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Tree risk assessment for enhancing urban green space resilience in Surakarta

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ABSTRACT

Surakarta City faces challenges related to limited Green Open Spaces and the increasing occurrence of tree failures due to climate change and deteriorating environmental conditions. During the rainy season of 2023, several significant tree failure events were recorded, with a total of 58 fallen trees by early 2024 with Kedunglumbu and Manahan subdistrict were identified as areas with the highest number of fallen trees. Therefore, this study aims to evaluate tree health and the risk of tree failure in residential areas of these two kelurahans using the Tree Risk Assessment (TRA) method. Observations were conducted on 717 trees from 47 species distributed across both subdistricts. The results show that most trees (666 trees or 92.9%) were classified as low risk, 35 trees (4.9%) as medium risk, and 16 trees (2.2%) as high risk. Tree species with highest risk included Kecrutan (*Vitex pinnata*), Waru (*Hibiscus tiliaceus*), and Ketapang (*Terminalia catappa* L.).

Keywords: tree risk, tree risk assessment, tree damage, Surakarta.

INTRODUCTION

Surakarta, covering an area of 46.72 km², faces significant challenges in accommodating anthropogenic needs while harmonizing spatial allocation for conservation. This condition has led to limitations in optimizing green open space (GOS) for mitigating environmental issues (Himawan and Nancy, 2022). Likewise, vegetation in Surakarta has become suboptimal in performing its function as a microclimate regulator (Sunarto et al., 2022).

Trees have a crucial role in enhancing urban resilience to climate change. They serve as vital vegetative strata attributes within green open spaces, providing essential ecosystem services such as cooling effects, evaporation regulation, shading, and modifying air movement and heat exchange. The canopy features and leaf characteristics of trees are key factors in these functions (Lai et al., 2019; Rahman et al., 2020; Graca et al., 2018; Gunawardena et al., 2017). According to Drew-Smythe et al. (2023), trees provide three main ecosystem services in urban areas: mitigating the urban heat island (UHI) effect, improving quality of life, and supporting biodiversity. Trees also contribute to temperature regulation and urban water provision, promoting livable urban conditions (Livesley et al., 2016; Shanahan et al., 2016). This has prompted many cities to focus on climate resilience transformation through the development of GOS, particularly urban forests (Frantzeskaki et al., 2019).

With its urban characteristics, most of the land in Surakarta has been utilized for anthropogenic purposes, predominantly built-up areas. As of 2022, public GOS availability was only 9.82% or approximately 458.71 hectares, far below the target set by regulations. However, this reflects the reality of land occupancy. The largest public GOS areas are in Jebres and Banjarsari districts, while private GOS occupies 11.7% of Surakarta's total administrative area, equivalent to 546.58 hectares. This limitation highlights the urgent need for further research to formulate strategies for increasing GOS that not only comply with regulations but also support environmental sustainability in Surakarta.

The presence of trees in urban areas faces several challenges, primarily due to land demand and increasingly unfavorable environmental conditions. Land in urban areas is often prioritized for anthropogenic activities that drive economic growth, making open spaces and vegetation cover appear more valuable when converted into infrastructure. Moreover, the urban environment is often unsuitable for tree growth and development. The conversion of natural land into asphalt roads, pavements, marble layers, and cement negatively impacts tree health, making them more vulnerable to damage and collapse, particularly during the rainy season. Poorly managed trees can cause damage or injury, especially during natural events such as strong winds or storms. However, branch or tree damage is often predictable and preventable with proper management. Therefore, urban tree management should consider both the social value of trees and public safety (Kumar, 2020).

A concrete example of this challenge was observed during the 2023 rainy season, which began in October, when a mass tree collapse occurred. According to the Surakarta Environmental Agency, 34 trees fell on January 4, 2024. Earlier, the first rainfall on October 24, 2023, had already caused 24 trees to fall, followed by similar incidents on November 11, 2023 (DLH Surakarta, 2024). The worsening climate phenomenon, triggering hydrometeorological disasters due to climate change, is expected to further increase pressure on urban trees in the future.

These tree-fall incidents have created negative public perceptions regarding large trees in cities. Material losses, infrastructure damage, and safety concerns have led to increased requests for tree felling and pruning from relevant authorities. This situation presents a dilemma, as urban management must prioritize public safety while simultaneously maintaining the essential ecosystem services provided by trees.

This condition underscores the urgency of assessing tree health and associated environmental risks. This study aims to evaluate tree health, assess tree risk conditions, and rehabilitate tree damage. The research is considered urgent to provide tree health information that can serve as a reference for maintenance or felling decisions. The findings will indirectly contribute to tree protection and management, preventing unplanned felling while also serving as an early warning for stakeholders regarding tree collapse risks.

METHODES

Research location and period

This research was conducted in urban residential areas of Surakarta, Central Java, focusing on Manahan and Kedunglumbu sub-districts, which recorded the highest number of fallen tree incidents from 2023 to the first quarter of 2024. The research will be carried out from September to December 2024.

Research tools and materials

The tools used in this research include the Tree Risk Assessment form, the Measure application for measuring tree height, ArcGis Software, Avenza Maps, Laptop, and Microsoft Office for data processing. Tree data and records of fallen tree incidents were obtained from the Surakarta Environmental Agency.

Data collection and analysis techniques

Primary data were obtained through field observations and geotagging using Avenza Maps. Observations included identifying tree conditions, height, diameter at breast height (DBH), and existing structural damage. Sample collection was conducted using a purposive area sampling method. The study focused on two sub-districts—Manahan and Kedunglumbu—which were selected based on tree fall incident data recorded in Surakarta from 2023 to the first quarter of 2024. These areas had the highest frequency of tree fall events, making them priority locations for tree risk evaluation.

From the total residential area in each sub-district (63.03 hectares in Manahan and 30.42 hectares in Kedunglumbu), 30% of the land area was selected as the sampling zone, following Widya (2013), who suggests that 25–30% sampling is appropriate for large populations. This resulted in sampling areas of 20.16 hectares in Manahan and 9.09 hectares in Kedunglumbu.

Within the selected sampling zones, all trees with a DBH starting from 20 cm (as classified as trees rather than shrubs) were observed and recorded, without applying further inclusion or exclusion criteria. This approach ensured that the tree population data reflected the actual profile of trees with potential risk within the designated high-risk residential areas.

This research employs a mixed-method approach, combining qualitative and quantitative analyses. Risk evaluation was conducted using the Tree Risk Assessment (TRA) approach developed by the International Society of Arboriculture (ISA), as outlined in Tree Risk Assessment: Best Management Practices (Dunster et al., 2017). The assessment followed the ISA Level 2: Basic Assessment method, which involves systematic visual inspection of the tree's condition—focusing on the roots, trunk, branches, and canopy—and the surrounding environment.

The TRA used a matrix-based evaluation combining three components:mLikelihood of Failure – the probability of structural failure in part or all of the tree, Likelihood of Impact – the probability that a target (human, property, infrastructure) will be present if failure occurs, and Consequences of Failure – the expected severity of damage or harm.

The combination of these components follows a two-step matrix to determine the overall risk rating, categorized into four levels: Low, Moderate, High, and Extreme. This standard framework ensures a consistent and transparent evaluation of tree risk.

Additionally, spatial analysis was performed using ArcGIS to map the distribution of observed trees and visualize relative risk levels based on their locations and conditions.

RESULT AND DISCUSSION

Tree species composition in Kedunglumbu and Manahan

Field observations in Kedunglumbu and Manahan identified a total of 47 tree species and 6 unidentified trees, with a total of 717 individual trees recorded in the study area (Figure 1).

The most dominant species was Glodokan Tiang (*Polyalthia longifolia*), accounting for 156 trees (21.8%) of the total. This result aligns with previous research conducted in Surakarta by Roziaty (2021), which also identified *Glodokan Tiang* (*Polyalthia longifolia*) as one of the dominant species. This tree is commonly found in urban areas due to its tidy canopy structure and rapid adaptability (Mukhlisin, 2015).

Mango (*Mangifera indica*) ranked second with 93 trees (13%), followed by *Angsana* (*Pterocarpus indicus*) with 77 trees (10.7%). These

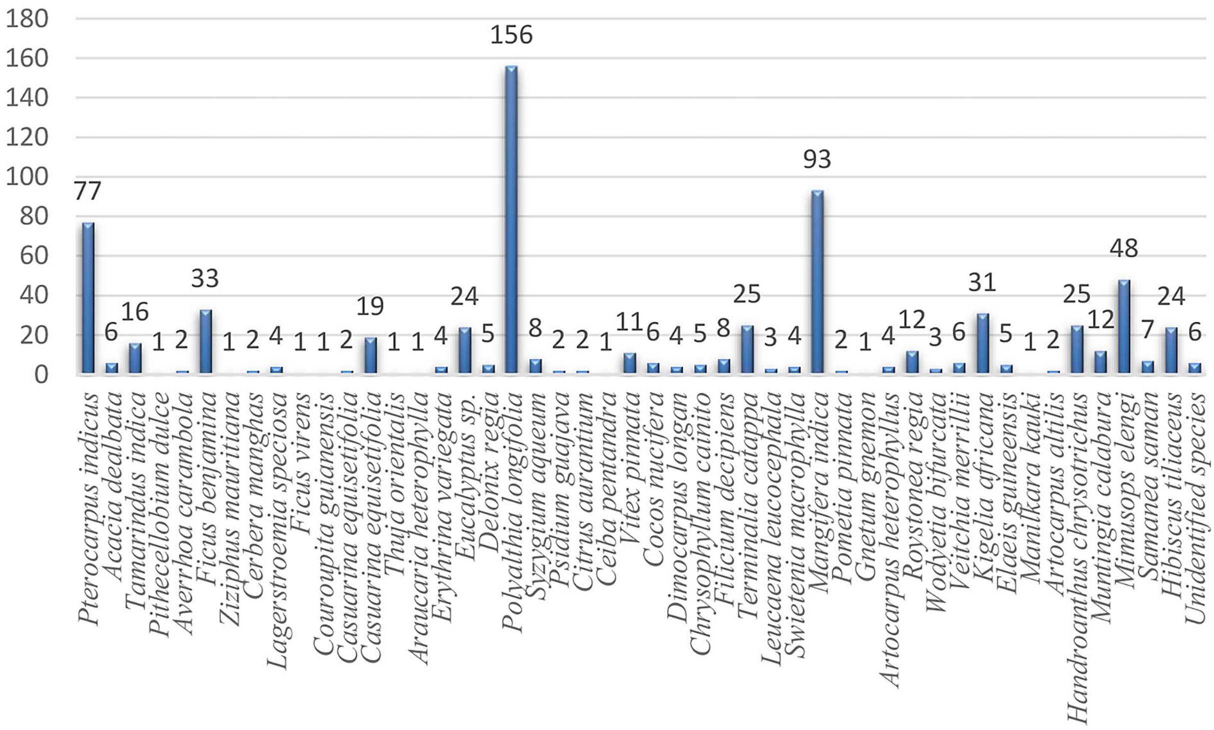

Figure 1. Number of individual trees by species

species are popular in urban settings; *Mangga* (*Mangifera indica*) is known for its moderate air humidity control function, making it an effective shade tree (Mahardi, 2013), while *Angsana* (*Pterocarpus indicus*) has a high capacity for absorbing greenhouse gases, thus contributing to urban air quality (Samsoedin, 2012).

Additionally, *Tanjung* (*Mimusops elengi*) and *Kigelia* (*Kigelia africana*) were recorded in significant numbers, with 48 trees (6.7%) and 31 trees (4.3%), respectively.

Other tree species were found in smaller numbers, including Asem Londo **(***Pithecellobium dulce***)**, Bidara **(***Ziziphus mauritiana***)**, Bunut **(***Ficus virens***)**, Cemara Kipas **(***Thuja orientalis*), Cemara Norfolk **(***Araucaria heterophylla*), Kapuk Randu **(***Ceiba pentandra***)**, and Melinjo **(***Gnetum gnemon***)**, with only one individual recorded for each. The low occurrence of these species may be due to limited research area coverage or differences in planting preferences.

Analysis of tree damage in the residential areas of Kedunglumbu and Manahan

Based on observations of 717 trunks, canker was identified as the most dominant type of disease, with 240 occurrences, accounting for 33.47% of the total observed damages (Figure 2). The data show that the canker category significantly exceeds other types of diseases, such as open wounds, which were recorded 164 times (22.87%), and stem fractures, which occurred 57 times (7.9%). The high incidence of canker is likely due to physical damage caused by human activities, such as improper pruning or untreated wounds, which provide entry points for pathogens like fungi or bacteria. Additionally, under certain conditions, such as rain and strong winds, pathogenic bacteria that cause canker can spread, further increasing its prevalence (Pertiwi, 2019). However, 188 trees (27.24% of the total observed trees) were found to be in normal condition (Figure 3).

For branches, the most common type of damage was broken or dead branches, with 303 occurrences, or approximately 42.25% of total identified branch damages. The data indicate that this category dominates, significantly exceeding other categories such as open wounds (109 occurrences, 15.2%) and Epicormic shoot (50 occurrences, 6.97%). The high number of broken or dead branches may be caused by various factors, including extreme weather conditions that weaken or kill branches. Environmental pressures, such as competition among branches for sunlight, also contribute significantly (Haikal, 2020). Dead branches in the study area were often not pruned promptly, increasing the risk of further damage to the trees.

Other damage categories, such as branch canker (42 occurrences, 5.85%) and fractured branches (7 occurrences, 0.97%), were less frequent compared to broken or dead branches. Meanwhile, minor categories like hollow branches, conks, lianas, and termite nests each accounted for less than 1% of recorded cases (Figure 4).

In root observations, the focus was on buttress roots, which are located above the soil surface and function to support the tree. Most observed roots were in normal condition, totaling

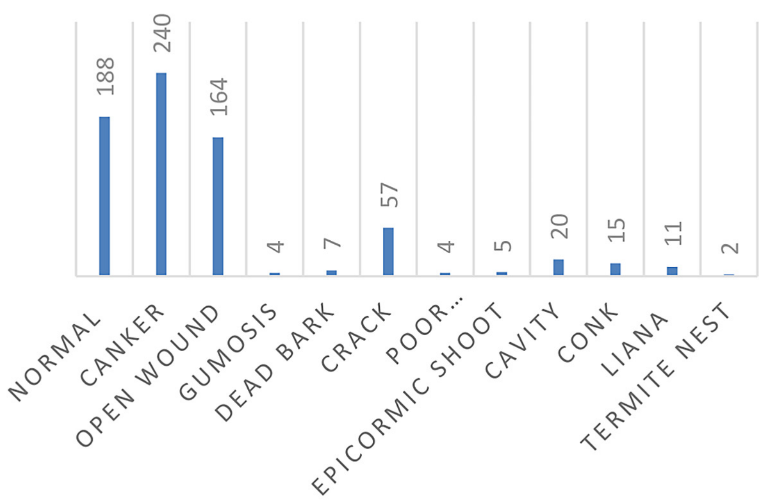

Figure 2. Types of damage on tree stems

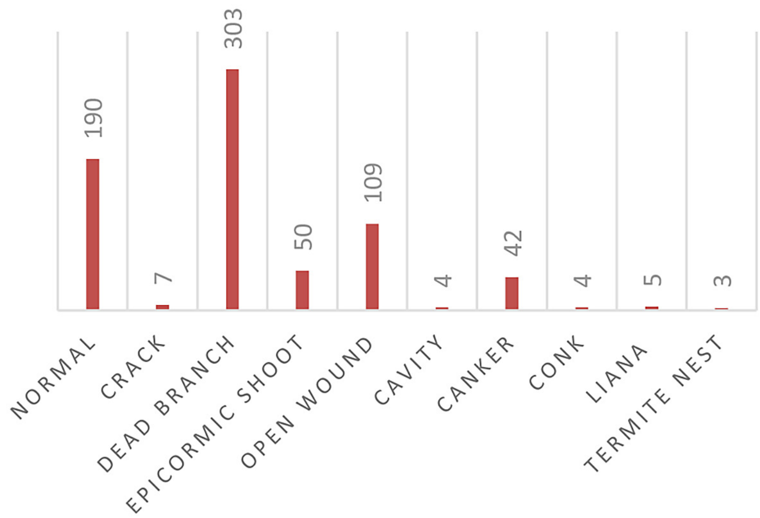

Figure 3. Types of damage on tree branches

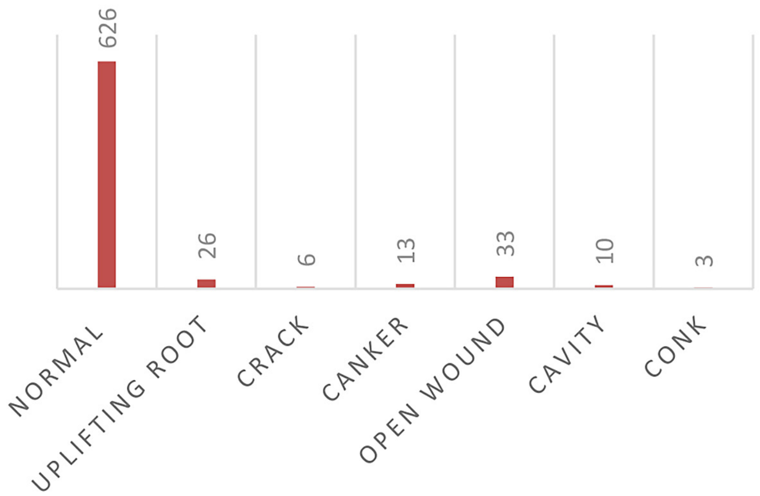

Figure 4. Types of damage on tree roots

626 occurrences, or about 87.3% of all observations, indicating that the majority of trees have healthy buttress roots capable of providing strong stability.

However, various types of root damage were also found. The most common damage was open wounds, with 33 occurrences (4.6%), typically caused by human activities such as digging and soil compaction. Other observed damages included exposed roots (26 occurrences, 3.62%), usually resulting from shallow root growth and compacted soil. Root canker was recorded 13 times (1.81%), indicating possible pathogen or fungal infections. Less frequent damages included hollow roots (10 occurrences, 1.39%), fractured roots (6 occurrences, 0.83%), and conks (3 occurrences, 0.41%) (Figure 5).

The most common leaf disease category was leaf discoloration, with 102 occurrences, accounting for approximately 14.22% of the total observed trees. The second most frequent category was leaf shedding, with 34 occurrences (4.74%). Meanwhile, damaged leaf buds/shoots were recorded 33 times (4.6%). Minor categories, such as missing/dead leaves, infected leaves, and lianas, each accounted for 3 occurrences (0.41%), 1 occurrence (0.13%), and 1 occurrence (0.13%), respectively. Leaf damage is generally caused by nutrient deficiencies or tree responses to environmental stress, such as drought or seasonal changes (Ningrum, 2020). Nonetheless, most observed leaves were in normal condition, with 543 cases (75.73%), indicating that the majority of trees had healthy foliage systems.

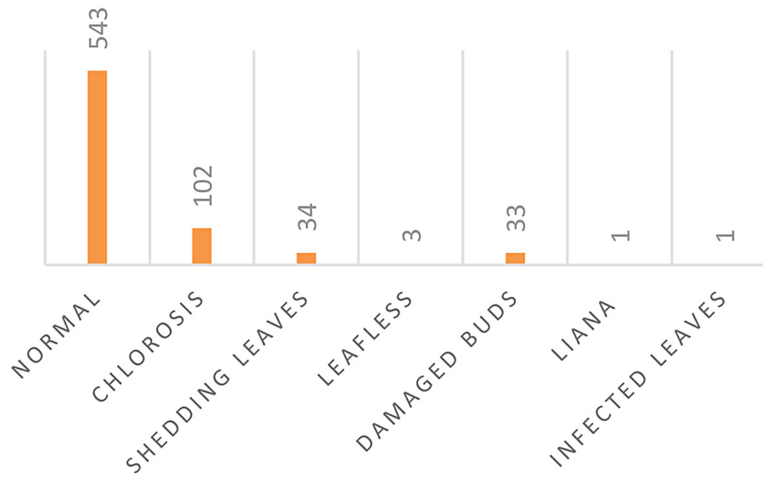

Figure 5. Types of damage on tree leaves

Tree risk assessment analysis

Based on the tree risk assessment using the Matrix evaluation in the Tree Risk Assessment form, which combines tree damage values, target zone, and consequence values, it was found that the majority of trees, totaling 666, fall into the low-risk category. This indicates that the combination of damage likelihood and impact consequences from these trees is minimal, meaning the resulting risk does not require special management attention. This category includes trees with a likelihood of damage that is either somewhat likely or unlikely, with consequences ranging from negligible to minor (Figure 6).

A total of 35 trees fall into the moderate-risk category, meaning the risk of damage is more significant compared to the low-risk category. Trees in this category have a combination of very likely or somewhat likely damage, with consequences generally ranging from minor to significant. These risks require monitoring and specific mitigation actions to ensure environmental safety. Furthermore, 16 trees are classified as high-risk, indicating a greater potential for damage with more serious impacts. Trees in this category typically have a likelihood of damage that is possible or very likely, with consequences that range from significant to severe. These trees require priority attention to prevent potential major losses (Table 1).

The trees above exhibit various types of structural damage within a single tree, such as trunk fractures, cavities, cankers, and broken or dead branches. These damages increase the risk of tree failure, especially in areas with potential targets such as main roads, dining establishments, residential houses, and public facilities.

However, no trees were found in the Extreme category (0 trees). This indicates that there is no combination of damage likelihood and consequence severity that reaches the most critical level, which could cause major disruptions or unacceptable losses (Figure 7).

In Manahan, out of 401 observed trees, the majority (91.0%) fall into the Low Risk category, indicating that the potential damage to targets and the overall impact of these trees are minimal. 6.0% of trees are classified as Moderate Risk, while 3% of trees fall into the High Risk category, signifying that these trees have a relatively higher risk of causing damage to targets (Figure 8).

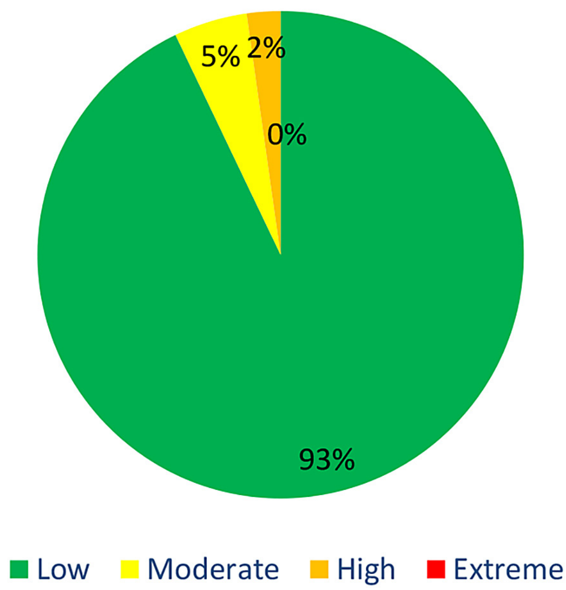

Figure 6. Tree risk percentage

Table 1. List of high-risk trees

Tree code	Coordinate (X)	Coordinate (Y)	Species name	DBH (cm)	Type of damage	Target
HP7	110.8297	-7.57219	Cemara Laut (*Casuarina equisetifolia*)	25.5	Canker, Trunk Crack, Broken/Dead Branches, Chlorosis	Main road, utility pole, sidewalk lamp, building power lines
TP78	110.8329	-7.57139	Waru (*Hibiscus tiliaceus*)	63.7	Epicormic shoot, Cavity, Open Wounds on Trunk and Branches	Passing vehicles, parking lot, pedestrians, food stalls
FP15	110.8298	-7.57261	Trembesi (*Samanea saman*)	57.3	Trunk Crack, Leaning, Broken/ Dead Branches	Main road, parking area, food stalls, sidewalk, utility pole
FP32	110.8309	-7.57297	Glodokan Tiang (*Polyalthia longifolia*)	23.2	Broken/Dead Branches, Leaning Tree	Food stalls, road
S13	110.8134	-7.55151	Angsana (*Pterocarpus indicus*)	63.0	Trunk Crack, Open Wounds, Cavity and Branches	Secondary road
P12	110.8138	-7.55098	Kecrutan (*Spathodea campanulate*)	91.4	Cavity, Canker, Trunk Crack, Open Wounds on Trunk and Branches	Restaurant area, local road
P13	110.8139	-7.55092	Kecrutan (*Spathodea campanulate*)	80.6	Trunk Crack, Open Wounds, Gummosis, Termite Nest, Cavity and Branches	Restaurant area, local road
P14	110.8140	-7.55062	Kecrutan (*Spathodea campanulate*)	95.2	Trunk Crack, Open Wounds, Cavity and Branches	Restaurant area, local road
P15	110.8138	-7.55006	Ketapang (*Terminalia catappa*)	36.6	Cavity, Concave Defect, Open Wounds, Termite Nest on Trunk and Branches	Main road, residential yard
P19	110.8132	-7.55225	Talok (*Muntingia calabura*)	23.9	Open Wounds, Canker, Trunk Crack, Cavity and Branches, Chlorosis	Street vendors, local road
P21	110.8120	-7.55248	Waru (*Hibiscus tiliaceus*)	65.9	Cavity, Trunk Crack, Open Wounds, Termite Nest, Epicormic shoot on Trunk and Branches	Street vendors, local road
P22	110.8119	-7.55249	Waru (*Hibiscus tiliaceus*)	95.5	Open Wounds, Cavity, Trunk Crack on Trunk and Branches	Street vendors, local road
P23	110.8119	-7.55246	Akasia (*Acacia*)	100.6	Open Wounds, Canker, Trunk Crack, Gummosis, Termite Nest, Cavity and Branches	Local road, residential area
P24	110.8118	-7.55244	Ketapang (*Terminalia catappa*)	23.2	Canker, Open Wounds on Trunk and Branches, Chlorosis	House, food stalls, local road
P24	110.8128	-7.55267	Ketapang (*Terminalia catappa*)	25.5	Cavity, Trunk Crack, Open Wounds, Gummosis, Termite Nest on Trunk and Branches	Workshop, local road, residential area
P25	110.8127	-7.55267	Palem Putri (*Roystonea regia*)	30.6	Open Wounds, Dead Trunk	House, local road, street vendors

Meanwhile In Kedunglumbu Subdistrict, 95.3% of trees are categorized as Low Risk, indicating that nearly all trees in this area pose very minimal damage risk to targets. A total of 3.5% of trees fall into the Moderate Risk category, while only 1.3% are classified as High Risk, suggesting that very few trees have the potential to cause significant damage. Furthermore, no trees in Kedunglumbu fall into the Extreme Risk category. Overall, Kedunglumbu Subdistrict exhibits a distribution highly concentrated in the Low Risk category, with only a few trees posing a higher risk of damage.

Similar to Manahan, no trees in Kedunglumbu are classified as Extreme Risk, meaning that no trees pose a severe threat of significant damage. However, compared to Kedunglumbu, Manahan has a higher proportion of trees in the Moderate and High Risk categories, indicating that the risk of tree-related damage to targets is slightly higher in Manahan (Figure 9).

Based on the graph above, several key points can be concluded regarding the distribution of risk across various tree species at the evaluation site. Overall, the majority of trees at the location fall into the low-risk category, with certain species dominating this group. For example, Glodokan Tiang (*Polyalthia longifolia*) is the most common species in this category,

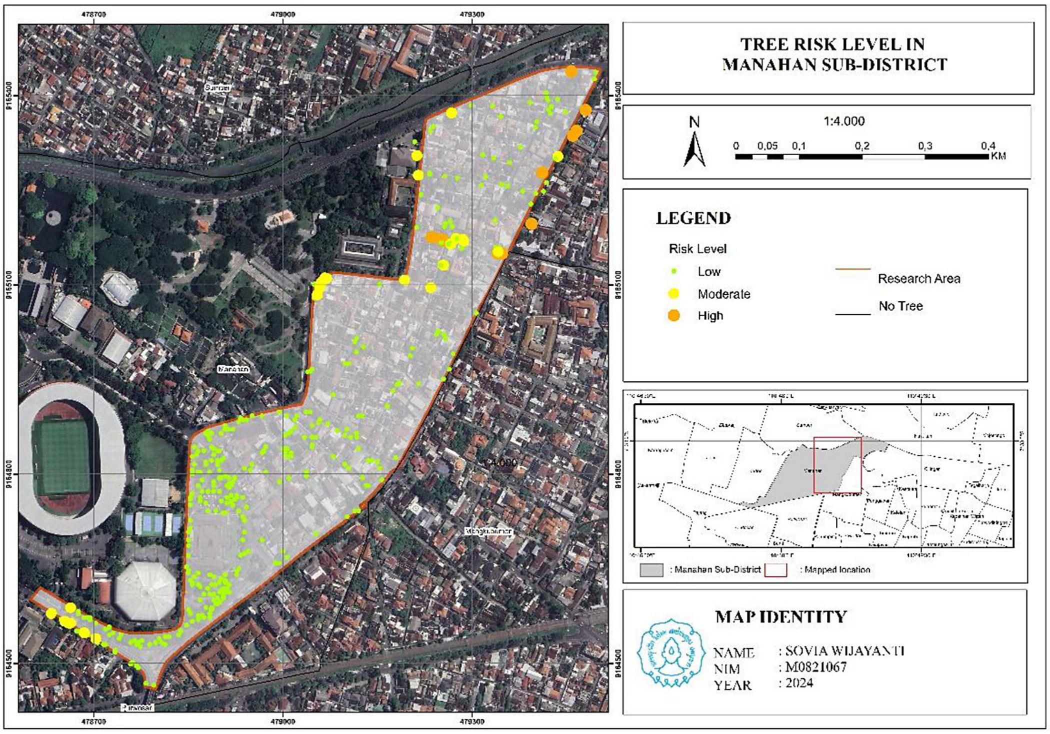

Figure 7. Tree risk level map in Manahan sub-district

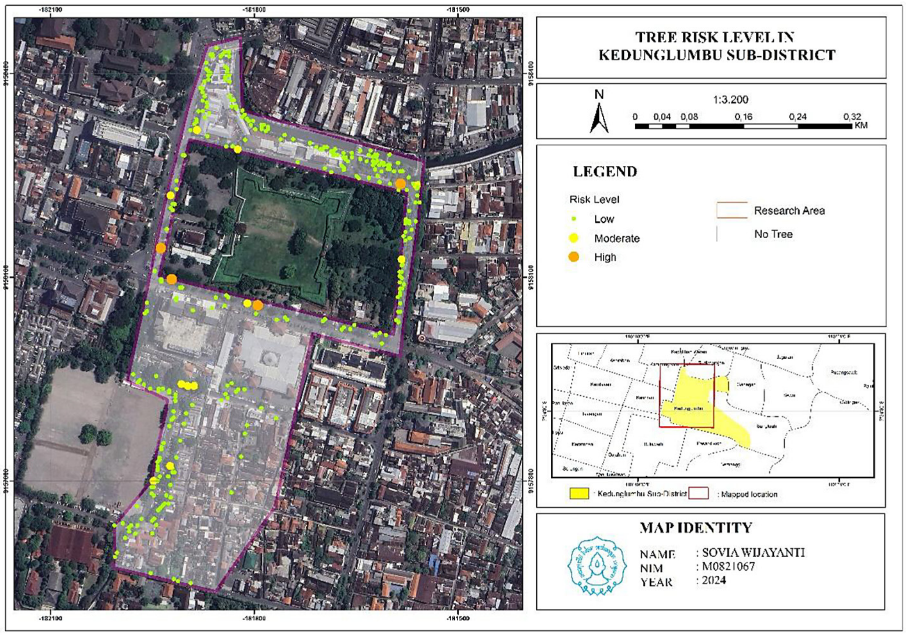

Figure 8. Tree risk level map in Kedunglumbu sub-district

with 146 out of 156 trees (approximately 94% of the total species population) classified as low risk. Other species, such as Mango (*Mangifera indica*) and Ketapang (*Terminalia catappa*), also have a high proportion in the low-risk category, at 95% and 88% of their total species population, respectively.

In the moderate-risk category, several species have a significant proportion, although their numbers are relatively smaller compared to the low-risk category. For instance, 10.4% of Angsana (*Pterocarpus indicus*) trees (out of 77 total) and 10.5% of Cemara Laut (*Casuarina equisetifolia*) trees (out of 19 total) fall into this category.

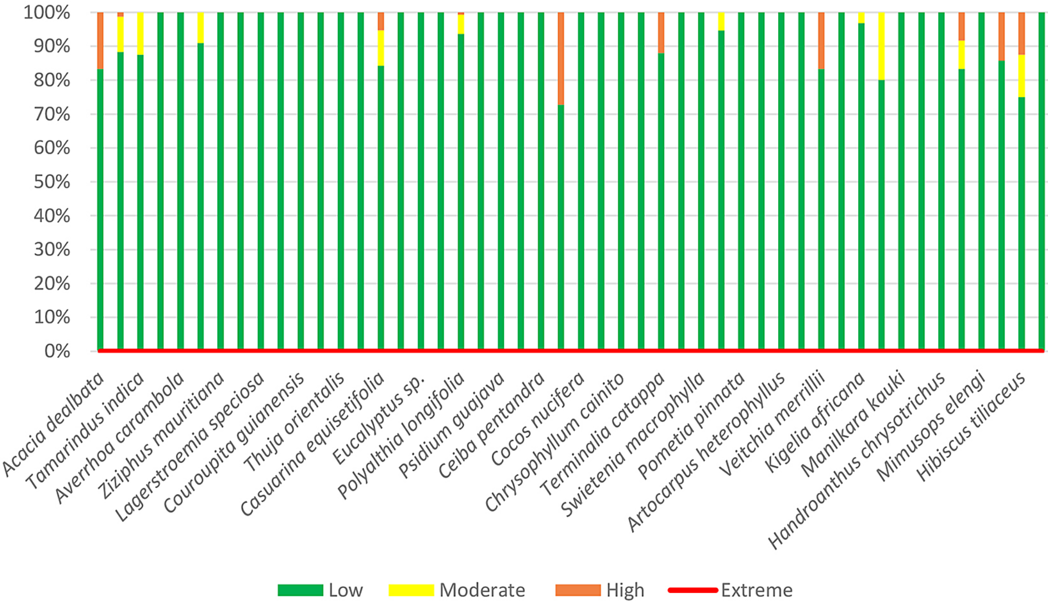

Figure 9. Risk percentage by tree species

Trees such as Talok (*Muntingia calabura*) and Waru (*Hibiscus tiliaceus*) also have notable proportions in the moderate-risk category, at 8.3% and 12.5%, respectively.

Although small in number, trees in the high-risk category require special attention due to the potential hazards they may pose. High-risk trees exhibit various types of structural damage within a single tree, such as trunk fractures, cavities, cankers, and broken or dead branches. These damages increase the likelihood of tree failure, especially in areas with potential targets, including highways, residential houses, and public facilities. The most frequently found species in the High-Risk category include Kecrutan (*Spathodea campanulate*), Waru (*Hibiscus tiliaceus*), and Ketapang (*Terminalia catappa*), each with three high-risk trees. Conversely, a study in GOS Udayana, Bali, conducted by Latifah (2020), found that Trembesi (*Samanea saman*) dominated the high-risk category, along with Sengon Buto (*Albizia chinense*). Tree damage in GOS Udayana generally consisted of trunk decay, fungal growth, and dead branches, with trees located in areas with permanent targets such as highways and green open spaces.

The primary difference between the two locations lies in species diversity and types of damage, where the study in Surakarta's residential areas shows a greater variety of high-risk species, while the study in GOS Udayana found a higher concentration of risk in Trembesi (*Samanea saman*) and Sengon Buto (*Albizia chinense*) species.

Mitigation strategies for tree damage in Kedunglumbu and Manahan sub-districts

Mitigating the risk of tree damage in Kedunglumbu and Manahan Sub-Districts is a crucial step to ensure the sustainability of the tree ecosystem and the safety of the surrounding environment. Based on research findings, branch breakage, trunk cankers, and open wounds are the most commonly found types of damage. This mitigation includes routine maintenance, environmental management around trees, and periodic evaluation using the TRA method.

One of the primary mitigation measures is regular branch pruning to remove dead, broken, or potentially hazardous parts. This pruning is conducted not only to reduce the risk of branch breakage due to external factors such as strong winds and heavy rain but also as a preventive measure against the spread of pathogens that often enter through open wounds on the trunk or branches (Latifah et al., 2020). In addition to government-initiated pruning, residents can also request pruning through established official mechanisms, especially if a tree poses a high risk to the surrounding environment (Aritama, 2019).

Besides pruning, treating open wounds on trees is also an essential part of mitigation. Open wounds caused by mechanical factors such as cuts, nail placement, or impacts can serve as entry points for pathogens such as fungi and bacteria that cause decay. Therefore, after pruning or if wounds are found on a tree, the affected area must be promptly cleaned and protected using fungicides or bactericides to reduce the risk of further infection. Strengthening tree structures is also necessary, particularly for trees with large branches that have narrow branching angles or double trunks. Methods such as cable installation (cabling) and bracing can be applied to enhance the stability of branches at risk of breaking, thereby reducing the likelihood of damage due to excessive load or extreme weather conditions (Rachmadiyanto, 2019).

Beyond direct actions on trees, managing the surrounding environment is also an important factor in mitigation efforts. Proper green space planning can reduce stress on trees, such as by preventing soil compaction that can hinder root growth and cause structural instability. Human activities around trees, such as nailing into trunks or excavation that damages root systems, need to be controlled to prevent further damage. Regular monitoring and evaluation using the TRA method are essential to identify trees classified as high-risk. Trees deemed hazardous, especially those in areas with high human activity such as main roads and public spaces, should be prioritized for pruning, maintenance, or even removal if their structural condition is beyond preservation.

The role of local government in tree and green open space (GOS) management is also a crucial aspect of tree risk mitigation. According to Regional Regulation No. 8 of 2015, the local government is responsible for maintaining, developing, and increasing public and private sector awareness regarding tree and GOS conservation. Educating the public about the vital role of trees in urban ecosystems and proper maintenance techniques can serve as a strategic step to ensure the sustainability of both the ecological functions and aesthetic value of trees in the study area.

CONCLUSIONS

Based on research conducted to evaluate tree risk in relation to environmental conditions in the residential areas of Surakarta City, several key findings were obtained. The most dominant tree species identified was Glodokan Tiang (*Polyalthia longifolia*), accounting for 156 individuals or 21.8% of the total tree population. Among the 717 trees observed, the majority were in good condition with minimal damage; however, a number of trees showed significant structural issues, especially in their trunks and branches. The most frequently observed types of damage were broken or dead branches, which occurred 303 times (42.25%), followed by trunk cankers, recorded 240 times (33.47%). In terms of risk classification, most trees (666) were categorized as low risk, while 35 were medium risk and 16 were high risk, with no trees falling into the extreme risk category. Notably, high-risk trees were typically located in high-traffic areas such as main roads and public spaces, indicating the need for prompt mitigation measures to reduce potential hazards.

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