International Journal of Health Science (IJHS)

E-ISSN: 2827-9603
P-ISSN: 2827-9603

Research Article

Analysis Of Fire And Rescue Service Coverage In Surabaya City

Amanda Fharadita Olivia Rakhmad

Epidemiology Division, Department of Epidemiology, Population Biostatistics, and Health Promotion, Faculty of Public Health, Universitas Airlangga; amandarakhmad@gmail.com

Abstract: In addition to the spatial analysis, this study also considered the implications of population density and urban development patterns on the effectiveness of fire and rescue services. Sub-districts with high population densities and complex road networks, such as Rungkut and Dukuh Pakis, were particularly vulnerable due to delays in response time caused by traffic congestion and narrow street access. Furthermore, newly developed residential and industrial zones, particularly in the outskirts like Benowo and Pakal, showed inadequate emergency coverage due to the lack of nearby fire stations and limited road connectivity. The study underscores the importance of incorporating demographic and infrastructural data into emergency planning. Fire service planning that solely relies on theoretical models such as circular buffer zones tends to overlook the real-world constraints posed by road networks, traffic conditions, and topographic barriers. As a result, relying on network-based service area analysis provides a more realistic and operationally relevant perspective for decision-making. To enhance coverage, the study recommends optimizing station placement through Geographic Information System (GIS)-based modeling that factors in dynamic urban growth, accessibility, and service demand projections. Establishing satellite fire stations or deploying mobile fire units in the underserved sub-districts could be effective interim solutions while longer-term infrastructure developments are underway. Moreover, collaboration between fire departments, urban planners, and transportation authorities is essential to integrate fire safety considerations into city planning processes. By doing so, Surabaya can not only improve its emergency response performance but also build urban resilience in the face of increasing fire risks due to climate change and urban expansion.

Keywords: Buffer Zone; Fore Department; Service Area; Service Coverage; Surabaya.

Received: 01 July, 2025
Revised: 15 July, 2025
Accepted: 29 July, 2025
Online Available: 31 July, 2025
Curr. Ver.: 31 July, 2025

1. Introduction

Disaster risk management in public health is a systematic approach that integrates preparedness, response, recovery and mitigation. [1]. Prevention, mitigation and preparedness for disasters are needed as an effort to reduce the impact of disasters, especially casualties in a certain area and time. Decree of the Minister of Home Affairs Number 364.1-306 of 2020 concerning Guidelines for the Development of Fire Fighting Volunteers explains that the type of basic service that must be provided by the fire department is rescue and evacuation services for fire victims, which must be received by all citizens who become and/or are affected by fire, within a response time of 15 minutes. [2]

The success of Surabaya City in achieving the title as a pilot city in 2024 with the Response Time 7 Minute Free Blackout Service (Roti 7 Lapis) program is a manifestation of the comprehensive reform of the emergency service system [3] . This predicate was obtained thanks to Surabaya City's success in recording an average response time of 7 minutes. This figure significantly exceeds the national standard of 15 minutes by the Ministry of Home Affairs and demonstrates the efficiency and effectiveness of disaster management services in Surabaya City.

Fire protection management in Indonesia is specifically regulated in the Minister of Public Works Regulation No. 20/PRT/M/2009 on Technical Guidelines for Fire Protection Management in Urban Areas. This regulation mandates that each Fire Management Area (WMK) must be designed to ensure that service coverage does not exceed a travel distance of 7.5 km and that response time is less than 15 minutes. For high density areas that are already built up and occupied, protection standards are tightened with the obligation that the area must be reachable by the nearest fire station with the obligation that the area must be reachable by the nearest fire station with a maximum radius of 2.5 km .[4]

Evaluation of compliance and effectiveness of service coverage with the regulatory framework can be done through Geographic Information Systems (GIS). GIS is a system used in decision making based on spatial analysis [5] . The GIS concept integrates cartographic principles, statistics, and computing technology to obtain an efficient and effective way of analyzing geographic data [6] . One of the features of GIS is the ability to analyze proximity through distance-based analysis between layers to produce values or count areas [7] . Such proximity analysis can be done by utilizing buffer analysis and network analysis techniques.

The application of buffer analysis makes it possible to identify zones or areas of reachability around specific features based on Euclidean distance, often used in emergency planning for quick estimation of theoretical service coverage (Number Analytics, 2025). However, network analysis offers a more operationally realistic perspective by accounting for actual road networks, impedances, and travel conditions (ArcGIS Pro documentation, 2025; Hashtarkhani et al., 2024).

A buffer is defined as a zone drawn around a point, line, or polygon that includes all areas within a certain straight-line distance from the feature (Wikipedia Buffer Analysis, 2023). In contrast, network analysis evaluates movement through real-world roads, intersections, and access constraints to delineate service areas (ArcGIS Network Analyst service areas, 2025; Kiparisov & Lagutov, 2024).

This study aims to spatially analyze fire and rescue service coverage in Surabaya City by comparing buffer-based (radius) coverage with network analysis–based (road-miles) coverage to identify sub-districts with actual service gaps. It acknowledges that macro-level coverage assumptions do not incorporate additional variables such as water source locations, micro-accessibility (e.g., road width, portals), topographic constraints, or dynamic traffic conditions—meaning findings represent idealized scenarios rather than real-world constraints.

Previous case studies support the importance of network-based approaches for emergency services. For example, Hashtarkhani et al. (2024) demonstrated that travel time catchments based on network data enable more equitable accessibility assessments in healthcare services. Similarly, Yunus et al. (2023) utilized GIS-based network service delineation to identify under-served fire service areas in Kano, Nigeria, revealing critical access gaps unrecognizable in buffer-based models. Kiparisov and Lagutov (2024) further highlighted how combining GIS and network analysis enhances urban resilience assessment following extreme events by capturing actual travel limitations. Additionally, research in Victoria, Canada emphasized the advantage of network-based catchment zones over simple buffers when evaluating spatial-temporal availability of public facilities (Yao et al., 2021).

Collectively, these studies reinforce the need for network-based evaluation in emergency planning to accurately identify vulnerable areas and to inform targeted intervention and station placement strategies.

2. Proposed Method

The type of research conducted is descriptive quantitative research with a spatial approach. This research uses statistical analysis contained in buffer analysis and network analysis to determine service coverage. The population in this study is the location of 21 fire stations in Surabaya City and listed in the Strategic Plan of the Surabaya City Fire and Rescue Service for 2021-2026. The data analysis method used is spatial analysis using ArcGIS Pro 3.4.0 Geographic Information System (GIS) software. The data used in this study are detailed in Table 1.

Table 1. Research Data

No	Data Type	Scale	Year	Data Format	Source of Data Acquisition
1	Fire Station Location	-	2025	Tabular	Fire and Rescue Department of Surabaya City
2	Administrative Boundary	1:25.000	2022	.shp	Geospatial Information Agency
3	Road Network	1:25.000	2022	.shp	Geospatial Information Agency

The research methodology used in analyzing the range of fire and rescue services in the city of Surabaya is described in the research flow diagram in Figure 1.

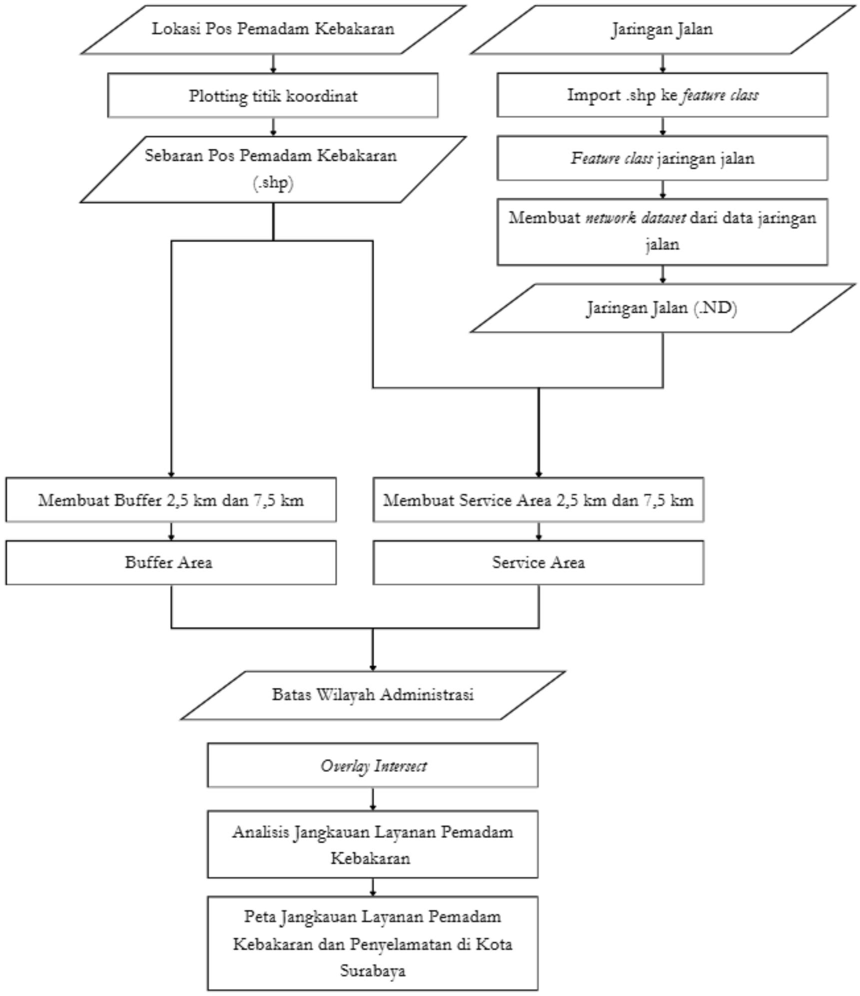


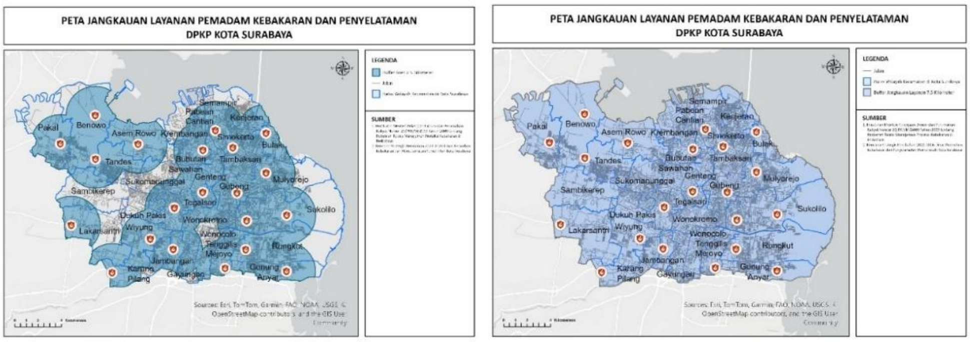
Figure 1. Research Flow Chart

The stages of this research are divided into three parts, namely:

- Data Preparation and Collection
  This section includes preliminary studies that support the determination of research locations and data collection conducted online.
- Data Processing
  This section includes plotting the coordinate points of the location of fire extinguisher posts, creating service areas and buffer zones, and making intersects between the areas that have been made with the administrative boundaries of Surabaya City.
- Data Analysis
  This section includes analyzing the range of fire fighting and rescue services based on the location of fire stations using service area analysis and buffer zones and drawing conclusions from the analysis that has been carried out.

3. Results and Discussion

The result of this research is a map of fire and rescue service coverage based on the placement of 21 fire stations in Surabaya City which is calculated with a buffer zone and service area of 2.5 km and 7.5 km. Visualization of the range of fire and rescue services formed can be seen in Figure 2 and Figure 3.



(a) (b)

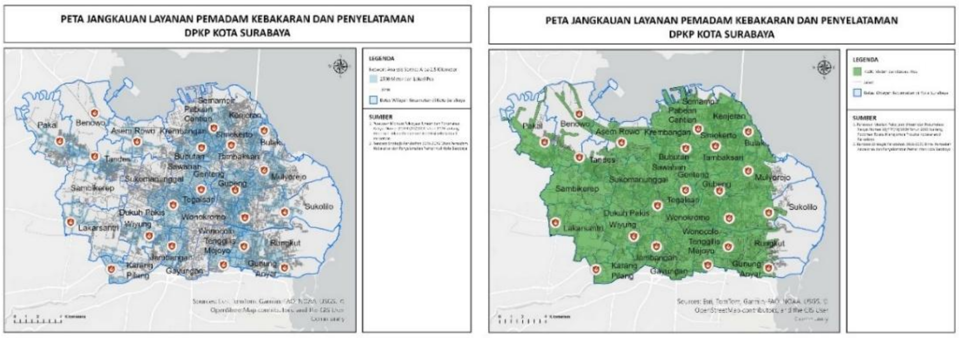
Figure 2 Map of Fire and Rescue Service Reach of Surabaya City with Buffer Analysis. (a) 2.5 km Buffer Zone, (b) 7.5 km Buffer Zone

Figure 2 shows information that in the 2.5 km Buffer Zone, fire and rescue services have not been able to reach all existing areas, while in the 7.5 km Buffer Zone, all areas have been served by fire and rescue services. Information on the coverage of fire and rescue services with buffer analysis within a radius of 2.5 km and 7.5 km is described in Table 2.

Table 2. Distribution of Fire and Rescue Service Coverage of Each Sub-district with 2.5 km and 7.5 km Buffer Analysis

Sub-district Service Area Status	Radius 2.5 km		Radius 7.5 km	
	n	%	n	%
Reached Entirely	10	32	31	100
Partially Reached	21	68	0	0
Total	31	100	31	100

Table 2 shows that at a radius of 2.5 km, there are 10 sub-districts (32%) whose areas are fully covered by fire and rescue services and 21 sub-districts (68%) are still partially covered. At a radius of 7.5 km, all sub-districts in Surabaya City are fully covered by fire and rescue services.



(a) (b)

Figure 3 Map of Fire and Rescue Service Coverage of Surabaya City with Network Analysis. (a) Service Area 2.5 km, (b) Servie Area 7.5 km

Figure 3 shows information that in the 2.5 km Service Area, fire and rescue services have not been able to reach all existing areas. Similarly, in the 7.5 km Service Area, there are still some areas that have not been reached by fire and rescue services. Information on the coverage of fire and rescue services with network analysis within a distance of 2.5 km and 7.5 km is described in Table 2.

Table 3. Distribution of Fire and Rescue Service Coverage of Each Sub-district with Netwok Analysis Service Area 2.5 km and 7.5 km

Sub-district Service Area Status	Distance 2.5 km		Distance 7.5 km	
	n	%	n	%
Entirely Affordable	1	3	23	74
Partially Reached	30	97	8	26
Total	31	100	31	100

Table 3 shows that at a distance of 2.5 km, there is 1 sub-district (3%) whose area is fully covered by fire and rescue services and 30 sub-districts (97%) are still partially covered. While at a distance of 7.5 km, there are 23 sub-districts (74%) whose areas are fully covered by fire and rescue services and 8 sub-districts (26%) that are still partially covered.

Discussion

- Reach of Fire and Rescue Services in Surabaya City

  Analysis of fire and rescue service coverage in Surabaya City based on the placement of 21 fire stations revealed a gap between theoretical and operational service coverage. The buffer analysis uses modeling of coverage based on straight (Euclidean) distances which gives an optimistic picture of meeting regulatory standards. At a radius of 2.5 km, which is the ideal standard according to Permen PU No. 20/PRT/M/2009, the results show that service coverage is not yet comprehensive. Although 10 sub-districts (32%) are fully served, the majority of wilatahs (68%) are only partially covered. This indicates that theoretically, there are still many densely populated areas that are outside the ideal prosimity radius of the nearest post. However, when the radius is expanded to 7.5 km, which is the maximum travel distance within a WMK, the buffer analysis shows that 100% of sub-districts in Surabaya City are covered. From this perspective, theoretically, the placement of the 21 existing posts is already qualified to cover the entire city area according to the maximum distance standard set.

  A much more realistic picture is provided by the service area network analysis, which modifies the conclusions of the buffer analysis by taking into account the constraints of the road network infrastructure. At a distance of 2.5 km, the service coverage drops dramatically, with only one sub-district (3%) being fully served. The remaining 97% of sub-districts are only partially covered. This data highlights how the topology of the road network, the presence of one-way roads, and physical barriers significantly limit the real accessibility of the fire fleet, despite their geometric proximity.

  An important finding emerged in the service area analysis with a distance of 7.5 km. In contrast to the buffer results which show 100% coverage, the network analysis reveals that there are still 8 sub-districts (26%) which are only partially covered. This finding has the important implication that there are areas in Suabaya City that are operationally outside the maximum service coverage of 7.5 km even though they are theoretically served. This suggests that road network accessibility constraints can create more vulnerable service gaps because the travel time to reach locations based on distance can exceed the set standard.

  A direct comparison between the two analysis methods confirms that reliance on buffer-based coverage models alone can lead to misinformation and ineffective policies. The gap between 100% theoretical coverage in the 7.5 km buffer and only 74% operational coverage in the 7.5 km service area is quantitative evidence of road infrastructure playing a decisive role in the effectiveness of emergency services. The placement of 21 fire stations in Surabaya City may be optimal in terms of geographical distribution, but not necessarily optimal in terms of operational accessibility. Therefore, service improvement strategies can not only focus on increasing the number of posts but also consider route optimization, traffic management for emergency vehicles, and placement of smaller posts for areas identified as difficult to reach.

- Identification of Districts with Gaps in Fire and Rescue Services

  Another important finding of this research is the identification of sub-districts that experience service gaps, namely the disparity between theoretical service coverage (the results of the buffer analysis) and operational service coverage (the results of the service area network analysis). This gap is a key indicator of potential vulnerability in an area, where coverage assumptions on paper do not match the reality of accessibility on the ground. Figures 2 and 3 show that the most significant gap was identified in the analysis with a distance parameter of 7.5 km. Buffer analysis at a radius of 7.5 km shows the result that all sub-districts in Surabaya City are fully covered. This result provides a geographical ideal, the placement of 21 fire stations is able to cover the entire city area according to the maximum distance standard set by the regulation.

  However, the picture changes drastically when the analysis is conducted using the service area method which takes into account the road network. This analysis reveals that there are 8 sub-districts whose status has decreased to 'partially affordable', namely

Asemrowo, Benowo, Dukuh Pakis, Gunung Anyar, Mulyorejo, Pakal, Rungkut, and Sukolilo. The identification of these sub-districts is very important because being partially reached (service area 7.5 km) implies that there are specific areas within the sub-district that cannot be reached by fire trucks within the 7.5 km distance limit. The potential causes of these gaps can be multifactorial such as geographical location where some of these sub-districts are located in urban fringe areas where road network connectivity is likely to be more limited than in city centers, road network topology where access limitations, dead ends, or circuitous routes can significantly increase actual travel distances despite short straight distances, and physical barriers such as rivers, toll roads, or railways. This finding confirms that road network-based evaluation is indispensable for strategic planning, as it can reveal vulnerable areas that are not detected by conventional radius-based analysis.

6. Conclusions

The conclusions of this research are;

- There is a significant gap between the theoretical and operational service coverage of fire brigades in Surabaya City where the service area network analysis proves that road infrastructure is the determinant that creates service gaps in 8 sub-districts, even though the geographical placement of 21 fire brigade posts is optimal.
- This research identifies eight specific sub-districts including Asemrowo, Benowo, Dukuh Pakis, Gunung Anyar, Mulyorejo, Pakal, Rungkut, and Sukolilo, as experiencing gaps in firefighting and rescue services because the 7.5 km service area network analysis proves the existence of real accessibility barriers that are not detected by conventional buffer analysis.

References

[1] Adil, A., & Triwijoyo, B. K. (2021). Sistem informasi geografis pemetaan jaringan irigasi dan embung di Lombok Tengah. Matrik: Jurnal Manajemen, Teknologi Informasi dan Rekayasa Komputer, 20(2), 273–282. https://doi.org/10.30812/matrik.v20i2.1112

[2] Alviana, K., Lumbantobing, L., Irsyad, A., & Ibrahim, M. R. (2023). Analisis buffer dalam sistem informasi geografis untuk pemilihan jarak terdekat pom bensin dari jangkauan gedung Fakultas Teknik Universitas Mulawarman. Kreativitas Teknologi dan Sistem Informasi, 1(2), 40–45.

[3] ArcGIS Pro documentation. (2025). Service area analysis layer—ArcGIS Pro | Documentation. ESRI.

[4] Darwis, H. (2021). Penggunaan bahan alami dalam produk rumah tangga ramah lingkungan. Jakarta: Pustaka Hijau.

[5] Ewaldo, K., & Naulibasa, G. V. (2022). Analisis penyebaran dan radius jangkauan fasilitas kesehatan di Kabupaten Way Kanan berbasis sistem informasi geografis. Jurnal Teknologi Sistem Informasi dan Aplikasi, 5(1), 30. https://doi.org/10.32493/jtsi.v5i1.15378

[6] Hashtarkhani, S., Schwartz, D. L., & Shaban Nejad, A. (2024). Enhancing health care accessibility and equity through a geoprocessing toolbox for spatial accessibility analysis: Development and case study. arXiv. https://doi.org/10.48550/arXiv.2403.05575

[7] Isnaini Salsabilah, I. (2023). Pemodelan network analysis terhadap keterjangkauan fasilitas puskesmas Kota Malang. Jurnal SOLMA, 12(2), 522–535. https://doi.org/10.22236/solma.v12i2.12119

[8] K.N., Silvany, S., & Supratikta, H. (2024). Dampak sistem informasi geografis (SIG) terhadap proses pengambilan keputusan pemasaran berbasis sebaran titik lokasi dalam menentukan nilai minimarket. Multidisciplinary Indonesian Central Journal, 1(3), 1230–1236.

[9] Kiparisov, P. O., & Lagutov, V. V. (2024). Integrated GIS and network-based framework for assessing urban critical infrastructure accessibility and resilience: The case of Hurricane Michael. arXiv. https://doi.org/10.48550/arXiv.2412.13728

[10] Nugraha, I. (n.d.). Pemetaan jalur evakuasi tsunami dengan metode network analysis (studi kasus: Kabupaten Lampung Selatan). (Belum dipublikasikan secara formal).

[11] Number Analytics. (2025, January). Mastering buffer analysis in geospatial analysis. Number Analytics Blog.

[12] Peraturan Menteri Pekerjaan Umum. (n.d.). Tentang Standar Pelayanan Minimum. [Peraturan resmi].

[13] Ridwan, V. F. (2021). Penerapan buffer analysis dalam bidang teknik sipil dan lingkungan. Jurnal Applied Civil and Environmental Engineering, 1(2), 61–66. https://doi.org/10.31963/jacee.v1i2.2998

[14] Rizal, S., & Syaibana, P. L. D. (2022). Analisis keterjangkauan dan pola persebaran SMA/MA negeri di Kabupaten Banyuwangi menggunakan analisis buffering dan nearest neighbor pada aplikasi Q-GIS. Techno.Com, 21(2), 355–363. https://doi.org/10.33633/tc.v21i2.5996

[15] Rose, D. A., Murthy, S., Brooks, J., & Bryant, J. (2017). The evolution of public health emergency management as a field of practice. American Journal of Public Health, 107(S2), S126–S133. https://doi.org/10.2105/AJPH.2017.303947

[16] Yao, Y., Zhang, Y., Yao, T., Wong, K., Tsou, J. Y., & Zhang, Y. (2021). A GIS-based system for spatial-temporal availability evaluation of the open spaces used as emergency shelters: The case of Victoria, British Columbia, Canada. ISPRS International Journal of Geo-Information, 10(2), 63. https://doi.org/10.3390/ijgi10020063

[17] Yunus, S., Falola, J. A., & Musa, I. (2023). Emergency response demand and supply: A GIS-based network analysis for fire station service coverage delineation in Kano metropolis, Nigeria. Geosfera Indonesia, 8(1), 61–82. https://doi.org/10.19184/geosi.v8i1.36694