PENA TEKNIK
JURNAL ILMIAH ILMU - ILMU TEKNIK

Vol. 7, No.2, September (2022)
p-ISSN 2502-8952
e-ISSN 2623-2197
https://ojs.unanda.ac.id/index.php/jiit/index

Fire Vulnerability Assessment using Multicriteria Analysis in Makassar City

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Keywords

Multicriteria Analysis; Fire; Vulnerability; Makassar; GIS

Abstract

The safety aspect, especially the fire disaster, is essential for Makassar City because of its role as a metropolitan city and a center of activity in the Eastern Indonesia Region. The dense population and activities make Makassar City vulnerable to fires. A vulnerability assessment can assist in urban disaster management, especially in highlighting areas of fire disaster mitigation. Based on this urgency, this study aims to identify fire-prone areas in Makassar City. This study examines the fire vulnerability of Makassar City from population density, building density, frequency of previous fire events, fire fires, distance to the availability of clean water, and dangerous buildings. Fire susceptibility criteria are based on stakeholder assessments involving disaster experts, city planners, and firefighters through the Analytical Hierarchy Process. Spatial assessment using multi-criteria analysis through the Simple Additive Weighting method, which is integrated with the Geographic Information System to allow spatial weighting. The study results show that the western and northern parts of Makassar City are very prone to fires. This area is an early development area for Makassar City, characterized by a dense population and buildings with various activities.

1. INTRODUCTION

Makassar City, the largest metropolitan city in the Eastern Indonesia Region, accommodates various urban activities every second. The high population due to the influence of urbanization in Makassar City demands an increase in urban facilities services. Judging from its vitality, Makassar City should be able to accommodate various urban activities with a sense of security and comfort to increase the productivity of city residents. However, like other cities in Indonesia, Makassar City is also inseparable from urban problems, one of which is fire. Fire is a disaster that is difficult to predict when it will occur, and the risk of the amount of loss caused is quite considerable, so responsive conditions are needed to overcome it. In addition, Makassar City, with its densely populated condition, is prone to and prone to fires.

The massive development in Makassar City has resulted in changes in physical, social, environmental, and other aspects of Makassar City, which indirectly have implications for the city's ability to perceive environmental changes and disasters that may occur. Almost every month, tourism in Makassar City experiences fires. Based on data from the Makassar City BNPB fire incident report, the number of incidents in Makassar City in 2020 was recorded at 105 cases. From 2015 to 2020, the number of fire incidents tends to fluctuate.

Disaster vulnerability is a characteristic of an area over a certain period to reduce the ability to respond to specific adverse impacts (Hizbaron, 2021). Fire vulnerability has threats from natural and non-natural factors and social factors. Fire susceptibility refers to the physical aspect of the occurrence of fire. There are nine essential criteria in fire-prone areas: land use, building density, number and location of fires, air sources, hydrants, building materials, electricity networks, and disaster response time (Dahlia, 2018). Several other factors, such as road width, building layout, and internal activities by Irawan and Faiz (2021). In his research, Widiyantoro (2016) uses vulnerability variables such as population density, building density, building size, the distance between buildings and their construction, road width, and distance to fire. From a different

perspective, Chisty and Rahman (2020) review fire events through community awareness and readiness and their ability to deal with fires to property and connections between communities. Mustika (2018) also mentions the building on a micro-scale. Factors that influence fire risk, especially in high-rise buildings, are means of protection, accessibility of fire cars, life safety facilities, and building fire safety. The previous factors are factors or variables considered influential in the level of fire risk. Several general factors can be drawn, such as population density, building density, existing fire services, previous fires, distance to air sources, and hazardous buildings. To be clear, the following is a table of literature reviews of previous studies that are relevant to the topic:

Table 1. Relevant Previous Researches

Author, Year, and Title	Research Result
Widiyantoro, B. A (2016). Analisis Tingkat Resiko Bencana Kebakaran di Kecamatan Mariso Kota Makassar Berbasis Sistem Informasi Gegrafis (SIG)	This study assesses the Mariso District disaster in 2016 using the weighting method. This study revealed that the fire risk occurred in a controlled area, with no fire protection equipment and low accessibility at the location.
Dahlia. S, et al (2018). Pemetaan Zonasi Daerah Rawan Kebakaran mmenggunakan Citra Quickbird di Kecamatan Tambora Provinsi DKI Jakarta	This study discusses fire hazard mapping using quickbird imagery in Tambora District, DKI Jakarta. The approach taken is natural and social science. The variables considered are land use, building density, road width, rivers, public perception of the frequency of fires, historical events, and mitigation efforts. This study reveals that fire-prone areas tend to occur in areas with high fire frequency, an inadequate number of hydrants, unsafe electricity networks, narrow road access, and dominated by semi-permanent buildings.
Taridala. S, et al (2017). Model Penilaian Risiko Kebakaran Perkotaan dengan Sistem Pakar berbasis Gis Grid-Based	This study aims to assess the risk of fire in Kendari City. The method used is to combine expert systems in grid-based spatial analysis. The results showed that the areas with a fire risk d=very high were built-up areas with densely populated areas dominated by semi-permanent buildings. High-risk areas have low accessibility and are in a hilly morphology.
Srivanit, M. (2011). Community risk assessment: spatial patterns and GIS-based model for fire risk assessment-a case study of Chiang Mai municipality	This research was conducted in Chiang Mai Municipality, and one of the objectives was to assess fire risk. The method used is MCDA (Multicriteria Decision Analysis). Factors considered include the type of building material, building height, density, population density, hazardous buildings, distance to fire sources, accessibility, distance to fire stations, hydrants, frequency of fires, and distance to water sources. The study results found that prone areas are in the study area. The vulnerability factor with the highest weight is the type of building material and the density of the building.
Widyatmadja, W., & Purwanto, T. H. (2013). Aplikasi Penginderaan Jauh dan Sistem Informasi Geografis untuk Pemetaan Zonasi Kerawanan Kebakaran Permukiman dengan Memanfaatkan Citra Quickbird di Kecamatan Balikpapan Selatan.	This study maps fire vulnerability using quickbird imagery with scoring and weighting in South Balikpapan. The variables considered are the availability of hydrants, water sources, and road quality. The results of the assessment accuracy reach a value of 89%, which is quite suitable for studying urban areas.
Isma, F. et al (2021). Kajian Daerah Rawan Kebakaran Kota Langsa Menggunakan Metode Weight Product (WP).	This research was conducted in Langsa City using the Weight Product method. Factors to consider are population density, built-up area, frequency of occurrence, the reach of firefighters, road ratio, and water supply. This study found that most areas have a low level of fire susceptibility with regional characteristics, namely low population density and sufficient water supply.
Wang, K., et al (2021). A POIs based method for determining spatial distribution of urban fire risk.	This research was conducted in Zhengzhoung to analyze fire vulnerability using the point of interest (POIs) by considering expert scoring through the AHP technique. This study assesses the function of the building. As a result, fire-prone areas are dominated by residential areas. The weakness of this

Author, Year, and Title	Research Result
	method is that it uses points so that considerations related to the size of the building cannot be identified.

Fire vulnerability assessment is the main foundation of efforts to prevent, mitigate, and improve preparedness for fire disasters. Several studies that use fire vulnerability assessments, namely Taridala et al. (2018), assess based on the clean air network system with fire vulnerability. Another infrastructure is the optimization of the location of the fire post (Bagir and Buchori, 2012). In addition, a fire hazard assessment is also needed for fires that are useful for transportation systems (Avdeeva, M, 2022). Fire mapping is also needed in preparing fire mitigation (Neto and Ferreira, 2020).

A city must have a fire hazard assessment based on the city's development. Studies in China on fire data reveal that the use of fire data and updating of fire data has a significant impact on reducing fires and fire consequences (Liu et al., 2022). Previously, Widiyantoro (2016) assessed sub-districts in Makassar City with a focus on the Mariso District. However, this assessment was limited to one sub-district, not comprehensive in Makassar city. In addition, this research was conducted in 2016, which is quite long compared to the massive development in Makassar City every year. So, more or less, there has been a change in the structure and pattern of space in Makassar City, which makes this research necessary to get a complete picture of fire vulnerability in Makassar City.

Reflecting on the previous and based on the urgency of the vitality of Makassar City as a metropolitan city, it is essential to do this at a depth related to fire hazards in Makassar City. Thus, this study aims to identify fire-prone areas that are expected to influence reducing fires in Makassar City.

2. METHODS

The data used are primary and secondary data. Primary data consists of expert preferences for the importance of fire susceptibility criteria. Secondary data includes spatial data on administrative boundaries, land use, frequency of fire occurrences, building functions, and population. Primary data were obtained through interviews and questionnaires by two experts including academics in the field of spatial planning for residential areas, urban planners and government, namely the fire department. At the same time, secondary data was obtained through literature studies and data collection agencies.

Previous research has explored many fire assessments with various analytical methods and techniques. Some of them use methods and techniques such as Point of Interest (POIs), Computational Fluid Dynamics (CFD), Fire Risk Analysis Method for Engineering through Building Information Modeling (BIM), Dynamic Risk Assessment (DRA), and AHP using expert choice applications (Wang, L. et al., 2021; Zhang, F. et al., 2022; Wang, L. et al., 2021; Feng, J. R. et al., 2022; Taridala, S. et al., 2018). The variety of methods, analytical techniques, and tools that can be used to analyze fire assessments facilitate fire assessments and affect the accuracy of the assessment. The determination of the method used, of course, is based on the conditions and character of the area. Socio-cultural differences and space activities will form differences in the tendency of different fire patterns. Therefore, the determination of analytical methods and techniques was chosen by involving the opinions of experts who certainly understand the character of the study area. The method considered appropriate is the analytical hierarchy process which involves experts in determining the priority weight of the fire susceptibility variable. In addition, the spatial assessment is carried out using the simple additive weighting method spatially using the QGIS 3.16 application to quantify and visualize the assessment.

In stages, the fire hazard assessment is divided into two stages: determining the criteria and level of importance using the analytical hierarchy process and spatial analysis of fire hazard using the simple additive weighting method. The analytical hierarchy process includes four stages: problem decomposition, comparative assessment, value synthesis, and consistency testing (Saaty, 2008). The assessment uses pairwise comparisons through a number scale that shows how much more critical or dominant an element value is than another. The

results will eventually be validated with a logical consistency test. Calculations are valid and logical if the consistency ratio does not exceed 10% or 0.1 logical consistency formula as below.

$$CI = \frac{\lambda \max - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

Where:
CI = Consistency Index
RI = Ratio Index
CR = Consistency Ratio

After obtaining the weights of each criterion of importance, proceed with spatial analysis using the Simple Addititve Method (SAW). The SAW method is a multi-criteria analysis method known as weighted addition which was first written by Churchman and Ackoff (1945). Previously, the SAW method has been applied by several researchers for disaster vulnerability assessment as done by Setyani and Saputra (2016). The stages are determining the criteria, determining the suitability rating for each criterion, making a normalized decision matrix, then adding up the values of each weighted criterion (Chackraborty and Yeh., 2012., and MacCrimmon, 1968). Normalization can be done using the formula adapted by Chackraborty and Yeh (2012) and Vafaei et al. (2022).

$$r_{ij} = \frac{x_{ij}}{x_j^{\max}} \quad (3)$$

Where:
r_{ij} = Normalised ratings
X_{ij} = Performance ratings of j
X_j^{max} = Maximum performance rating among alternatives for j attribute

The normalized score then continued by calculating the total value of each criterion on the alternative using the provisions adopted by Chackraborty and Yeh (2012) and Vafaei et al. (2022).

$$V_{ij} = \sum_{i=1}^{n} w_j r_{ij} \quad (4)$$

Where:
V_i = Preference value of decision alternative of i
w_j = The normalized values of j
r_{ij} = Weight of j

3. RESULT AND DISCUSSION

3.1 Fire vulnerability criteria

Determination of criteria is done through literature study and policy review related to fire hazards. Literature review and policy rules used are the Decree of the State Minister of Public Works No.11/KPTS/2000

of 2000, Regulation of the Minister of Public Works number 20/PRT/M/2009 of 2009, Hazardous building standards by the National Fire Protection Association (NFPA), Dahlia (2018), Taridala (2018), Widiyantoro (2016), and Irawan and Faiz (2021). The criteria used for this study consisted of six criteria, namely population density, building density, fire extinguisher range, distance to water availability, dangerous buildings, and frequency of fire occurrences. The results of the weight calculation for each criterion can be seen in Table 2 below:

Table 2. Weight of Importance of Fire Vulnerability Criteria

Criteria	Weight
Densely populated area	0.29
Congested area	0.25
Dangerous building	0.22
Areas of high fire frequency	0.12
Far from the availability of water sources	0.06
Far from the reach of fire services	0.06

Based on the analysis of the importance of the criteria, it was found that densely populated areas are the criteria with the highest weight of fire hazard of 0.29 or 29%. The results show that the lowest criteria have the same weight between the availability of water sources and the range of fire services, with a weight of 0.06. Densely populated areas are considered to have the highest level of importance or, in other words, criteria that significantly impact fire susceptibility because they take into account the material and life losses that may occur. Apart from being densely populated, it is also densely populated. The tendency is that the fire will enlarge when it is in a dense area and spread more quickly if it is densely built with semi-permanent materials. Areas with high building density are usually in the middle of urban areas. They are slum areas, so most building materials used are flammable. In addition to building materials, several buildings are vulnerable due to the functions and activities in these buildings. Areas with dangerous buildings such as warehouses, flour factories, plastic factories, and others are counted as vulnerable areas because they are at high risk in the event of a fire. Furthermore, in areas with a high frequency of fires, based on theory, there is a tendency for areas that frequently experience fires to experience repeated fires, although not absolutely. Other criteria, such as the distance from water availability and the range of fire fighting services, are considered the lowest priority because they consider the condition of Makassar City, which has several reservoirs, rivers, and other water sources in urban areas. In addition, the existing infrastructure also makes it possible to store water and retrieve water reasonably quickly.

3.2 Fire vulnerability spatial analysis

fire hazard assessment is carried out for the entire Makassar City area, except for the islands. The research area covers 14 sub-districts, as depicted in Figure. 1. The analysis was carried out using vector-based spatial analysis. According to the research area, the vulnerability assessment begins by forming a grid measuring 100 x 100 meters in a hexagonal shape. Each grid has an identification number that distinguishes it as an alternative to simple additive weighting calculations later. The formed grid follows the shape of the research location in as many as 15,694 grids. After the primary grid is formed, it is continued with an assessment of the physical condition of the land by comparing it to the fire hazard indicators. The score is a value that indicates fire susceptibility in terms of influential criteria. The higher the score/rating value on the grid against the criteria, the more prone the grid is to fire. The scores used in the calculations were obtained through a study of the literature and related regulations, as shown in Table 3.

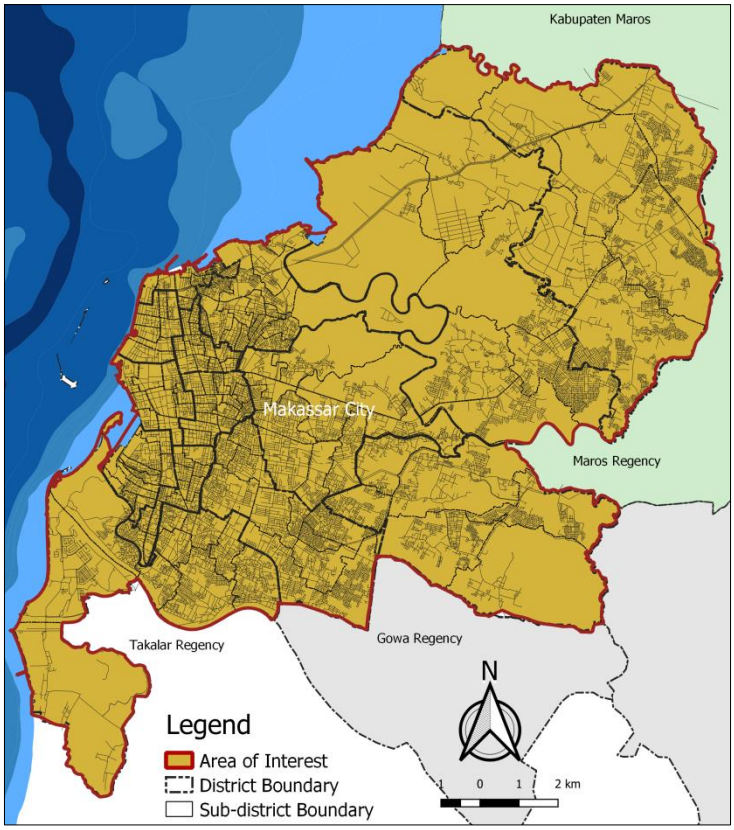


FIgure 1. Area of Interest

Table 3. Criteria Rating Value

Criteria	Indicator	Rating
Densely populated area	High population density (> 200 people/Ha)	3
	Mederate population density (151-200 people/Ha)	2
	Low population density (<150 people/Ha)	1
Building density	Very high building density (> 81 Buildings/Ha)	5
	High building density (61-80 Buildings/Ha)	4
	Moderate high building density (41-60 Buildings/Ha)	3
	Low building density (11-40 Buildings/Ha)	2
	Very low building density (< 10 Buildings/Ha)	1
Distance to water source	Distance to water source is far (> 1000 m)	3
	Distance to water source is moderate (250-1000m)	2
	Distance to water source is nearby (<250 m)	1
Firefighter's reach	Distance to fire station is far (>7,5 km)	3
	Distance to fire station is moderate (2,5-7,5 km)	2
	Distance to fire station is nearby (<2,5 km)	1
Dangerous building	Plastic warehouse and factory, flour factory,	5
	Warehouse and paper mill, rubber factory and storage, granary	4
	Printing, textile factory, agricultural equipment warehouse	3
	Parking, petrol station,	2
	Apartments, schools, fire stations, hospitals, museums, prisons, schools, offices	1
Fire frequency	Frequently Happening	3
	Rarely happening	2
	Happened	1

Based on this value, each grid is assessed according to the characteristics of the grid. The assessment results were then normalized for each criterion as in the provisions of MacCrimmon (1968) by dividing the value of the criteria by the maximum value that can be obtained on each grid for each criterion. The assessment for each criterion is carried out through spatial analysis, as shown in Figure 2. The population results, as in part (a), show that the area is marked red on the map. Furthermore, the distribution of buildings tends to be scattered in various areas in Makassar City, several dangerous buildings are close to each other, and that is a flour factory located in the Soekarno-Hatta Port Area. For the previous incident, it can be seen in Figure 2 that the eastern part of Makassar City, especially the Tamangapa Landfill in Manggala District, is the area that most frequently experiences fires. The criteria for the distance to the air source based on the results of the water source area buffer can be seen that the Makassar urban area has a distance to the air source < 600 meters, so it is pretty capable in the event of a large enough fire.

Furthermore, for the criteria for building density, as shown in the Figure 2, it can be seen that when the building is in the north of Makassar City, which is an area that helps and includes the area, it can be vulnerable in the event of a fire. For fires, if analyzed with a buffer, several areas with distances exceeding <600 meters are obtained. Areas above the city limits include the southern part of Makassar City, which interacts with Takalar Regency, and the eastern part of Makassar City, located with Maros Regency. After the assessment is carried out for each day, it is continued by calculating the total value of each criterion on the grid as the SAW method by MacCrimmon (1968).

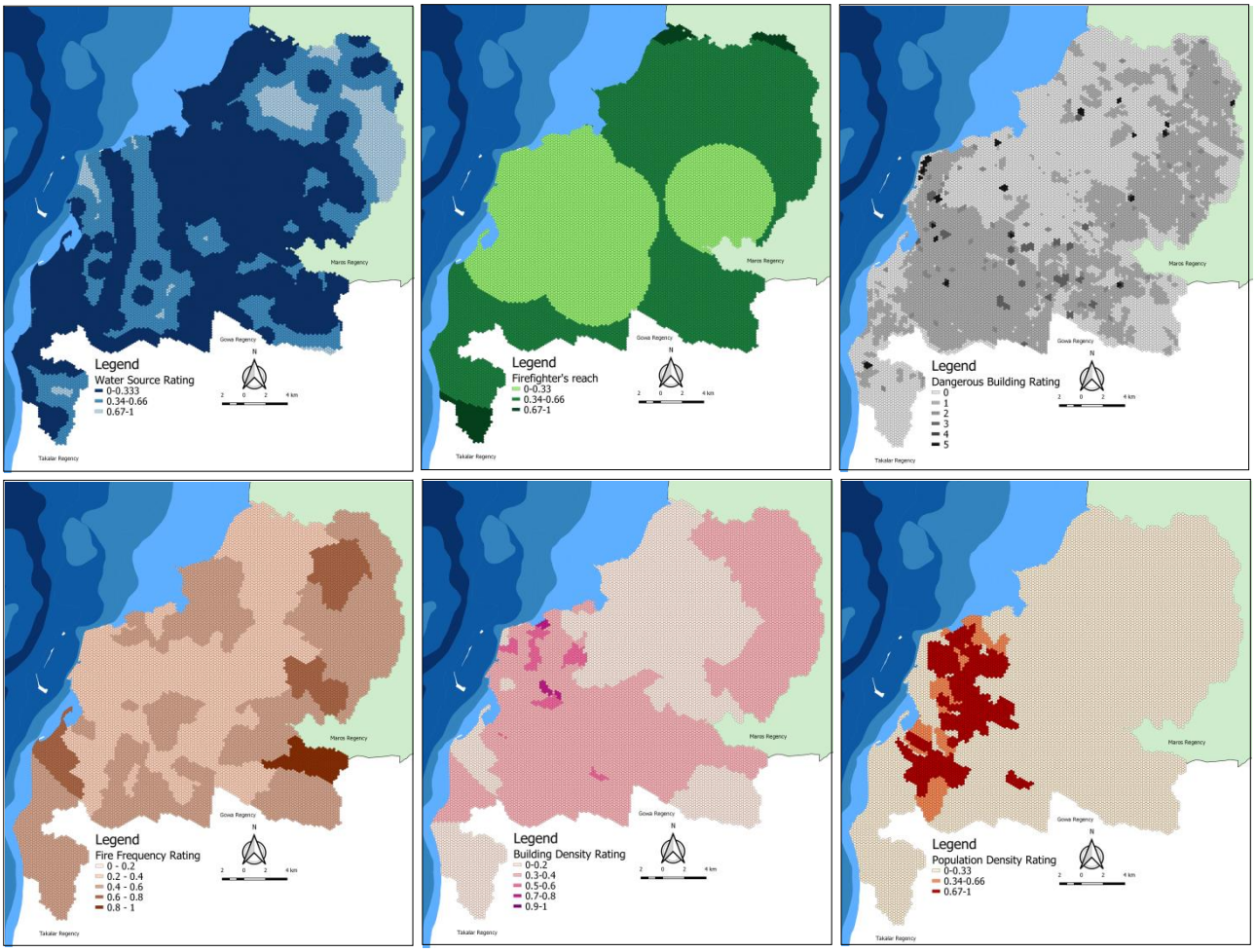


Figure 2. Results of Simple Weight Additive Analysis for Each Variable

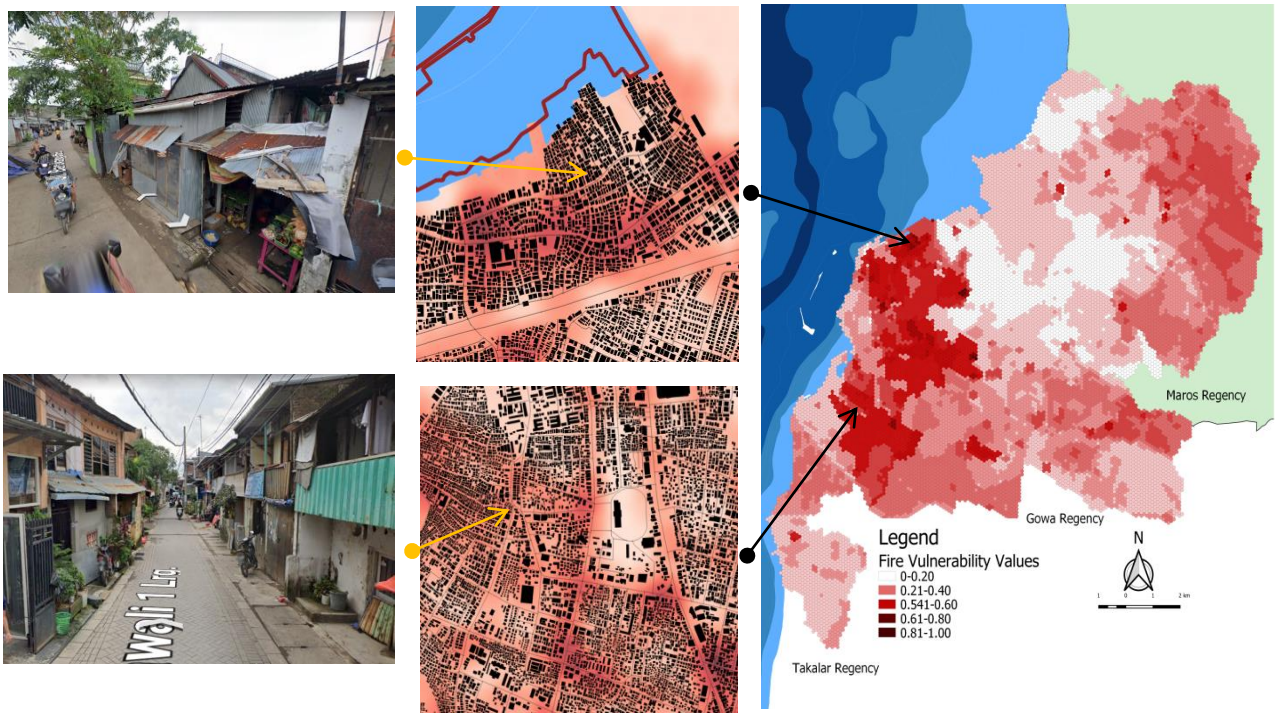


Figure 3. Map of Fire Hazards and Physical Condition of Fire Prone Areas in Makassar City

The analysis results show that the vulnerable areas tend to be in the northern and western parts of Makassar City. As shown in Figure 3(a), the northern part of Makassar City is located on Jl. Barukang Utara is a residential area with a dense population and buildings. In addition, this area has also experienced frequent fires before. The close distance between houses with a small road network will make it difficult for firefighters in the event of a fire. Many of the buildings in this area are semi-permanent houses. The materials used for building are flammable materials such as wood, plywood, and others, so they are more vulnerable in the event of a fire. In addition, there are no clear hydrants and evacuation routes in the event of a fire.

Furthermore, Figure 3(b) is located on Jl. Rajawali 1 Lr. 13B is a residential area with a high building density as well. In addition to the high building density, this area is densely populated with a relatively small road network width. The frequency of fires in this area is relatively low. This area is also quite close to the fire department because it is in an urban area. In addition, this area is also quite close to water sources. However, the density of buildings and residents makes this area prone to fires.

As shown in Figure 3, it can also be noted that the eastern part of Makassar City tends to be quite vulnerable. It is due to the density of buildings, the reach of firefighters, dangerous buildings, and the distance to water sources. Several points in the eastern part of Makassar City also have a relatively high frequency of fire occurrences.

4. CONCLUSIONS

Among the six fire susceptibility criteria, namely population density, building density, presence of dangerous buildings, distance to water sources, reach of firefighters, and frequency of previous fire events, the AHP results show that the importance of the criteria for densely populated areas is the greatest in the assessment of fire susceptibility. It reached a value of 0.29. The lowest criteria are the distance from the water source and the reach of the fire extinguisher, with a value of 0.06 each.

The fire vulnerability assessment results show that the northern and western parts of Makassar City are very prone to fires. It is caused by population density, building density, and the high frequency of fires. So, if viewed as a whole, fire mitigation should be deepened in the northern and western parts of Makassar City. As

a study note and suggestions for developing this assessment, the authors suggest further researchers consider the hazard and resilience factors in assessment indicators. In addition to reducing bias in the assessment, more complex data such as road width, the distance between buildings, and the level of community understanding of fire, temperature, and wind flow is recommended. The author also suggests conducting a time series assessment to see various fire vulnerability trends like fluid assessment and urban climate.

5. ACKNOWLEDGMENTS

The author would like to thank all those who have contributed their support, criticism, and suggestions to complete this research.

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