A Geospatial Analysis of Motorcycle Accident Risk Factors in Khon Kaen Municipality, Thailand: Examining the Chain of Survival and Potential Strategies

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DOI: https://doi.org/10.52939/ijg.v20i9.3547

Abstract
The study utilizes a geospatial approach to analyze the risk of motorcycle accidents in Khon Kaen Municipality, Thailand. We focus on identifying high-crash areas involving motorcyclists and investigating factors contributing to the severity of accidents and potential survival rates. The analysis is framed within the "Chain of Survival" framework, specifically focusing on how the location of ambulance stations affects the Emergency Medical Service (EMS) response times. Additionally, we explore various traffic management strategies, with an emphasis on their effectiveness in reducing nighttime accidents. The primary goal of this research is to gain a comprehensive understanding of the spatial distribution of motorcycle accidents and to identify key factors influencing their outcomes. Our findings reveal that motorcycle accidents constitute the highest number of traffic accidents in the area, with a significant proportion occurring in the southwest of Khon Kaen Municipality during late night hours. Given the importance of early intervention within the EMS, we suggest locating EMS stations close to areas with a high incidence of accidents concerning the effective response time, as recommended at two specific points. However, due to limitations in the number of EMS teams available, these recommended points may experience delays in response times, particularly during late-night hours when traffic accidents peak. Ultimately, the insights gained from this study will inform data-driven recommendations aimed at optimizing both emergency response systems and traffic management strategies to enhance road safety in Khon Kaen Municipality.

Keywords: Ambulance Response Times, Chain of Survival, Geospatial Analysis, Motorcycle Accidents

1. Introduction

Traffic accidents are a significant global public health concern, with fatalities rising from 1.25 million in 2013 to 1.35 million in 2016, as reported by the World Health Organization in 2018 [1]. These accidents result in an estimated 50 million injuries and nearly 3,700 deaths annually, with developing and middle-income countries disproportionately affected [1] and [2]. Thailand, a middle-income nation in Southeast Asia, reflects this troubling trend. The country has experienced a sharp increase in private vehicles on the road, leading to negative economic impacts and loss of life, with motorcycle accidents being the most common type of fatal traffic incident [2] and [3]. Notably, motorcycles account for over 50% of all vehicles in Thailand, with their numbers increasing by 8% over the past eight years, according to data from the Department of Land Transport [4]. This growth aligns with the grim reality that 80% of traffic fatalities in Thailand involve motorcyclists, based on recent accident statistics [5]. Emergency Medical Services (EMS) are essential components of healthcare, playing a crucial role in saving lives and reducing both mortality and morbidity rates.

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) |

Across Asia, the development of EMS systems varies widely, resulting in significant disparities in prehospital care models and system coverage at both regional and national levels [6].

In Thailand, the EMS system has been evolving since 1989, with a pilot project for prehospital care launched in 1995, followed by the expansion of services to hospitals nationwide [7]. The Thai EMS system operates on a two-tiered ambulance model: Advanced Life Support (ALS) is provided by hospital-based ambulances, equipped with personnel skilled in advanced medical procedures, while Basic Life Support (BLS) is offered by non-public health sector organizations, capable of delivering basic emergency care with a larger team compared to ALS. Despite these advancements, a significant number of Out-of-Hospital Cardiac Arrest (OHCA) patients still arrive at hospitals using Non-EMS vehicles—a scenario commonly seen in other middle- income countries [8]. This reliance on alternative transportation methods can result in treatment delays and suboptimal outcomes. Improving access to EMS system is a significant challenge for healthcare planners. Due to the sudden and unpredictable nature of severe injuries, it is crucial to design systems that serve the entire population, as trauma can occur to anyone at any time with little or no warning. The "chain of survival" in EMS is essential for increasing survival rates. In Khon Kaen, an effective EMS system depends on a well-coordinated "chain of survival" to optimize patient outcomes. This sequential framework consists of six critical, time-sensitive steps, described as follows:

- Early detection: Prompt recognition of emergency symptoms by bystanders is crucial, and education programs for bystanders can greatly improve early detection rates.
- Early notification: Rapid activation of the EMS system through accurate use of emergency contact information (e.g., 1669) is essential. Detailed and precise reporting by bystanders enables dispatchers to allocate the most appropriate response team.
- Early response: Quick deployment of EMS providers to the scene is critical. Ideally, the “response time”—the interval between dispatch and arrival at the scene—should be under 8 minutes, as demonstrated in a 2015 study [9].
- Early on-scene care: Upon arrival, healthcare providers must swiftly assess and simultaneously treat life-threatening conditions. Minimizing “on-scene time”—the duration from arrival to departure—is particularly important for trauma patients. The “platinum 10” principle stresses the importance of limiting on-scene time to 10 minutes or less for critically injured patients who require specialized care at specific facilities. Additionally, the “golden hour,” which refers to the first hour after a traumatic injury, is considered vital for improving survival rates [10].
- Early transport: Efficient transport of patients to appropriate healthcare facilities is crucial. “Transport time”—the duration from scene departure to hospital arrival—should be minimized while ensuring continuous reassessment and adjustment of care during transit.
- Definitive care: The final link in the chain of survival is the delivery of patients to facilities equipped with specialized resources, such as advanced equipment, skilled personnel, and expertise, necessary for effectively managing critical conditions.

This study leverages Geographic Information System (GIS) technology to investigate traffic accident patterns involving motorcyclists engaged in risky behavior, focusing on the spatial distribution of these incidents within Khon Kaen Municipality, Thailand. By adopting a geospatial approach, the research enables continuous monitoring and provides comprehensive spatiotemporal data, pinpointing areas with high injury rates. Furthermore, it integrates geospatial analysis with the "chain of survival" framework, particularly in identifying the optimized EMS vehicle parking and station locations to reduce response times.

2. Study Area

In 2020, data from the Thai Road Accidents Data Center for Road Safety Culture (Thai RSC) reported 659,314 traffic injuries and 11,160 deaths nationwide [11]. Notably, Khon Kaen Municipality, located in northeastern Thailand (Figure 1), ranks 14th nationally in traffic accidents and holds the top spot within Khon Kaen Province. This municipality has a unique advantage for geospatial analysis due to a consistent geocoding system implemented over the past 20 years. As the fourth-largest city in Thailand, Khon Kaen Municipality has a population of 412,758 [12].

3. Data and Methodology

This study implemented the geospatial analysis of motorcycle accident risk factors in Khon Kaen Municipality, Thailand, as shown in Figure 2.

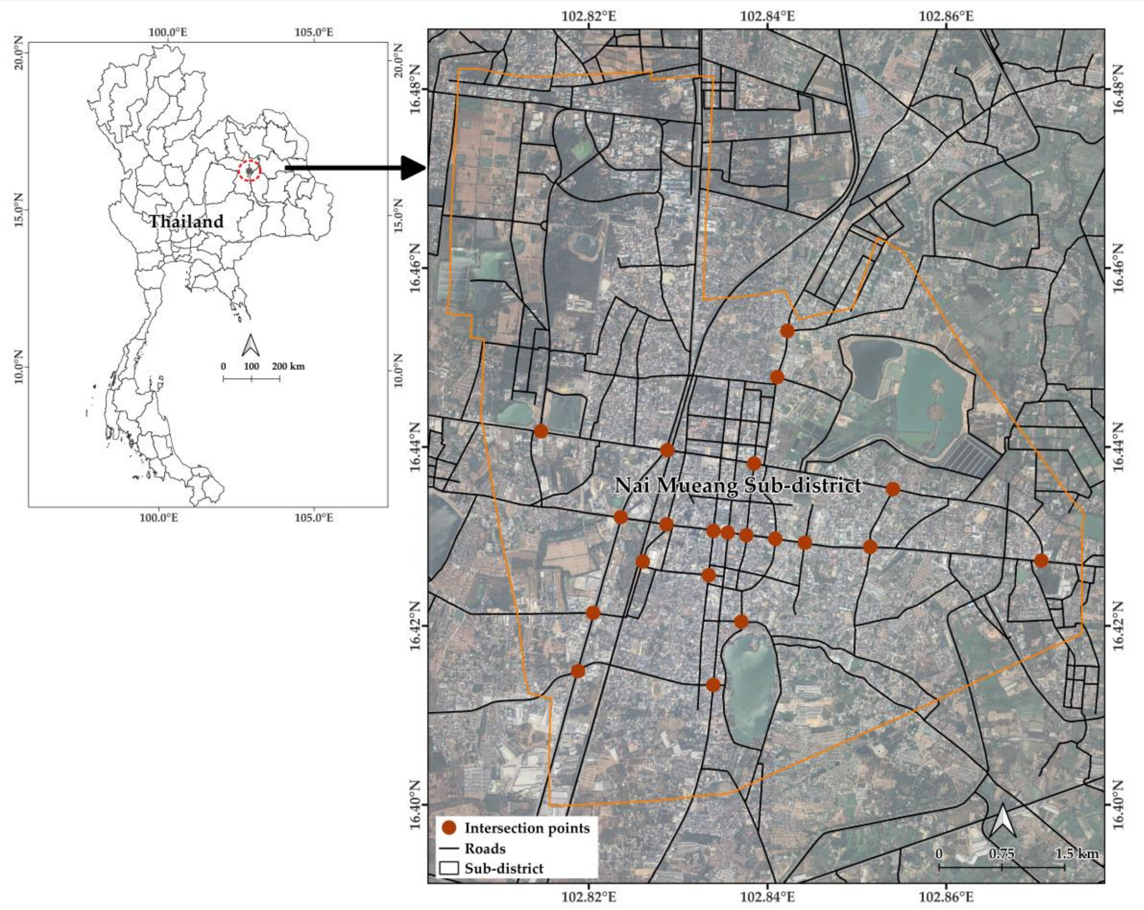

Figure 1: Study area in Khon Kaen Municipality; Khon Kaen Province, Thailand

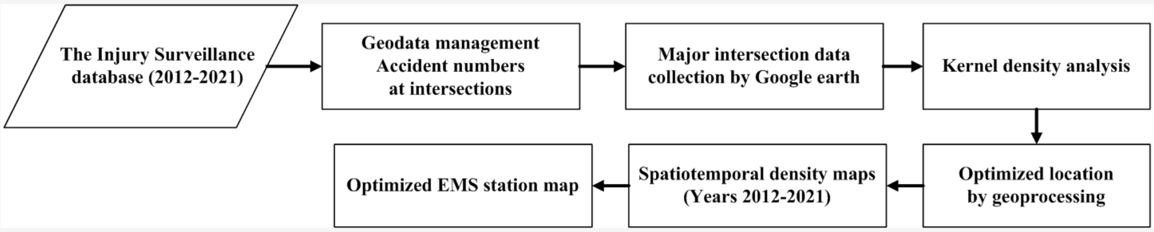

Figure 2: Implemented diagram for geospatial analysis of motorcycle accident risk factors

3.1 Data Used

The current research employs a cross-sectional analysis. Using geocoding data sources, geo datasets for the top ten motorcycle accident locations each year were collected between January 2012 and December 2021. Statistics on motorcycle injuries were gathered and linked from the Injury Surveillance database. The data collection process was approved by Khon Kaen Hospital (No. 66045) and the Mahasarakham University Ethical Review Committee for Human Research (No. 207-234/2566), under the guidelines of the Declaration of Helsinki.

3.2 Methodology

3.2.1 Data preparation

This research included data management for each of the ten core years under study. The statistical information encompassed a wide range of factors, including crash sites, demographics, driver and passenger positioning, alcohol and helmet use, accident times, and medical facility outcomes. Using this dataset, the geographic concentrations of motorcyclist injuries in the research area were mapped.

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The geospatial dataset used in this study consists of the coordinates (X, Y) of the top ten motorcycle accident locations, along with their associated accident risk factors. These data were processed and converted into a usable dataset using QGIS software version 3.30. The map projection employed was WGS 1984 zone 48N, and accident risks were defined as weights assigned to each location. This dataset was crucial for mapping accident densities across various periods in the study.

3.2.2 Kernel Density Function

The Kernel Density Function [13] and [14] was used to create spatial density maps for injuries sustained by motorcyclists. This function calculates the concentration of data points within a given dataset. We generated the spatial distribution of injury density maps, which were calculated using Equation 1 [13].

$$Density = \frac{1}{radius^2}\sum_{i=1}^{n}\left[\frac{3}{\pi}p_i\left(1-\left(\frac{d_i}{radius}\right)^2\right)^2\right]$$

Equation 1

Where:

$i = 1,\ldots,n$ are the numbers of points in each time step (each year)

p_i is number of injuries (each year)

d_i is the distance between point i to n.

In this study, the weight assigned was the number of injuries recorded each year. Density evaluation was conducted using the Kernel Density Function in QGIS software version 3.30, applied to geospatial datasets that included accident sites and their associated injury rates. The resulting maps illustrated the spatial distribution of accident density and identified high-risk crash zones at various levels. Additionally, this geospatial study divided injury rates into six time periods to assess spatiotemporal accident trends and density variations. The average number of accidents over nine years was used as the weight for density analysis.

3.2.3 Optimized location mapping

The identifying optimized location of EMS vehicle parking was analyzed and mapped using the geoprocessing tool in ArcGIS software, focusing on proximity to injury points. The analysis involved buffering the EMS services region, encompassing all major accessible intersection points. This work created buffer polygons with a distance of 1,250 m around the available EMS stations. In this study, we considered the maximum time within 15 minutes to reach an accident site. This approach ensures that EMS resources are optimally distributed to respond effectively to emergency situations.

4. Results and Discussion

4.1 Demographic Data

The findings are detailed in Table 1, which comprehensively reviews the demographic factors involved in motorcycle crashes, including gender, age, vehicle type, risk factors and time of day. As shown in Table 1, motorcyclists have the highest injury rate, accounting for 95.32% of all vehicle-related injuries. This high rate is due to the widespread use of motorcycles as both public and private transportation. Over the past decade, motorcycles have grown increasingly popular due to their ability to navigate poor road conditions and congested traffic more effectively than larger vehicles. Even when adjusted for distance traveled, the fatality rate for motorcyclists and their passengers is approximately 35 times higher than that of other motor vehicle types [15]. Each year, the frequency of motorcyclist injuries among men steadily increases for 60.76% compared to women, a trend consistent with patterns observed in other regions. Male riders are more likely to engage in risky driving behaviors, such as aggressive driving and speeding, compared to female riders [16] and [17]. The demographic data indicates a higher risk for individuals aged 21 to 30, as this age group experiences a greater incidence of accidents (37.83%).

These incidents are strongly associated with specific demographics, particularly males under 35 involved in single-vehicle collisions [18]. This confirmed that gender and mobility are closely intertwined, with a complex relationship that highlights significant differences in the travel habits of men and women. Generally, women travel shorter distances daily compared to men, largely because women tend to make more trips on urban roads, while men are more likely to travel on rural roads. Women's mobility is often concentrated around the home, in contrast to men's broader range of movement [19]. This difference impacts their choice of transportation modes; women are more likely to use sustainable options like public transport and walking, whereas men are more inclined to rely on private vehicles [20]. Therefore, the analysis of the rate ratio (Rate men/Rate women), regardless of age, shows that men always have a higher risk of serious and fatal injuries in all modes of transport and road types [21]. The data revealed that drivers sustained more injuries than passengers, accounting for 86.02% of all injuries. This finding aligns with previous results observed across all vehicle-related injuries prior to the spatial analysis [22].

Table 1: Demographic profiles of intersection-motorcyclist injuries in Khon Kaen Municipality for all ten based years

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total (%)
Type of vehicles											
Motorcycles	221	198	201	142	154	205	357	155	153	151	3012 (95.32)
Other 2-3	1	2	1	3	1	0	0	0	1	8	20 (0.63)
wheels	7	3	3	2	4	0	9	3	5	2	70 (2.22)
Pic up truck	1	4	2	4	3	8	3	2	5	2	59 (1.87)
Sedan	0	4	0	6	2	2	2	0	3	0	19 (0.60)
Gender: Male	140	121	119	87	92	122	203	98	103	93	1,830 (60.76)
Female	81	77	82	55	62	83	154	57	50	58	1,182 (39.24)
Age: 0-10	2	1	1	0	2	3	4	2	1	1	27 (0.92)
11-20	79	68	61	47	59	57	111	31	48	47	974 (33.16)
21-30	77	70	75	51	47	78	130	66	60	57	1,111 (37.83)
31-40	29	35	33	22	26	29	40	25	19	16	430 (14.64)
41-50	19	9	11	10	11	17	41	17	9	15	235 (8.00)
51-60	9	8	12	6	5	15	19	8	9	10	153 (5.21)
60+	1	0	0	0	0	2	0	1	2	0	7 (0.24)
Motorcyclists	221	198	201	142	154	205	357	155	153	151	3,012 (100.00)
Drivers	190	165	172	123	136	182	315	128	140	135	2,591 (86.02)
Passenger	31	32	29	17	18	23	42	27	13	15	416 (13.81)
Helmet: No	106	83	91	62	55	82	132	69	68	62	1,334 (44.69)
Yes	109	114	108	79	99	123	222	85	85	86	1,651 (55.31)
Alcohol: Yes	42	55	52	30	28	61	77	44	51	47	797 (26.91)
No	174	141	147	105	124	142	277	108	99	101	2,165 (73.09)
Intersection*											
MB	48	34	39	35	9	41	15	10	19	15	265 (14.96)
ML	33	36	21	24	25	23	21	16	18	15	232 (13.10)
MS	20	16	21	9	23	13	26	31	29	27	215 (12.14)
SC	24	21	23	16	16	22	0	11	11	9	153 (8.64)
SR	15	19	25	15	0	17	12	0	0	15	118 (6.66)
TST	0	0	17	0	15	11	13	21	15	17	109 (6.15)
RSR	0	0	17	13	10	25	0	17	11	0	93 (5.25)
GL	15	20	14	0	0	24	0	0	9	0	82 (4.63)
MMP	0	0	0	0	19	0	17	12	14	15	77 (4.35)
SN	0	0	12	0	13	0	15	14	0	10	64 (3.61)
Time											
8.01-12.00	37	26	27	18	23	27	30	18	18	22	246 (13.90)
12.01-16.00	28	20	35	21	26	27	26	19	26	13	241 (13.62)
16.01-20.00	38	33	46	23	34	39	35	22	32	30	332 (18.76)
20.01-24.00	48	53	42	34	31	31	42	27	21	24	353 (19.94)
00.01-04.00	45	39	38	31	25	54	35	47	39	45	398 (22.49)
04.01-08.00	25	27	13	15	15	27	23	21	17	17	200 (11.30)

*Intersection name: (Mitraparp-Bankork) MB, Mitraparp-Laonadee (ML), Mitraparp-Sricharn (MS), Sricharn-Chatapadoong (SC), Tedsabarn-Sricharn-Teparak roundabout (TST), Railway station roundabout (RS), Glangmuang-Laonadee (GL), Mitraparp-Maliwan-Prachasamosorn (MMP), and Sricharn-Namuang (SN)

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This is likely because weekend crashes were significantly more frequent at night, and crashes occurred most often during morning hours (commuting to work) on weekdays. Nearly 90% of these crashes involved motorcycles with a single rider [23]. When examining risk behaviors like helmet use, it was found that 55.31% of victims wore helmets, making them more common among those injured than those who did not. This finding is consistent with previous studies in Brazil, where 90% of victims wore helmets, but only 18% also used boots and a jacket [24]. Additionally, proper helmet fastening is crucial to prevent helmet roll-off during a crash [25]. It was found that 26.91% of the injuries were associated with alcohol use. Alcohol consumption was significantly linked to motorcycle injuries, with rates ranging from 19% to 33%, highlighting its role as a dangerous behavior. It is a major contributing factor in both fatal and non-fatal motorcycle accidents involving motor vehicles [26]. The findings emphasize the strong connection between alcohol consumption and motorcycle accidents, highlighting the risks associated with such behavior. Among the top ten intersections with the highest injury rates, those connected to the Mitraparp Highway, including MB, ML, MS, SC and MMP, respectively, exhibited a particularly high number of injuries as indicated in Figure 3.

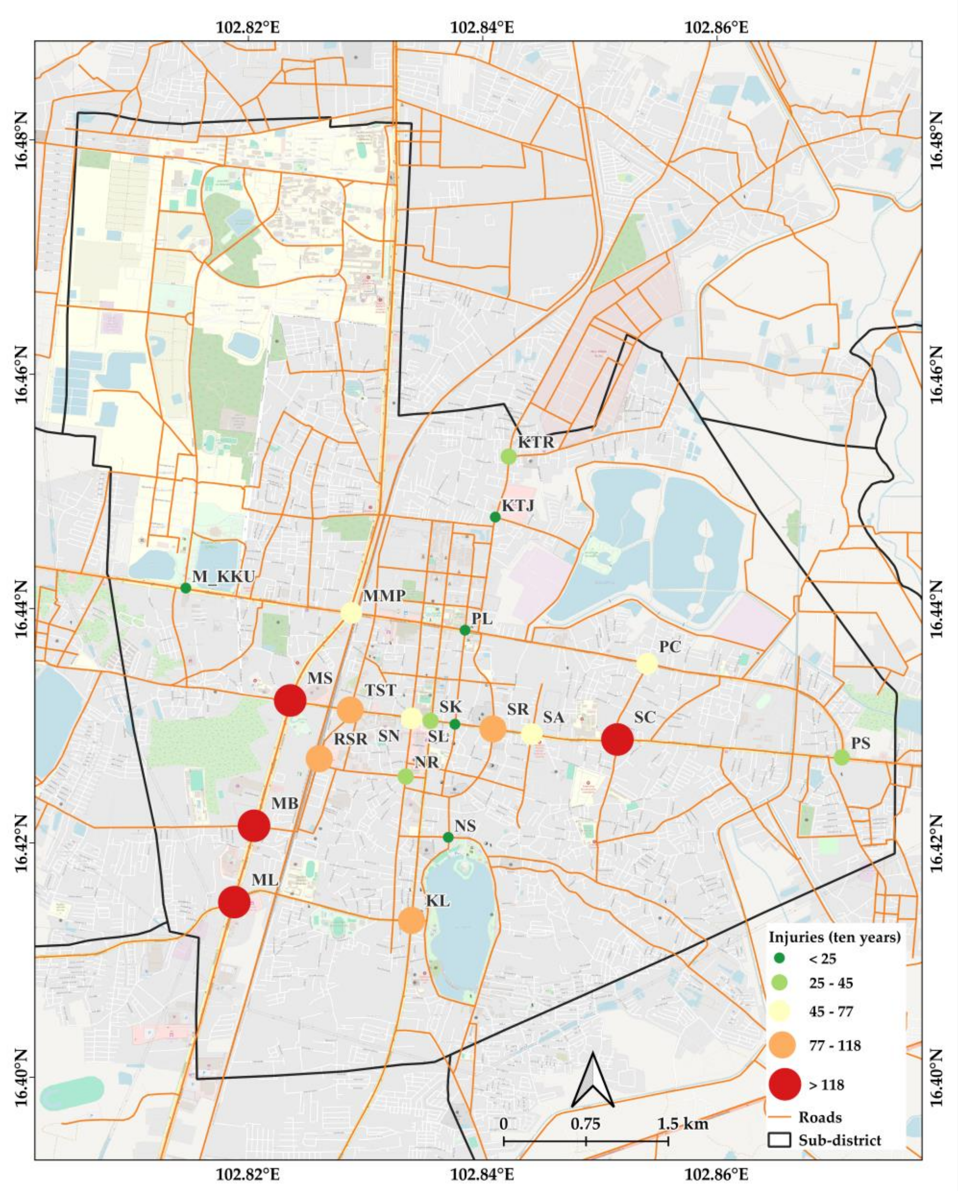

Figure 3: The accumulative ten years (2012-2021) of motorcycle injuries in each intersection point in Khon Kaen municipality, Thailand

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This finding supports the idea that road geometry has a significant impact, with higher vehicle speeds, crash rates, and fatality frequencies typically occurring on wider major roads, or "arteries." Moreover, four-legged intersections generally have more conflict points, resulting in a greater number of crashes and injuries compared to three-legged, T-intersections [27].

The frequency of motorcycle casualties overall increased significantly when considering the time of day during traffic collisions, especially between 00:01 and 04:00 am (22.49%). This period has been identified as crucial, with an increased risk of accidents involving motorcycles. This finding is consistent with data that shows collisions that happen at night, with or without light, contribute to higher seriousness [28]. These results highlight the need to identify and minimize the increased dangers related to riding a motorbike at night. Several possible risk variables, including tiredness and drowsiness, may be exaggerated since they are rarely taken into account in reports of traffic accidents, particularly when Powered Two-Wheel (PTW) collisions are involved [20]. As an example, even if there is less traffic during the evening, PTW users are more likely to suffer a serious injury or lose their life if traveling at night [29]. Additionally, the study verified that insufficient sleep affected young motorcycle riders' ability to avoid crashes. This effect is mostly linked to slower response speeds brought on by sleep deprivation [30]. Driving in the middle of the day (from 12:00 p.m. to 3:59 p.m.) and late at night (from 12:00 a.m. to 3:59 a.m.) was linked to a greater risk of serious injury among young people. Young motorists frequently travel after midnight, which reflects their diverse individual tastes [31].

4.2 Accidents Mapping by Geospatial Analysis

When comparing statistics from 10 years apart, there seems to have been a noticeable change in the high rate of motorcycle injuries nationwide. At first, the southwest region of Khon Kaen Municipality had a greater share of motorcycle injuries. Nonetheless, it was determined that the center-east of the municipality currently has the highest number of motorcycle injuries for the current year (see Figure 4).

The spatial distribution maps of all motorcycle injuries across ten-year periods according to various time frames are shown in Figure 4. The maps were grouped into six separate periods comprising T1 (8.01-12.00), T2 (12.01-16.00), T3 (16.01-20.00), T4 (20.02-00.00), T5 (00.01-04.00), and T6 (04.01-08.00). On the map, the various types or tints correspond to the different proportions of motorcycle accidents during these periods, presenting temporal patterns and high-risk locations visually. It was shown that there was a greater density of motorcycle injuries at night. In particular, the southwest region of Khon Kaen Municipality, more precisely at T5, was shown to have the largest number of motorcycle accidents during the dark hours of T4 and T5 (see Figure 5).

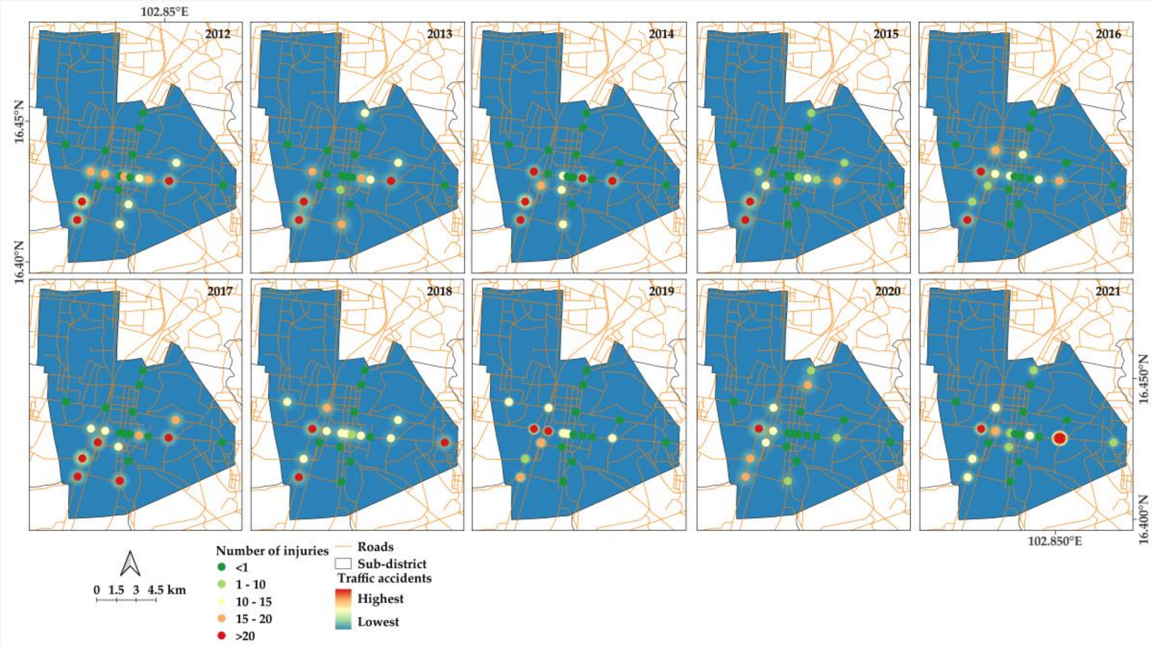

Figure 4: The spatial distribution maps with different densities of motorcyclist injuries in Khon Kaen Municipality

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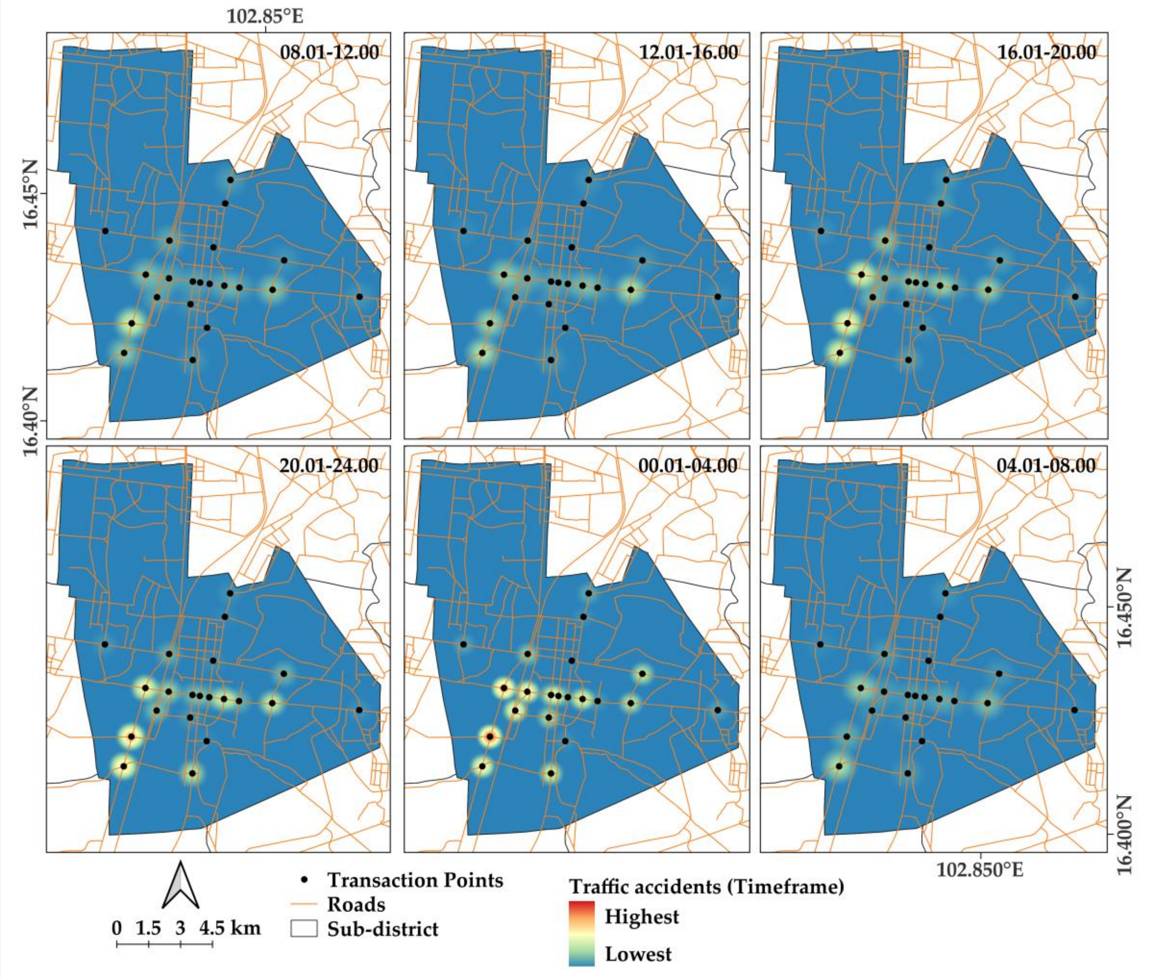

Figure 5: The spatial distribution maps of motorcyclist injuries in Khon Kaen Municipality with different densities and different timeframes for ten years

Over 10 core years, the central business center was a persistent site of motorcycle accidents in terms of their density [32]. The data also shows that the southwest region had the greatest number at night, especially in the vicinity of dining establishments and places of entertainment, when assessing densities across periods. This is consistent with other studies that discovered a link between the number of on-site facilities and incidents linked to alcohol use [33]. The Kernel Density method works well with approximately 30 to 50 sampling points to obtain a reliable KDE estimate. This study used only 21 points of intersection locations for mapping density areas over ten years. Our findings confirmed the high accuracy, smoothness, and reliability of the density estimation. However, when using fewer sampling points (<20 points), there are concerns about the reliability of the KDE results.

4.3 Accidents and Location of EMS Station and Main Hospital

The locations of the three available EMS stations, along with the main hospital, presents in Table 2. The table shows that the EMS station at Khon Kaen Shrine is closest to five of the top ten intersections, ranging from 188 to 1200 meters. The EMS vehicles from these stations can access the accident location within 15 minutes. The second EMS station is closest to three of the top ten intersections, spanning from 434 to 1000 meters. These two points are recommended for parking EMS ambulances, especially between 16:00 and 04:00. Additionally, since two of the top ten intersection accidents occurred closest to Khon Kaen hospital, it is also recommended as a parking point. These three recommended parking points are depicted in Figure 6. From the data in Table 2, the potential location of one, two, and three EMS stations, to estimate the optimized location of actual stations as indicated in Figure 6.

Table 2: EMS stations/hospital and accident ranking/mean distance

EMS station, Hospital Address	Lat.	Long.	Near by intersection	Accident ranking	Distance (meters)
1 At the Khon Kaen shrine	16.43106	102.82846	Tedsabarn-Sricharn-Teparak	6	188
			Sricharn-Namuang	10	540
			Mitraparp-sricharn	3	570
			Railway Station-Roundabout	7	750.7
			Mitraparp-Maliwan-Prachasamosorn	9	1,200
2 Near to Kaennakorn Wittayalai School	16.41576	102.82252	Mitraparp-Bankork	1	987.1
			Mitraparp-Laonadee	2	434.7
			Glangmuang-Laonadee	8	1,208
3 At the Khon Kaen Hospital	16.43233	102.84775	Sricharn-Robmuang	5	1,230
			Sricharn-Chatapadoong	4	219

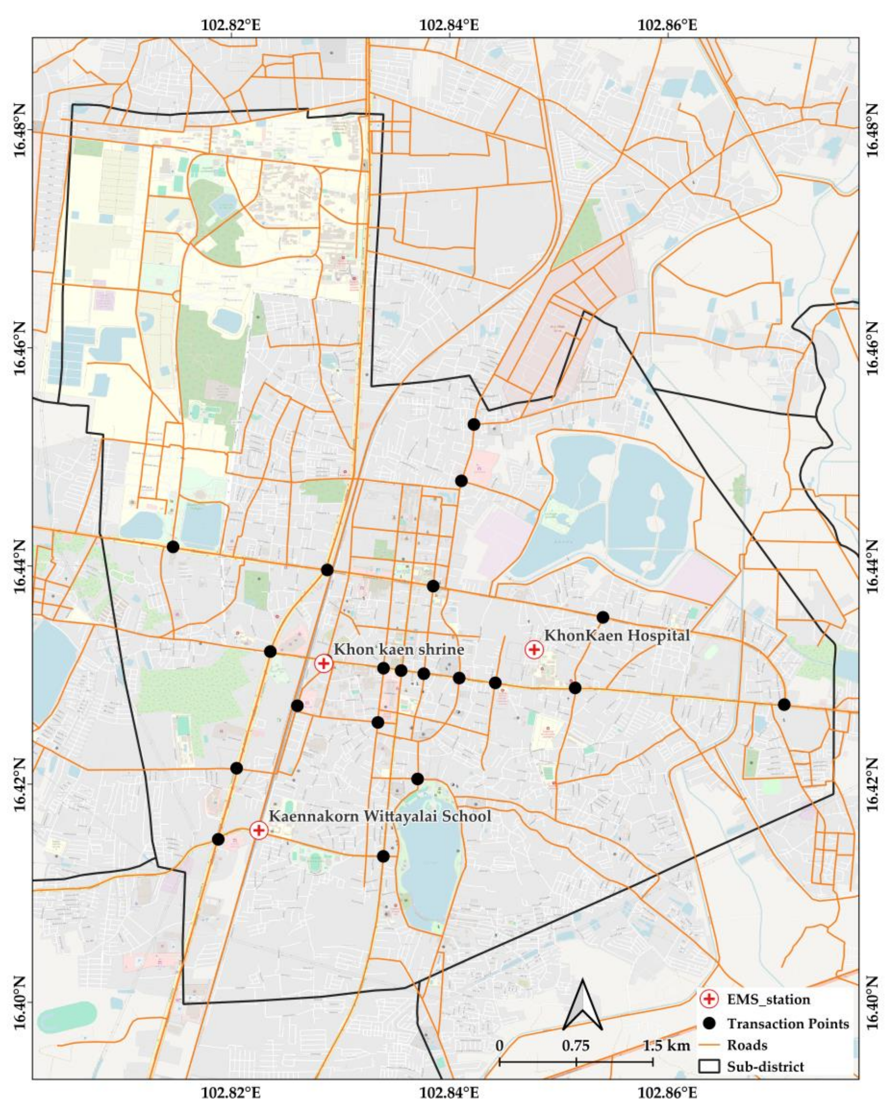

Figure 6: Geospatial optimization of 1, 2 or 3 parked EMS units for best response time

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Concerning the impact of ambulance station location on EMS response time and potential survival benefit. In Khon Kaen City, the potential proximity of EMS stations to high-risk areas, such as intersections with frequent accidents, is proposed as a strategy to improve response times and potentially enhance patient outcomes. This section explores the potential impact of such an approach. Studies have established a correlation between shorter response times and improved survival rates in certain emergencies, particularly cardiac arrest and time-sensitive conditions like stroke. For example, a one-minute reduction in response time for cardiac arrest patients has been associated with a significant increase in survival rates [34], for a more generic analysis of time to survival see [35], and for a geospatial approach see [36]. Strategically locating EMS stations closer to high-risk areas could theoretically reduce response times by decreasing the distance traveled by ambulances, overall response times may be shortened, potentially leading to improved patient outcomes, especially in time-critical situations. This can also benefit in another way by optimizing resource allocation. Indeed, stations located in high-call volume areas could improve resource allocation by reducing travel time and allowing units to return to service more quickly, thereby improving overall system efficiency.

Since the ALS team is limited to providing advanced life-saving interventions in the emergency room. Therefore, if there is an urgent need to reach an accident scene quickly, having a BLS team on standby at a location near the scene and then rapidly transferring the patient to the ALS team could be beneficial. This system is known as a dual dispatch EMS system. More BLS teams could be stationed near high-risk areas [36]. They would be ready to provide essential initial care and then transfer the patient halfway to the ALS team. This approach could be an effective solution.

5. Conclusion

Due to the limitations of the secondary data, certain factors related to traffic accidents, such as helmet fastening, drivers' experience, possession of a driving license, type of impact, or road conditions at the time of the crash (e.g., road construction or rainy weather), could not be analyzed. Therefore, the author needed to reference other studies to discuss and potentially confirm the observed phenomena. While strategic station/parked EMS unit placement offers potential benefits, it is important to keep in mind that establishing and maintaining additional stations can be the cost-effectiveness of such strategies needs careful evaluation. Parked EMS unit(s) could cost much less, especially in terms of absorbing call volume fluctuations; indeed, high-risk areas may not experience consistent call volumes, potentially leading to underutilization of resources in certain potential station locations. To reduce the number of road incidents sobriety checks should be set up, particularly at night in the southwest region, which is an area frequented by those seeking entertainment. Traditional checkpoints might also be positioned conveniently in the central east throughout the day. Future research might examine the connection between the number of entertainment venues and the distance from traffic incidents, which would provide insightful information for focused mitigation efforts.

This study generated density maps over ten years using a database of motorcycle accidents near major intersections. In future work, applying a linear reference system and allocation analysis could enhance the effectiveness of mapping density patterns by incorporating motorcycle accident locations and hospital locations, focusing on line features.

Acknowledgment

This research project was financially supported by Mahasarakham University.

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