Jurnal Teknik Sipil & Perencanaan 25 (1) (2023) p 52-61

JURNAL TEKNIK SIPIL & PERENCANAAN

10.15294/jtsp.v25i1.42955

Risk Assessment of Fire Hazards in Semarang City Residential Areas

Raditya Hari Murti[1, a)] Hendra Adi Wijaya [2,] Indira Laksmi Widuri [3,] Julmadian Abda [4,] Mada Sophianingrum[7,] Muhammad Rizki Islami [5,] Ahady Farrel Febriyanto[6,] Eduardo Erlangga Drestanta[8]

[1]*Public Works Polytechnic,* [2]*Public Works Polytechnic,* [3]*Public Works Polytechnic,* [4]*Public Works Polytechnic,* [5]*Diponegoro University,* [6] *Diponegoro University*[6]*, Diponegoro University*[7]*, Sorbonne Université*[8]

[a)]Corresponding author: radityahm@gmail.com

Abstract: According to data from the Semarang City Fire Department from 2013 to 2016, 1028 fire incidents occurred in the city, with the highest incidence in 2015 resulting in 399 cases and material losses amounting to IDR 398.3 billion. These figures indicate that Semarang City has the highest incidence rate of fire cases in Central Java Province. Despite this, studies on the risk and mitigation of fire hazard disasters in Semarang City are still lacking. This study aims to identify fire risks, mitigate disaster hazards in Semarang City, and provide recommendations for arranging relevant buildings and environments. A qualitative descriptive method was employed, with interviews conducted with key persons and GIS analysis utilized to assess the risk of fire. The results reveal that 14 villages in Semarang City have a high level of fire hazard risk, with Rejosari Village having the highest level of fire risk due to a history of fire incidents, including fatalities, and the density of buildings and limited access. However, inhabitants lack awareness of this hazard, which highlights the need to increase community understanding and the installation of fire protection and safety facilities, including hydrants, in densely populated buildings and areas to reduce the risk of fire hazards.

Keywords: *fire, building, built environment, risks, vulnerabilities, capacity, hazards*

INTRODUCTION

According to the World Bank, it is expected that by 2045, 70% of Indonesians will reside in urban areas due to urbanization, leading to several issues such as slums due to a lack of land. This phenomenon will result in increased disaster risk in crowded urban residential areas. Urbanization, environmental degradation, socioeconomic disparity, and poor governance will have a growing impact on several factors that contribute to disaster-related losses [1].

In the last decade alone, disasters have resulted in the loss of approximately 700,000 lives, injured over 1.4 million people, and displaced 23 million individuals in Indonesia. The Badan Nasional Penanggulangan Bencana (BNPB) has reported 207 disaster events in Indonesia until 2020. Dense settlements are becoming one of the most disaster-prone areas. Semarang City, with an average population density of 4431.92 inhabitants per km2, is well-known for having the highest population density in Central Java Province.

Fire disasters are one of the most dangerous disasters that threaten the lives of urban populations [2]. According to data from the Semarang City Fire Department, there were 1028 fire incidents in Semarang City from 2013 to 2016, with the highest material losses of IDR 398.3 billion in 2015. These figures indicate that Semarang City has the highest incidence of fire cases in Central Java Province.

In accordance with Law Number 24 of the Year 2007 concerning Disaster Management, fires can be categorized as either natural or non-natural disasters depending on their cause. Residential fires are thus classified as non-natural disasters due to human (social) negligence being the main cause. In densely populated areas, fires can quickly spread from one house to another, requiring extra attention to encourage people to be more cautious.

Disaster management emphasizes the importance of mitigating catastrophes, including assessing the risk of urban fires. Fire risk is often referred to as the potential for damage in the form of loss of life, property, and security, caused by the relationship between the number of fire accidents and vulnerabilities. It can also result in negative consequences such as economic activity breakdown and environmental damage. [3]

The causes of settlement fires have been widely studied and are diverse. However, spatial factors such as settlement and building density are often considered in estimating fire risk [4]. A study conducted in West Jakarta found a correlation between settlement density and the high risk of fires. Experts also discovered a correlation between home fire rates and population and building characteristics. [5]

ther factors affecting fire insecurity include frequency of occurrence, land use, building characteristics (e.g., semi-permanent structures made of wood, zinc, and asbestos), and infrastructure availability (e.g., number of hydrants and accessibility) [6]. Although the frequency of fires is not necessarily proportional to the density and characteristics of the building, physical arrangements associated with fire risk in buildings are crucial for reducing the likelihood of fires. [7]

Several studies have focused on previous fires, such as [8] which discusses the geographical information system of fire-prone agricultural land in Singkawang City. Discussions have also focused on fire protection infrastructure [9], community preparedness for fire, and the assessment of fire services using geographic information systems (GIS) [11]. This study aims to assess the extent of the risk of fire hazards, particularly in densely populated areas of Semarang City, and to determine the level of mitigation needed to reduce fire risk.

TABLE 1. Research Discussion and Research Gap with Proposed Research

Researchers	Research Discussion	Research Gap with Proposed Research
Fitri Imansyah, 2021	Sistem Informasi Geografis Lahan Pertanian Rawan Kebakaran di Kota Singkawang	• Studies were conducted on different scopes of activity (agricultural areas) with different loci (Singkawang City).
Sari et al., 2021	Evaluasi Pelayanan Sarana Dan Prasarana Proteksi Kebakaran Pada Permukiman Perkotaan	• Studies were conducted in a different locus (Sidoarjo City). It didn't include any particular utilization of GIS analysis.
Valentine & Bolaji, 2021	Fire Disaster Preparedness among Residents in a High-Income Community	• Studies didn't specify the risk of a fire hazard; the locus is different (Nigeria).
Singh et al., 2021	Interpreting Benchmark Assessment of Emergency Fire Service using Geoinformation Technology	• Studies only focused on the availability of fire suppression facilities; the locus is different (India).

METHODOLOGY

This study utilizes a multi-method approach based on the Hyogo Framework of Action for disaster research. The framework comprises four stages, as follows:

1. In the first stage, hazard variables are identified, which involves determining the parameters of hazards in Semarang City by referencing local policies, laws, and regulations, such as the Regulation of The Mayor of Semarang City No. 11 the Year 2009.

2. The second stage focuses on identifying vulnerability variables, specifically the extent of damage to residential areas in Semarang City caused by fire disasters.
3. The third stage entails assessing the capacity of regions and communities to mitigate disaster threats and potential losses.
4. In the final stage, Semarang City residential areas vulnerable to fire disasters are profiled, with recommendations provided on building and environmental arrangements to reduce fire risk.

TABLE 2. Data of Case Study

Variable	Data	Year	Data Sources
Hazard	Temperature	2022	USGS
	Percentage of slums	2020	Decree of the Mayor of Semarang
	Frequency of occurrence	2021/latest year	Fire Service
Vulnerability	Building Density	2022	BIG
	Land Use	2022	Bappeda Semarang, Ministry of ATR/BPN
	Vulnerable group/gender	2022	BPS Semarang City, survey.
	Population density	2022	BPS Semarang City, survey.
Capacity	Number of Disaster Response Groups	2021	BPBD, survey
	City Plan Policy (RTRW, KDB, etc.)	2022	Bappeda Semarang
	Number of fire extinguishers	2022	Fire Service

Source: Author's Analysis, 2023

In Semarang City, this study was conducted using a village-level analytic unit. GIS is utilized to help with the analysis. The first step in the study involved analyzing the degree of fire risk in residential areas, followed by an examination of possible mitigation measures in the villages with the highest fire risk. The fire disaster risk assessment process involved calculating the risk, vulnerability, and capacity to fire disasters. The first step in risk assessment was to determine the threat level of fire hazard.

Fire Hazard Analysis

In accordance with the Regulation of the Head of the National Disaster Management Agency (Perka BNPB) No. 2 the Year 2012 concerning General Guidelines for Disaster Risk Assessment, potential threats can be due to human actions or natural factors. The hazard level calculation involved assessing the level of threat due to these factors. Table 3 shows several parameters due to human factors, while surface temperature is the relevant natural variable, with higher surface temperatures indicating a higher level of fire threat.

TABLE 3. Fire Threat Calculation Based on Human Factors

Parameter	Weights (%)	Class			Score
		Low	Moderate	High	
Frequency of fire events (%)	60	<2%	2 – 5%	>5%	Class/Max Grade Class
Economic losses (billion rupiah)	6	<1 M	1 – 3 M	>3 M	
Death toll	28	-	1 person	>1 person	
Slums	6	Not Slums	Light Slums	Heavy Slums	

Source: Perka BNPB No. 2 the Year 2012, modified

TABLE 4. Land Surface Temperature Classification (Natural Factor)

Temperature °C	Score
17-27	1
27-29	2
29-40	3

Source: Perka BNPB No. 2 the Year 2012, modified

The calculation assumes that human factors cause the largest building/settlement fires. As a result, the weight of the human threat is greater, as seen in the formula below.

$$Hazard\ Level = Human\ Threats * 0.7 + Climate\ Threats * 0.3$$

Fire Vulnerability Analysis

To determine the level of fire vulnerability, this study measures both societal and environmental vulnerability. The greater the vulnerability of a region to social and environmental factors, the higher its fire vulnerability. Social vulnerability is assessed by calculating the demographic and neighborhood components. The demographic aspect is determined by measuring the ratio of vulnerable populations such as children and the elderly, as well as population density. The neighborhood aspect is assessed by calculating the ratio of slums and the urban-rural status (see Table 5).

TABLE 5. Social Vulnerability Scoring

Aspects	Variable	Weight	Parameter	Score
Neighborhood	Urban-Rural Status	30	Urban	1
			Rural	3
	Slum Area	70	Not Slum	1
			Light Slum	2
			Moderate Slum	3
Demographic	Population Density	50	2 - 38 people/ha	1
			38 - 93 people/ha	2
			93 - 292 people/ha	3
	%Child	25	0 - 20% (low)	1
			20 - 40% (moderate)	2
			> 40% (high)	3
	%Elder	25	0 -8% (low)	1
			8 - 14% (moderate)	2
			> 14% (high)	3

Source: Author's Analysis, 2023

After obtaining vulnerability results from demographic and neighborhood aspects, a matrix analysis was carried out to assess social vulnerability (Table 6).

TABLE 6. Social Vulnerability Index Matrix

Social Vulnerability Index		Neighborhood		
		low	moderate	high
Demographic	Low			
	moderate			
	High			

Source: Adapted from Widiastutik & Bukhori, 2018

The density of existing buildings determines environmental vulnerability. This building density index was obtained using Landsat-8 satellite imagery data using Normalized Difference Built-up Index (NDBI) calculations, with the following formula:

$$NDBI = \frac{MIR - NIR}{MIR + NIR}$$

Source: Mwangi et al., 2018.

NDBI results will show the level of building density; the higher the NDBI value, the higher the building density, with the scores as can be observed in Table 7.

TABLE 7. NDBI classification

NDBI	Classification	Score
-1 – 0	Non-Built-Up	1
0 – 0,1	Sparse Building Density	1
0,1 – 0,2	Meeting Building Density	2
0,2 – 0,3	Very Tight Building Density	3

Source: adapted from Handayani et al., 2017

After determining social and environmental vulnerability, fire vulnerability is calculated as the average of the two elements using the formula below.

$$\frac{Social\ Vulnerabilties + Environmental\ Vulnerabilties}{2}$$

Fire Capacity Analysis

The capacity index is determined based on the level of disaster resilience within a region. In the context of fire disaster analysis, the capacity index can be calculated by assessing the capacity of institutions and facilities. The institutional capacity index is derived from the presence of disaster resilience institutions, such as Disaster Resilient Villages (Kelurahan Tangguh Bencana), as shown in Table 8.

TABLE 8. Institutional Capacity Scoring

KTB	Skor
Exist	0,75
None	0,25

Source: Author's Analysis, 2023

The capacity index based on facilities is obtained by analyzing the service area of the fire station using network analysis. Then scoring is carried out according to the level of the service area (in minutes) (see Table 9).

TABLE 9. Facility Capacity Scoring

Service Area (Minutes)	Score
0-15	0,75
15-30	0,5
>30 / Uncovered	0,25

Source: Author's Analysis, 2023

After assessing institutional and facility capacity, the following calculations are performed to determine the level of fire capacity:

$$\frac{Institutional\ Capacity + Facility\ Capacity}{2}$$

Fire Risk Analysis

Fire risk level analysis is calculated after hazards, vulnerability, and capacity analysis had been performed. This risk of fire can be obtained using the calculation formula:

$$\left(\sqrt[3]{(Vulnerability * Hazard)} * (1 - Capacity)\right)$$

Source: Perka BNPB No. 2 Year 2012

Framework analysis can be shown in further detail in **Figure 1**.

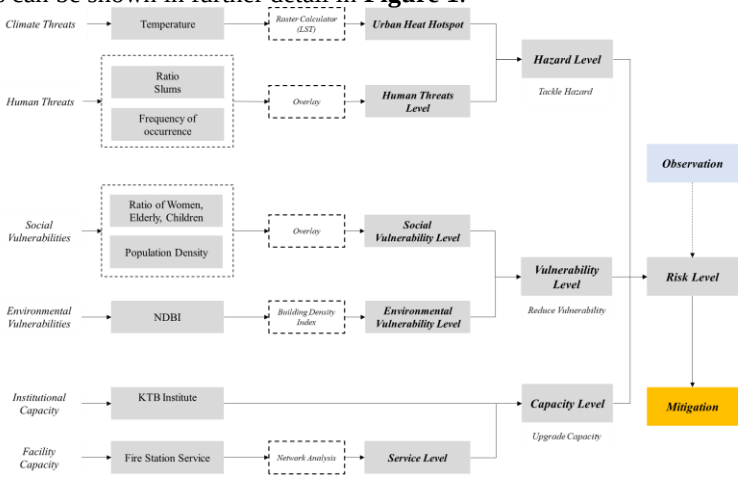
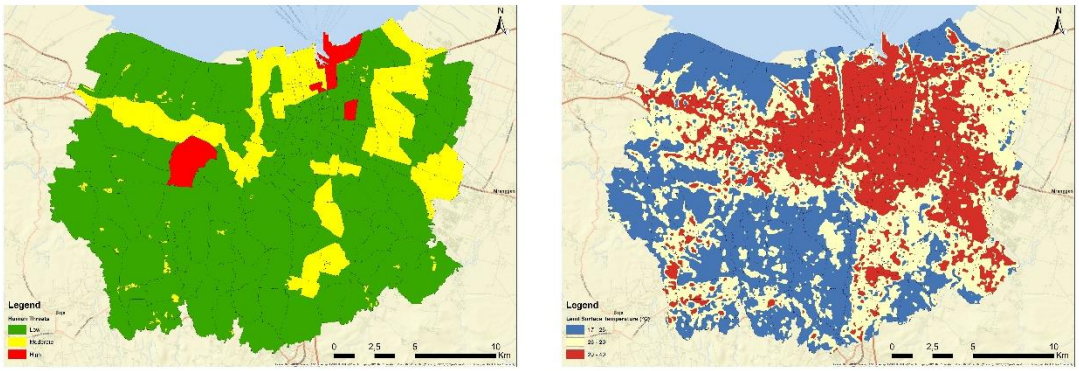


FIGURE 1. Analysis Framework

RESULT AND DISCUSSION

Fire Hazard

According to data from the Semarang City fire service, there were 569 occurrences of building/building fires in Semarang City from 2017 to 2021, dispersed over several regions. Based on this data, the incidence of fires in Semarang City can be mapped, as shown in Error! Reference source not found., which reveals that from 2017 to 2021, numerous sites in Semarang City suffered frequent fire incidents, particularly Rejosari Village, Tanjung Emas Village, and Ngaliyan Village. The three villages are the ones with the highest number of building fires in the last five years.



(a) (b)

FIGURE 2. (a) Fire Hazard Map Based on Human Factors, (b) Land Surface Temperature (Climate Factors)

Based on the results of the analysis of threats due to human factors and natural factors, it was found that the threat of fire hazards in Semarang City is dominated by a low threat level of more than 67% of its total area (see **Figure 2** and **Table 10**). Only a few locations have a high potential or level of fire hazard threat. Some of them are Rejosari Village and Tanjung Emas Village.

TABLE 10. Percentage of *Hazard Level* of Fire Hazard in Semarang City

Hazard Level	Area (Ha)	Percentage (%)
Low	26139,24	67,21
Moderate	12227,86	31,44
High	523,74	1,35

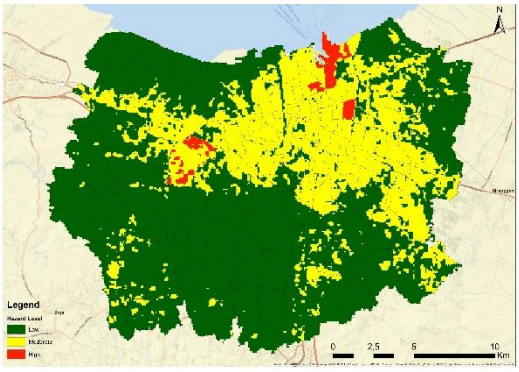


FIGURE 3. Map of Fire Hazard Level in Semarang City

Fire Vulnerability

Based on demographic parameters in Semarang City, population density remains level between low, middle, and high levels (see Figure 4 and Figure 4). The senior population ratio in Semarang City is relatively low, however, the proportion of child residents is quite dominant. Furthermore, based on its geographical position, Semarang City is dominated by dense urban regions, especially along main roads, which will increase exposure to fire hazards.

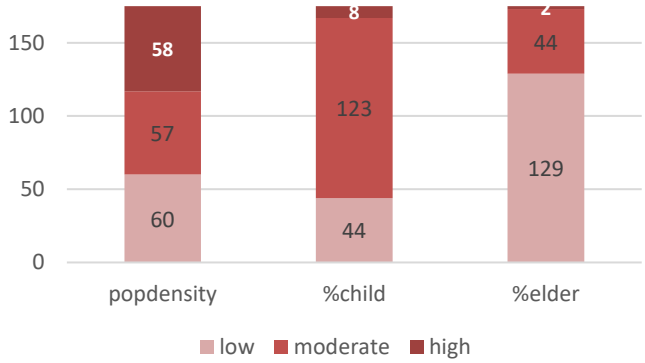
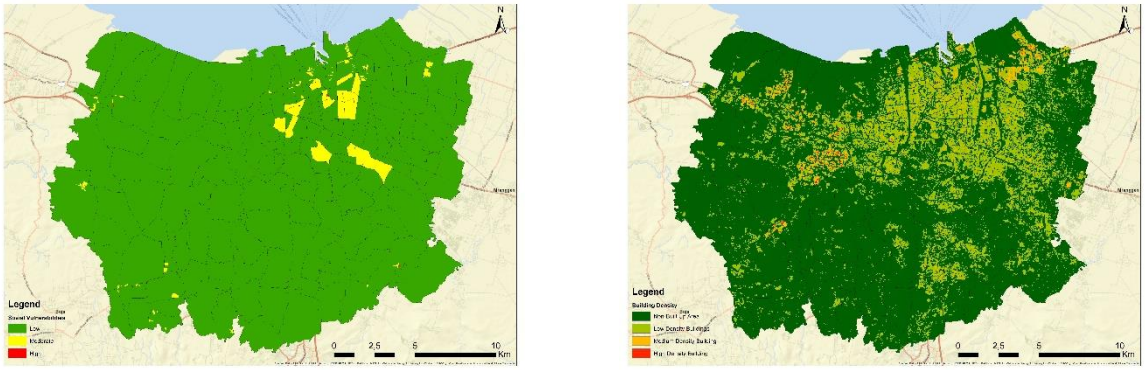


FIGURE 4. Demographic Characteristics of Semarang City



(a) (b)

FIGURE 5. (a) Social Vulnerability Map, (b) Environmental Vulnerability Map

Based on the examination of social and environmental vulnerability, it was determined that 95% of the Semarang City area is relatively resistant to fire hazards **(Table 10)**. Rejosari, Bugangan, Sarirejo, Kebonagung, Pendirikan Lor, Pendirikan Kidul, Barusari, Bojong Salaman, Tegalsari, Lamper Lor, Lamper Tengah, and Sendangguwo, on the other

hand, have a high vulnerability **(Figure 6)**. According to the findings of the investigation, several of these villages are exposed to fire threats due to high building density, making the region more sensitive than the other locations.

TABLE 11. Level of Vulnerability to Fire Hazard in Semarang City

Vulnerability	Area (Ha)	Percentage
Low	37080.98	95,3200
Middle	0.99	0,0025
High	1818.67	4,6800

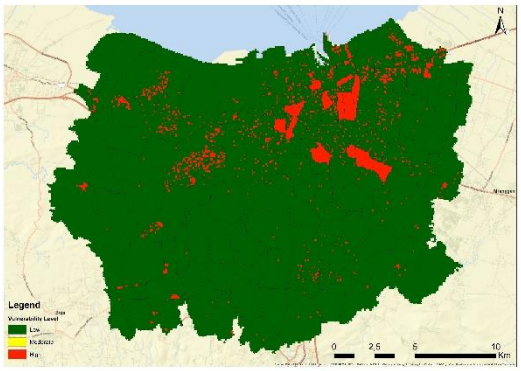
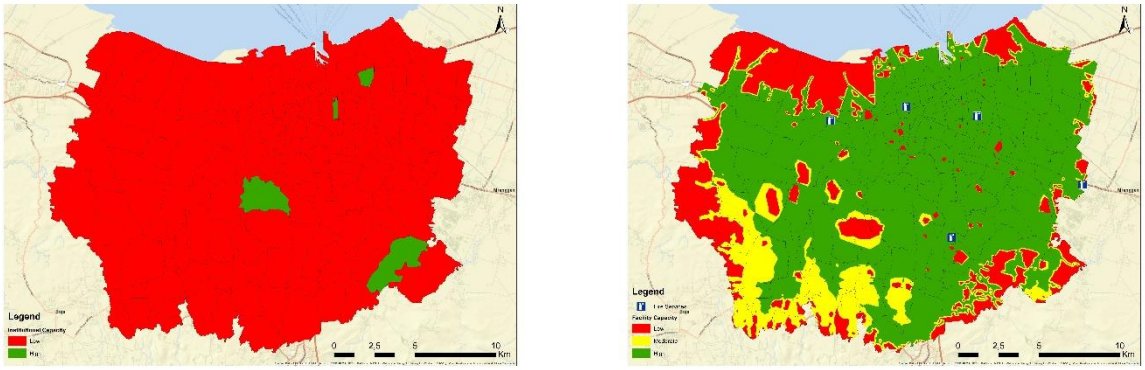


FIGURE 6. Map of Vulnerability to Fire Hazard in Semarang City

Fire Capacity



(a) (b)

FIGURE 7. (a) Institutional Capacity Map, (b) Facility Capacity Map

Based on the results of the analysis, considering the institutional capacity and existing facility capacity, Semarang City is mainly characterized by areas with a medium capacity level of 67% (refer to Table 11). These findings suggest that Semarang City has a good level of preparedness to deal with fire hazards. However, areas with a high capacity level are concentrated in the downtown area, near several fire station points, providing better service coverage than areas far from these facilities (Figure 7).

According to the analysis results on institutional capacity and existing facility capacity, Semarang City is dominated by areas with a medium capacity of 67% (refer to Table 11). This suggests that Semarang City is sufficiently capable of dealing with fire hazards. Areas with a high capacity level are concentrated in the downtown area, close to various fire station points, resulting in a better service area than in other areas farther from the fire station facilities.

Fire Risk

TABLE 12. Fire Risk Level in Semarang City

Fire Risk	Area (Ha)	Percentage (%)
Low	27267,74	70,12
Moderate	9438,95	24,27
High	2180,31	5,61

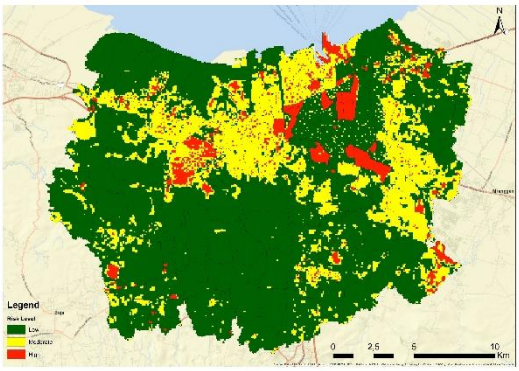


FIGURE 8. Map of Risk Level to Fire Hazard in Semarang City

According to the investigation's findings, it is revealed that 14 villages in Semarang City are at high risk of fire hazards. These villages include Rejosari, Bugangan, Kebonagung, Sarirejo, Kranggan, Kauman, Pendirikan Kidul, Pendirikan Lor, Barusari, Bojong Salaman, Tegalsari, Lamper Lor, Lamper Tengah, and Sendangguwo. The high-risk status can be attributed to the relatively high levels of vulnerability and fire hazard in these villages. Therefore, despite having a high capacity, the risk of fire will still be high if the level of vulnerability and fire hazard remains high.

CONCLUSION

This study demonstrates that GIS can quantify fire hazards, particularly in residential areas of Semarang City. This study's findings yield various facts. The city center has the greatest fire hazard level while having a pretty effective firefighting capacity. Of essence, this is related to historical experience. From a spatial point of view, Rejosari and Bugangan are the riskiest settlements among the others. Both settlements are highly populated places with a record of significant fire incidence. This circumstance could be a result of a lack of information about fire hazards. To lessen the danger of fire hazards in Rejosari Village, the most basic mitigation to be carried out is to raise community awareness and explore the addition of fire handling facilities (hydrants) in dense building areas. However, some sections in the suburbs are at significant risk of fire. Suburban residents face a moderate threat, but their capacity is limited. It should also be of concern to local governments, who should take a different approach.

From a causative point of view, the risk of fire hazards in the city of Semarang, particularly in 14 urban settlements, is relatively significant due to the risk posed by the human component. According to historical records, numerous fires occur, with the human factor being responsible for most of them. Improved facilities are required to lessen the likelihood of fire hazards in Semarang, particularly in densely built-up regions. Various fire-related socializations and training are also required to raise public understanding of fire threats and methods to overcome and prevent fires from spreading.

ACKNOWLEDGMENTS

The author would like to acknowledge the Public Works Polytechnic for supporting this research, as well as Dewi Zulianti, Desti Kusuma Nur Amalina, and Anthony Erba Prakosa for their help in carrying out this research.

REFERENCES

[1] R. Shaw, J. M. Pulhin, dan J. J. Pereira, *Climate change adaptation and disaster risk reduction: Overview of issues and challenges*, vol. 4, no. 2010. Elsevier, 2010. doi: 10.1108/S2040-7262(2010)0000004007.

[2] K. Huang, "Population and Building Factors That Impact Residential Fire Rates in Large U.S. Cities," 2009.

[3] Y. Zhang, "Analysis on comprehensive risk assessment for urban fire: The Case of Haikou city," *Procedia Eng.*, vol. 52, hal. 618–623, 2013, doi: 10.1016/j.proeng.2013.02.195.

[4] S. Stevens, L. Gibson, dan D. Rush, "Conceptualising a GIS-based risk quantification framework for fire spread in informal settlements: A Cape Town case study," *Int. J. Disaster Risk Reduct.*, vol. 50, no. March, hal. 101736, 2020, doi: 10.1016/j.ijdrr.2020.101736.

[5] C. Setiawan, R. Handawati, dan Ermalia, "Analysis of Influence Settlement Density on the Fire Hazards Settlement at Cengkareng Subdistrict, West Jakarta," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 412, no. 1, 2020, doi: 10.1088/1755-1315/412/1/012011.

[6] S. Dahlia *et al.*, "Pemetaan Kerawanan Kebakaran Menggunakan Pendekatan Integrasi Penginderaan Jauh Dan Persepsi Masyarakat Di Kecamatan Tambora Jakarta Barat," vol. 11, no. 1, hal. 1–23, 2019.

[7] M. I. R. Winandari, P. Wijayanto, dan Faradila, "Fire risk based on building density in the dense settlement," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 780, no. 1, 2021, doi: 10.1088/1755-1315/780/1/012053.

[8] F. Fitri Imansyah, "Sistem Informasi Geografis Lahan Pertanian Rawan Kebakaran di Kota Singkawang," *J. Sist. dan Teknol. Inf.*, vol. 9, no. 2, hal. 289, 2021, doi: 10.26418/justin.v9i2.44496.

[9] P. Y. Sari, S. Soma, dan L. D. Rohmadiani, "Evaluasi Pelayanan Sarana Dan Prasarana Proteksi Kebakaran Pada Permukiman Perkotaan," *TATALOKA; Vol 23, No 2 Vol. 23 No. 2, May 2021DO - 10.14710/tataloka.23.2.298-306*, Mei 2021, [Daring]. Tersedia pada: https://ejournal2.undip.ac.id/index.php/tataloka/article/view/7093

[10] N. N. Valentine dan W. A. Bolaji, "Fire Disaster Preparedness among Residents in a High Income Community," *Int. J. Disaster Manag.*, vol. 4, no. 2, hal. 23–32, 2021, doi: 10.24815/ijdm.v4i2.21026.

[11] P. P. Singh, C. S. Sabnani, dan V. S. Kapse, "Interpreting Benchmark Assessment of Emergency Fire Service using Geoinformation Technology," *Int. J. Disaster Risk Reduct.*, vol. 63, hal. 102432, 2021, doi: https://doi.org/10.1016/j.ijdrr.2021.102432.

[12] R. Widiastutik dan I. Bukhori, "Kajian Risiko Bencana Longsor Kecamatan Loano Kabupaten Purworejo," *J. Pembang. Wil. Kota*, vol. 14, no. 2, hal. 109, 2018, doi: 10.14710/pwk.v14i2.19258.

[13] P. W. Mwangi, F. N. Karanja, dan P. K. Kamau, "Analysis of the Relationship between Land Surface Temperature and Vegetation and Built-Up Indices in Upper-Hill, Nairobi," *J. Geosci. Environ. Prot.*, vol. 06, no. 01, hal. 1–16, 2018, doi: 10.4236/gep.2018.61001.

[14] M. N. Handayani, B. Sasmito, dan A. Putra, "Analisis Hubungan Antara Perubahan Suhu Dengan Indeks Kawasan Terbangun Menggunakan Citra Landsat (Studi Kasus : Kota Surakarta)," *J. Geod. Undip*, vol. 6, no. 02, hal. 517–525, 2017.