



PLANNING MALAYSIA:

Journal of the Malaysian Institute of Planners

VOLUME 23 ISSUE 4 (2025), Page 287 – 304

ASSESSING THE TYPOLOGY OF FALLEN TREES RISK IN SURAKARTA CITY, INDONESIA

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Abstract

Surakarta City has a significant risk of fallen trees. Because of its long urban history, it has many old, diverse, and historic trees. On one side, it indicates the existence of historical urban vegetation, but on the other side, the old trees have a high risk of falling. The tropical climate causes extreme weather risks that have often occurred in recent eras. The urban stakeholders seek to keep the diverse trees to ensure the urban vegetation proportion in the city. This article explores the typology of fallen tree risks in Surakarta. The research used the spatial analysis of the geographic information system. It was supported by historical data on fallen trees in Surakarta compiled from urban institutions and electronic newspapers over the last three years. The correlation analysis supported this research in exploring the relationship between the level of fallen tree hazard, the existence of main roads impacted by the fallen trees, and the existence of urban green space. The occurrences of fallen trees were dominated along the main streets in the city, including primary and secondary roads. Furthermore, there is a correlation between the hazard of fallen trees and urban green space in the city. The sub-districts have a high proportion of urban vegetation in a linear relationship to the risk of fallen trees in the city. These results could be the implications of the Surakarta urban planning policy for disaster risk management.

Keywords: Fallen Trees, Urban Green Space, Urban Disaster Risk, Surakarta

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INTRODUCTION

Urban vegetation is an essential element in a city. It has several functions, including reducing carbon emissions, reducing the city's heat island effect, improving the urban climate, and supporting urban health to support the urban ecology. It is a critical issue in urban management. The law of the Republic of Indonesia No. 26 of 2007 concerning spatial planning mentions that a city's ideal proportion of open space, including green and water spaces, is about 30 % of the total area. However, many cities in Indonesia have difficulties in achieving this proportion (Yusuf et al., 2023). The existence of green open space for local climate instruments in Indonesian Cities is one of the three lowest countries in Southeast Asia (Priyanta & Zulkarnain, 2024). Based on this situation, many Indonesian cities seek to preserve the existence of urban vegetation to avoid reducing open space in the city. Commonly, one type of urban vegetation is the trees along the urban streets. The urban trees functioned as reducing land surface temperatures, carbon emissions, inundations, urban greening, and the city's beautification (Guo et al., 2023; Grote et al., 2016; Ow & Ghosh, 2017; Olawuyi, 2019; Hamzah et al., 2024). The high density of urban trees is what we refer to as the optimum functional system of urban vegetation. Conversely, urban trees pose a disaster risk due to the fallen trees, particularly during the rainy season. Frequently, storms occur in the cities during the rainy season (Huo & Chen, 2020) and produce fallen trees in the city, consequently causing urban damage and human deaths. Not only does the fallen tree risk occur due to the storm, but several factors contribute to the fallen tree risk, such as the problem of the tree's condition, including branches, roots, and trunk; the tree species; and the tree's age (Mendes et al., 2024; Ardestani et al., 2020). Research on fallen tree risk is needed to improve urban management, particularly urban risk reduction and ecological landscape systems (Hui et al., 2022; Delshammar et al., 2015; Abdullah et al., 2024). Urban tree management is a crucial issue, not only in Indonesia but also in other countries in Southeast Asia, such as Malaysia, Thailand, and Singapore (Kanniah, 2017; Nor and Abdullah, 2019; Intasen et al., 2017; Tan et al., 2021; Lazim and Misni, 2016; Srinurak et al., 2024). Our research limits the spatial perspectives seeking to understand the fallen tree risk toward the existence of urban green spaces in the city, including along roads and urban parks. The problem of the tree's condition is not a focus of this research, and the tree's condition factors and extreme weather are considered potential confounders.

Surakarta, as a historical Javanese city, has a high density of urban trees along the urban streets. Many trees are old and need regeneration (Indrawati et al., 2021). Nevertheless, Surakarta also has the problem of limited green open spaces. Surakarta's Green spaces are approximately 9 (nine) % of the city's area. They are under standard from the ideal proportion of open green space based on the law of spatial planning in Indonesia (Absori et al., 2020; Harahap et al., 2021). The limitation of green spaces produces an ecological function problem. The

existence of urban parks and urban vegetation should be improved in Surakarta (Suhardono et al., 2024; Zaky et al., 2023; Nurhayati et al., 2024). On the other hand, fallen trees often occur in Surakarta. The last occurrence of the critical fallen trees disaster in Surakarta occurred during a rainstorm on January 3rd, 2024. At that time, dozens of fallen trees caused urban damage, including several vehicles being hit by the fallen trees and damage to urban electricity. This situation produces insecurity in society due to the risk of falling trees (Camacho-Cervantes et al., 2014; Portoghesi et al., 2023). These facts indicate that Surakarta has a high risk of falling trees, but this city also needs to increase the number of green space areas. Based on these situations, this research assumed that the existence of urban green zones directly correlates with a higher probability of fallen tree occurrences. It assesses the typology of urban fallen tree risk to improve urban planning, mainly urban mitigation towards the fallen tree risk, and also the perspectives for the appropriate increase of urban green space in Surakarta.

RESEARCH METHODOLOGY

This research uses a case study concerning Surakarta City. It has a high-density population and is a historic city in Central Java, Indonesia. This city has existed and been planned by the Mataram Kingdom since the 18th century. Surakarta City area is about 4672.00 hectares, divided into 54 sub-districts. Rapid urbanisation has produced a massive reduction in green space in Surakarta. The research focuses on the typology assessment of fallen tree risk in this city. It uses the quantitative method supported by the spatial analysis of geographic information systems (GIS) and the correlational statistical analysis. The spatial analysis uses the open-source Quantum GIS (QGIS), and the correlation analysis utilises the open-source statistical program, namely JASP. QGIS was used to identify the locations of fallen trees and how they have spread in the city over the last three years. From the identification of fallen tree locations, the number of occurrences in each sub-district could be calculated to assess statistically and spatially the levels of fallen tree risk in Surakarta. Meanwhile, JASP revealed the correlation between the risk of falling trees and the existence of open green spaces and urban vegetation in Surakarta. The data, including fallen trees, areas of urban green space, and impacted main roads by fallen trees, were analysed using the correlation analysis supported by the JASP tool. This research uses a quantitative approach supported by the statistical and spatial data retrieved from the agencies of Surakarta Municipality, particularly the environmental office and the regional disaster management agency. The data collection was based on secondary data from local institutions and newspapers. The data and information on fallen tree occurrences provided by the local institutions, including Surakarta Disaster Management Agency and the official website of municipality data (<https://solodata.surakarta.go.id/>), were combined with the information on fallen

trees in the local newspapers (Solopos, Portal Berita RRI) during the last three years. The interviews of officials and field observation are needed to support data triangulation.

The research process is conducted in several phases, including identifying fallen trees in the city and conducting hazard analysis of fallen trees. Then, this research determines the typologies of fallen tree risks based on the level of fallen tree hazard and the existence of urban green space. The first step was exploring the historical and statistical data on fallen tree occurrences. The records of fallen tree occurrences were converted into frequency and aspatial data. The second step was the spatial mapping of fallen trees in the city. GIS was utilised to indicate the location and spatial data of fallen trees in the city. In this step, the main roads impacted by the fallen trees were also identified. Ground checking was also carried out to verify the fallen trees, particularly recently. The third step was the analysis of the fallen tree hazard level. This phase classified the potential hazard of fallen trees into three levels: low, medium, and high. The level classification was calculated from each sub-district's average maximum and minimum fallen tree incidents. The fourth step was identifying green space areas in the city based on its sub-districts. The fifth step is to determine the typology of fallen tree risk based on the hazard level, the main roads impacted by the fallen trees, and green space areas in the city. Correlation analysis was implemented in this research to prove the relationship between those factors. The standardisation of correlation analysis was used for the interpretation of statistical results. The research result will reveal the typology of fallen tree risk in Surakarta. This finding reinforces the appropriate urban management for mitigating fallen tree risk.

Table 1: The scoring technique

Criteria	Range/ Value	Scoring	Classification
Level of fallen tree hazard	$= \frac{\text{Highest Value} - \text{Lowest value}}{\text{number of class (3)}}$	0 – 1 st range	Low
		2 nd range	Medium
		3 rd range	High
Percentage of main roads impacted by fallen trees	$= \frac{\text{Number of fallen trees occurrences on main roads}}{\text{Number of fallen trees}} \times \text{Percentage (\%)}$		
Percentage of urban green space	$= \frac{\text{Total area of green space in each sub – district}}{\text{Total area of sub – district}} \times 100 \text{ Percentage (\%)}$		

Source: Author's identification (2024)

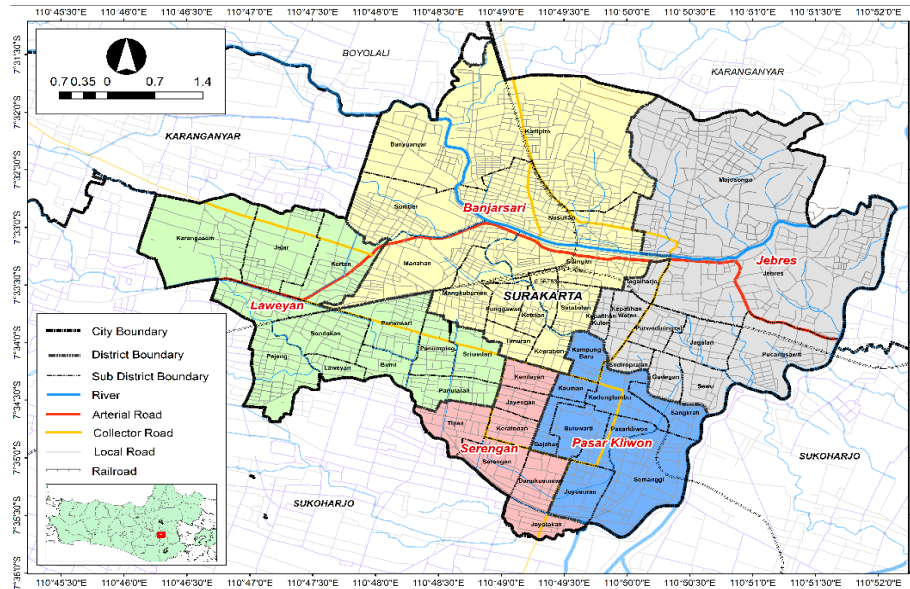


Figure 1: The Administration of Surakarta City
Source: Municipality of Surakarta, 2023, with the author's modifications

ANALYSIS AND DISCUSSION

Fallen Trees Occurrences during the Last 3 Years

Surakarta has frequently experienced incidents of fallen trees over the past three years, from 2021 to 2023. It has been recorded that 34 out of 51 sub-districts in Surakarta have experienced at least one fallen tree incident during this period. These incidents mainly occur at the beginning of the rainy season, especially when strong winds accompany heavy rain.

Based on data gathered from various sources, such as the Surakarta Disaster Management Agency and the Surakarta Municipality Data Website (<https://solodata.surakarta.go.id/>), combined with information on fallen trees from local newspapers (Solopos, Portal Berita RRI), there were 93 fallen tree occurrences during three years (data from 2022 to mid-2024). 34 from 54 sub-districts of Surakarta City experienced fallen trees. 20 sub-districts that have not experienced any incidents of fallen trees in the past three years. This situation indicates that the majority of sub-districts have fallen tree risks. Manahan Sub-District in Banjarsari District has recorded the highest number of fallen tree incidents over the past three years, with 8 (eight) incidents. Of these eight incidents, six occurred around the Manahan Stadium and the adjacent city park. Another sub-district in Banjarsari District with many incidents is Nusukan, which experienced 6 (six) incidents. However, the difference is that in Nusukan, the trees fell in residential areas and main roads. This number resembles several other sub-districts, such as Tipes (in Serengan District), Sriwedari (in Laweyan

District), and Jebres (in Jebres District). However, there were many sub-districts where the fallen tree took place one time, including Sudiroprajan, Sewu, Serengan, Semanggi, Punggawan, Panularan, Kepatihan, Kemlayan, Karangasem, Joyosuran, Jayengan, Jajar, and Jagalan. The number of fallen tree occurrences during the last three years can be seen in Figure 2.

Most tree-fall incidents occurred in the central part of Surakarta, characterised by dense land cover. Meanwhile, the sub-districts that have experienced few or no incidents are mainly located on the outskirts of Surakarta, such as Joyotakan, Danukusuman, Laweyan, Sumber, and Sangkrah. During the three years, 20 incidents of fallen trees occurred in 2022, 43 incidents in 2023, and at least 30 incidents in 2024 (until mid-2024). The distribution and location of fallen tree accidents during the last three years can be seen in Figure 3.

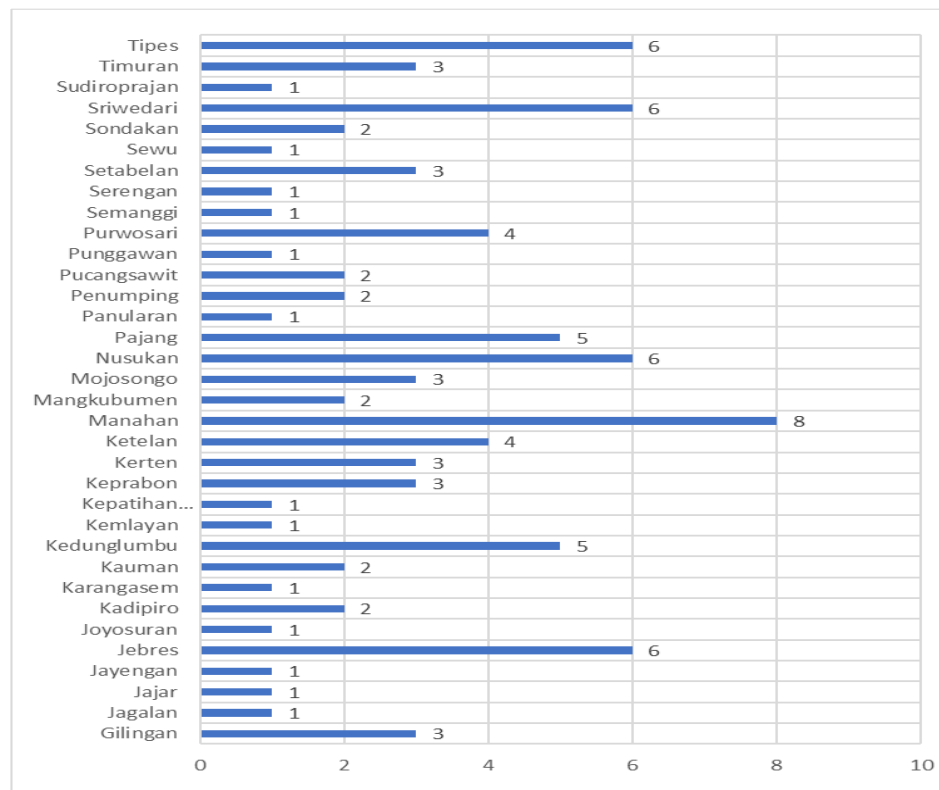


Figure 2: The number of fallen trees in each sub-district in Surakarta City during the last 3 years (2021-2023)

Source: Surakarta Disaster Management Agency, 2022; Municipality of Surakarta, 2023; local newspapers (Solopos, Portal Berita RRI)

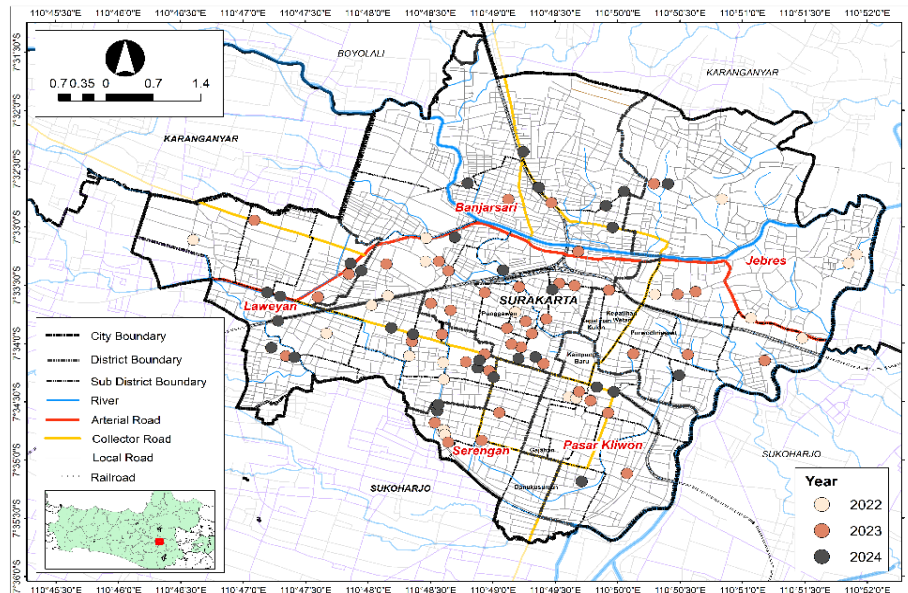


Figure 3: The distribution and location of fallen trees during the last 3 years

Source: Surakarta Disaster Management Agency, 2022; Municipality of Surakarta, 2023; Local newspapers (Solopos, Portal Berita RRI)

The Level of Fallen Tree Hazard

Like in many urban areas, fallen trees pose significant hazards in Surakarta that can impact public safety, infrastructure integrity, and environmental health. So, it is essential to identify the level of fallen tree hazards over the past three years. The level is determined by how many times fallen trees occur in each sub-district. Table 2 describes the frequency and location of fallen trees during the last three years.

Table 2: The frequency and location of fallen trees in Surakarta during the last 3 years

Frequency of Fallen Trees over 3 Years	Level of Fallen Tree Hazard	Sub-district
0-2	Low	Sudioprajan, Sondokan, Sewu, Serengan, Semanggi, Punggawan, Pucangsawit, Penumping, Panularan, Mengkubumen, Keplatihan, Kemlayan, Kauman, Karangasem, Kadipiro, Joyosuran, Jayengan, Jajar, Jagalan, <u>No occurrence:</u> Banyuanyar, Banjarsari, Joglo, Kestalan, Ketelan, Sumber, Gandekan, Kepatihan Kulon, Purwodiningratan, Tegalharjo, Laweyan, Bumi, Baluwarti, Gajahan, Kampung Baru, Mojo, Pasar Kliwon, Sangkrah, Danukusuman, Kratonan
3-5	Medium	Pajang, Kedunglumbu, Purwosari, ketelan, Timuran, Setabelan, Mojosongo, Kerten, Keprabon, Gilingan
>5	High	Tipes, Sriwedari, Nusukan, Jebres, Manahan

Source: Author's Calculation (2024)

The Main Roads Impacted by the Fallen Trees

Fallen trees cause direct losses, such as physical damage to buildings and vehicles, and can lead to macroeconomic losses if they occur on major roads that drive urban mobility. The impact is such infrastructure damage to traffic congestion and errors that disrupt public and private transportation mobility, reducing productivity. Based on this situation, the identification of main roads impacted by the fallen trees is needed to assess the risks of the fallen trees in the city. The main roads are the essential elements of the city, so when fallen trees occur on the main roads, their impact is higher than when fallen trees occur on streets in settlements. The percentage of main roads impacted by fallen trees can be shown in Table 3 as follows.

Table 3: Percentage of main roads impacted by the fallen trees

Sub-district	Number of fallen trees	Number of fallen tree occurrences on main roads	Percentage of main roads impacted by fallen trees
Manahan	8	3	38%
Pucangsawit	2	0	0%
Kedunglumbu	5	3	60%
Sriwedari	6	2	33%
Jebres	6	4	67%
Kestalan	0	0	0%
Kampungbaru	0	0	0%
Sewu	1	0	0%
Gilingan	3	2	67%
Mangkubumen	2	2	100%
Pajang	5	2	40%
Sangkrah	0	0	0%
Nusukan	6	3	50%
Jagalan	1	1	100%
Purwosari	4	3	75%
Sondakan	2	1	50%
Setabelan	3	2	67%
Semanggi	1	0	0%
Tegalarjo	0	0	0%
Gandekan	0	0	0%
Kerten	3	1	33%
Joyosuran	1	0	0%
Joyotakan	0	0	0%
Buluwarti	0	0	0%
Kadipiro	2	2	100%
Tipes	6	4	67%
Karangasem	1	0	0%
Serengan	1	0	0%
Laweyan	0	0	0%
Sumber	0	0	0%
Sudiroprajan	1	1	100%

Sub-district	Number of fallen trees	Number of fallen tree occurrences on main roads	Percentage of main roads impacted by fallen trees
Ketelan	4	2	50%
Mojosongo	3	2	67%
Panularan	1	1	100%
Purwodiningratan	0	0	0%
Bumi	0	0	0%
Punggawan	1	1	100%
Penumping	2	2	100%
Kepatihan Wetan	1	1	100%
Danukusuman	0	0	0%
Jayengan	1	1	100%
Pasarkliwon	0	0	0%
Keprabon	3	2	67%
Banyuanyar	0	0	0%
Kepatihan Kulon	0	0	0%
Jajar	1	0	0%
Kauman	2	2	100%
Gajahan	0	0	0%
Timuran	3	2	67%
Kratonan	0	0	0%
Kemlayan	1	1	100%
Total area	93	53	57%

Source: Author's Calculation (2024)

As previously described, more than half (57%) of fallen tree occurrences in Surakarta City occurred on main roads, which can cause traffic and potentially macro-scale economic disruptions. Manahan sub-district, which experienced the highest amount of fallen trees, only had three incidents on the main road. Meanwhile, sub-districts such as Jebres and Tipes each had four incidents of fallen trees on main roads. Only 7 (seven) sub-districts, such as Pucangsawit, Sewu, Semanggi, Joyosuran, Karangasem, Serengan, and Jajar, experienced fallen trees where main roads were unaffected.

The Existence of Urban Green Space

The urban green space in Surakarta includes the railway buffer zone, the river buffer zone, and urban parks and forests. The sub-district of Jebres has the highest urban green space area in Surakarta, with 74.29 hectares. Green space is one of the important urban elements. The ideal area of urban green space is more than 30 %. However, this number is difficult to implement in Indonesian cities, including Surakarta. The urban green space of Surakarta is only 426.80 hectares or 9.14 % of its total area. The sub-district of Manahan has the highest proportion of green space, about 30.22 %, in Surakarta. On the other hand, 5 (five) sub-districts, including Kauman, Gajahan, Timuran, Kratonan, and Kemlayan, have a proportion of green space under 1 (one) %. The classification and proportion of

urban green space in Surakarta can be detailed in Table 4. This situation indicates that urban green space is not evenly distributed in the city.

Table 4: Classification and Percentage of Urban Green Space

Sub-district	Area of rail-way buffer zone (Ha)	Area of river buffer zone (Ha)	Area of urban parks and forests (Ha)	Total area of urban green space (Ha)	Area of sub-district (Ha)	Percentage of urban green space (%)
Jebres	2.77	12.95	58.56	74.29	432.24	17.19
Manahan	3.57	3.29	40.13	46.99	155.50	30.22
Pucangsawit	5.61	6.20	2302	3483	128.14	27.18
Kadipiro	6.70	7.67	13.86	28.24	506.06	5.58
Mojosongo	0.00	8.16	18.24	26.39	545.41	4.84
Nusukan	6.15	8.01	7.07	21.23	196.09	10.83
Pajang	2.83	9.17	7.13	19.13	164.25	11.65
Gilingan	10.18	3.05	2.94	16.17	125.98	12.83
Kedung lumbu	1.80	1.39	12.89	16.08	59.34	27.10
Semanggi	4.22	3.64	3.19	11.05	159.99	6.91
Mangkubumen	6.04	3.24	1.72	11.00	87.04	12.64
Karangasem	0.00	3.40	7.09	10.49	193.25	5.43
Sriwedari	0.00	1.22	9.27	10.48	54.08	19.39
Sumber	0.00	6.57	0.83	7.40	146.94	5.04
Purwosari	2.89	2.43	1.52	6.84	80.27	8.52
Kerten	0.00	3.85	2.96	6.81	111.73	6.10
Sondakan	1.90	2.03	2.80	6.73	80.63	8.34
Sewu	0.00	1.68	4.68	6.36	47.40	13.42
Jagalan	1.63	4.10	0.32	6.05	61.90	9.78
Kampungbaru	0.00	1.16	3.68	4.83	35.73	13.53
Sangkrah	1.86	2.32	0.27	4.44	41.04	10.83
Banyuanyar	0.00	2.22	1.67	3.89	145.83	2.67
Joyosuran	0.00	2.83	0.71	3.54	59.18	5.99
Kestalan	2.44	0.83	0.11	3.39	24.29	13.94
Tipes	0.00	1.42	1.85	3.27	59.76	5.48
Setabelan	0.00	0.59	2.58	3.17	44.40	7.15
Baluwarti	0.00	0.00	3.12	3.12	54.10	5.76
Serengan	0.00	2.61	0.44	3.05	56.62	5.38
Panularan	0.00	1.04	1.59	2.63	56.30	4.68
Joyotakan	0.00	1.12	1.30	2.42	41.50	5.84
Gandekan	0.00	2.16	0.00	2.17	34.52	6.28
Jajar	0.00	0.52	1.61	2.13	122.09	1.74
Danukusuman	0.00	1.85	0.00	1.86	52.98	3.51
Penumping	0.00	0.81	1.01	1.82	48.16	3.77
Purwodiningratan	1.12	0.62	0.00	1.74	38.86	4.47
Tegalharjo	1.45	0.00	0.00	1.45	22.62	6.42
Bumi	0.00	1.11	0.33	1.44	32.77	4.40
Kepatihan Wetan	0.69	0.34	0.41	1.44	39.56	3.64
Punggawan	0.00	0.26	1.01	1.28	33.77	3.78

Sub-district	Area of rail-way buffer zone (Ha)	Area of river buffer zone (Ha)	Area of urban parks and forests (Ha)	Total area of urban green space (Ha)	Area of sub-district (Ha)	Percentage of urban green space (%)
Pasarkliwon	0.00	1.18	0.07	1.25	37.74	3.31
Sudiroprajan	0.00	1.18	0.00	1.18	23.51	5.03
Laweyan	0.00	0.42	0.74	1.16	22.91	5.06
Ketelan	0.00	0.72	0.41	1.13	23.25	4.87
Keprabon	0.00	1.03	0.00	1.03	33.61	3.07
Jayengan	0.00	0.00	1.00	1.00	29.97	3.33
Kepatihan Kulon	0.00	0.27	0.12	0.39	18.92	2.08
Kauman	0.00	0.00	0.00	0.00	20.72	0.02
Gajahan	0.00	0.00	0.00	0.00	25.02	0.00
Timuran	0.00	0.00	0.00	0.00	28.56	0.00
Kratonan	0.00	0.00	0.00	0.00	33.58	0.00
Kemlayan	0.00	0.00	0.00	0.00	32.67	0.00

Source: Author's Calculation (2024)

The area of urban parks and forests is the most common type of green space in Surakarta City, offering residents essential environmental benefits and recreational opportunities. Sub-districts like Jebres and Manahan even have urban parks and forests spanning more than 40 hectares, and overall, their urban green space areas are about 74.29 hectares and 46.99 hectares, contributing to over 28.41% of the total green space in Surakarta City (see Table 3). However, its proportion of green space area is only 17.19 % of the Jebres sub-district area, which is relatively low. These expansive areas enhance the quality of life and play a crucial role in maintaining ecological balance in densely populated urban settings. Conversely, sub-districts with smaller urban parks and forests tend to have less overall green space. Each sub-district in Surakarta has a different distribution of urban green space characteristics. In the middle of Surakarta, the urban green space mainly consists of city forests and parks. Meanwhile, the urban green space primarily consists of a cemetery in the northern part, which contains some of the Banjarsari Sub-district and Jebres Sub-district. The location of fallen trees and green space in Surakarta can be shown in Figure 4.

The Typology of Fallen Tree Risk

One key factor in urban risk management is understanding urban disaster risk typology. In this context, exploring fallen tree hazard typology is essential in mitigating and managing Surakarta's urban fallen tree risk. Table 5 describes the typology of fallen tree risk relating to the urban green space and the main road impacted by fallen trees.

Table 5: Typology of fallen tree risk

Sub-district	Total area of urban green space (Ha)	Percentage of urban green space (%)	Percentage of main roads impacted by fallen trees	Level of fallen tree hazard
Jebres	46.99	30.22	38%	High
Manahan	34.83	27.18	0%	Low
Pucangsawit	16.08	27.10	60%	Medium
Kadipiro	10.48	19.39	33%	High
Mojosongo	74.29	17.19	67%	High
Nusukan	3.39	13.94	0%	Low
Pajang	4.83	13.53	0%	Low
Gilingan	6.36	13.42	0%	Low
Kedung lumbu	16.17	12.83	67%	Medium
Semanggi	11.00	12.64	100%	Low
Mangkubumen	19.13	11.65	40%	Medium
Karangasem	4.44	10.83	0%	Low
Sriwedari	21.23	10.83	50%	High
Sumber	6.05	9.78	100%	Low
Purwosari	6.84	8.52	75%	Medium
Kerten	6.73	8.34	50%	Low
Sondakan	3.17	7.15	67%	Medium
Sewu	11.05	6.91	0%	Low
Jagalan	1.45	6.42	0%	Low
Kampungbaru	2.17	6.28	0%	Low
Sangkrah	6.81	6.10	33%	Medium
Banyuanyar	3.54	5.99	0%	Low
Joyosuran	2.42	5.84	0%	Low
Kestalan	3.12	5.76	0%	Low
Tipes	28.24	5.58	100%	Low
Setabelan	3.27	5.48	67%	High
Buluwarti	10.49	5.43	0%	Low
Serengan	3.05	5.38	0%	Low
Panularan	1.16	5.06	0%	Low
Joyotakan	7.40	5.04	0%	Low
Gandegan	1.18	5.03	100%	Low
Jajar	1.13	4.87	50%	Medium
Danukusuman	26.39	4.84	67%	Medium
Penumpng	2.63	4.68	100%	Low
Purwodiningratan	1.74	4.47	0%	Low
Tegalharjo	1.44	4.40	0%	Low
Bumi	1.28	3.78	100%	Low
Kepatihan Wetan	1.82	3.77	100%	Low
Punggawan	1.44	3.64	100%	Low
Pasarkliwon	1.86	3.51	0%	Low
Sudioprajan	1.00	3.33	100%	Low
Laweyan	1.25	3.31	0%	Low
Ketelan	1.03	3.07	67%	Medium
Keprabon	3.89	2.67	0%	Low
Jayengan	0.39	2.08	0%	Low

Sub-district	Total area of urban green space (Ha)	Percentage of urban green space (%)	Percentage of main roads impacted by fallen trees	Level of fallen tree hazard
Kepatihan Kulon	2.13	1.74	0%	Low
Kauman	0.005	0.02	100%	Low
Gajahan	0.00	0.00	0%	Low
Timuran	0.00	0.00	67%	Medium
Kratonan	0.00	0.00	0%	Low
Kemlayan	0.00	0.00	100%	Low

Source: Author's Calculation (2024)

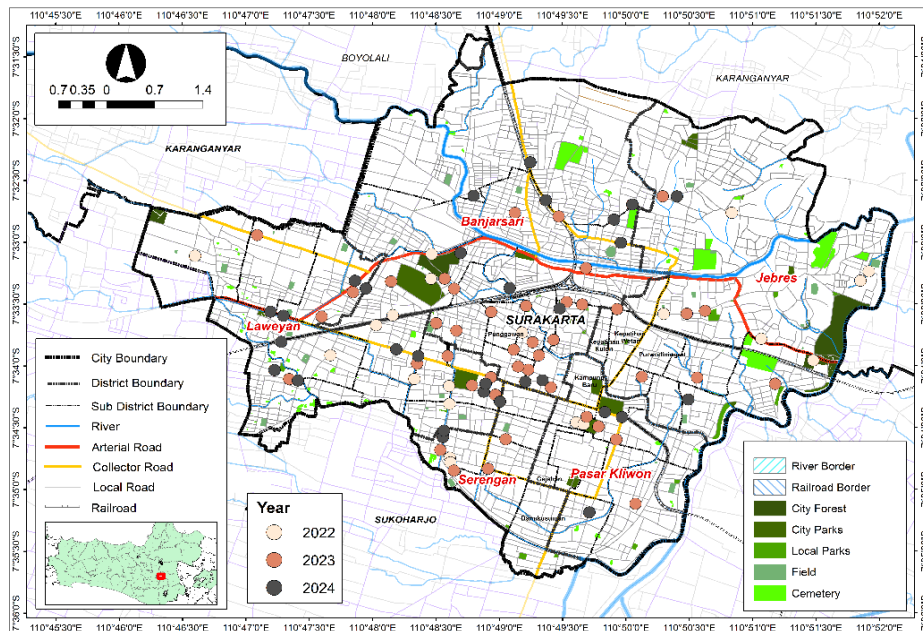


Figure 4: Green space and location of fallen trees in Surakarta City

Source: Surakarta Environmental Agency (2023), Author's Identification (2024)

Using correlation analysis in JASP software, the typology of fallen tree incidents in Surakarta City can be identified by examining the relationship between variables such as the total area of urban green space, the percentage of main roads impacted by fallen trees, and the level of fallen tree hazards. The analysis tries to determine whether there is a statistically significant relationship between these variables, which can provide valuable insights into the patterns and risk factors associated with fallen trees in urban environments. The result of the correlation analysis can be described in Table 6.

Table 6. Pearson's Correlation

Variable		V1	V2	V3	V4
V1	Pearson's r	-			
	p-value	-			
V2	Pearson's r	0.648	-		
	p-value	< .001	-		
V3	Pearson's r	0.112	-0.051	-	
	p-value	0.432	0.723	-	
V4	Pearson's r	0.539	0.441	0.233	-
	p-value	<0.001	0.001	0.1	-
V1: Total area of urban green space			V2: Percentage of urban green space		
V3: Percentage of main roads impacted by fallen trees			V4: Level of fallen tree hazard		
Correlation coefficient interval: 0.00-0.199 (very low), 0.20-0.399 (low), 0.40-0.599 (medium), 0.60-0.799 (strong), 0.80-1.00 (very strong)					

Source: Author's Analysis (2024)

Based on the correlation analysis table above, it is known that the correlation between the total area of urban green space and the level of fallen tree hazards has a Pearson's r value of 0.539, with a significance level of <0.001. This indicates a positive, significant, and medium correlation between the total area of urban green spaces and the level of fallen tree hazard in each sub-district. The positive and significant correlation means that if there is a correlation between those factors and an increase in the total area of urban green space, the level of fallen tree hazard will also increase. The medium correlation means those factors are moderately correlated, and others probably have a strong correlation. Meanwhile, the correlation between the percentage of urban green space and the level of fallen tree hazard has a Pearson's r value of 0.441, with a significance level of <0.001. This indicates a positive, significant, and medium correlation between the percentage of urban green space and the level of fallen tree hazard. In other words, an increase in the percentage of urban green spaces in a sub-district is associated with a higher level of fallen tree hazard. The logical statement concerning the percentage of urban green space is interpreted as the total area of urban green space towards the level of fallen tree hazard. Conversely, the correlation between the percentage of the main roads impacted by fallen trees and the level of fallen tree hazard has the p-value of these two variables is 0.1 or more than 0.005. It indicates no correlation between the percentage of main roads impacted by fallen trees and the level of fallen tree hazards in each sub-district.

More green space is correlated with the fallen tree risk predicted by the existence of old trees' ages in Surakarta. Many trees have existed since the kingdom's era. The trees along the main roads and those in urban parks are dominated by mature trees. However, further research could concern the potential confounders, including the tree specification, such as species, age,

root failure, and structural defect, influencing the fallen tree risk. Furthermore, the effects of climate change on extreme weather could be a factor that could be assessed in further studies.

CONCLUSION

The risk of fallen trees is an essential challenge in urban management in Surakarta City. The research described the increase in fallen tree risks during the last three years. The occurrences of fallen trees were dominated along the main roads in the city, including primary and secondary roads. Several sub-districts have high fallen tree hazards, including Tipes, Sriwedari, Nusukan, Jebres, and Manahan. Furthermore, the research demonstrates that urban green space is not evenly distributed in the city. The research findings conclude that the fallen tree hazard level correlates with the existence of urban green space. Most sub-districts have a high proportion of urban green space and a high risk of fallen trees. By addressing these challenges, urban stakeholders can enhance the resilience of fallen trees through proactive and integrated approaches to urban risk management. The number of green spaces in Surakarta City needs to be increased, but it needs to be balanced by managing urban trees. The mitigation of fallen trees should be done by identifying urban trees. Regularly monitoring and maintaining urban trees proactively should support the tree identity cards developed by urban stakeholders recently. The existence of tree identity cards should inform the specific tree species and tree ages so that preventive maintenance can be carried out well. It relates to the implications of urban planning and management policy that could improve the resilience of urban environments to natural hazards.

ACKNOWLEDGMENTS

The researchers thank the Institute of Research and Community Service, Universitas Sebelas Maret, which has funded this research through the Non-State Budget of Universitas Sebelas Maret No. 194.2/UN27.22/PT.01.03/2024

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Received: 2nd May 2025. Accepted: 10th September 2025