

Spatial Analysis of Residential Fire Vulnerability Using Geographic Information Systems for Disaster Mitigation in Tambora District, West Jakarta

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ABSTRACT

Purpose of the study: Aim of this study was to analyze the spatial distribution of residential fire vulnerability in Tambora District, West Jakarta, and to identify vulnerability levels using Geographic Information Systems as a basis for supporting disaster mitigation and urban fire risk management strategies.

Methodology: Quantitative descriptive research with a Geographic Information Systems approach was employed in this study. ArcGIS 10.8 software developed by Esri was used for spatial data processing. Overlay analysis, scoring techniques, field observations, and secondary data obtained from Google Maps imagery and related institutions were utilized to assess residential fire vulnerability.

Main Findings: Results revealed that residential fire vulnerability in Tambora District was spatially distributed into low, moderate, and high categories. High-vulnerability areas were generally characterized by dense settlements and limited accessibility. GIS-based overlay analysis successfully generated a fire vulnerability map and identified priority areas requiring disaster mitigation measures and improved fire management strategies.

Novelty/Originality of this study: Novel contribution of this study lies in the application of GIS-based spatial analysis to evaluate residential fire vulnerability in densely populated settlements of Tambora District. Spatial visualization produced through overlay analysis provides more comprehensive information for supporting evidence-based disaster mitigation and contributes to the development of urban fire vulnerability studies.

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1. INTRODUCTION

Rapid urban development has led to increasing population density and more intensive land use in residential areas. These conditions have contributed to the emergence of various urban problems, including residential fire disasters [1], [2]. Residential fires are among the most common hazards occurring in densely populated urban environments. Such disasters not only cause substantial material losses but also disrupt social

and economic activities within affected communities [3], [4]. Therefore, effective disaster mitigation requires an approach capable of identifying fire vulnerability from a spatial perspective.

Tambora District in West Jakarta is characterized by highly dense settlements and complex urban structures. The high concentration of buildings, limited accessibility, and inadequate supporting infrastructure increase the potential for fire incidents and accelerate fire propagation [5]-[7]. In recent years, several fire events have occurred in the area and resulted in significant economic losses and social impacts. These conditions indicate that residential fire hazards remain a serious challenge for urban disaster management [8]-[10]. Consequently, comprehensive information regarding the spatial distribution of fire vulnerability is required to support mitigation efforts in the area.

Previous studies on residential fire vulnerability have mainly focused on identifying causal factors and assessing fire risks through statistical analysis and field observations. Several researchers have employed Geographic Information Systems (GIS) to produce vulnerability maps as part of disaster risk reduction strategies. However, most of these studies have emphasized descriptive analysis without thoroughly examining the spatial characteristics of urban settlements [11]-[13]. In addition, studies addressing fire vulnerability in extremely dense residential environments are still relatively limited. This situation suggests that the application of spatial analysis using GIS still offers opportunities for further development in urban disaster studies.

The utilization of Geographic Information Systems plays an important role in supporting disaster mitigation and urban planning. Spatial information generated through GIS analysis can provide valuable insights for policymakers in determining priority areas and improving emergency response strategies [14], [15]. In addition, vulnerability maps can enhance community preparedness and optimize the allocation of fire protection facilities and resources [16]. Accurate information regarding fire-prone areas is essential to minimize potential losses caused by urban fire disasters. Hence, GIS-based spatial analysis has become a relevant and effective approach for supporting residential fire mitigation in urban environments.

Despite the growing number of studies concerning residential fire hazards, several research gaps remain unresolved. Previous studies have not adequately explained the spatial variations of fire vulnerability in heterogeneous and densely populated urban areas such as Tambora District [17], [18]. Furthermore, detailed spatial information is essential for identifying priority areas that require disaster mitigation measures. The lack of such information may reduce the effectiveness of urban fire management and preparedness programs [19]-[21]. Therefore, there is a need for a more systematic and spatially oriented assessment of residential fire vulnerability.

The novelty of this study lies in the application of spatial analysis using Geographic Information Systems to identify residential fire vulnerability as a basis for disaster mitigation in Tambora District, West Jakarta. Unlike previous studies that primarily focused on descriptive assessments, this study emphasizes the spatial distribution and pattern of fire vulnerability across the study area [22], [23]. The integration of spatial analysis enables the production of more comprehensive and visually informative results for decision-makers. The findings are expected to contribute to the development of evidence-based disaster mitigation strategies and urban risk management. Therefore, this study provides an important contribution to the advancement of GIS applications in urban disaster and residential fire vulnerability studies.

Residential fire vulnerability in densely populated urban areas requires careful spatial assessment because settlement characteristics and accessibility may influence disaster preparedness and response. In Tambora District, spatially detailed information can support the identification of locations that may require priority attention in fire mitigation planning [24]-[26]. This information is important for supporting evidence-based decisions concerning prevention, preparedness, and the allocation of fire protection resources. Therefore, this study aims to analyze the spatial distribution of residential fire vulnerability in Tambora District, West Jakarta, using Geographic Information Systems. The findings are expected to provide spatial information that can support local disaster management and the development of more targeted residential fire mitigation strategies.

2. RESEARCH METHOD

2.1. Study Area and Research Design

This study was conducted in Tambora District, West Jakarta, Indonesia, which is characterized by densely populated residential areas and a high potential for fire incidents. A quantitative descriptive research design with a Geographic Information Systems (GIS) approach was employed to analyze the spatial distribution of residential fire vulnerability [27]. The study focused on identifying areas with varying levels of fire vulnerability based on several physical and environmental factors [28]. GIS was utilized as the primary tool for processing and analyzing spatial data efficiently. The results of the analysis were intended to support disaster mitigation and urban fire risk management in the study area.

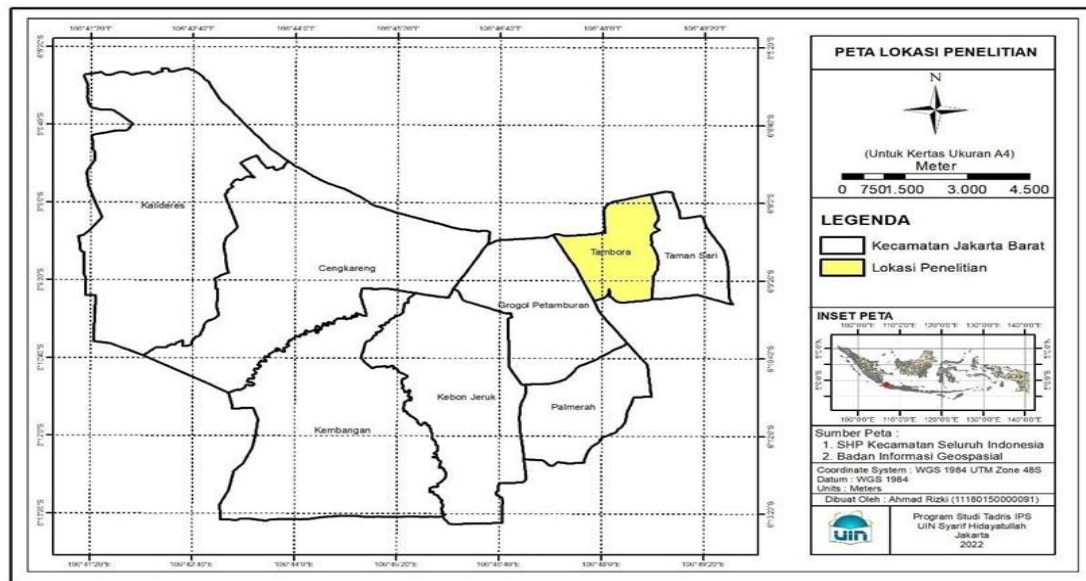


Figure 1. Location of the Study Area in Tambora District, West Jakarta

2.2. Data Collection and Research Variables

The study utilized both primary and secondary data to assess residential fire vulnerability in the study area. Primary data were obtained through field observations, while secondary data were collected from Google Maps imagery and related institutions. Several variables influencing fire vulnerability were considered, including building density, building materials, settlement layout, electrical network conditions, water sources, road accessibility, and fire station locations. These variables were selected because they represent important factors affecting the occurrence and spread of fires in residential areas. The integration of these datasets provided comprehensive information for spatial analysis using GIS.

Table 1. Research Variables Used in Residential Fire Vulnerability Assessment

Variables	Indicators
Building Characteristics	Building density, building materials, settlement layout
Accessibility	Distance from main roads, road width
Supporting Facilities	Water sources, hydrant distribution
Fire Protection	Distance from fire stations
Infrastructure Condition	Electrical network condition

2.3. Spatial Data Analysis

Spatial analysis was carried out using Geographic Information Systems to process and visualize the distribution of residential fire vulnerability [29]. Each variable was assigned a score based on its contribution to fire occurrence and fire propagation. The scoring method classified the parameters into three categories representing low, moderate, and high vulnerability conditions. Furthermore, all thematic layers were integrated through an overlay analysis to produce a comprehensive fire vulnerability map. The resulting spatial information was used to identify areas with different levels of residential fire vulnerability in Tambora District.

2.4. Classification of Residential Fire Vulnerability

The classification of residential fire vulnerability was determined based on the cumulative scores obtained from all research variables. The total scores were grouped into three categories consisting of low, moderate, and high vulnerability levels. Areas with higher scores indicated a greater potential for fire occurrence and fire spread. This classification facilitated the interpretation of spatial patterns and the identification of priority areas for disaster mitigation. Consequently, the fire vulnerability map served as an important tool for supporting urban fire risk management.

Table 2. Classification of Residential Fire Vulnerability

Total Score	Vulnerability Level
0–9	Low
10–18	Moderate
19–27	High

2.5. Research Framework

The research framework consisted of data collection, variable identification, scoring, overlay analysis, and map generation [30]. Spatial data obtained from various sources were first processed and transformed into thematic layers. Each layer was then assigned scores and integrated using overlay techniques within the GIS environment [31]. The output of the analysis was a residential fire vulnerability map showing the spatial distribution of vulnerability levels in Tambora District. The generated map can be used as supporting information for disaster mitigation and urban planning policies.

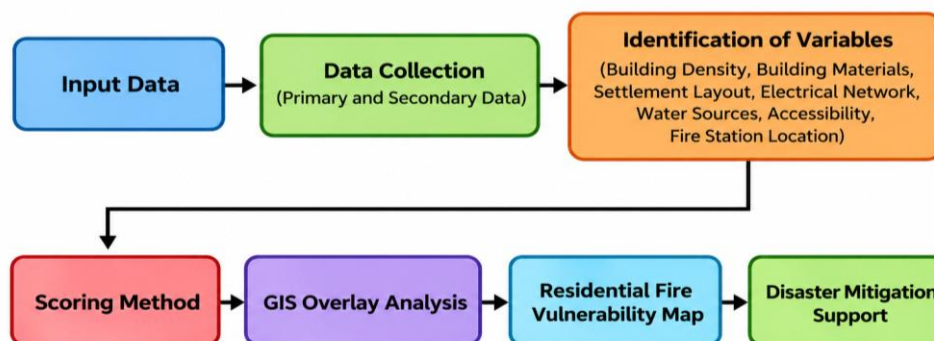


Figure 2. Research Framework for Residential Fire Vulnerability Analysis

3. RESULTS AND DISCUSSION

3.1. Spatial Characteristics of the Study Area

The study area is characterized by densely populated residential settlements and complex urban structures. The spatial distribution of settlements indicates variations in building density and accessibility across Tambora District. These characteristics influence the exposure of residential areas to fire hazards. The presence of supporting facilities also varies among locations within the study area. Therefore, understanding the spatial characteristics of the area is essential for assessing fire vulnerability.

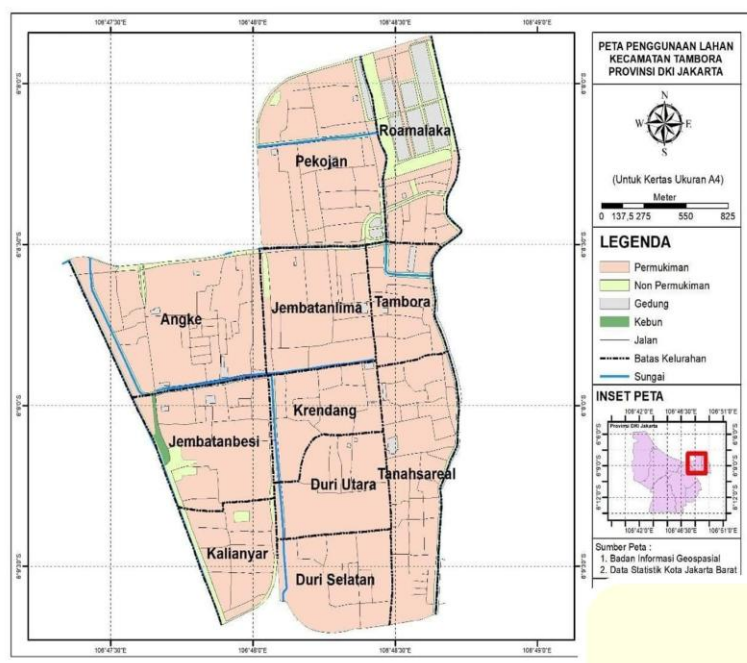


Figure 3. Spatial Characteristics of Tambora District, West Jakarta

3.2. Spatial Distribution of Fire Vulnerability Factors

The analysis identified several factors contributing to residential fire vulnerability in the study area. These factors include building density, settlement layout, road accessibility, electrical network conditions, water sources, and fire station locations. Variations in these parameters resulted in different levels of vulnerability

across the district. Areas with unfavorable conditions generally exhibited greater exposure to fire hazards. The distribution of these factors formed the basis for subsequent spatial analysis.

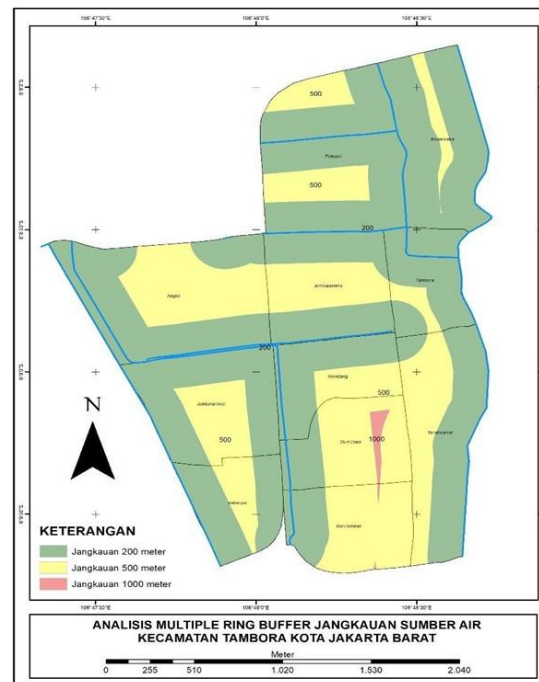


Figure 4. Distribution of Residential Fire Vulnerability Factor.

3.3. Spatial Analysis of Residential Fire Vulnerability

Overlay analysis using Geographic Information Systems produced a fire vulnerability map for Tambora District. The analysis revealed the existence of low, moderate, and high vulnerability zones throughout the study area. High-vulnerability areas were predominantly associated with dense settlements and limited accessibility. Moderate-vulnerability areas were distributed in locations with relatively adequate infrastructure conditions. Meanwhile, low-vulnerability areas tended to have better supporting facilities and lower population density.

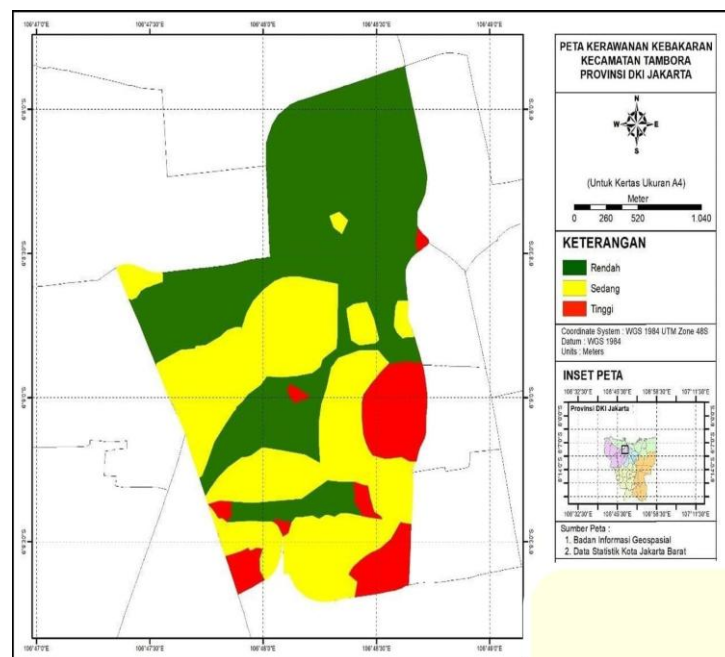


Figure 5. Residential Fire Vulnerability Map in Tambora District, West Jakarta

3.4. Classification of Residential Fire Vulnerability Levels

The results of the classification indicate that residential fire vulnerability in Tambora District can be grouped into three categories. Each category reflects different levels of susceptibility to fire occurrence and

propagation. Areas classified as highly vulnerable require priority attention in disaster mitigation planning. The classification results provide important information for urban fire risk reduction programs. Consequently, the resulting spatial information can support evidence-based disaster management strategies.

Table 3. Classification of Residential Fire Vulnerability Levels

Vulnerability Level	Interpretation
Low	Low potential for fire occurrence and spread
Moderate	Moderate potential for fire occurrence and spread
High	High potential for fire occurrence and spread

Results obtained from the spatial analysis revealed that residential fire vulnerability in Tambora District is strongly influenced by differences in physical and environmental characteristics. High-vulnerability areas were generally associated with dense settlements, limited accessibility, and inadequate supporting facilities. In contrast, areas with better infrastructure conditions tended to exhibit lower vulnerability levels. GIS-based overlay analysis successfully identified the spatial distribution of low, moderate, and high vulnerability zones. These findings highlight the importance of spatial characteristics in determining fire susceptibility in urban residential areas.

Spatial information generated from the vulnerability map provides a comprehensive overview of fire-prone areas within the study area. Areas categorized as highly vulnerable require greater attention because they are more likely to experience rapid fire spread and severe impacts. Moderate- and low-vulnerability zones, on the other hand, possess relatively more favorable environmental conditions. Classification results also facilitate the identification of priority locations for disaster risk reduction programs. Consequently, GIS-based analysis offers valuable support for urban fire management and mitigation planning.

Previous studies have emphasized the important role of Geographic Information Systems in assessing disaster vulnerability and supporting risk reduction efforts. Several researchers reported that building density, accessibility, and supporting infrastructure significantly affect the occurrence and propagation of residential fires [32], [33]. Similar findings were observed in the present study, indicating that spatial characteristics remain essential determinants of fire vulnerability. Consistency between the current findings and earlier studies strengthens the reliability of GIS applications in disaster assessment [34], [35]. Accordingly, this study provides additional evidence supporting the effectiveness of spatial analysis in urban fire risk management.

A distinctive contribution of this study lies in the integration of spatial analysis to evaluate residential fire vulnerability in Tambora District, West Jakarta. Unlike conventional approaches that mainly emphasize descriptive assessments, the present study focuses on the spatial distribution and pattern of vulnerability across densely populated settlements [36], [37]. More detailed information regarding the relationship between physical characteristics and fire susceptibility was obtained through GIS-based overlay analysis. Visual representation in the form of vulnerability maps further enhances the usefulness of the findings for decision-making processes [38]. Such an approach contributes to the development of GIS applications in urban disaster mitigation studies.

Practical implications arising from this research are closely related to disaster mitigation and urban planning. Information derived from the vulnerability map can assist local governments in identifying priority areas for improving fire protection facilities and emergency response systems [39]. Community preparedness programs may also benefit from the spatial information produced by this study. Incorporating fire vulnerability data into urban development policies could reduce the potential impact of future disasters [40], [41]. Therefore, GIS-based analysis can contribute to more effective and sustainable urban disaster management.

Despite providing valuable insights into residential fire vulnerability, several limitations should be acknowledged. Analysis conducted in this study relied primarily on available spatial data and selected variables representing fire vulnerability conditions [42]. Socioeconomic factors, community preparedness, and dynamic environmental changes were not included in the assessment. Use of overlay analysis may also be insufficient to fully represent the complexity of urban fire dynamics. Future studies are therefore encouraged to incorporate additional variables and more advanced spatial modeling techniques to improve the accuracy and comprehensiveness of vulnerability assessments..

4. CONCLUSION

Application of Geographic Information Systems (GIS) successfully facilitated the spatial analysis of residential fire vulnerability in Tambora District, West Jakarta, as part of disaster mitigation efforts. Results derived from the overlay analysis indicated the presence of low, moderate, and high vulnerability zones, reflecting differences in physical and environmental characteristics across the study area. Spatial information generated from the analysis provided a comprehensive understanding of fire-prone areas and enabled the identification of priority locations for risk reduction measures. Findings obtained from the study highlighted the importance of GIS-based analysis in supporting urban fire management and evidence-based disaster mitigation

planning. Practical benefits of the resulting vulnerability map may assist policymakers and related stakeholders in improving preparedness and optimizing fire protection facilities in densely populated settlements. Further research is recommended to incorporate additional socioeconomic variables and advanced spatial modeling approaches to enhance the accuracy and applicability of residential fire vulnerability assessments in urban environments.

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