A Geographic Information Systems-Based Analysis of Response Time and Hospital Coverage Area in Sukhothai Province, Thailand

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Abstract

In this study, Geographic Information Systems (GIS) were employed to analyze emergency medical services (EMS) coverage and response times in Sukhothai Province, Thailand. The primary objective was to evaluate the efficiency and reach of EMS in different districts, taking into consideration various response time scenarios. Utilizing ArcMap software, buffer zones were created around hospitals to represent EMS coverage areas based on distances corresponding to response times of 5, 8, 10, 15, 20, and 25 minutes. The research employs buffer zones to calculate coverage areas for response times ranging from 5 to 30 minutes, based on an average EMS speed of 40 kph. Findings reveal significant variations in EMS coverage, with densely populated areas generally well-served within a 20-minute response time, while remote and mountainous regions face substantial access challenges. Even at a 30-minute response time, 17.23% of the province remains uncovered, primarily in mountainous areas. The study highlights that no district achieves full coverage within a 10-minute response time, particularly in peripheral sub-districts. Analysis of district-level data exposes stark disparities, with smaller districts like Si Nakhon showing higher coverage percentages compared to larger, more challenging terrains such as Si Satchanalai. These results emphasize the need for targeted improvements in EMS infrastructure, resource allocation, and innovative solutions to ensure equitable access to emergency care across Sukhothai Province. The study provides valuable insights for policymakers and healthcare planners to optimize EMS deployment and enhance emergency response capabilities in the region.

Keywords: Coverage Area, Emergency Medical Services (EMS), Emergency Response Strategy, Healthcare Delivery, Response Time

1. Introduction

The emergency medical system was developed to minimize deaths, alleviate suffering from accidents, and reduce the costs associated with delays in patient care. It aims to prevent improper transportation and ensure that patients are directed to appropriate hospitals. For the public to benefit from this system, operators must provide timely assistance, thereby helping to prevent deaths and disabilities among emergency patients [1]. An effective emergency medical center requires adequate resources, including qualified personnel and facilities equipped for emergency treatment. Prompt care can be life-saving or prevent severe complications before patients reach the hospital. Emergency medical units operate 24/7, with a central reporting center that dispatches the appropriate team based on the situation to assist and transport patients to hospitals. This system, known as the Emergency Medical Service (EMS), is crucial for saving lives [2].

In Thailand, EMS units are present in every province, but their capabilities and effectiveness vary. Differences in operating systems, personnel, equipment, protocols, and management practices can impact service quality Response time in Emergency Medical Services (EMS) is a critical metric that measures the duration from when an emergency call is received to when EMS personnel arrive at the scene. Faster response times are crucial for improving patient outcomes, especially in time-sensitive emergencies such as cardiac arrests, strokes, or trauma. Quick arrival of EMS can significantly impact the effectiveness of medical interventions and increase the likelihood of survival and recovery.

Additionally, the Ministry of Public Health mandates that emergency medical services should reach the scene within 8 to 10 minutes, but some patients may not receive timely assistance. Statistically, the percentage of critically ill patients receiving emergency treatment at the scene within 8 minutes decreased from 49.76% in 2012 to 32.3% in 2022, but then increased slightly to 41.03% in 2023 [3].

The National Institute for Emergency Medicine (NIEM) was officially established in Thailand in 2008 under Section 14 of the National Emergency Medicine Act [4]. As a public organization, NIEM is tasked with managing and coordinating efforts between government and private agencies. Its primary mission is to reduce mortality and minimize medical costs associated with delays in providing initial care at the scene of emergencies. By improving the efficiency of first aid and subsequent transfer to hospitals, NIEM aims to address the increasing number of critically ill emergency patients and enhance overall emergency medical response. In Emergency Medical Services (EMS), response time is a critical metric that measures the efficiency and effectiveness of emergency response. It refers to the total duration from when an emergency call is received by the dispatch center to the moment the EMS team arrives at the scene of the incident. This timeframe typically includes [5]:

- Call Receipt Time: The moment the emergency call is answered by the dispatch center.
- Dispatch Time: The interval from when the call is received to when the appropriate EMS team is dispatched.
- Travel Time: The duration it takes for the EMS unit to reach the scene from the time it is dispatched.

Response time is a key indicator of the quality of emergency medical services, as it directly impacts the outcomes of emergency care. Faster response times are crucial for timely intervention, which can significantly affect patient survival rates and recovery, especially in life-threatening situations. Reducing response times is a major goal for EMS systems to improve patient outcomes and overall service efficiency [6]. In recent years, the optimization of healthcare services has become a pivotal concern for regional development, particularly in underserved and remote areas. Geographic Information Systems (GIS) offer a powerful toolset for analyzing spatial data, enabling detailed assessments of healthcare accessibility and response times [7] and [8]. This study focuses on Sukhothai Province, Thailand, a region where healthcare coverage and response times are critical for improving public health outcomes.

Sukhothai Province, located in northern Thailand, is characterized by a diverse topography that ranges from mountainous regions to flat plains. This geographical variability poses unique challenges for healthcare service delivery, including issues related to hospital accessibility and emergency response efficiency. Despite significant advances in healthcare infrastructure, disparities in service availability and response times persist, impacting the quality of care received by residents. The objective of this research is to utilize GIS-based analysis to assess the spatial distribution of hospitals and evaluate their coverage areas in relation to emergency response times within Sukhothai Province. By mapping the locations of healthcare facilities and analyzing their service areas, we aim to identify gaps in coverage and areas where response times are suboptimal. This analysis seeks to provide actionable insights that can inform policy decisions and improve healthcare delivery strategies in the province.

This research emphasizes the critical importance of timely access to incident areas for providing emergency medical services. To address this, Geographic Information Systems (GIS) are utilized to analyze the coverage area of emergency medical services in Sukhothai Province. The analysis is conducted based on the response time requirements set by the EMS Office. By employing GIS, the study aims to clearly delineate service areas, enhancing both access and effectiveness in delivering life-saving care to patients. Through this study, we hope to contribute to a more nuanced understanding of the spatial dynamics of healthcare access in Sukhothai, ultimately supporting efforts to enhance the efficiency and effectiveness of healthcare services in the region.

2. Study Area

Sukhothai Province, located in northern Thailand at the latitudes of 16°40′N to 17°50′N and, the longitudes of 95°18′E to 100°12′E as illustrates in Figure 1(a), bordered by Phitsanulok to the east, Kamphaeng Phet to the west, Tak to the north, and Uttaradit to the south [9]. The province has the total area of 6,596 sq.km. and divided into 9 districts as depicts in Figure 1(a) with the total population of approximately 700,000 people [10]. Sukhothai's demographic distribution varies from dense urban areas around Sukhothai city to more sparsely populated rural regions. The population numbers of each district in the province depicts in Figure 1(b). Each district has a hospital located within its boundaries, with the hospital's name corresponding to the district's name.

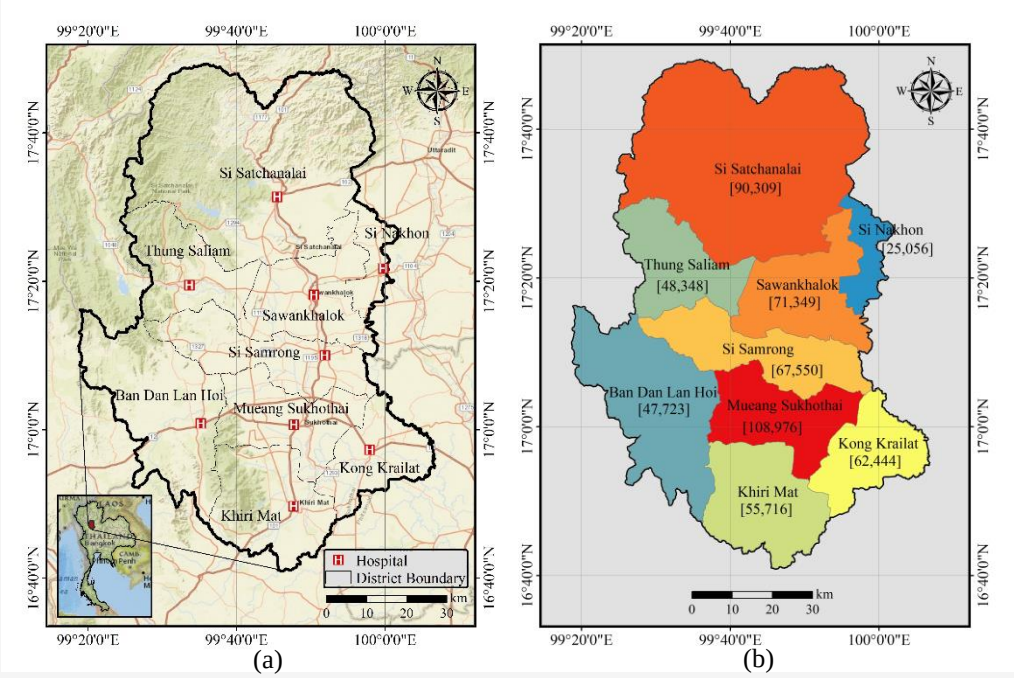

Figure 1: Sukhothai province, Thailand (a) Geographic location (b) Population numbers

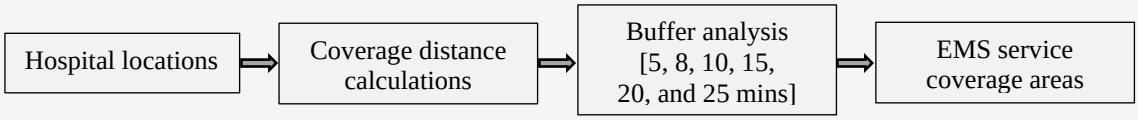

Figure 2: EMS service coverage area analysis

Table 1: Relation between response time and distance at an average speed of 40 kph

Time (mins)	5	8	10	15	20	25	30
Distance (km)	3.33	5.33	6.67	10.00	13.33	16.67	20.00

3. Methodology

To assess hospital coverage areas and response times in Sukhothai Province, this study employs Geographic Information Systems (GIS) to provide a comprehensive spatial analysis. The study work flow presents in Figure 2. The methodology involves mapping the locations of the hospitals across the province. The locations were acquired from Google map available at *https://google.com/maps*. The coverage area is determined from Equation 1:

$$d = \frac{v}{t}$$

Equation 1

Where: d = distance that corresponding to response time (km)
v = average velocity of EMS service (km/min)
t = response time (min)

The maximum speed for EMS services in Thailand is limited to 80 kph [11]. However, this speed cannot be consistently maintained due to factors such as traffic, road conditions, and turning points. Consequently, an average speed of 40 kph (0.667 km/min) was used in this study. The relationship between distance and response time is shown in Table 1.

The distances in Table 1 were used to determine the coverage area radiating from each hospital in the study area. The analysis utilized the buffer geoprocessing tool in ArcMap software to calculate these coverage areas from the buffered zones. The buffer tool in Geographic Information Systems (GIS) is a powerful spatial analysis tool used to create a zone of a specified distance around a geographic feature, such as a point, line, or polygon. This zone, or buffer, represents the area within a certain distance from the feature and is useful for analyzing proximity and accessibility [12]. The application in coverage area determination of the Buffer Tool are as follows:

- Distance Measurement: The buffer tool allows users to define a specific distance around a feature. For example, if a hospital is the feature, a buffer of 5 kilometers can be created to show the area within 5 kilometers of that hospital.
- Zone Creation: The tool generates a new layer in the GIS with the buffered zone. This zone is essentially a polygon that outlines the area around the original feature, which can be adjusted for various distances depending on the analysis needs [13].
- Healthcare Facility Analysis: In the context of analyzing hospital coverage areas, the buffer tool can be used to visualize and measure the reach of healthcare facilities. For instance, by creating buffers around each hospital with a radius corresponding to response time targets (e.g., 8 minutes or 10 minutes), analysts can determine the geographic extent within which emergency medical services should ideally reach patients.
- Service Area Mapping: Buffers help in mapping the service areas of hospitals, enabling the identification of regions that fall within or outside these areas. This is crucial for understanding coverage gaps and ensuring that all regions, especially underserved or remote areas, have adequate access to emergency medical services [14].
- Accessibility Analysis [15]: By overlaying multiple buffers for different hospitals, GIS can show the cumulative coverage and highlight areas where services overlap or where there is a lack of coverage. This helps in evaluating the effectiveness of the current service distribution and planning improvements.
- Response Time Assessment: Buffers can also be used to assess response times. By creating buffers around emergency service units or hospitals based on the average travel time, analysts can visualize which areas are covered within the acceptable response time and identify any regions that may require additional resources or adjustments in service delivery.

In summary, the buffer tool in GIS is essential for determining and visualizing coverage areas around key facilities, such as hospitals. It provides valuable insights into spatial accessibility and helps in planning and optimizing emergency medical services to ensure timely and effective care for all regions. This approach allows for a detailed understanding of the accessibility and efficiency of emergency care, supporting targeted improvements and strategic planning.

4. Results and Discussion

The coverage areas of each hospital within the study area were calculated using the buffer zones illustrated in Figure 2. The figure shows that EMS coverage areas for response times of 5, 8, and 10 minutes encompass the areas surrounding each hospital within their respective districts. However, the entire district is not covered by the 10-minute response time, as depicted in Figure 2(a) to Figure 2(c). For a response time of 15 minutes (10 km radius), the overlapping EMS coverage areas are primarily on the eastern side of the province. Three districts—Sai Satchanalai, Thung Saliam, and Ban Dan Lan Hoi—do not overlap with the other six districts in Sukhothai province (Figure 2(d)). At a 20-minute response time (13.33 km radius), all EMS coverage areas are interconnected, except for Thung Saliam hospital (Figure 2(e)). By a 25-minute response time, the EMS coverage areas of each hospital overlap, as shown in Figures 2(f) and 2(g). Detailed EMS coverage areas for the corresponding response times and distances are presented in Table 2.

Access to the incident area for emergency medical services (EMS), as specified by the Ministry of Public Health, should be within 8 to 10 minutes, with a maximum coverage distance of approximately 10 km. This distance is based on the allowable maximum speed of EMS, which is 80 kph. However, maintaining this speed consistently is challenging due to factors such as road conditions, traffic, weather, topography, driver skill and behavior, vehicle load, route efficiency, and altitude. Previous studies indicate that the average speed of EMS in urban areas is approximately 34 kph. Consequently, an average speed of 40 kph was used to determine the EMS coverage area. Table 2 presents the EMS (Emergency Medical Services) coverage areas corresponding to various response times and distances.

The data reveals a direct relationship between response time and coverage area. Specifically, with a response time of 5 minutes, EMS services cover an area of 302.77 square kilometers, which constitutes 4.59% of the total area. As the response time increases to 8 minutes, the coverage area expands to 765.28 square kilometers, or 11.60% of the region. At a 10-minute response time, the EMS can cover 1,194.83 square kilometers, accounting for 18.11% of the total area.

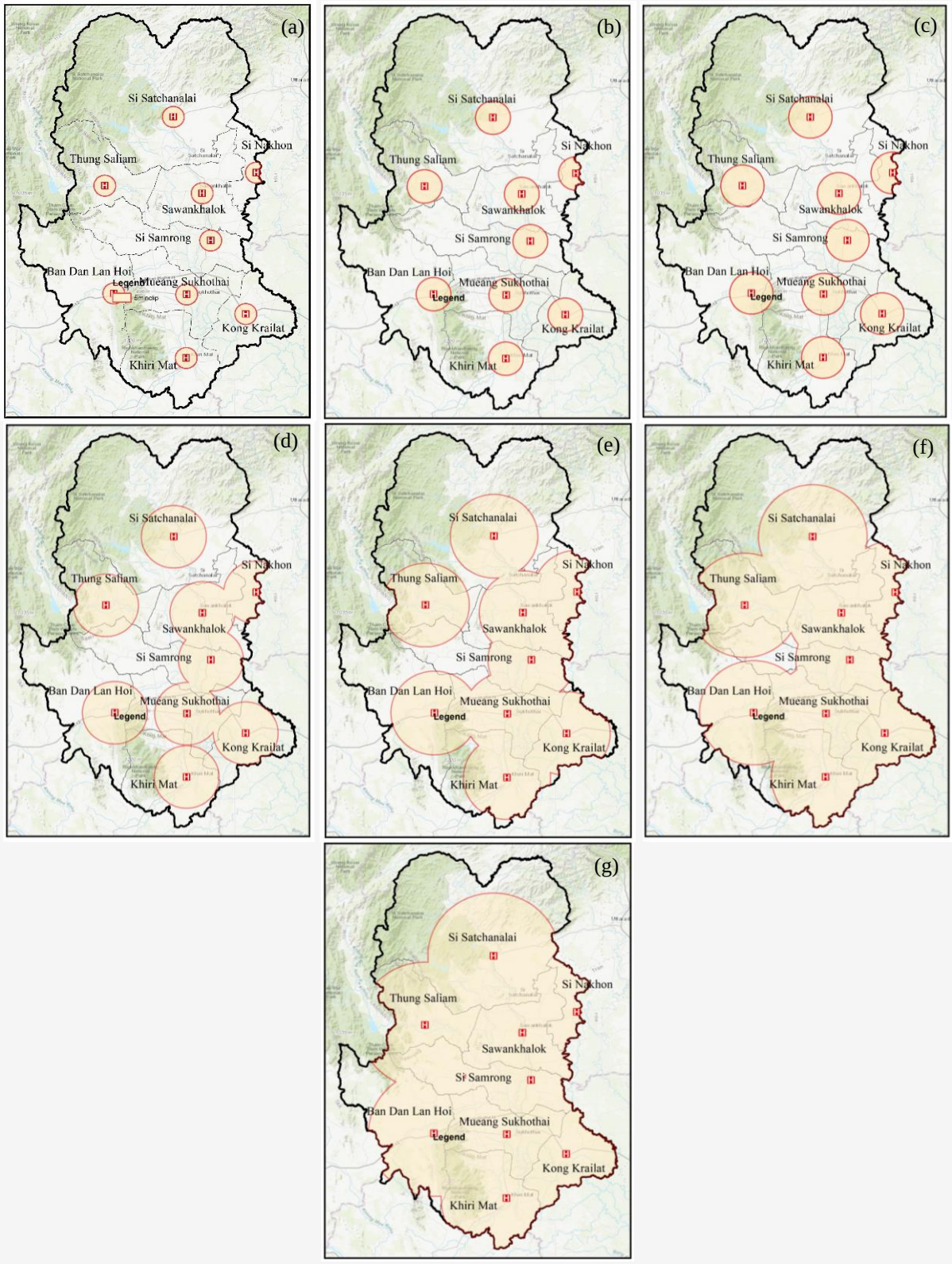

Figure 2: EMS coverage areas determined from response time: (a) 5 minutes (b) 8 minutes (c) 10 minutes (d) 15 minutes (e) 20 minutes (f) 25 minutes and (g) 30 minutes

Table 2: EMS coverage areas for the corresponding response times and distances

No.	Response time (min)	EMS distance (km)	EMS coverage area [sq.km]	Percentage of EMS coverage area [%]
1	5	3.33	302.77	4.59
2	8	5.33	765.28	11.60
3	10	6.67	1,194.83	18.11
4	15	10.00	2,611.72	39.60
5	20	13.33	3,941.28	59.75
6	25	16.67	4,912.18	74.47
7	30	20.00	5,459.38	82.77

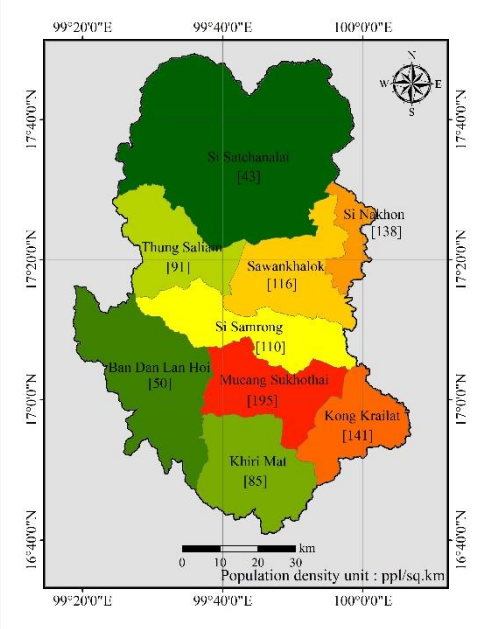

Figure 3: Population density by district in Sukhothai province

However, it becomes evident that a response time of 10 minutes is insufficient to provide coverage throughout the individual districts within the study area. A significantly larger portion of the area, 82.77%, is covered when the response time is extended to 30 minutes, corresponding to 5,459.38 square kilometers. Despite this extensive coverage, certain mountainous regions in the northern and eastern parts of the province, particularly in Si Satchanalai and Ban Dan Lan Hoi districts, remain outside the reach of EMS services. This indicates that topographical challenges and the distribution of EMS resources limit the effectiveness of emergency response in these areas. The diminishing marginal increase in coverage area percentage as response times extend suggests that while longer response times allow for greater coverage, the benefits reduce as the area approaches full coverage. This highlights the importance of balancing response times with practical resource allocation to optimize EMS efficiency and effectiveness.

Figure 3 highlights that high population density areas in Sukhothai Province include Mueang Sukhothai, Kong Krailat, Si Nakhon, Sawankholok, and Si Samrong districts, with population densities of 195, 141, 138, 116, and 110 people per square kilometer, respectively. These densely populated areas are covered within a 20-minute response time, as shown in Figure 2(e). As previously noted, this study uses an average speed of 40 kph, however, increasing the average speed would reduce the response time in these densely populated areas to less than 20 minutes. The coverage areas for 5, 8, and 10 minutes shown in Figures 2(a) to 2(c) are too small and lack detail. To better illustrate the coverage areas for these response times, detailed maps of EMS coverage for each district are provided in Figure 4. Figure 4 shows the EMS coverage areas for 5, 8, and 10-minute response times across all 9 districts in Sukhothai Province. It is evident that hospitals are strategically located within the city and near major roads.

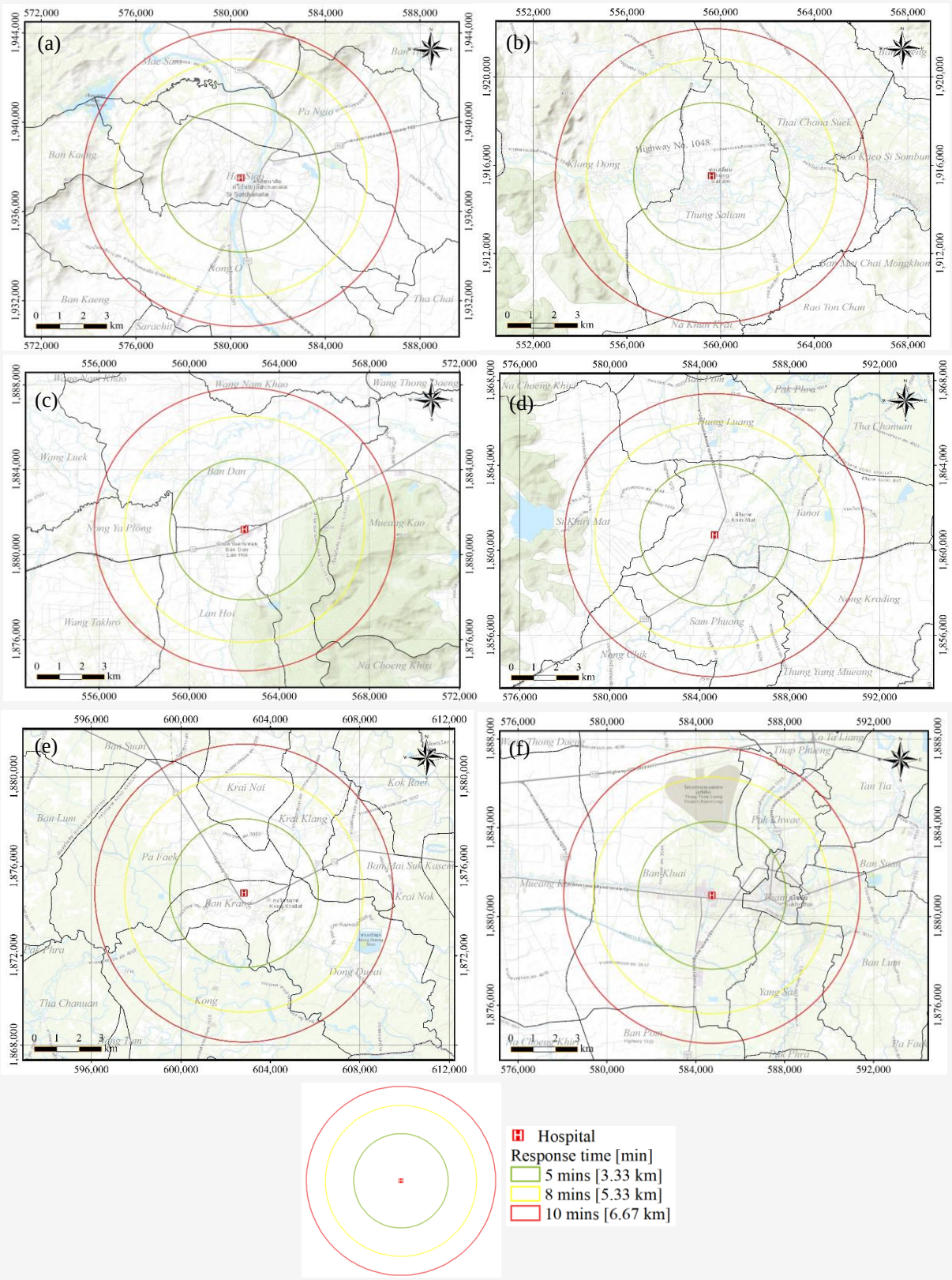

Figure 4: EMS coverage areas determined from response time of 5, 8, and 10 minutes, (a) Si Satchanalai (b) Thung Saliam (c) Ban Dan Lan Hoi (d) Khiri Mat, (e) Kong Krailat, (f) Mueang Sukhothai
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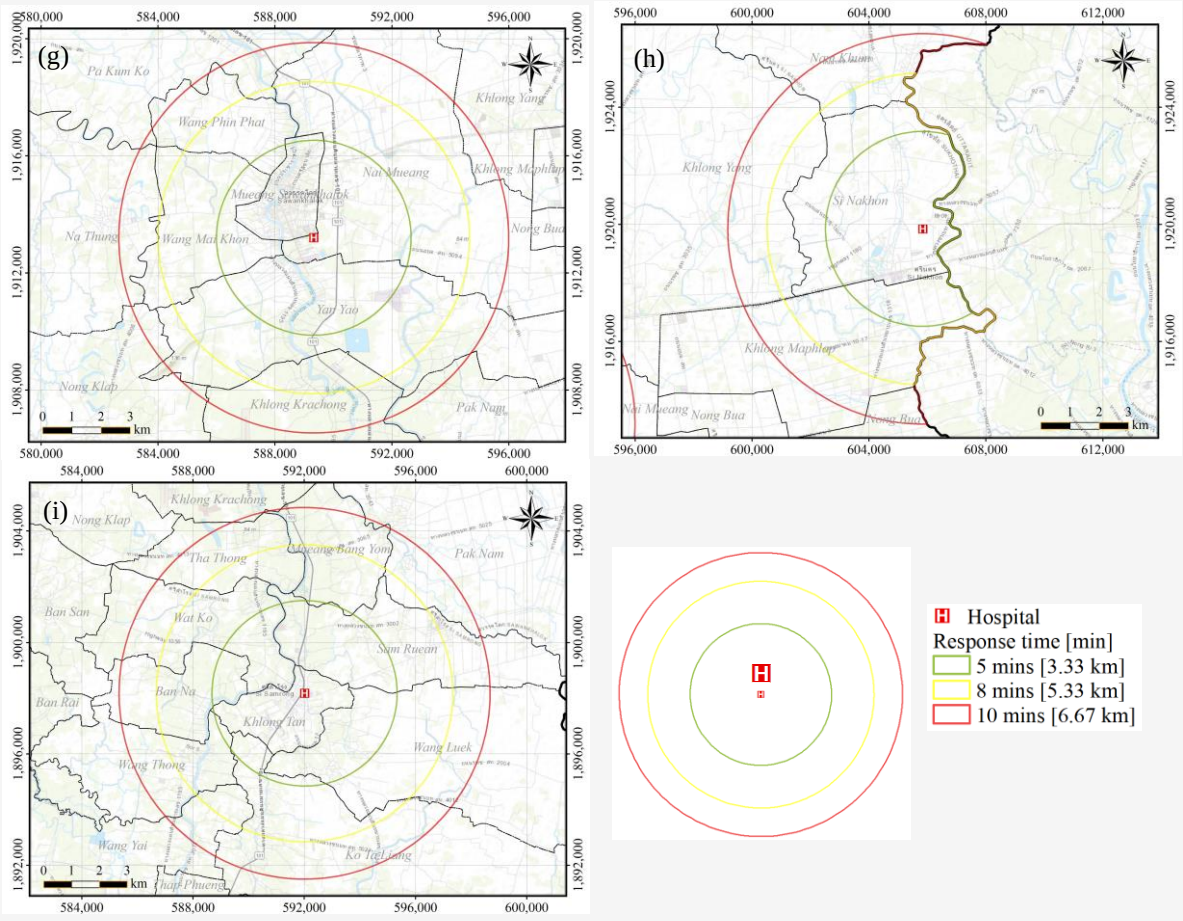

Figure 4: EMS coverage areas determined from response time of 5, 8, and 10 minutes (g) Sawankhalok (h) Si Nakhon (i) Si Samrong (Continue from previous page)

Additionally, some hospitals, such as Ban Dan Lan Hoi, Kong Krailat, and Mueang Sukhothai, are situated along Highway 12, while Khiri Mat and Si Samrong hospitals are located along National Highway 101. Consequently, the coverage distances are likely to increase with higher average ambulance speeds. The response time coverage areas vary by district in Sukhothai Province. Some districts benefit from shorter response times, providing faster EMS access, while others, particularly those with challenging terrain or located farther from emergency facilities, experience longer response times. In districts with shorter response times, EMS coverage is more comprehensive, ensuring that a greater percentage of the population can receive timely emergency care. Conversely, in districts with longer response times, particularly in the mountainous regions such as Si Satchanalai, Thung Saliam, and Ban Dan Lan Hoi, EMS coverage is less extensive, potentially delaying access to emergency services. This disparity highlights the need for targeted improvements in EMS infrastructure and resource allocation to ensure more equitable access to emergency care across the province. The figure also reveals that no district is fully covered within a 10-minute response time, particularly in sub-districts that are far from the central city area (Nai Muaeng). The response time coverage area for each district is detailed in Table 3. Table 3 presents the Emergency Medical Services (EMS) coverage areas, measured as a percentage of the total district area, for various response times (5, 8, and 10 minutes) across nine districts in Sukhothai Province. The total area of each district is also provided, offering insight into the extent of EMS reach relative to the geographical size of the districts.

The data reveal significant disparities in EMS coverage across different districts. For example, Si Nakhon, despite being one of the smaller districts by area (181.71 sq.km), demonstrates the highest percentage of coverage at all response times: 4.80% for a 5-minute response, 12.29% for an 8-minute response, and 19.21% for a 10-minute response.

Table 3: Response time coverage areas by districts in Sukhothai province

No	District	Total Area [sq.km]	EMS Coverage area [%]		
			5 min	8 min	10 min
1	Mueang Sukhothai	557.57	1.57	4.01	6.26
2	Ban Dan Lan Hoi	957.53	0.91	2.33	3.65
3	Khiri Mat	657.83	1.33	3.40	5.31
4	Kong Krailat	442.32	1.97	5.05	7.89
5	Si Satchanalai	2,116.63	0.41	1.06	1.65
6	Si Samrong	612.46	1.42	3.65	5.70
7	Sawankhalok	617.22	1.41	3.62	5.66
8	Si Nakhon	181.71	4.80	12.29	19.21
9	Thung Saliam	532.57	1.64	4.19	6.55

This suggests that EMS services in Si Nakhon are particularly efficient, likely due to favorable infrastructure or proximity to EMS facilities. Conversely, larger districts such as Si Satchanalai, with a total area of 2,116.63 sq.km, show much lower EMS coverage percentages, with only 0.41%, 1.06%, and 1.65% for 5, 8, and 10-minute response times, respectively. This indicates significant challenges in providing timely EMS access, possibly due to the district's large area and the presence of difficult terrain, which is known to hinder rapid emergency response.

The differences in EMS coverage percentages can be attributed to several factors, including geographical challenges, infrastructure availability, and the distribution of EMS resources. For instance, Ban Dan Lan Hoi, with a relatively large area of 957.53 sq.km, also exhibits low coverage percentages of 0.91%, 2.33%, and 3.65% for the respective response times. These figures highlight the limitations faced in reaching remote or less accessible regions, where mountainous terrain and sparse road networks may impede the speed and efficiency of EMS response. The variations in EMS coverage underscore the need for a strategic allocation of EMS resources. Districts like Si Nakhon, with high coverage despite a smaller total area, could serve as models for optimizing EMS deployment strategies. On the other hand, districts with extensive areas and low coverage percentages, such as Si Satchanalai and Ban Dan Lan Hoi, may require additional EMS units, improved road networks, or the establishment of new EMS stations to enhance coverage and reduce response times.

In summary, Table 3 illustrates the uneven distribution of EMS coverage across the districts of Sukhothai Province, highlighting the challenges and limitations faced in ensuring equitable emergency medical care. The data suggest a pressing need for targeted improvements in EMS infrastructure, particularly in larger and more geographically challenging districts. By addressing these disparities, it is possible to improve emergency response times and ensure that all residents of Sukhothai Province have access to timely medical assistance.

5. Conclusion

This study analyzed Emergency Medical Services (EMS) coverage areas in Sukhothai Province, Thailand, using various response times and distances. The findings reveal significant disparities in EMS coverage across the province's nine districts. While densely populated areas such as Mueang Sukhothai, Kong Krailat, and Si Nakhon are generally well-served within a 20-minute response time, more remote and mountainous regions face considerable challenges in accessing timely emergency care. The analysis shows that even with a 30-minute response time, which covers 82.77% of the total area, certain mountainous regions in Si Satchanalai and Ban Dan Lan Hoi districts remain unreached. This highlights the impact of geographical factors and resource distribution on EMS effectiveness. The study also demonstrates that no district achieves full coverage within a 10-minute response time, particularly in sub-districts far from central city areas.

These findings underscore the need for strategic improvements in EMS infrastructure and resource allocation. To enhance emergency care access across Sukhothai Province, policymakers should consider:

- Establishing additional EMS stations in underserved areas
- Improving road networks in challenging terrains
- Optimizing the distribution of EMS resources based on population density and geographical constraints
- Exploring alternative solutions for hard-to-reach areas, such as air ambulance services

By addressing these disparities, Sukhothai Province can work towards ensuring more equitable and timely access to emergency medical services for all its residents, ultimately improving health outcomes and emergency response capabilities.

6. Limitations

The study's limitations primarily stem from the reliance on GIS-based analysis, which, while robust, cannot account for all real-world variables affecting EMS response times, such as traffic conditions, road quality, and weather events. Additionally, the static nature of the coverage area maps does not reflect potential changes in population density, road infrastructure, or EMS resource availability over time. The study also assumes optimal EMS operation without considering possible operational inefficiencies or delays. Future research could benefit from integrating dynamic data and real-time analytics to provide a more comprehensive assessment of EMS effectiveness. Furthermore, the scope is limited to Sukhothai Province, and the findings may not be directly applicable to other regions with different geographic or socio-economic characteristics.

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