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Vulnerability Assessment of Fallen Trees Along Arterial Road of Bukit Soeharto Grand Forest Park Using Google Street View

Penilaian Kerawanan Pohon Tumbang di Sepanjang Jalan Arteri Taman Hutan Raya Bukit Soeharto Menggunakan Google Street View

Ali Suhardiman[1*], Frans Milan[1], Yosep Ruslim[1], Ariyanto[1], & Hari Siswanto[1]

[1]Forestry Study Program Undergraduate Program, Faculty of Forestry, Mulawarman University, Samarinda 75123, Indonesia
*Email: suhardiman@fahutan.unmul.ac.id

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Natural disaster, Potential FallenTrees, Forest Road, Google Street View, Bukit Soeharto Grand Forest

ABSTRACT

The incidence of fallen trees along the roadside was widespread across various locations in Indonesia, particularly in areas where trees naturally thrive. Therefore, this research aimed to explore Google Street View (GSV) to obtain information regarding the potential of fallen trees. A novel approach was proposed using panoramic photos available in GSV data from May 2021 and then subjected to testing along Balikpapan–Samarinda Arterial Road, covering a distance of 33 km, which traversed Bukit Soeharto Grand Forest Park (BSGFP). Leaning trees, trees with imbalanced canopy proportion, dying trees, and trees in rough topography became the criteria specified from GSV photos to determine potentially fallen trees. The results showed that 224 trees along Arterial Road met those criteria, translating to approximately 6.79 trees per kilometer of Arterial Road. The analysis revealed that an imbalance canopy proportion was the primary cause of fallen trees, supported by investigations and comparisons with the corresponding GSV photos before the collapse. The Arterial Road Balikpapan-Samarinda poses moderate fallen tree vulnerability, scoring between 25% and 50%.

KATA KUNCI
Bencana alam, Pohon rawan tumbang, Jalan hutan, Google Street View, Tahura Bukit Soeharto

INTISARI

Penelitian ini bertujuan untuk mengekplorasi teknologi informasi Google Street View (GSV) sebagai pendekatan baru dalam menilai pohon rawan tumbang di jalan-jalan yang melintasi areal atau kawasan hutan dengan pohon-pohon berjajar di kiri kanan jalan. Lokasi pengujian GSV adalah jalan arteri Balikpapan – Samarinda sepanjang 33 km yang melintasi Taman Hutan Raya (Tahura) Bukit Soeharto. Pohon yang batangnya miring atau condong ke arah badan jalan, pohon yang proporsi tajuknya mengarah ke badan jalan, pohon kering atau mati, pohon yang berada di area lereng atau tebing yang keberadaannya lebih tinggi dari badan jalan merupakan kriteria pohon rawan tumbang yang dapat diidentifikasi melalui foto panorama GSV. Penelitian ini berhasil mengindentifikasi 224 pohon yang rawan tumbang atau dengan kerapatan 6,79 pohon/km jalan arteri. Proporsi tajuk pohon yang mengarah ke badan jalan menjadi penyebab paling banyak pohon tersebut roboh atau tumbang dari hasil perbandingan antara pohon yang telah tumbang di lapangan dan foto GSV sebelum pohon tersebut tumbang. Secara umum, tingkat kerawanan pohon tumbang di sepanjang jalan arteri Tahura Bukit Soeharto masuk kategori sedang (25-50%).

Introduction

Due to its geographical and geological conditions, Indonesia is prone to natural disasters like earthquakes, tsunamis, floods, landslides, typhoons, and tornadoes. These disasters have resulted in environmental damage, loss of property, and caused casualties. Fallen trees become a natural disaster in specific cases of high rainfall and severe winds (Hidayati 2008). These events occur in metropolitan areas and forest regions with public roadways. Numerous public roads cross wooded areas, such as in the Kalimantan region, where a public road runs from south to north through Bukit Soeharto Grand Forest Park (BSGFP). This forest, situated between the developing tropical cities of Balikpapan and Samarinda, holds significance as a part of the development area for the New Capital called "Ibu Kota Nusantara" or IKN.

Several roadside tree incidents are attributable to climate phenomena, such as heavy rainfall and strong winds. However, the internal condition also contributes to these occurrences, particularly hollow areas in tree trunks. Hollows naturally occur in trees and are crucial to promote forest succession (Chave et al. 2005). Apolinario and Martius (2004) reported that approximately 37.7±9.9% of fallen trees in the Central Amazon forest of Brazil were associated with hollows inside trunks. These hollows can also result from several diseases showing tree decay symptoms. According to Ruxton (2014), hollows inside tree trunks play a crucial role in chemical processes that protect the tree against microbial threats or damage on the surface of the bark. It is not always feasible for a plant to afford equal protection to all tissues. Hence, the interior of the trunks is often less safeguarded. The exterior plays a crucial role in supporting trees against various threats, including wind and insects, and more chemical processes occur on this side. The inner trunks receive a smaller portion of the protective chemical process, leading to more rapid degradation. Aside from metabolic conditions, fallen trees are also influenced by environmental factors, including the presence of leaning trees. These factors can collectively contribute to the occurrence of fallen trees along the roadside.

The incident of fallen trees along the roadside is widespread across various locations in Indonesia. The risk is notably higher in areas where trees are naturally growing, such as forests or botanical gardens. Assessing potential fallen trees is necessary in public places, such as botanical gardens, to protect visitors. Hanum et al. (2020) investigated the internal defect of *Joannesia princeps* in "Eka Karya" Bali Botanical Garden using acoustic tomograph equipment called ArborSonic. The research reported that tree trunks decayed up to 49% from their basal area (0.425 m^2) at 107 cm from the ground. Another research by Hanum et al. (2023) in the same location explored the decay of 80 trees (31-60 cm of dbh) and found that *Bischofia javanica* had 62% decay inside trunks. In particular, subterranean termites caused decay in *Syzygium racemosum*.

On February 14, 2021, the online edition of "Koran Kaltim", a local newspaper, reported incidents of fallen trees on Balikpapan-Samarinda Arterial Road, which transversed BSGFP (Sabri 2021). These incidents occurred at three different locations, namely Km 43, Km 37, and Km 32, in Batuah Village, Loa Janan District, Kutai Kartanegara Regency. A similar situation was previously reported by the online news portal "Inibalikpapan" on October 11, 2016. The report mentioned fallen trees in the Km 58 of the arterial roads in the BSGFP area. These trees fell in heavy rain and strong winds that afternoon (Amir 2016).

The BSGFP harbors a substantial number of trees that have grown naturally or were deliberately planted as part of the rehabilitation efforts following multiple fire events. To mitigate the threat posed to the community by these trees, the Regional Disaster Management Agency (*Badan Penanggulangan Bencana Daerah* or BPBD) East Kalimantan (2015) has taken the initiative to monitor and manage different plants and trees in medians and roadsides. The implementation of tree clearance along the roadsides of Balikpapan-Samarinda Arterial Road, specifically on Soekarno-Hatta Road, was completed on 13 January 2021 (Kaltim Post 2021). Approximately 160 trees have been pruned along ± 28 km of Arterial Road, from Km 30 to Km 58. This measure aimed to enhance road safety and reduce the risk of road accidents induced by fallen trees.

Surveys (Arenallo et al. 2020; Hanum et al. 2020) and visual observations (Fink 2009) are commonly used methods to assess the vulnerability of fallen trees. The method of directly observing tree conditions through field survey activities can provide fairly accurate data but its collection requires considerable time, cost, and human resources (Camarretta et al. 2019; Corte et al. 2020). Therefore, there is a pressing need for a breakthrough in data collection methods concerning the vulnerability of fallen trees, making the process faster, more accessible, and cost-effective through the use of various contemporary approaches and technologies.

The Google Street View (GSV) is an internet-based information technology, that provides panoramic photos of thousands of places around the world for free and brings a different way of analyzing phenomena in nature (Anguelov et al. 2010). The GSV data has been widely explored by scientists in various areas, recently becoming a prominent topic of research. The photos cover more than 90 countries and the most well-known internet-based application, providing street imageries (Biljecki & Ito 2021). The GSV was used to identify the time of building construction in Victoria, Australia (Li et al. 2018) while Hu et al. (2020) used GSV to analyze the microclimate in urban areas. The available published articles on GSV explore city infrastructure, health environment issues, urban perception, transportation, greenery, walkability, urban morphology, real estate, and socio-economics. Previous GSV research was mainly conducted in mainland China, Europe, and North America, while Southeast Asia including Indonesia, has comparatively less in this regard (Biljecki & Ito 2021).

However, no research has specifically explored potential fallen trees assessment using GSV, creating a gap that needs to be further explored. Therefore, this research aimed to explore GSV to acquire information regarding the likelihood of fallen trees along the Balikpapan-Samarinda Arterial Road which transversed the BSGFP area. The information on potential fallen trees can be used to plan mitigation actions in areas where people may be harmed by the incident of falling trees.

Methods

Data Collection

Data collection was carried out at the boundary line between the BSGFP area and the Balikpapan-Samarinda Arterial Road segment that crossed the

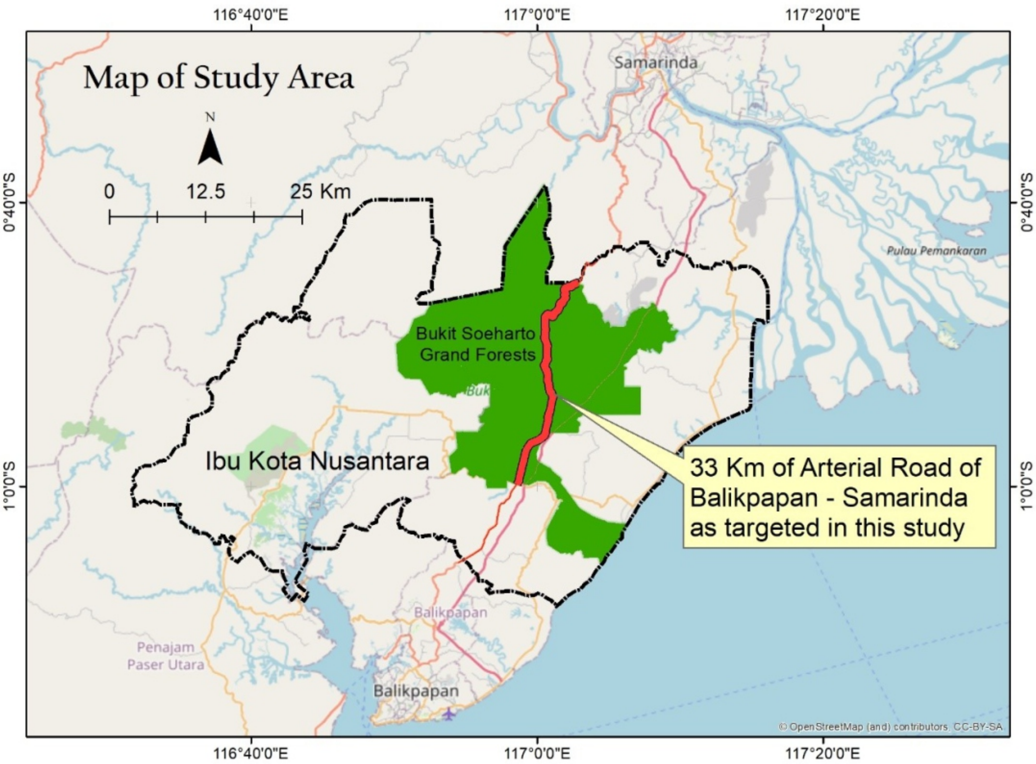

Figure 1. Map of the research location showed Balikpapan–Samarinda Arterial Road that crossed the BSGFP area as part of the Ibu Kota Nusantara (IKN) area

BSGFP area in East Kalimantan Province (Figure 1). The Arterial Road was constructed in the 1960s and became fully operational in 1970, connecting Balikpapan and Samarinda, two major cities in East Kalimantan. This thoroughfare transversed a distinctive lowland Dipterocarp forest, including the BSGFP, an area designated for biodiversity conservation. However, forest fires have severed the forest several times since 1982. In the 1990s, forest rehabilitation using fast-growing species occurred in the BSGFP area. The settlers had also illegally occupied the forest areas close to settlements. In 2022, the BSGFP was officially part of the IKN area.

Data collection included the remains or traces of fallen trees in former stumps, pieces of trunks, and others. The primary data of street-view panoramic photos were available online through the https://www.google.co.id/maps/ website portal. Along Balikpapan–Samarinda Arterial Road, GSV provided a series of panoramic photos labeled by year and month of acquisition. This research used a collection of street-view panoramic photos from May 2021.

Fallen Trees Identification

Identification of fallen trees was conducted by observing the criteria from panoramic photos available at GSV along Arterial Road that crossed the BSGFP area. The criteria for fallen trees were as follows (Figure 2).

I. Trees with sloping trunks or leaning towards the body of the road.
II. Trees whose canopy proportions were predominantly pointing to the road.
III. Trees without leaves, and possessed dry trunks.
IV. Trees in the area of slopes or cliffs whose existence was higher than the body of the road.

The GSV photos that met the criteria for potentially fallen trees along Balikpapan-Samarinda Arterial Road were subsequently extracted to obtain the exact coordinates. Subsequently, the photos and corresponding coordinates were carefully processed and securely stored in the designated Google Earth account, which had been duly prepared for this purpose.

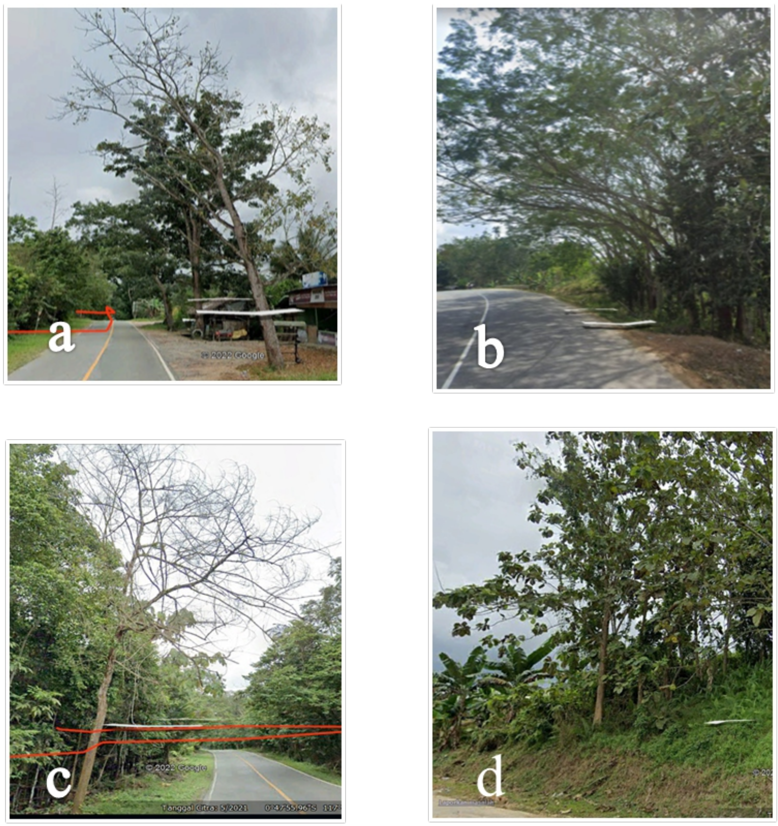

Figure 2. The criteria for fallen trees seen from GSV: (a) trees whose trunks are sloping or leaning towards the road body; (b) trees whose canopy proportions point to the road body; (c) dry/dead trees; (d) trees located in slope or cliff areas whose presence is higher than the body of the road.

Validation of Potentially Fallen Trees

Due to the time gap between the photograph or panoramic photos (May 2021) and the analysis in 2022, it is reasonable to assume that there may have been fallen tree occurrences between these periods. Consequently, it becomes necessary to authenticate and interpret the obtained GSV photos. A total of 30 random samples of potentially fallen trees from GSV were selected, after which field inspections were conducted based on the coordinates. At each designated location, photos were captured from two vantage points along the roadside, situated at a distance of 5-10 meters (Figure 3). This approach aimed to enhance the available information on the condition of trees and enable a comprehensive comparison with GSV photos. The field investigations used the Avenza Maps application to locate and record the sampled trees.

Vulnerability Level Assessment of Fallen Trees

The vulnerability level assessment was carried out by weighting four criteria for potentially fallen trees. The weight determination used the information on trees that had factually fallen along Balikpapan–Samarinda Arterial Road. The data collection involved observation of the marks or remains of fallen trees and matching them with those in the GSV display.

The data were further processed and calculated as the percentage of each criterion of trees. This percentage value was used as a weight to assess the vulnerability level of fallen trees on the left and right sides of the BSGFP road from the GSV source. Percentage values or weights were then assigned to all identified potentially fallen trees. The weight of this research reflected the real cause of trees falling. Therefore, it was better to adjust weight when replicating this research in other locations. From the previous process, the distribution of potentially fallen trees identification used GSV photos in the Google Earth application. Based on photo observations, each tree with the potential to fall had one or more combinations of criteria. The vulnerability level assessment and distribution of each potential fallen tree recorded from GSV photos used the sum of weight values. The sum of weight values for each tree was further classified using quartile equal percentage intervals to simplify the vulnerability level. The low vulnerability level has a total weight of ≤25%, while the very high vulnerability level has a total weight of >75%. The moderate and high vulnerability levels have a total weight of 25% - 50% and 50% - 75%, respectively.

The Density of Fallen Trees

The density calculation was conducted by dividing the number of trees identified in GSV by the length of the distance of the research location, which was 33 km.

Results and Discussion

Compatibility Between Google Street View and Field Conditions

Based on the analysis of 30 tree samples observed in the field, 27 retained the original condition, similar to GSV data, while the remaining three were either not located or had collapsed. It suggested that the

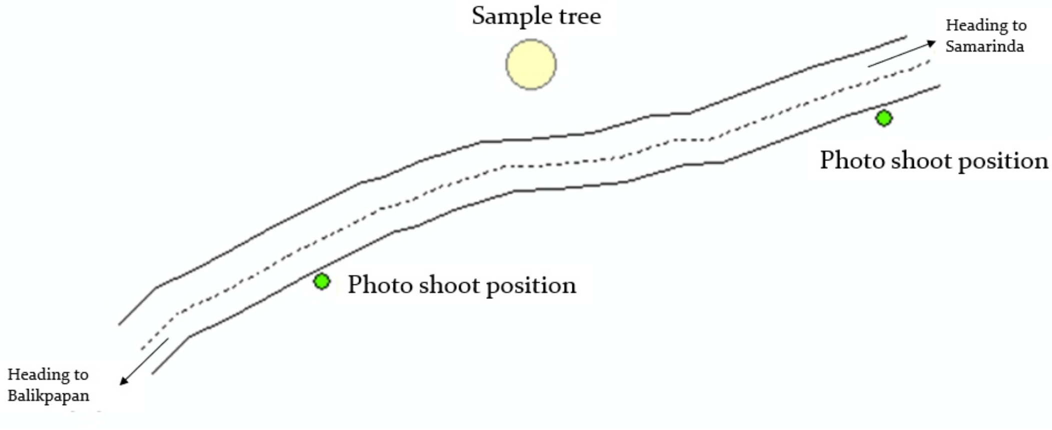

Figure 3. Photo-taking positions on samples of fallen trees observed in the field.

conditions of some trees remained unchanged from the time GSV was taken to the period of field observation, excluding the collapsed samples. Among the 27 trees, the prevailing species were trembesi (*Samanea saman* (Jacq.) Merr.) and meranti (*Shorea* sp.), alongside several others such as teak (*Tectona grandis* L.f.) and acacia (*Acacia mangium* Willd.). These trees had a diameter distribution ranging from 15 to 60 cm and were on varying slopes from flat to rather steep (0% - 19%).

Distribution of Potentially Fallen Trees from Google Street View

GSV tracing conducted on Balikpapan–Samarinda Arterial Road situated in BSGFP, spanning 33 Km, successfully identified 224 trees with the potential to fall. These trees showed characteristics that fulfilled the four criteria for potentially fallen trees. Furthermore, the observations reported that the identified trees often showed more than one criterion simultaneously in their GSV display (Table 1). The combination of criterion II and other criteria was more prevalent than other criteria, with a total occurrences of 134 fallen trees. Criterion I became the second with a total occurrences of 80 fallen trees. The Criterion II domination was attributed to the tree's ability to grow the canopy in the direction of sunlight to fill empty spaces. The road width, which exceeded 8 m, played a significant role in the phenomenon. The space above the road body, known as the canopy gap, became occupied by tree canopy growing on both sides. Therefore, trees showed disproportionate growth and tended to incline towards the road, given the absence of obstructing canopies. Criterion I experienced a directional growth pattern influenced by light factors, causing tree trunks to extend toward the road body (Bauhus et al. 2017). According to Wilkins (1989), plants naturally lean toward the direction of light, causing a difference in growth from the irradiated organ. This growth reaction, known as phototropism, was investigated by Charles Darwin in 1880, where the coleoptil from the grass sprouts of Avena and Phalaris was very sensitive to light. During the research, when the tip of the coleoptil was illuminated unilaterally, it moved toward the light source.

Criterion IV showcased the smallest number of trees, totaling 33, compared to the other criteria. The research area on Balikpapan–Samarinda Arterial Road featured a gentle slope, with only a few steep to very steep slopes. The observations showed 78 fallen trees under criterion III, influenced by the specific locations where these trees grew along Arterial Road. Additionally, Meunpong et al. (2019) suggested that excessive vehicular traffic around trees affected soil structure, resulting in compaction. The reduced ability of the soil to absorb oxygen and slower water percolation rate hindered the development of tree roots in these areas.

Information on Fallen Trees

Numerous incidents of fallen trees in Balikpapan–Samarinda Arterial Road resulted in disruptions to travel. However, there was no official record of these incidents by government authorities, including the Technical Implementation Unit of BSGFP Agency (*Unit Pelaksana Teknis Dinas* or UPTD), the area's manager. UPTD BSGFP focused on promptly clearing

Table 1. Criteria or combined criteria for distribution of potentially fallen trees.

No.	Criteria/Combined Criteria	Number of Trees
1	I	5
2	II	57
3	III	50
4	IV	16
5	I, II	61
6	I, III	8
7	I, IV	1
8	II, III	6
9	II, IV	5
10	III, IV	10
11	I, II, III	4
12	I, II, IV	1
	Total	**224**

Remark: I = Trees with sloping trunks or leaning towards the body of the road; II = Trees whose canopy proportions were predominantly pointing to the road; III = Trees without leaves, and possessed dry trunks; IV = Trees in the area of slopes or cliffs whose existence was higher than the body of the road.

Table 2. Data on fallen trees on the BSGF road.

No.	Tree	Coordinate Point		Criterion			
		Longitude	***Lattitude***	**I**	**II**	**III**	**IV**
1	Fallen Tree 1	117° 0' 47.126" E	0° 55' 3.201" S	x	x		x
2	Fallen Tree 2	117° 0' 44.831" E	0° 52' 27.963" S	x	x		
3	Fallen Tree 3	117° 0' 36.706" E	0° 51' 45.433" S	x		x	
4	Fallen Tree 4	117° 0' 36.888" E	0° 51' 44.348" S	x	x		x
5	Fallen Tree 5	117° 0' 34.429" E	0° 51' 40.310" S		x		
6	Fallen Tree 6	117° 0' 32.858" E	0° 51' 37.130" S	x	x		
7	Fallen Tree 7	117° 0' 41.394" E	0° 50' 45.752" S	x	x	x	x
8	Fallen Tree 8	117° 0' 40.482" E	0° 50' 54.949" S		x		
9	Fallen Tree 9	117° 1' 12.193" E	0° 47' 48.179" S		x	x	x
10	Fallen Trees 10	117° 1' 12.688" E	0° 47' 48.203" S		x	x	x
11	Fallen Trees 11	117° 1' 12.717" E	0° 47' 48.112" S		x	x	x
12	Fallen Trees 12	117° 0' 34.182" E	0° 49' 41.981" S		x	x	
13	Fallen Trees 13	117° 0' 33.604" E	0° 49' 39.832" S			x	
14	Fallen Trees 14	117° 0' 33.563" E	0° 49' 39.467" S			x	
15	Fallen Trees 15	117° 0' 34.167" E	0° 49' 39.144" S			x	
		Total		**6**	**11**	**9**	**6**

Table 3. The results of the weighting calculation on each criterion of fallen trees.

No.	Criterion	Number of Fallen Trees	Proportion (Weight)
1	I	6	19%
2	II	11	34%
3	III	9	28%
4	IV	6	19%
	Total	**32**	**100%**

fallen trees to minimize traffic disturbances and ensure smooth travel. For this reason, data collection included observation of the marks or remnants of fallen trees along the roadside of BSGFP. The coordinates of these formerly fallen tree stubs were then documented and cross-referenced with the GSV display (Table 2). It was crucial to underscore the importance of accurate data collection to address this issue effectively and enhance road safety.

Fallen trees adhering to criterion II, specifically those with the canopy extending towards the road body, showed the highest occurrence, totaling 11. Criterion II accounted for nine trees, while Criteria I and IV showed the lowest frequency, comprising six trees for each. The data were processed and calculated in percentage terms, yielding the outcomes for weighting criteria concerning fallen trees (Table 3). Criterion II had the highest weight percentage of 34%, while the lowest was in criteria I and IV, with a total weight of 19% each. This value suggested that most of the fallen trees on Balikpapan–Samarinda Arterial Road were due to the canopy pointing to the road body. The ever-growing canopy caused an increase in the volume and weight of biomass, which became heavier when it rained. Subsequently, the percentage value of the weight was used to assess the vulnerability level of fallen trees.

The Vulnerability Level of Fallen Trees

Out of 224 trees in GSV, the largest category comprised those with a moderate vulnerability level, totaling 126 trees (Table 4). This phenomenon was attributed to 91 trees meeting two specific criteria (Table 1). The predominant type of fallen trees with moderate vulnerability was those in criterion II, accounting for 34% of the total. Trees characterized by a very high vulnerability level had the smallest representation compared to the others, comprising only four. Trees meeting three to four criteria amounted to five, with four having a weight exceeding 76%.

In urban areas, including public spaces, fallen trees might cause damage to infrastructure and harm human life (Hou & Chen 2020). Cases of falling trees were reported in Bogor Botanical Garden in 2005, 2014, and 2015, causing casualties to visitors (Indes-putra et al. 2023). Therefore, developing an action plan based on a scientific approach was crucial to reduce the risk of fallen trees in public spaces. In this context, GSV was one of the promising tools to provide

Table 4. The vulnerability level of fallen trees.

No.	Vulnerability Level	Number of Trees
1	Low (≤ 25%)	21
2	Moderate (≥25 – 50%)	126
3	High (>50% - 75%)	73
4	Very High (>75%)	4
	Total	**224**

Table 5. The density of fallen trees on Bukit Soeharto Grand Forests road.

No.	Vulnerability Level	Number of Trees	Density (Number of trees/km)
1	Low	21	0,64
2	Moderate	126	3,82
3	High	73	2,21
4	Very High	4	0,12
	Total	**224**	**6,79**

information on the risk of fallen trees through photo comparison and analysis. As a recent technology, the research explored photo panoramic from GSV primarily for urban forest monitoring. A series of GSV photos was an essential source for detecting any changes in the urban landscape at a certain period. Moreover, this tool was often used to assess tree characteristics, structure, and health conditions (Liang et al. 2023).

In the future, the design of urban landscapes in cities should adapt to the potential risks and impacts of climate change. This design became crucial mainly due to the worldwide growing initiatives to plant trees in urban areas for better green living environments (Sousa-Silva et al. 2023). Indonesia, in particular, had adopted the concept of a forest city in developing the new capital city, IKN. However, a forest city would lead to severe problems without anticipating potential fallen trees. This research successfully tested a novel approach to detecting potential fallen trees in urban forests using GSV, which could be used as an alternative way to prevent any future incident.

Conclusion

In conclusion, 224 trees have the potential to fall, and the most frequently encountered species met criteria I and II. Fallen trees with a moderate vulnerability level had the highest number of 126. This prevalence could be attributed to 91 trees meeting two criteria, and the most commonly found species were in criteria II, weighing 34%. The total density of fallen trees amounted to 6.79 trees/km, showing an average of 6-7 trees in every kilometer on BSGFP road. Based on the results, GSV was a promising tool for identifying trees with the potential to fall, offering an efficient alternative to direct visual observation methods in the field, which could be time-consuming and expensive.

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