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GIS-based urban village regional fire risk assessment and mapping

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ABSTRACTS

Fires in residential areas are one of the threats out of 13 disasters in Indonesia. Fires are disasters based on their causes, classified as disasters caused by human negligence. This research aims to identify residential fire incidents, assess fire risk levels, and map the risk level. We used the geographic information system (GIS) analysis approach and direct observation of the study area. The research location was in the Tamansari sub-district in Bandung City. The subdistrict of Tamansari consists of 20 neighborhood units (*rukun warga*/ RW) with 22,995 people and 6,598 households. We conducted a field survey from December 2019 to March 2020. We used a spatial approach to analyze fire risk in this residential area by using GIS to map urban-village regional fire incidents and assess the risk level. There were four fire hazard variables: population density, building density, building quality, road class. On the other hand, vulnerability variables are based on the community's social parameters: population density, percentage of old age and children under five, people with disabilities, and the population's sex ratio. The hazard and vulnerability maps overlay showed three neighborhood units (*rukun warga*/ RW) with a high risk of fire, eight RWs with a moderate risk of residential fires, and nine RWs with a low risk of residential fires. The areas with low-risk categories must remain vigilant because the width of the roads in these areas is relatively narrow.

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1. INTRODUCTION

Fire is a disaster that, based on the causes of its occurrence, is classified as a natural disaster or a non-natural disaster caused by human negligence (man-made disaster). Natural factors that cause fire disasters are lightning, earthquakes, volcanic eruptions, drought, and many others, while human factors are gas leaks, electrical short circuits, low construction security systems, and others (Granda & Ferreira, 2019; Kumar, Jana, & Ramamritham, 2020; Zhang, Yao, & Sila-Nowicka, 2018). A fire in an area causes economic loss; therefore, it needs fire disaster management. Urban fire disaster management research is carried out in many countries such as China, India, Iran; with results showing that densely populated urban areas are at risk of fire (Chan et al., 2018; Kumar, Ramamritham, & Jana, 2019; Navitas, 2014; Waheed, 2014; Zhang, Yao, Sila-Nowicka, & Jin, 2020).

There are many methods for analyzing fire risk in urban areas. Fire risk analysis for residential buildings in China uses cluster scenarios and applications (Xin & Huang, 2013).

Research in Iran uses the fusion method of spatial information produced using unmanned aerial vehicles (UAVs) and attribute data surveyed from 150 high-rise buildings (Masoumi, van L.Genderen, & Maleki, 2019). Meanwhile, in Malmo, Sweden, research on identifying the distribution of fires has made social stress one of the variables (Guldåker & Hallin, 2014).

Fire is one of the threats of 13 disasters in Indonesia (Badan Nasional Penanggulangan Bencana, 2012). Fig 1 shows the data on fire incidents in Bandung City during 2019 (Dinas Kebakaran dan Penanggulangan Bencana Kota Bandung, 2020). The fire factor that often occurs in large cities such as Bandung tends to be caused by human factors. The shape and planning of houses that are not regular make fire disasters often occur in Bandung. The total population of Bandung City in 2020 reached 2.444.160 people, with a population density of 14.61 thousand people per km2 (BPS- Statistics of Bandung Municipality, 2021).

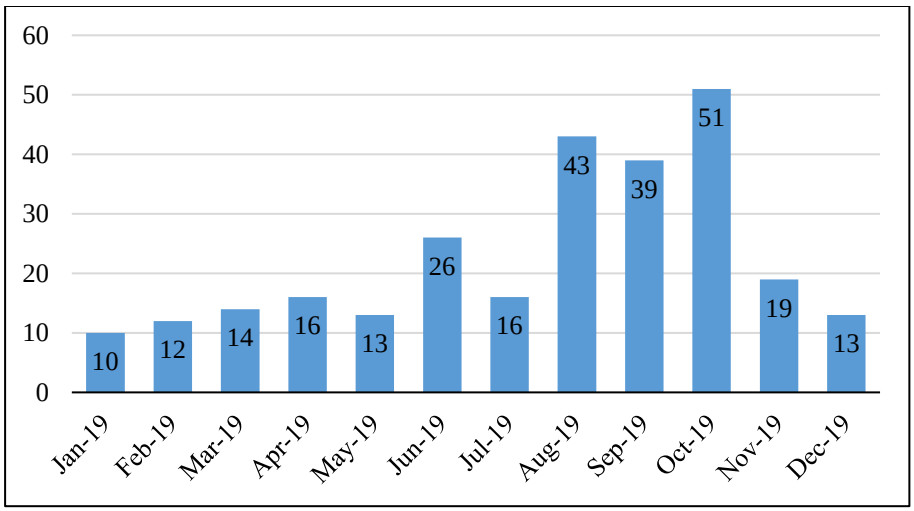

Fig 1. Fire incidents in Bandung City in 2019 (Dinas Kebakaran Dan Penanggulangan Bencana, 2020)

This research will focus on one of the urban villages in Bandung, a dense housing area located in Kelurahan Tamansari (Tamansari sub-district). Dense settlements that arise in the city of Bandung, which is not accompanied by good supervision, have caused the spatial pattern of the residential areas to become irregular and very difficult to control. The housing density makes a fire more potential because of a poor water pipe system, very narrow road, and low-quality building materials. This research aims to identify residential fire incidents, assess fire risk levels, and map the risk level.

2. METHOD

The location of the research project was in Tamansari sub-district. The study area consists of 20 neighborhood units (*rukun warga*/ RW) with 22,995 people and 6,598 households. We conducted the research project from December 2019 to March 2020. By using geographic information system (GIS) analysis and direct observation of the study area. The data collection method is primary and secondary data.

We used a spatial approach to analyze fire risk in this residential area. We applied GIS to map urban-village regional fire incidents and assess the risk level. Two main variables in this study to calculate fire risk are hazard and vulnerability. The level of disaster risk, using a formula, namely R = H x V/C (Where: R = Risk; H = Hazard; V = Vulnerability; C= Capacity) (Badan Nasional Penanggulangan Bencana, 2012). Capacity is the ability of regions and communities to reduce threats and losses due to disasters. This research does not include capacity in spatial analysis.

There were four fire hazard variables, namely: population density, building density, building quality, road class (Table 1). On the other hand, vulnerability variables are based on the community's social parameters: population density, percentage of elderly and toddlers, people with disabilities, and the population's sex ratio (Table 2).

Table 1. Fire hazard variables (Badan Nasional Penanggulangan Bencana, 2012)

Variables	Level of hazard	Weight
Population Density	< 150 persons/ Ha (Low)	1
	150 - 200 persons/ Ha (Moderate)	2
	>200 persons/ Ha (High)	3
Building Density	<40 Units/ Ha (Low)	1
	40-80 Units/ Ha (Moderate)	2
	>80 Units/Ha (High)	3
Building Quality	<5% (Low)	3
	5 – 15 % (Moderate)	2
	> 15% (High)	1
Road Density	>105 m/Ha (High)	3
	75-105 m/Ha (Modertae)	2
	<75 m/Ha (Low)	1

Table 2. Fire vulnerability variables

Variables	Level of Vulnerability	Weight
Population Density	< 150 persons/ Ha (Low)	1
	150 - 200 persons/ Ha (Moderate)	2
	>200 persons/ Ha (High)	3
Number of Elderly and Todler	<20 % (Low)	1
	20-40 % (Moderate)	2
	>40% (High	3
Number of Disabled Residents	<20 % (Low)	1
	20-40 % (Moderate)	2
	>40% (High)	3
Population Sex Ratio	92,38 – 98,88 (Low)	1
	98,89 – 105,39 (Moderate)	2
	105,4 – 111,9 (High)	3

3. RESULTS AND DISCUSSION

3.1. Distribution of Fire Locations in Tamansari Sub-district

Tamansari sub-district has a dense population density of up to 228 people/hectare due to urbanization. Therefore, the need for land is very high, but the availability of land is insufficient, causing dense settlements in urban areas, which triggers a fire disaster that will occur due to the quality of the building and the unstable condition of the building material. Based on data from the Bandung City Fire and Disaster Management Service, there were fire incidents in the Tamansari sub-district in 2015 – 2018. The fires in the Tamansari subdistrict in 2015-2020 occurred at several points, and those were in RWs of 1, 4, 9, 10, 11,15, and 20, period (Fig 2). Fig 3 shows one of the fire incidents in Tamansari subdistrict.

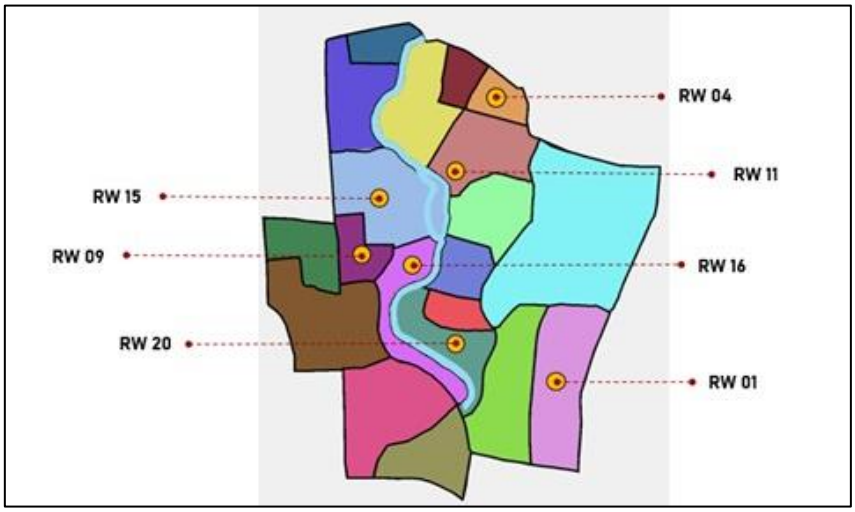

Fig 2. Fire incidents in Taman Sari sub-district in 2015-2020

Fig 3. Fire incident in Tamansari subdistrict

3.2. Fire hazard level

The level of fire hazard was obtained from four fire hazard factors using the overlay method. Table 3 shows the total weight of parameters is 11 (the maximum is 12). Table 4 shows five RWs with low levels, four RWs with moderate levels, and 11 RWs with a high fire hazard level.

Based on the residential fire hazard map, it appears that the Tamansari Village is dominated by a high fire hazard (Fig 4). In contrast, the area with a low level of hazard is the trade and service area. The physical condition of the area is an essential factor in the fire hazard in urban village settlements, as studied in the Bandung (Permana, Susanti, & Wijaya, 2019) and Surabaya City Areas (Navitas, 2014). Figs 5 and 6 show the physical condition of the urban village in Tamansari subdistrict.

Table 3. Scores of fire hazard in Tamansari subdistrict

Parameter	Fire hazard	Weight
Population Density	>200 person per hectare	3
Building Density	>80 Units per hectare	3
Building Quality	5 – 15 %	2
Road Density	>105 meters per hectare	3
Total		**11**

Table 4. Level and areas of fire hazard in Tamansari subdistrict

Neighborhood Units (*Rukun Warga*/ RW)	Area (hectares)	Level of Hazard
1	7.7	low
2	6.7	low
3	17.2	low
4	1.9	high
5	1.7	high
6	1.8	high
7	4.8	moderate
8	3.4	low
9	2.3	moderate
10	5.2	low
11	5.3	high
12	4.5	high
13	2.6	high
14	1.7	high
15	7.3	high
16	3.8	high
17	7.9	moderate
18	7.4	high
19	4.1	moderate
20	4.6	high

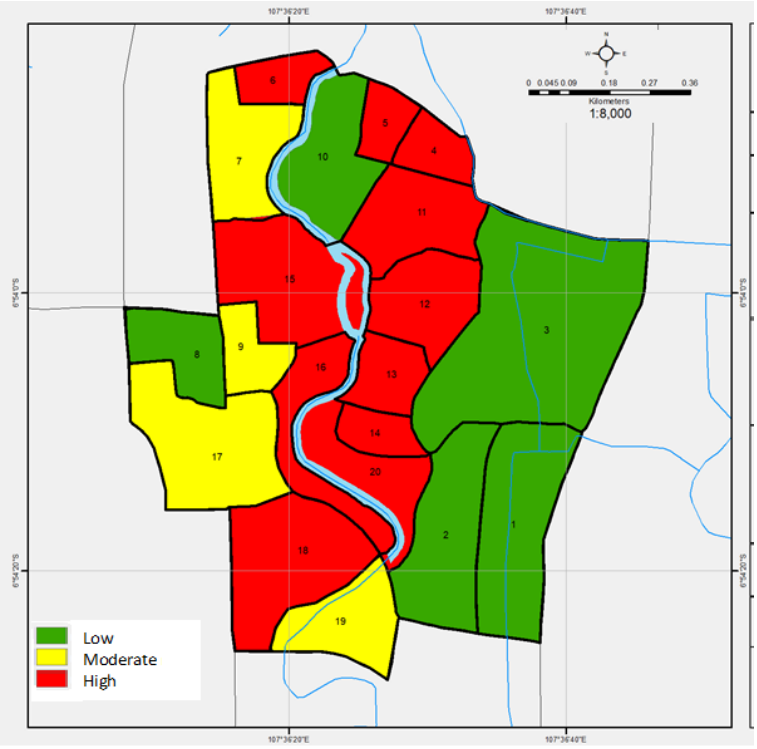

Fig 4. Map of fire hazard in Tamansari subdistrict

Fig 5. Dense settlement in urban village (Tamansari subdistrict)

Fig 6. An example of low-quality building materials in Tamansari subdistrict

3.3. Fire Vulnerability Map

Vulnerability is a community or social condition that leads to or causes an inability to face the threat of disaster (Trainor et al., 2009). The vulnerability parameter used in this study is the social vulnerability parameter. This social vulnerability is described through the condition of the population, which includes the sex ratio, disabled population, dependent age group of the elderly and infants, and population density where these factors can cause them to be in a vulnerable condition (Sutanti, Tjahjono, & Syaufina, 2020; Y. Zhang, 2013).

Table 5 shows the results of the combined analysis of the four vulnerability factors above are further classified into three classes, namely low, medium, and high so that the level of fire vulnerability in the Tamansari subdistrict has a score of 8. This result can be categorized into moderate residential fire vulnerability.

Table 6 shows the level and area of fire vulnerability in the Tamansari subdistrict. There are nine RWs with low levels, seven RWs with moderate levels, and four RWs with a high level of fire vulnerability.

Fig 7 shows the fire vulnerability of the urban village (Tamansari subdistrict), caused by the social conditions of the people in the residential area. Based on social conditions, the vulnerability level is dominated by RWs with low levels.

Table 5. Scores of fire vulnerability in Tamansari subdistrict

Parameters	Fire Vulnerability	Scores
Population density	>200 persons/hectare (High)	3
Number of elderly and toddler (%)	20-40 % (Low)	1
Number of disable resident (%)	<20 % (Low)	1
Sex ration (%)	92.38 – 98.88 (Low)	3
Total		**8**

Table 6. Level and areas of fire vulnerability in Tamansari subdistrict

Community Units (*Rukun Warga*/ RW)	Area (hectares)	Level of Vulnerability
1	7.7	Low
2	6.7	Low
3	17.2	Low
4	1.9	Moderate
5	1.7	Moderate
6	1.8	Low
7	4.8	Low
8	3.4	Low
9	2.3	High
10	5.2	Low
11	5.3	Moderate
12	4.5	Moderate
13	2.6	High
14	1.7	Low
15	7.3	High
16	3.8	High
17	7.9	Moderate
18	7.4	Moderate
19	4.1	Low
20	4.6	Moderate

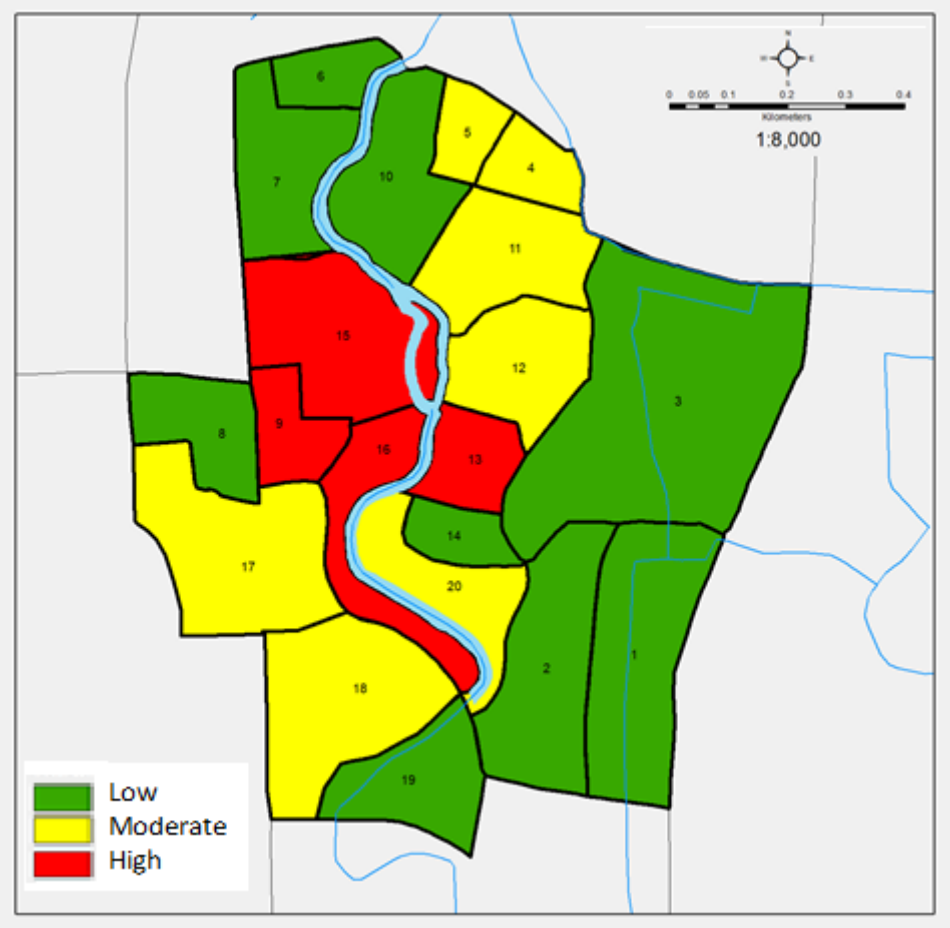

Fig 7. Map of fire vulnerability of Tamansari subdistrict

3.4. Fire Risk

Table 7 and Fig 8 describe the fire risk due to multiplying the hazard and vulnerability, showing three RWs with high risk, eight RWs with medium risk, and nine RWs with low risk.Fire risk shows that the area of the Tamansari subdistrict is dominated by low risk. Meanwhile, the low-risk area does not mean there is no potential for fire to occur. Tamansari subdistrict has a narrow road width that makes it challenging to handle fires in residential areas, so it can be higher even though the risk is low.

Research on fire mitigation scenarios in dense settlements in Sukahaji, Bandung, showed that capacity optimization as a mitigation measure could be the main alternative in handling fire hazards in areas with medium-high population density. In addition, the early warning system is a crucial factor in mitigation efforts (Sagala, Adhitama, Sianturi, & Al Faruq, 2016).

To increase capacity in urban village housing, a proposed method by using existing resources for an emergency response include mosque loudspeakers, fire extinguishers, and preparing evacuation routes (Pamungkas, Rahmawati, Larasati, Rahadyan, & Dito, 2017).

Table 7. Scores of fire risk of Tamansari subdistrict

Neighborhood unit (RW)	The score of hazard (H)	The score of vulnerability (V)	Risk(H X V)	Level of risk
1	1	1	1	low
2	1	1	1	low
3	1	1	1	low
4	3	2	6	moderate
5	3	2	6	moderate
6	2	1	2	low
7	2	1	2	low
8	2	1	2	low
9	2	3	6	moderate
10	1	1	1	low
11	3	2	6	moderate
12	3	2	6	moderate
13	3	3	9	high
14	3	1	3	low
15	3	3	9	high
16	3	3	9	high
17	2	2	4	moderate
18	3	2	6	moderate
19	2	1	2	low
20	3	2	6	moderate

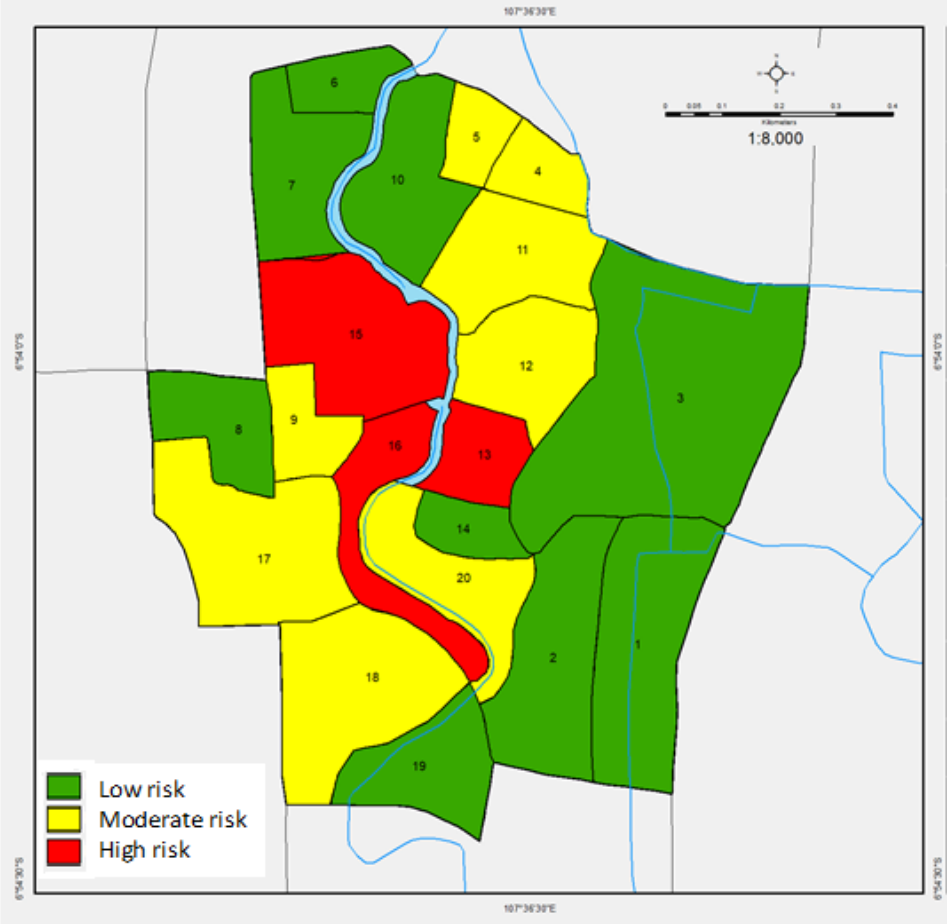

Fig 8. Map of fire risk of Tamansari subdistrict

4. CONCLUSION

Tamansari subdistrict is an urban village with dense settlements, which causes fire disasters to occur often. Dense buildings and low building materials caused these incidents. Based on the fire hazard and vulnerability analysis, Tamansari subdistrict has a very high fire hazard level with a score of 11 of 12. The level of vulnerability based on social aspects shows that Kelurahan Tamansari has a low vulnerability value of 8. The fire risk map in the Tamansari subdistrict is dominated by areas with a low risk of fires. The fire risk map shows three RWs with high levels, eight RWs with moderate levels, and nine RWs with a low level of fire risk.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

6. ACKNOWLEDGMENT

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