



<https://doi.org/10.64211/oidaijsd190413>

Assessment on Impact of Risky Trees on the Sustainable Management of Urban Green Spaces Using Geospatial Technology: Special Reference to Colombo Municipal Area in Sri Lanka

Guruge P.S.D ¹, Herath H.M.B.S ^{2*}

^{1,2} Department of Geography, Faculty of Humanities and Social Sciences,
University of Sri Jayewardenepura, Sri Lanka.

*Corresponding author: badraherath@sjp.ac.lk

© Authour (s)

OIDA International Journal of Sustainable Development, Ontario International Development Agency, Canada.

ISSN 1923-6654 (print) ISSN 1923-6662 (online) www.oidaijsd.com

Also available at <https://www.ssrn.com/index.cfm/en/oida-intl-journal-sustainable-dev/>

Abstract: Urban green spaces are fundamental elements of sustainable cities, providing ecological, social, and health benefits within the overall constructed environment that is the living urban environment. Nevertheless, the existence of risky trees, which may be structurally unstable, diseased, or likely to fail, presents a substantive threat to the safety, equity, and sustainability of green spaces. This study seeks to assess the implications of risky trees for the sustainable management of urban green spaces utilizing geospatial technology, using the Colombo Municipal Area as an illustrated case. The main objective is to explore the influence of risky trees on urban green space management sustainably in the urban realm using geospatial technology. The specific objectives are to map the spatial distribution of risky trees in urban green spaces using geospatial approaches, assess risk rating and contributing causes, and develop management recommendations for urban tree risk management to support public safety and planning strategically for urban trees. In this methodology, field observations, Geographic Information Systems (GIS) and LiDAR data were utilized to map tree locations and features of the tree canopy. To evaluate risk, weighted overlay, buffer analysis, hotspot and kernel density mapping, correlation, and regression were all applied as analytical tools. Risk scoring and indexing clarified the most hazardous trees and categorized trees based on risk level, while Multi-Criteria Decision Analysis (MCDA) helped direct sustainable management strategies. Data collection took place along designated roads selected in Kurunduwatta and Thimbirigasyaya GNDs where trees were purposively sampled based on tree density and urban activity. Tree characteristics and tree defects were the principal risk factors, but they were highly influenced by environmental variables and distance to the nearest road edge and buildings. Overall, the study found 75 trees to have high risk, 29 trees to have moderate risk and 19 trees to have low risk. The study concludes that risky urban trees pose serious threats to public safety and to the sustainable management of the green spaces located in the Colombo Municipal Area. A modified sustainable tree risk management strategy that utilizes a geospatial tool is suggested to prioritize the maintenance and/or removal of risky trees and aid in future urban planning.

Keywords: Geospatial Technology, Risky Trees, Sustainable Urban Planning, Urban Green Spaces, Urban Tree Risk Assessment

Introduction

Urban environments are dynamic spaces composed of gray infrastructure and green systems that enhance eco-friendly urbanism. Recognizing the global significance of green infrastructure underscores the importance of urban green spaces. These spaces exist as small patches of plants or extensive urban forests and provide aesthetic value while helping with biodiversity, climate regulation, and public health. The integration of green

infrastructure is vital to the sustainable and resilient design of urban areas. Most people prefer living in neighborhoods or communities with urban green spaces, when these spaces are well-maintained.

Urban trees play a crucial role in urban forests and contribute to green infrastructure in significant ways [1]. They are the longest-living species on the planet, providing links to the past, present, and future. Urban trees are defined as woody perennial plants growing within urban settings [2] and are essential for urban greening, visibly dictating landscapes. Compared to trees in natural habitats, urban trees generally experience poorer growing conditions [3,4]. Urban trees grow in many locations, including streets, private yards, parks, and institutional grounds. The value of urban trees increases as they mature and provide financial and ecological benefits in the form of improved air quality, heat island mitigation, noise pollution reduction, rainwater runoff filtration and absorption, pollutant filtration, and shade. Additionally, urban trees support biodiversity by providing habitat for various species of animals and continually support wildlife presence while stabilizing ecosystems.

Urban trees are not without risks [5]. As the urban environment grows both in density and complexity, the safety and health of urban trees are threatened by a variety of extremes, such as severe weather events. Tree risk refers to the potential of a hazardous tree to cause injury or damage. In urban environments, the urbanization process has surfaced the need to assess trees and their potential hazardous traits, while considering their increased density [6]. Tree Risk Assessment (TRA) follows a systematic process in assessing the risk of trees, with the goal of providing information about the risk of trees [6]. Management of trees is critical to ensuring continued benefits of urban trees and developing a relationship with tree risk and public safety.

Geospatial technologies advance urban tree risk assessment and management by integrating contemporary tools that allow geographic mapping and analysis of human and environmental interactions (American Association for the Advancement of Science, 2019). Technologies such as Geographic Information Systems (GIS), Remote Sensing (RS), and Light Detection and Ranging (LiDAR) assist in the identification and assessment of urban tree risk by interpreting spatial relationships and environmental conditions. In particular, the measurements acquired with LiDAR can provide accurate details about both tree height and canopy spread, improving risk assessments. Major urban centers such as New York, London, and Singapore have used geospatial technology to manage urban trees effectively [6].

It is important to manage urban tree risks in the context of urban sustainability. Typically, risk management refers to forecasting the possible public safety issues linked to urban trees and resolving these risks, such as tree failure. Traditional tree failure risk assessments identify risks using periodic evaluations of the trees, based on prescribed criteria. When evaluating risk, geographic information enriches evaluations by mapping the geographic relationships and factors pertaining to risks [6]. A consideration of urban tree risk management will lower exposure to liability and foster urban resilience through protecting biodiversity and diminishing climate change challenges [7]. A proactive tree management approach will enhance urban health, while maximizing social, environmental, and economic benefits related to urban greenery.

This study highlights the growing demand for new, data-centric approaches for the assessment of urban trees in rapidly developing cities, such as Colombo, Sri Lanka. Colombo's role as the largest city and commercial capital of Sri Lanka presents a highly densely populated area with rapidly changing built infrastructure needing progressive environmental management with sustainable management approaches for urban green infrastructure. Geospatial technology provides an opportunity to monitor urban trees more accurately, develop an understanding of risks, and inform decisions regarding urban planning. The significance of this study is in the application of geospatial technology to address knowledge gaps relating to urban tree management in a rapidly developing urban context such as Colombo. This study will apply spatial statistical analysis to assess urban tree risk and offer urban planners safeguards in managing trees.

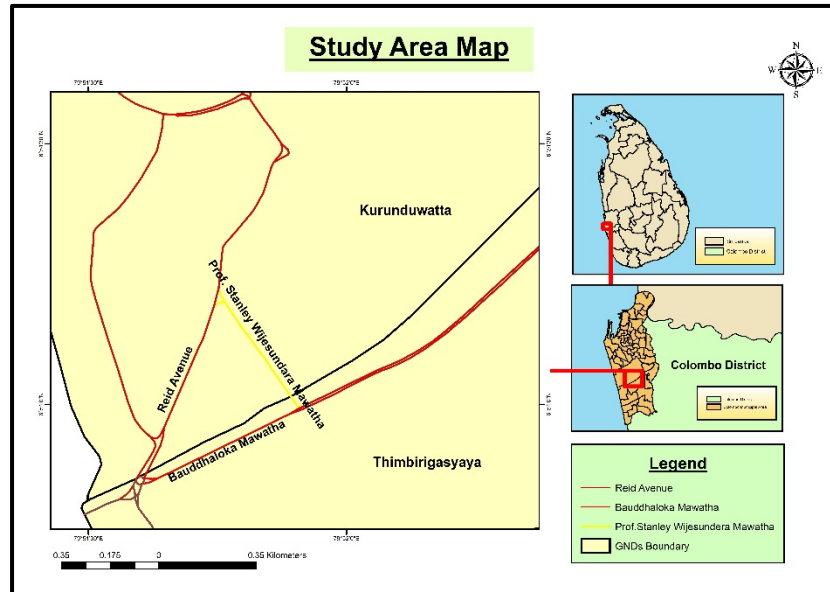
Materiald and Methods

Study Area

For this study that examines the use of geospatial technology for urban tree risk assessment and management, the study area consists of the Kurunduwatta and Thimbirigasyaya Grama Niladhari Divisions (GND) within the Colombo Municipal Council (CMC) area in Colombo District in the Western Province of Sri Lanka. These two GNDs are administrated by the Thimbirigasyaya Divisional Secretariat Division (DSD). As noted, the study area is at the center of Colombo city, which has major roads, institutional areas, and residential areas, in a high-density development. This study specifically examines trees along Baudhdhaloka Mawatha, Reid Avenue and Prof. Stanley Wijesundera Mawatha, located in these selected GNDs, corresponding to Wards 36 and 40. The road sections investigated in this study were Baudhdhaloka Mawatha from the Institute of Human Resource Advancement (IHRA) to Thummulla Junction; Reid Avenue from Thummulla Junction to Arcade Independence Square; and Prof. Stanley Wijesundera Mawatha from the

IHRA to the Professor Stanley Wijesundera Statue. These roads were chosen as they are strategically situated in urban areas with high pedestrian and vehicle traffic, and with large trees in the road reserve, which may present differing levels of risks to the public and infrastructure. The selections also represent locations with a range of land use types, leading to a multi-faceted examination of urban tree risk in the context of a changing urban setting.

Figure 1: Study Area Map



Source: Compiled by the Author, 2025

Sample and Sampling Technique

The purposive sampling method was utilized to identify trees for assessment. This method focuses on selecting specific trees that are situated adjacent to main roads, ensuring the sample represents trees at higher risk due to their distance to urban infrastructure. The criteria for sample selection include: trees with a Diameter at Breast Height (DBH) greater than 10 cm (FAO, 2000), trees within 1 meter of main road edges, trees exhibit visible structural defects, such as trunk or branch damage and trees are located near sensitive urban elements like high-traffic roads or densely built environments.

The sample size consisted of trees distributed across the Kurunduwatta and Thimbirigasyaya Grama Niladhari Divisions (GNDs) within the Colombo Municipal Area. The sample size was established according to the study's specific objectives, which aim to assess tree related risks in urban settings with significant exposure to pedestrians, vehicles, and built environments. Due to the higher probability of hazardous trees being situated directly adjacent to major roads and heavily developed urban settings, the sample focused on trees within these high-risk areas to maintain relevance and precision in risk assessment. The selection ensured spatial representation within the study area, providing comprehensive insights into urban tree risks. For the sample technique, data collection involved the use of geospatial tools, such as Kobo Toolbox and Place App, to accurately map tree locations and record their attributes. Visual assessments were also conducted to evaluate structural defects, focusing on indicators such as trunk cracks, leaning stems, and branch weaknesses. This combination of targeted sampling and advanced data collection techniques ensured that the study captured the critical characteristics of urban trees and their associated risks.

Methods of Data Collection

Data collection was tailored to meet all specific objectives of the examination. To address the first objective, spatial information on the trees, including their locations and attributes (height, age, diameter at breast height, canopy spread, and root conditions), were collected through field surveys utilizing the Kobo Toolbox and Place App, and the species were verified. In addition to the field survey datasets, LiDAR data (Survey Department), satellite imagery (USGS Earth Explorer), aerial imagery (Google Earth Pro), and OpenStreetMap layers were included. Environmental variables like rainfall intensity, wind exposure, and soil conditions were acquired from various sources including the Department of Meteorology, Global Wind Atlas, CHRS rainfall datasets, and SoilGrids.org.

For the second objective, a visual inspection was completed to assess tree health, structural defects, leaning angle, and proximity to roads and buildings. Additional datasets were obtained from the Road Development Authority and Urban Development Authority (land use maps), traffic studies, and the Colombo Municipal Council and Forestry Department records. For the third objective, stakeholder consultations were completed with Colombo Municipal Council, Forestry Department, and the Urban Development Authority to obtain their insights of current policy and management of the trees, consult research, information, and reports, and the Colombo City Development Plan, along with other examples of international best practices, were analyzed to obtain landscape and tree risk management insight.

Methods of Data Analysis

The data analysis process involved both qualitative and quantitative techniques, integrating geospatial and statistical methods to evaluate urban tree risk within the selected study area. The analytical procedures were developed to address the three study objectives. To answer the first objective, examining the spatial distribution of risky urban trees, high-resolution satellite imagery and LiDAR data was analyzed for canopy extent, tree height, and structure. LiDAR point density and kernel density functions were used to identify high-density tree zones. Field data with GPS locations were incorporated with base maps in ArcGIS and QGIS to map the spatial distribution of trees within the study area.

To address the second objective, various geospatial and statistical methods were utilized to assess risk levels and contributing factors. A weighted overlay analysis was conducted that combined factors such as tree characteristics, tree defects, distance to infrastructure, environmental variables, with the established weights. Buffer analysis determined tree distance to roads, buildings, and utilities, while hotspot and kernel density analysis identified clusters of high-risk trees. Statistical regression and correlation analyses examined the relationship between environmental and structural variables and tree risk.

Results and Discussion

Identification, classification, and mapping of urban risky trees that pose potential hazards in the Colombo Municipal Area using geospatial technologies

Spatial distribution and density

Field and geospatial surveys identified a total of 123 urban trees across three major road segments: Reid Avenue, Baudhdhaloka Mawatha, and Prof. Stanley Wijesundera Mawatha within the Colombo Municipal Area.

There is significant variation in the spatial distribution of urban trees across the major roads selected in the Colombo Municipal Area. Reid Avenue recorded the greatest number of trees (57), although there was a definite imbalance in the left or right-side counts (right = 44; left = 13). Baudhdhaloka Mawatha was next in terms of tree counts (54), it was reasonably balanced (29 = right; 25 = left). Prof. Stanley Wijesundera Mawatha had the least number of trees reported (12; 7 = right; 5 = left). Overall, Reid Avenue has the call as a primary green corridor, whilst the trend of more trees on the right-hand side for all roads indicates likely differences in both available planting space and past planting practices, as well as pavement widths.

The Kernel Density Estimation (KDE) analysis revealed a clustered distribution of urban trees in the Colombo Municipal Area. Most of the high-density areas were along important roads leading south, where wider roads and institutional frontages typically had uniform plantings. In contrast, the areas towards the northern and outer sections of the municipal area had lower tree density due to the narrower road widths and shorter planting space. Overall, these findings suggest an uneven distribution of urban trees that clustered in association with important transportation corridors.

Species Composition

The most dominant species observed across all examined roads is *Samanea saman* (Rain Tree). It accounts for a substantial majority of the recorded trees, with an aggregate of 62 individual trees; each examined tree is roughly 50.4%. Its dominance is constantly observed on both sides of the roadsides. On Baudhdhaloka Mawatha, *Samanea saman* (Rain Tree) is particularly current, constituting 84 of the trees on the left side and 65.5% on the right side. A similar pattern is apparent in Prof. Stanley Wijesundera Mawatha, where it makes up 80% of the trees on the left and 57.1% on the right. Likewise, on Reid Avenue's left side, the rain tree comprises 77% of the recorded trees. This wide dominance highlights the species' popularity and suitability for urban surroundings, primarily due to its extensive canopy cover, fast growth, and capability to give ample shade along busy roadways. Other species like *Mangifera indica*, *Terminalia catappa*, and *Ficus benghalensis* are relatively represented. Several ornamental and native species appear only formerly or twice, indicating low overall species evenness despite moderate richness (23 total).

Land Use Context

Institutional, commercial, residential, and recreational/ open spaces are the primary land use categories that were considered while classifying the geocoded tree data. Approximately 47% of trees were in institutional zones, followed by 28% in recreational areas, 17% in residential areas, and 8% in commercial zones. Trees near institutional and recreational zones tended to be larger and older, while those in residential areas were younger but more directly exposed to buildings.

Preliminary identification of risky trees

All the trees examined during the primary assessment were linked as risky trees, as each one fulfilled at least one of the established criteria (Section 2.2). These criteria, derived from internationally recognized guidelines and contextualized for the urban environment of Colombo, served as the basis for classifying potential hazards. Whether due to significant trunk diameter, proximity to main roads, visible structural defects, or location near sensitive urban infrastructure, every tree assessed demonstrated characteristics that aligned with the assumed risk indicators.

Evaluation of tree risk levels and contributing factors

Tree Characteristics

Tree Height

The height of a tree is an important factor in determining tree risk in an urban setting, and in this study 80 tall trees (over 20 m) were classified as high risk because tall trees can be affected by wind stress and could cause extensive damage. A total of 28 trees with a height of 10-20 m posed a moderate risk, and 15 trees with a height less than 10 m posed a low risk. The results illustrate that urban areas with many tall trees will need follow-up monitoring and management to reduce hazards.

Tree Age

Tree age is an important aspect of structural stability and risk of trees in an urban setting. Most trees (111) were categorized as high-risk trees because they were all more than 100 years old and were identified as high-risk trees due to deterioration of structural integrity. There was a smaller group of mature trees (12) in the 10 to 100-year-old range that were categorized as moderate-risk trees. There were no young (<10-year-old) trees that are often categorized as low-risk trees. This finding indicates that with a larger proportion of old trees, the total risk profile for trees within the urban forest is high, suggesting that trees should be assessed and monitored based on age and that management decisions should consider the age and type of tree.

Diameter at Breast Height (DBH)

Diameter at Breast Height (DBH) is a measure for tree size and structural stability. In this study, 57 trees were classified in the high-risk category. This is due to the substantial biomass and mechanical load associated with this size. The trees in the high-risk category were at a significant risk of damaging trees. The trees in the medium and small risk categories had 33 trees each. Medium DBH trees represented a moderate risk, where low DBH trees represented a low risk. Ultimately, the findings demonstrate the importance of monitoring and managing larger diameter trees for urban tree risk.

Tree Canopy

Tree canopy spread is crucial for assessing ecological value and hazard potential in urban areas. The analysis indicated that 85 trees (high-risk) had a canopy spread over 10 m, increasing risks of branch failure and damage. Only 20 trees (medium-risk, 5–10 m) and 18 trees (low-risk, <5 m) were identified, with the latter having limited damage potential. The findings underscore the dominance of wide-canopy trees in the area and the need for effective canopy management in risk mitigation.

Critical Root Radius (CRR)

The Critical Root Radius (CRR) offers an assessment of tree anchorage and stability. The results indicated that most trees (61) were classified as small CRR (5–59 feet), ranking them as a high-risk tree type due to limited root spread and a higher likelihood of uprooting. Thirty trees fell into the medium CRR range (60–89 feet) and were classified as a moderate risk. Lastly, 31 trees classified as large (>90 feet) CRR were designated as a low-risk category. Overall, the predominance of trees with small CRR values suggests an increased risk of uprooting for urban trees, particularly during periods of extreme weather.

Statistical assessment of tree characteristics

The statistical assessment of tree characteristics clearly demonstrates that tree characteristics have a significant and measurable relationship with tree risk levels. Through both correlation and regression analyses, each variable showed a moderate positive association with the tree risk code, confirming that as these characteristics increase in magnitude, so too does the likelihood of risk.

Tree Defects

Tree defects are essential metrics of structural stability and risk levels. Assessment results show that 60 trees (48.8%) exhibited high defects (6–8/tree), and that they were high risk trees for factors which included trunk decay, branch splits, and root rot. 45 trees (36.6%) showed medium defects (3–5/tree), which were classified as moderate risk trees, and only 18 trees (14.6%) had low defects (0–2/tree) rated as low-risk trees. The results indicate that nearly half of the trees assessed show important structural defects and that tree defects are an important character to examine to better manage urban tree risk.

Statistical assessment of tree defects

The correlation and regression analyses confirm that tree defects are strong predictors of tree risk level, with several defects outperforming physical characteristics such as height or DBH in statistical strength. Defects such as dead branches, decay, fungal presence, and cracks should be treated as high-priority indicators during field inspections.

Environmental variables

Environmental variables are key in determining the health and stability of urban trees and directly contribute to the hazard of failure. Similarly, Environmental variables in urban areas, combined with individual physical defects and proximity to other infrastructure, can also elevate the hazards associated with tree failure. Rainfall intensity, wind exposure, and soil condition were assessed as external drivers of risk.

High rainfall months (April, May, September–November) increase soil saturation, reduce root stability, and heighten the chance of uprooting or decay, while drier months (January–February) correspond with low risk. Wind exposure peaks during the southwest monsoon (May–October), with sustained speeds and gusts that amplify failure risk, especially when combined with saturated soils. Soil types further shape risk: lateritic soils provide moderate anchorage but limited nutrients, whereas sandy clay regosols and eroded lands pose high risks due to shallow roots, poor drainage, and low stability. Together, these environmental factors interact to create seasonal risk variations, highlighting the importance of integrating them into urban tree risk assessment and management.

Statistical assessment of environmental variables

The results of the correlation and regression analyses confirm that rainfall intensity, wind exposure, and soil condition are all significant contributors to urban tree risk. These environmental stressors, acting either individually or cumulatively, can amplify existing vulnerabilities in urban trees. Among them, wind exposure is particularly critical and should be factored into both tree species selection and placement decisions in urban planning.

Location specific characteristics

Urban tree risk is determined by a range of tree-specific and environmental factors, but it is also influenced by the tree's spatial context. This study examined two key location-specific spatial dimensions: distance to the nearest road edge and distance to the nearest buildings.

Distance to nearest road edge

The distance to the nearest road edge is important to assess the risk to urban trees, because tree failure encounters pedestrians, vehicles, and traffic. Overall, the tree proximity analysis found all trees (100%) sampled were within 0–5 meters of the nearest edge of roadways, which classifies them as high-risk due to their proximity to traffic. This consistent proximity underscores the risk of safety to the public in a dense urban environment such as Kurunduwatta and Thimbrigasyaya GNDs, where a lot of large, mature trees are concentrated next to high-traffic roadways. The findings showcase that area tree management must consider safety measures first and foremost due to the consistent activity at the tree, vehicle, and pedestrian interface.

Distance to nearest buildings

Trees growing near buildings can be dangerous to lives and property, particularly during severe weather or if the building is already compromised. The analysis indicated that all the trees assessed were located 0–2 meters from the

nearest building footprint, which would place these trees entirely within the "high-risk" zone. Many were in the 0–1 meter "high-risk" zone, where they are immediately next to the building structures where risk of property danger or safety hazard is highest. In all, this emphasizes the need for careful monitoring and management of trees near urban buildings.

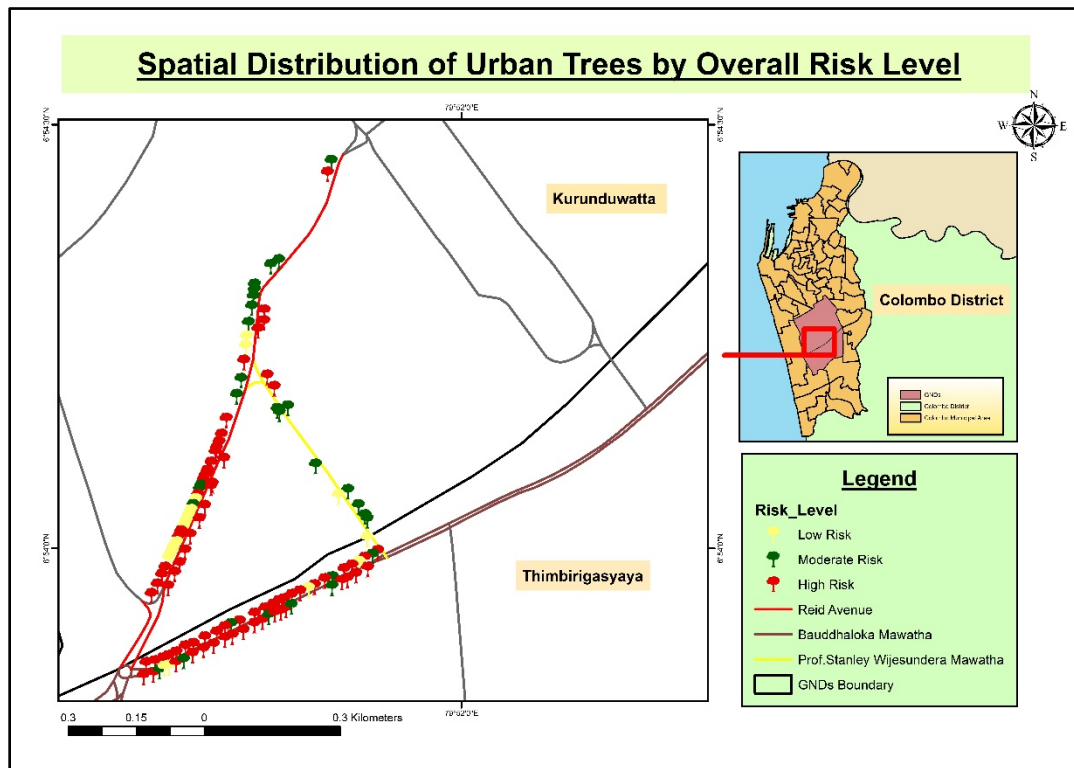
Statistical assessment of location-specific characteristics

The results of the regression and correlation analyses confirm that tree distance to critical infrastructure especially roads and buildings is an important component of urban tree risk assessment. While not intrinsic to the tree itself, these location-specific factors amplify the consequences of failure, thus elevating the tree's functional risk rating.

Spatial analysis of overall urban tree risk

The results of the Multi-Criteria Decision Analysis (MCDA) indicate that a total of 75 trees (61%) in the studied area were identified as high-risk trees, predominantly clustered along busy road corridors and densely built institutional or residential space. These trees pose the highest possible risk due to the cumulative effects of structural defects, environmental stressors, and proximity to the built environment. Another 29 trees (24%) were identified as moderate risk, requiring ongoing monitoring efforts and preventative management, while the remaining 19 trees (15%) were categorized as low-risk, and were mostly found in expansive areas and public or recreational areas with less external stressors. The distribution of the data overwhelmingly suggests the operational challenge of timely inspections and preemptive management in high-risk areas for the sake of protecting public space and the urban environment.

Figure 2: Spatial distribution map of urban trees by overall risk level



Source: Compiled by the Author, 2025

Conclusion

This study was undertaken to address the increasing hazards posed by urban trees in a rapidly developing urban environment, with a focus on integrating advanced geospatial tools for effective assessment and management. While urban trees serve as critical components of green infrastructure providing numerous environmental, aesthetic, and social benefits, their mismanagement or exposure to adverse environmental and structural conditions can turn them into public hazards. This research sought to bridge the gap between traditional arboriculture assessment methods and modern geospatial technologies, thereby offering a holistic and proactive framework for urban tree risk management.

By grounding the study in three primary research questions related to spatial distribution, influencing risk factors, and strategic recommendations, the study employed a multidisciplinary approach combining field surveys, GIS analysis, remote sensing, and LiDAR-based assessments. The selected area provided a dynamic urban context characterized by complex interactions between natural and built environments.

For effective management of tree risk in urban environments, the use of a centralized geospatial inventory tool is beneficial for the ongoing accountability of tree condition/health. Developing a formal tree risk assessment program will assist in the identification and prioritization of high-risk trees for maintenance. Allocating resources in high-risk communities efficiently is crucial to ensure the best use of staff and funding. Urban tree risk management should be part of adopt a united strategy in urban planning and all elements of disaster management to achieve safer, sustainable, more urban green space. Promoting public participation and coordination of stakeholders also increases public awareness and collaboration of tree care and urban forests. Improving on data access and funding to conduct research will improve evidence-based management and community resilience of urban forests.

The results demonstrated that tree-related risks are spatially concentrated in areas with higher human activity, road density, and proximity to build infrastructure. Key factors influencing urban tree risk included tree height, canopy spread, DBH (Diameter at Breast Height), age, and Critical Root Radius (CRR), along with environmental variables such as wind exposure, rainfall intensity, and soil conditions. High-risk zones were identified using spatial density and buffer analysis, highlighting the areas that require urgent intervention. This research contributes both academically and practically by offering a transferable methodology for urban tree risk assessment. It provides urban planners, disaster risk managers, and environmental policymakers with a valuable toolkit to enhance urban safety, resilience, and sustainability. Notably, the study introduces a scalable model that can be incorporated into Colombo Municipal Council's urban forestry management policies to mitigate risk, enhance green space planning, and support climate adaptation strategies.

Acknowledgement

First and foremost, I would like to thank my supervisor, Dr.H.M. Badra S. Herath, for all her guidance, continuous support, and constructive feedback throughout the duration of my research. Her expertise, encouragement, and dedication greatly contributed to the successful completion of this study. I also wish to thank the Department of Geography and the International Center for Multidisciplinary Studies, University of Sri Jayewardenepura, for providing the academic foundation, resources and collaborative environment required to successfully complete my research.

References

1. Cavender, N., & Donnelly, G. (2019). Intersecting urban forestry and botanical gardens to address big challenges for healthier trees, people, and cities. *Plants, People, Planet*, 1(4). <https://doi.org/10.1002/ppp3.38>
2. Roy, S., Byrne, J., & Pickering, C. (2012). A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban Forestry & Urban Greening*, 11(4), 351–363. <https://doi.org/10.1016/j.ufug.2012.06.006>
3. Mullaney, J., Lucke, T., & Trueman, S. J. (2015). A review of benefits and challenges in growing street trees in paved urban environments. *Landscape and Urban Planning*, 134, 157–166. <https://doi.org/10.1016/j.landurbplan.2014.10.013>
4. Scharenbroch, B. C., Carter, D., Bialecki, M., Fahey, R., Scheberl, L., Catania, M., Roman, L. A., Bassuk, N., Harper, R. W., Werner, L., Siewert, A., Miller, S., Hutyra, L., & Raciti, S. (2017). A rapid urban site index for assessing the quality of street tree planting sites. *Urban Forestry & Urban Greening*, 27, 279–286. <https://doi.org/10.1016/j.ufug.2017.08.017>
5. Klein, R., Koeser, A., Hauer, R., Hansen, G., & Escobedo, F. (2019). Risk assessment and risk perception of trees: A review of literature relating to arboriculture and urban forestry. *Arboriculture & Urban Forestry*, 45(1). <https://doi.org/10.48044/jauf.2019.003>
6. Smiley, E., Matheny, N., & Lilly, S. (n.d.). *Continuing education unit: Qualitative tree risk assessment*. ISA—International Society of Arboriculture. https://www.isa-arbor.com/events/conference/proceedings/2013/SMILEY_MATHENY_Tree_Risk_Assessment_Qualitative_AN_Feb_2012.pdf

7. Sjöman, H., Watkins, H., Kelly, L. J., Hirons, A., Kainulainen, K., Martin, K. W. E., & Antonelli, A. (2024). Resilient trees for urban environments: The importance of intraspecific variation. *Plants, People, Planet*. <https://doi.org/10.1002/ppp3.10518>

