms such as ArcGIS allows direct correlation between canopy change and land-use dynamics, making it particularly well-suited for assessing development-driven ecological stress (Nowak et al., 2021).

2.4 SUMMARY AND GAP

The literature clearly establishes the ecological and social importance of urban tree cover, the accelerating loss of canopy under development pressure, and the capacity of remote sensing and GIS to map these changes. However, Colombo’s canopy loss has rarely been analysed using tree-specific metrics such as those provided by Tree Cover Mapping, and almost never within a GIS based spatial correlation framework. This gap justifies the present study’s approach: quantifying two decades of canopy change and spatially linking it to patterns of urban development to inform both planning and policy.

3. Research Methodology

3.1. STUDY AREA

The Colombo Metropolitan Region (CMR) spans 245.8 km² and includes the commercial core of Colombo city as well as its administrative and suburban areas. As Sri Lanka’s political and economic capital, the CMR hosts a high concentration of government institutions, financial centres, residential neighbourhoods, and major transport corridors.

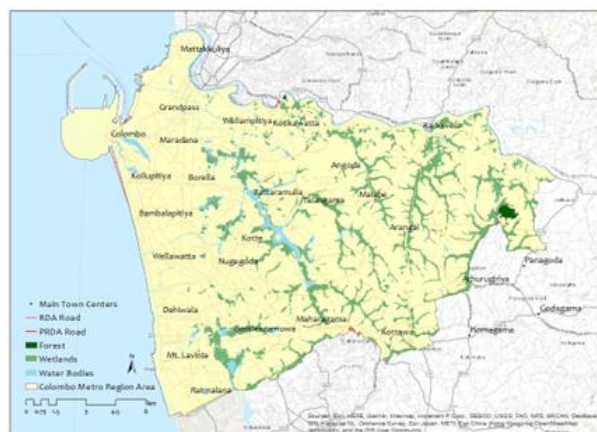


Figure 1: Study area Source: Author, 2025

Geographically, the region encompasses coastal belts, wetlands, dense urban centres, and rapidly developing peri-urban sectors. This diversity makes it both a dynamic growth hub and an ecologically sensitive landscape where competing land use demands place substantial pressure on tree cover. The CMR is also the focal area for the Colombo Metropolitan Regional Structure Plan 2040, reinforcing its relevance as a case study for understanding how development pressure affects urban green infrastructure.

3.2 METHODOLOGY

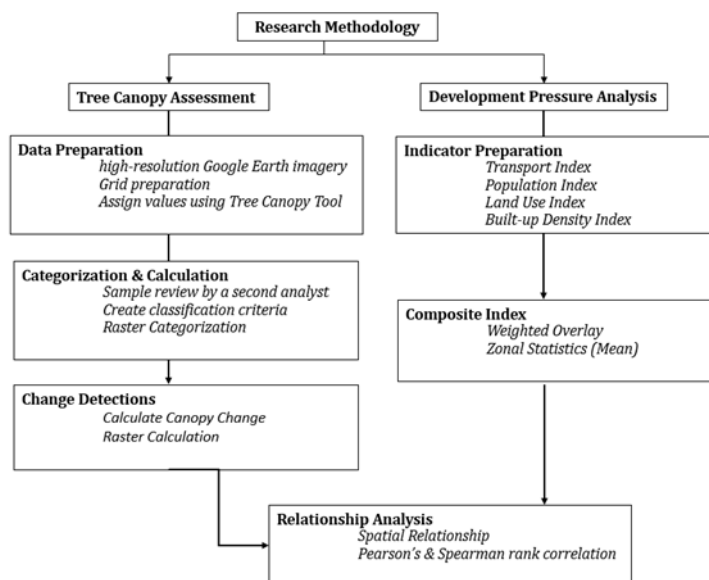


Figure 2: Methodology Source: Author, 2025

3.3 DATA SOURCES AND ANALYTICAL TOOLS

3.3.1 Data for tree canopy cover analysis

Table 1: Data for tree cover analysis

Data Type	Description	Source
Satellite Imagery	High-resolution imagery for selected years (e.g., 2004,2014,2024)	Google Earth

Source: Author, 2025

To maintain temporal consistency, imagery years were harmonized to 2004, 2014, and 2024, corresponding to the closest available high-quality Google Earth scenes with minimal cloud cover and clear vegetation visibility. Although slight seasonal variation exists across these images, all selected dates fall within comparable mid-year periods. This reduces the influence of leaf-flush seasonality, shadow length, and monsoonal vegetation changes, ensuring that canopy differences primarily reflect genuine landscape change rather than seasonal effects.

Tree canopy cover in 2004, 2014, and 2024 was estimated using high-resolution Google Earth imagery in combination with the Tree Cover Mapping approach. Following the sampling-based tree cover mapping workflow described in the U.S. Geological Survey Tree Cover Mapping Tool (Cotillon & Mathis, 2016), a systematic spatial framework was developed to visually interpret tree presence at evenly distributed point locations within 500m x 500m grid net covering the Colombo Metropolitan Area.

The size of the grid was determined considering the extent of the area, time taken to estimate tree canopy within each grid, and the average extent of tree present in an existing land use layer.

At each point, the visible land cover was manually identified as “tree cover” as a parentage based on canopy structure observed in the imagery. The proportion of points identified as “tree” canopy” estimated per grid cell was attributed to grid centroid and repeat the process citywide for each year.

A reviewer validation process was implemented, where 10% of the sampling locations were independently re-interpreted by a second analyst. Interpretation disagreements were reconciled through discussion to harmonize classification criteria and strengthen reliability across all mapped years.

Following attribution, values of centroid points were stratified in to (number) categories for mapping the tree canopy cover in ArcGIS Pro. Tree cover change was then quantified by subtracting canopy raster between 2004–2014 and 2014–2024 using the Raster Calculator tool. Resulting changes were categorized into canopy gain, loss, and no-change zones for spatial pattern interpretation.

Table 2 : Temporal change scoring system

2004		2014		2024	Score	
T1	>	T2	>	T3	10	Continually decreases
T1	>	T2	=	T3	9	
T1	=	T2	>	T3	8	
T1	>	T2	<	T3	7	
T1	<	T2	=	T3	6	
T1	=	T2	=	T3	5	No change
T1	=	T2	<	T3	4	
T1	<	T2	>	T3	3	
T1	<	T2	<	T3	2	Continually increases

To support spatial interpretation of long-term canopy trends at each grid, a temporal change scoring system was applied based on the directional change between the three observation years (2004 = T1, 2014 = T2, 2024 = T3). Each time point was assigned one of three score values: Null or ambiguous records (e.g., inconsistent directional shifts) were removed to avoid misclassification.

3.3.2 Data for Development Pressure Analysis:

Table 31: Calculation of Development Pressure Index

Development Pressure Index						
Index	Criteria			Index Weighted	Weighted	Overall, Weight
Transport Index		Road Layer (1:2000)	Line Density	4	50	25
				3		

	Motor Vehicle Roads (Road Density)	prepared by UDA		2	50	
				1		
	Public Transport Rout (Buffer)	Road Layer (1:2000) Prepared by UDA	0-0.2km	4		
			0.2-0.3km	3		
			0.3km-0.5km	2		
More than 0.5km			1			
Population Index	Population Density	Density Calculation	100m	4	50	25
			100m-200m	3		
			200m-300m	2		
			More than 0.5 km	1		
	Population Growth	Growth rate Calculation	0.5km	4	50	
			0.5km - 1.0km	3		
			1.0km - 1.5km	2		
			1.5km- 2.0km	1		
Landuse Index	Landuse (Reclassification)	Landuse Layer (1:2000) prepared by UDA	Transportation	6	100	25
			Commercial	5		
			Institutional	4		
			Industrial	3		
			Residential I	2		
			Recreational/Green/ Water Bodies Areas	1		
built-up density	Building (Polygon Convert in to point)	Building Layer (1:2000) Prepared by UDA	Point Density	4	100	25
				3		
				2		
				1		

Source: Author, 2025

To assess development pressure, a Composite Development Pressure Index (CDPI) was developed using a weighted raster overlay approach in ArcGIS Pro. Four thematic raster layers were included: (1) Accessibility - distance to major roads and distance to public transport routes, (2) Population density - raster derived from census spatial allocation, (3) Built-up intensity - impervious surface density and building height index rasters, and (4) Land use - commercial and industrial land-use raster classes. Each raster layer was normalized to a common 0–1 scale using min–max transformation, ensuring that higher values represent higher development pressure. Weighting for the Composite Development Pressure Index (CDPI) was assigned equally across the four components, with each receiving a weight of 0.25 to ensure balanced representation without emphasizing any single factor. The weighted rasters were then combined using the Weighted Overlay tool in ArcGIS Pro to produce the final CDPI surface, representing relative development intensity across the Colombo Metropolitan Region. In ArcGIS, development pressure was initially modelled at a finer resolution (50 m × 50 m) than the tree canopy grid (500 m × 500 m). To enable a comparable overlay analysis, the Zonal Statistics (Mean) function was used to aggregate the finer development pressure raster into the coarser canopy grid framework. This tool calculates the average value of all fine-resolution cells contained within each 500 m canopy grid cell using following equation, generating a mean development pressure score per zone for subsequent analysis.

where n = number of fine cells contained within coarse cell C

The mean development pressure value for C is then calculated as:

$$\text{Mean}(C) = \frac{1}{n} \sum_{i=1}^n x_i$$

x_i = development pressure value of the i^{th} fine cell

n = number of fine cells included inside coarse grid cell C

Pearson’s correlation was first used to evaluate the linear association between the Composite Development Pressure Index and the Tree Cover Reduction Index at the 500 m grid scale. Spearman’s rank correlation was then calculated to capture potential non-linear but monotonic relationships, as ecological interactions between development pressure and canopy change may not be strictly linear. All correlations were computed for $N = 947$ grid cells. This method is less sensitive to outliers and distribution assumptions, making it suitable for heterogeneous urban spatial data.

To identify vulnerable transitional areas, grid cells located within moderate and high development pressure classes were flagged as priority monitoring zones, particularly where canopy trends fell within the “continually decreasing” category. These areas were interpreted as being at risk of accelerated ecological decline if development intensification continues.

4. Data analysis

4.1 Overview of Tree Canopy Change (2004–2024)

Tree cover in the Colombo Metropolitan Area has declined steadily over the last two decades. Based on the Tree Cover

Mapping estimates in a 500 m × 500 m grid analysis, the total canopy cover dropped from 8,978 hectares in 2004 to 7,612 hectares in 2014, and further to 6,619 hectares in 2024. Given the study area's total land extent of 28,544 hectares, this reflects a reduction in canopy coverage from 31.45% (2004) to 23.19% (2024) a net loss of over 2,300 hectares of tree cover in 20 years.



Figure 3: Canopy Cover from 2004,2014 & 2024
 Source: Author, 2025

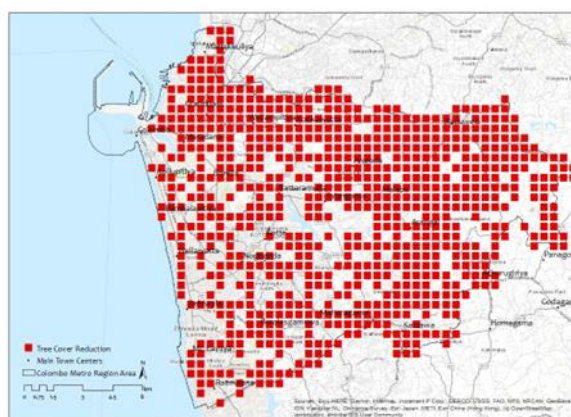


Figure 4: Tree Cover Reduction 2004-2024
 Source: Author, 2025

In 2024, the most prevalent tree cover range across the study area was the 30–40% category, indicating medium canopy density. These grid cells were primarily located in residential areas, such as Nugegoda and Wellawatta, which still maintain a mix of private gardens, street trees, and small public green spaces. Very Low (0–10%) and Low (10–30%) tree cover zones were concentrated in high-density commercial and mixed-use areas such as Pettah, Maradana, and portions of the Colombo Core area. These zones exhibit extensive impervious surfaces and minimal street-level vegetation. High (40–60%) and Very High (60–100%) canopy zones corresponded to public parks, institutional lands, conservation zones, and wetland buffers. Notable examples include Diyatha Uyana, the Parliament Grounds, Bellanwila, Attidiya Sanctuary, and Kimbulawala Park. figure 4 show how tree cover varied between 2004–2024. Each cell was analysed to determine whether there was an increase, a decrease, or no change in tree cover, using the Field Calculator. Cells with a score value of 10 indicate a continuous decrease in tree cover. The figure 4 highlights these cells with a value of 10, representing areas where tree cover continually decreased.

4.2 DEVELOPMENT PRESSURE ANALYSIS IN 2024 AND TREE COVER RELATIONSHIP

Overlaying tree cover data with development pressure surfaces revealed a clear inverse spatial pattern. Areas such as Borella, Battaramulla, and Nawala, which experienced high to very high development pressure, showed notable reductions in tree canopy between 2004 and 2024.

Conversely, areas under low development pressure such as wetland belts, public parks, and institutional zones maintained stable canopy levels or even showed localized increases.

A statistical correlation analysis using the 500 m grid cells showed a moderate, statistically significant positive relationship between the Tree Cover Reduction Index and the Composite Development Pressure Index (Pearson’s $r = 0.36$, $p < 0.001$; $N = 947$). Because ecological relationships often exhibit non-linear behaviour, a Spearman rank correlation was also calculated, which produced a comparable positive association (Spearman’s $\rho = 0.34$, $p < 0.001$). Together, these results confirm that grid cells experiencing higher development pressure tend to record greater tree canopy loss. This statistical signal is consistent with the spatial patterns described above, where higher-pressure areas generally exhibit stronger

canopy reduction and lower residual canopy cover. This statistical signal aligns with the mapped spatial trends observed across the study area.

Furthermore, qualitative comparison with land-use categories indicated that commercial and high-density residential zones generally exhibited lower canopy cover, while institutional and recreational lands supported significantly higher tree presence. These findings suggest that local land-use functions and planning controls influence canopy outcomes more directly than development intensity alone in certain neighbourhoods.

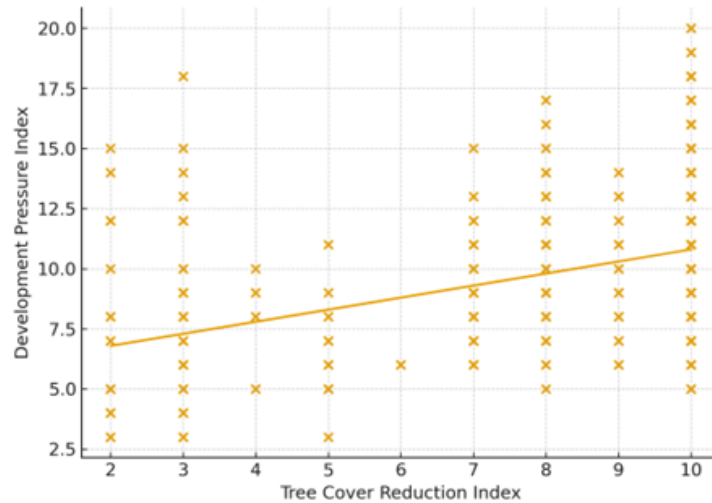


Figure 5: Relationship between tree cover change & Development Pressure
 Source: Author, 2025

Further analysis grouped the grid cells into tree cover classes and examined their associated development pressure categories. This helped identify threshold conditions and land-use dynamics:

Grids in the 30%–40% canopy range, which represent the most frequent class, were typically under moderate to high development pressure. This implies that this is a transitional canopy threshold, beyond which intensifying development begins to significantly reduce tree cover.

Grids with less than 10% canopy cover were predominantly in very high development pressure zones, often located in older urban centers and commercial corridors. These areas exhibit the most severe conflict between urbanization and ecological function.

In contrast, grids with more than 60% canopy cover were mostly within low-pressure zones, typically overlapping with conservation, recreational, or institutional lands. This suggests that land use zoning and public ownership play a protective role in maintaining high levels of vegetation.

4.3 SPATIAL EXCEPTIONS AND PLANNING INTERVENTIONS

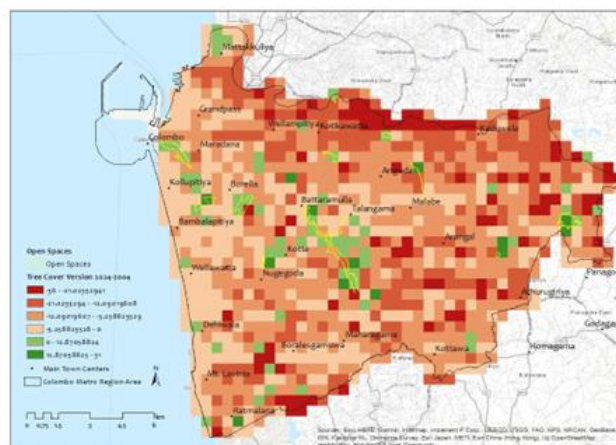


Figure 6: Tree cover variation from 2004 to 2024.
 Source: Author, 2025

A few localized areas showed tree cover gains between 2004 and 2024, despite being situated in relatively urbanized zones. Examples include areas around Diyatha Uyana, Kimbulawala Park, and segments along the Nawala Canal corridor. These areas coincide with urban greening interventions led by the Urban Development Authority (UDA) and local government authorities, including flood buffer landscaping, linear parks, and planned recreational spaces.

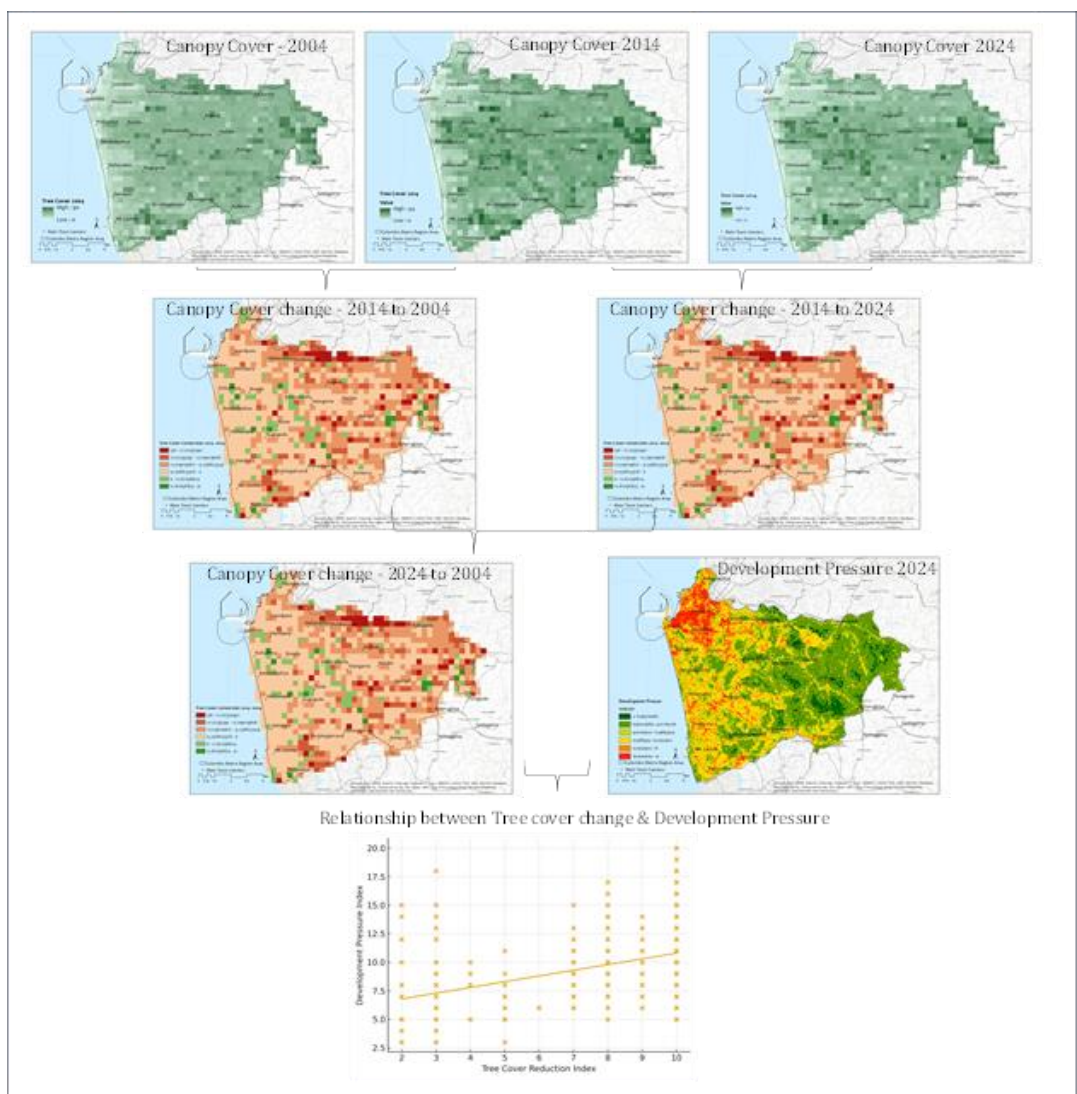
Such cases demonstrate that strategic planning and design interventions can enhance or preserve canopy cover, even in high-demand or rapidly developing areas. This affirms the value of integrating green infrastructure planning into urban policy as a proactive tool for climate adaptation, flood mitigation, and improving environmental quality.

4.4 TRANSITIONAL CANOPY LEVEL (30–40%)

Table 4: Spatial Hotspots of Tree Canopy Loss and Areas of Canopy Gain

Category	Location	Key Characteristics
Hotspot – High Loss & High Pressure	Pettah	Dense commercial core, near-zero canopy, high redevelopment intensity
	Maradana	Mixed-use corridor, high imperviousness, transport hub influence
	Borella	Institutional–commercial mix, rapid densification
	Battaramulla	Administrative expansion zone, infill development pressure
Positive Exception – Canopy Gain	Diyatha Uyana	Planned urban park, flood-buffer landscaping
	Kimbulawala Park	Recreational interventions, maintained public land
	Nawala Canal	Linear greening and restoration along canal corridor

Source: Author, 2025



Source: Author, 2025

To further validate the identification of the 30–40% canopy range as a transitional threshold, an additional cross-classification was carried out between canopy cover classes and development pressure categories. A simple contingency analysis showed that 57–62% of all grid cells in the 30–40% class fell within moderate or high development pressure zones, whereas only 14–18% of these cells occurred in low-pressure areas. This concentration indicates that the mid-canopy band is structurally positioned within areas experiencing ongoing land-use change.

A quantile-based inspection of canopy loss also demonstrated that grid cells within the 30–40% range contributed disproportionately to downward shifts in canopy class between 2004 and 2024. Nearly half of the cells that declined into the 10–30% range originated from the 30–40% class, suggesting that this canopy level is particularly sensitive to development intensification.

These findings provide quantitative support for treating the 30–40% canopy category as a transition zone a level at which canopy cover begins to exhibit measurable vulnerability to surrounding development pressure. As such, this range may serve as an early-warning indicator for targeted greening, zoning incentives, and tree protection measures.

5. Discussion

5.1 TREE COVER LOSS AND URBAN DEVELOPMENT DYNAMICS

This study confirms a sustained decline in tree canopy cover in the Colombo Metropolitan Region (CMR) over the last two decades, falling from 31.45% in 2004 to 23.19% in 2024 a net loss of over 2,300 ha. These results align with trends in other rapidly urbanizing South and Southeast Asian cities, where conversion to built-up uses occurs largely at the expense of vegetation (Seto et al., 2012; Andrieu et al., 2024).

By applying a grid-based approach, canopy change was analysed as a spatially differentiated process rather than a single aggregated figure. Hotspots such as Pettah, Maradana, Borella, and Battaramulla showed substantial declines, matching zones of high development pressure, which suggests that densification and commercial intensification are major drivers of ecological loss.

5.2 RELATIONSHIP BETWEEN DEVELOPMENT PRESSURE AND TREE CANOPY

Correlation analysis between the Tree Cover Reduction Index and the Composite Development Pressure Index revealed a moderate, statistically significant positive association (Pearson's $r = 0.36$; Spearman's $\rho = 0.34$; $p < 0.001$; $N = 947$). This confirms that, on average, grid cells under higher development pressure tend to experience greater canopy loss. However, the scatter remains widely dispersed, indicating that the relationship is far from deterministic and that localised land-use conditions, zoning decisions, and site-specific interventions still play a major role in shaping canopy outcomes. Very low residual canopy (<10%) clusters in older urban cores and major commercial corridors, whereas >60% canopy is largely confined to public parks, institutional lands, and wetland buffers.

5.3 INFLUENCE OF PLANNING AND ZONING CONTROLS

Exceptions to the general decline such as Diyatha Uyana, Kimbulawala Park, and segments of the Nawala Canal highlight the role of proactive planning. These areas benefited from targeted greening projects, flood-buffer landscaping, and linear park development led by the Urban Development Authority and Sri Lanka Land Development Cooperation. This reflects international findings that integrating green infrastructure into dense cities is achievable through policy alignment, design innovation, and institutional coordination (Gill et al., 2007; Meerow & Newell, 2017).

However, the lack of a formal canopy monitoring framework limits Colombo's ability to enforce green space regulations. The spatial model developed here offers a replicable method to fill this gap.

5.4 THRESHOLD EFFECTS AND TRANSITION ZONES

The dominance of the 30–40% canopy cover class in 2024 may represent a transitional threshold. Many of these zones are under moderate to high development pressure and could be at risk of accelerated canopy loss if development intensifies. This class is particularly important for early intervention measures such as zoning incentives, urban forestry programs, and targeted greening.

6. Implications for Urban Planning and Policy

Statistical analysis shows a moderate, significant positive association between development pressure and tree cover reduction (Pearson's $r = 0.36$; Spearman's $\rho = 0.34$; $p < 0.001$; $N = 947$), while the spatial analysis reveals clear inverse patterns in the remaining canopy: high-pressure zones generally have lower residual canopy cover and higher loss, whereas low-pressure zones retain higher levels. This combination suggests that citywide development intensity is an important driver of canopy decline, but that outcomes are still strongly mediated by site-specific land-use decisions, zoning enforcement, and targeted greening programmes.

In essence, the findings show that tree canopy outcomes are highly sensitive to local planning choices. While broad development pressures contribute to vegetation loss, targeted, site-level interventions can stabilise or even increase canopy cover, making them critical tools for climate adaptation, biodiversity support, and urban liveability.

7. Conclusion & Way forward

This study examined two decades of tree canopy change in the Colombo Metropolitan Area, revealing a steady decline from 31.45% in 2004 to 23.19% in 2024 a loss of more than 2,300 hectares. Using a grid-based Tree Cover Mapping assessment combined with GIS analysis, the research mapped where canopy loss was most concentrated and compared it with a composite index of development pressure.

Statistical correlation analysis between the Tree Cover Reduction Index and the Composite Development Pressure Index showed a moderate, significant positive association (Pearson's $r = 0.36$; Spearman's $\rho = 0.34$; $p < 0.001$; $N = 947$), and the spatial patterns were equally clear: high-pressure urban zones generally had higher tree cover reduction and lower residual canopy cover, while low-pressure areas particularly public parks, institutional lands, and wetland buffers retained or increased their tree cover. This confirms that development pressure is a key driver of canopy decline, even though local land-use decisions, zoning enforcement, and greening projects modulate the magnitude and distribution of loss.

The study also identified a transitional 30–40% canopy range in moderate-pressure areas, which may represent a tipping point toward accelerated loss if not addressed. By demonstrating a replicable, high-resolution monitoring method, this research provides practical evidence for embedding tree canopy targets, location-specific greening, and systematic monitoring into Colombo's long-term urban planning framework, supporting both ecological resilience and urban liveability.

In addition, future work may support urban planning processes more directly by integrating canopy data into zoning compliance monitoring, modelling the effects of green infrastructure policies in high-pressure zones, and aligning canopy restoration opportunities with ongoing urban redevelopment initiatives. These directions would strengthen the operational use of tree canopy monitoring as a decision-support tool for the Colombo Metropolitan Region.

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