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FEASIBILITY STUDY OF TSUNAMI EVACUATION ROUTES BASED ON ROAD PERFORMANCE USING THE INDONESIAN HIGHWAY CAPACITY MANUAL

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Resume

Earthquake and tsunami preparedness is important to plan, especially in the earthquake and tsunami-prone areas, such as Banda Aceh. This study evaluates the tsunami evacuation routes' performance using the width of the road, travel time and the Degree of Saturation (DS) parameter. Some of the Degree of Saturation (DS) of the road segment surprisingly reach 1.0 to 3.18, exceeding the recommended 0.75 standard DS ratio. That indicates that the existing roads cannot accommodate traffic flow during evacuation. This study recommends the evacuation process by walking. Thus, developing the pedestrian routes according to evacuation safety requirements is strongly encouraged. Further, more escape buildings reachable within 15 minutes of evacuation time should be planned in the area. The pedestrian routes need to be designed separately from that of the traffic flow.

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1 Introduction

Geographically, Aceh is prone to earthquake and tsunami disasters as it lies at the confluence of the two tectonic plates that can affect the earthquake and tsunami. The earthquake and tsunami on 26 December 2004 in the western seas of Sumatra Island near the island of Simeuleu were in Aceh. This earthquake triggered a tsunami killing more than 225,000 people in 11 countries and causing devastating destruction in many coastal areas [1]. One of the areas badly hit by the earthquake and tsunami is the Kuta Raja Sub-district in Banda Aceh. In 2012, another earthquake occurred, but without a tsunami. Yet, it caused traffic congestion in many places. Helderop and Grubesic [2] explored the implications of network disturbance in their study to provide vulnerability analysis and emergency response in the event of an exacerbation of an alternative network that maintains important information in the network.

To reduce the possible victims in an earthquake in any city or region, it would be necessary to assess the performance of the transportation network in response to demands to provide relief to travelers following an earthquake. One of the issues, mostly faced by cities worldwide, is natural disasters [3-4]. Most new technologies allow users to select the best route depending on numerous factors, including road length, grade and speed [5]. Travel time during crises, such as earthquakes and tsunamis, is an important factor. Recker et al. [6] stated that the sudden demand on the network, with the aim of uncertain travel, especially in times of crisis, is also a matter of considering the travel time reliability.

Some research on evacuation routes has been conducted [7], performing real-time shortest path prediction, excluding route blockage by fire. Meanwhile, the duration of river flooding was researched by Takahashi, Nakagawa and Higashiyama [8] and Inoue, Nakatani and Yabe [9]. Sakata, Hirano and Arikawa [10] focused on selecting the shortest path of each route that will not be traversed by the refugees caught in the anticipated tsunami. Optimization of the ant colony, modeling the natural food gathering behavior of ants, can search the shortest path in the shortest time, considering the absence of route blockages [11-12].

Understanding and institutionalizing the seamless link between critical urban infrastructure and disaster management have helped the developed world to establish effective disaster management processes. However, this link is conspicuously missing in developing countries, where disaster management has been more reactive than proactive [13]. Indonesia is one of the developing countries prone to disasters, such to earthquakes and tsunamis. Communities urgently need disaster mitigation efforts to minimize casualties and damage in the event of a tsunami. Planning should pay attention to the evacuation flows to avoid congestion to speed up the evacuation process. This research aimed to conduct a study on tsunami evacuation routes, including identifying the locations suitable as the evacuation sites when a tsunami occurs, as well as the road sections feasible for evacuation routes in the event of a tsunami based on the width of the road, velocity and degree of saturation (V/C).

The walking velocity of a group of elderly people is 0.751 m/sec, the slowest speed that can reach the evacuee speed. It is assumed that if they can reach the evacuation destination, other evacuees moving faster can also reach the evacuation shelter.

The widening of roads in urban areas with high densities needs to be done to facilitate evacuation [14]. In addition to road widening, there is a need for building new roads from urban areas with a high density to safe places. Those roads are corridor roads from downtown that can reduce congestion points at the intersection of roads due to the grid-shaped road network pattern and overcapacity.

The width of the road for evacuation depends on the road types, such as primary arterial road (minimum road width of 10 meters); secondary artery road (minimum road width of 8 meters), secondary collector road (minimum road width of 8 meters), secondary local road (minimum road width of 4 meters) and neighborhood road (minimum road width of 4 meters) [15].

The following are the evacuation route planning requirement [16]:

1) The 6 m standard road width is allowed to 4 m when a smaller capacity is required
2) The river stream is one of the disaster-prone areas.
3) Transportation system identification is based on the field observation, so the road used to evacuate can be determined and wide enough to accommodate refugees.
4) The building is the shortest and the nearest to the shelter. The route chosen must be the shortest to the safe area. In addition, the route chosen should not have many intersections. Most evacuation traffic delays occur at the intersection [17- 18].

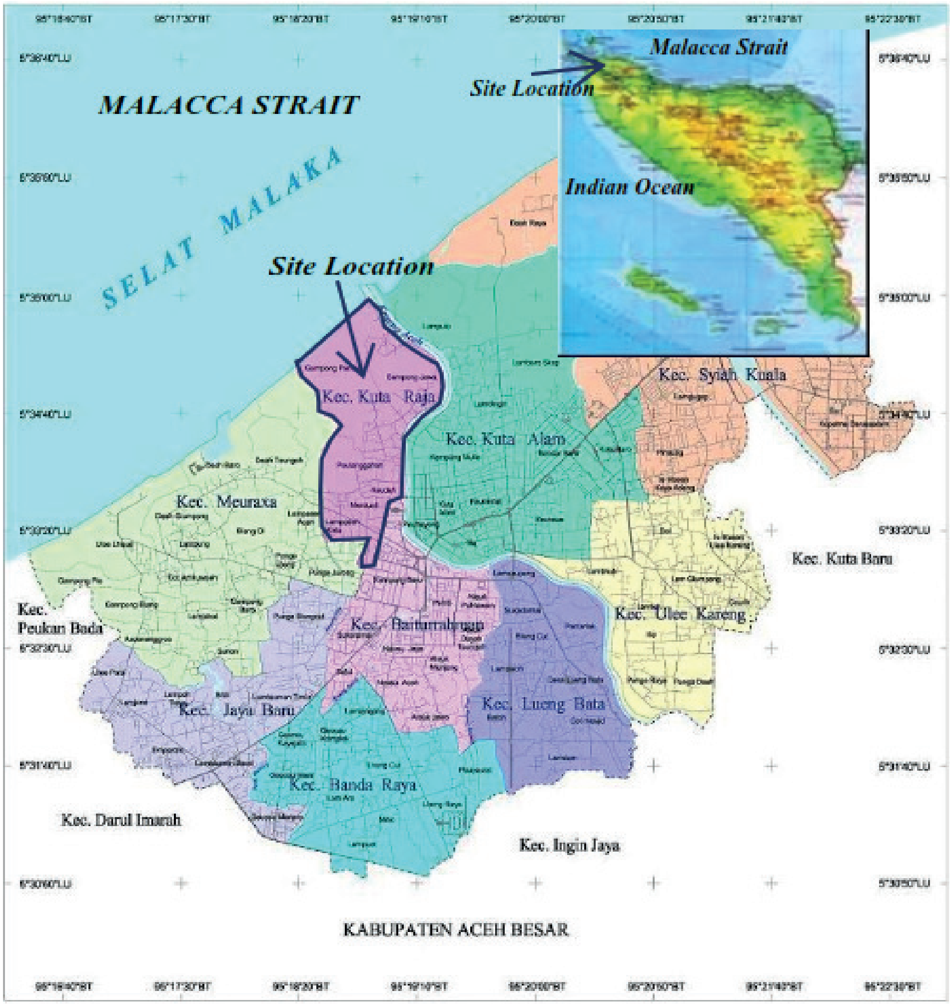

Figure 1 *Research Location*

***Table 1** The number of research samples*

Name of Village	Number of Households	Number of Samples
1. Gampong Jawa	557	55
2. Gampong Pande	199	20
3. Gampong Pelanggahan	639	63
4. Gampong Keudah	433	43
5. Gampong Merduati	923	90
6. Gampong Lampaseh Kota	548	54
7. Gampong Alue Deah Teungoh	389	38
8. Gampong Lampaseh Aceh	585	57
9. Gampong Deah Baro	197	20
10. Gampong Deah Glumpang	258	38
Total sample	4.728	478

The human response capability depends on the estimated time of arrival (ETA) of a tsunami, the time at which technical or natural warning signs (ToNW), determined by Institutional Decision Time (IDT) and Notification Time INT, can be received by the population), the Reaction Time (RT) of the population and the Evacuation Time (ET). The actual available Response Time (RsT) is then obtained by Post et al. [19].

Indonesia Tsunami Early Warning System (Ina-TEWS), as cited by Muhajir [20], the tsunami period following the earthquake is 43 minutes, with 8 minutes for institutional decision and notification, 10 minutes for community reaction, 17 minutes for travel time to reach safe evacuation point and 8 minutes to the higher floor (vertical evacuation). Therefore, evaluation of road performance as an evacuation route is crucial. This evaluation is useful for people's safety when earthquakes and tsunamis re-occur.

An indicator of the road performance in the Indonesian Highway Capacity Manual (IHCM) is the Degree of Saturation (DS). It is the value ratio between the traffic volume and the capacity of the road in units (pcu/h) [21]. Interaction with pedestrians is one of the main factors determining the road performance [22]. IHCM accommodates the pedestrian factor as side friction that will reduce the puck road performance.

2 Research methods

2.1 Location

The research is located in Kuta Raja Sub-district, Banda Aceh City, consisting of six villages, i.e. Gampong Jawa, Gampong Pande, Gampong Peulanggahan, Gampong Merduati, Gampong Keudah and Gampong Lampaseh Kota. This Sub-district is directly adjacent to the sea in the North. It is also located in the red zone of the tsunami (dangerous) with severe impacts during the 2004 tsunami [23]. The map of the research location can be seen in Figure 1. The borders of the Kuta Raja Sub-district are as follows [24-25]: - North: Malacca Strait

- South: Baiturrahman Sub-district
- West: Meuraxa Sub-district
- East: Kuta Alam Sub-district

2.2 Research samples

The data on the transport modes used for evacuation, the point of origin and the destination of evacuation were obtained by distributing questionnaires to the respondents (n = 478), the people in each village in the Kuta Raja sub-district. In addition, four villages in the District Meuraxa conduct evacuation through the Kuta raja sub-district. The number of respondents in each village is divided proportionally based on the number of households [25]. Table 1 presents the number of samples in each village and Figure 2 shows the flow chart of the research.

2.3 Data collection and processing

This research required data on the mode of transport used for evacuation, vehicle ownership, the number of households, the point of origin and destination of evacuation (safe points for evacuation purposes), the distance used to calculate evacuation time, the width of roads as the evacuation routes and the number of residents and buildings eligible for evacuation. The data of transport mode, population, vehicle ownership, origin and destination were required to predict the number of evacuation flows. Those data were obtained through questionnaires. Distance and road width was obtained by measuring the distance needed to calculate the evacuation time, while the width of the road was used to calculate the capacity of the evacuation route. Population data were used to obtain the city size adjustment factor (FCcs) to calculate the road capacity.

The data analysis steps are as follows:

1. Identifying the safe locations for tsunami evacuation

Table 2 *Average Speed Evacuation, [29]*

Walking Condition	Average Speed, m/s
- A Person pushing a perambulator	1.070
- A person with a child	1.020
- Independent walking elderly person	0.948
- A group of walking elderly people	0.751

Table 3 *Street transport Quality Index*

Route performance	DS = V/C ratio	Index
Very favorable	< 0.350	A
Favorable	0.350 - 0.500	B
Fairly favorable	0.500 - 0.750	C
Unfavorable	0.750 - 0.900	D
Very unfavorable	0.900 - 1.000	E
Obstruction and Congestion	> 1.000	F

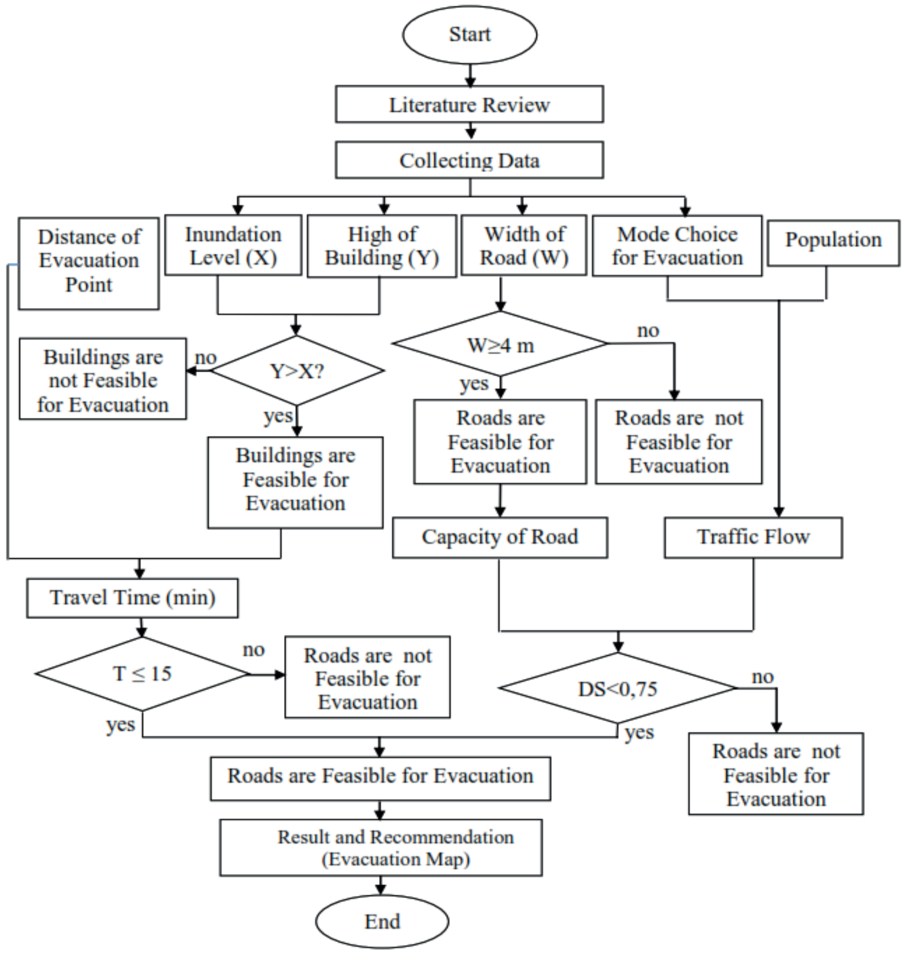

Figure 2 *Flow Chart of Research*

(high ground or vertical evacuation) based on the inundation height during the 2004 tsunami. A vertical evacuation from a tsunami is a building or earthen mound with sufficient height to elevate evacuees above the level of tsunami inundation. It is designed and constructed with the strength and resiliency needed to resist the effects of tsunami waves. Buildings for evacuation shelters can be single-purpose, multi-purpose facilities, single-hazard and multi-hazard considerations [26-27].

2. Identifying appropriate roads for evacuation routes based on the road width.
3. Calculating the distance and travel time of each road, assuming the speed was 14 km/h for motor

vehicles and 2.5 km/h for people on foot [28]. The Japan Institute for Fire Safety and Disaster Preparedness overviews the walking condition and average walking speed in disaster evacuation, as shown in Table 2 [29].

4. Calculating evacuation flows (V) on the evacuation route based on the mode of transport used by the community, assuming that all people would evacuate.
5. Calculating the capacity of each road segment. Road capacity (C) is calculated by IHCM:

$$C = Co * FCw * FCsp * FC_{SF} * FC_{CS}, \quad (1)$$

where:

Co = base capacity for the urban road,
FCw = coefficient factor of the road width for capacity,
FCsp = coefficient factor of separator for capacity,
FC_{SF} = coefficient of the factor of side friction for capacity,
FC_{CS} = coefficient factor of city size for capacity.

6. Calculating the performance of the evacuation routes. Indicator of the road performance to the Indonesian Highway Capacity Manual (IHCM) is the Degree of Saturation (DS), the ratio between the volume of traffic (V) and the capacity of a road (C) in passenger car units per hour (pcu/h) or V/C ratio [21]. Assessment of the road performance for evacuation routes in this study uses indicators as shown in Table 3.

3 Results and discussion

This study discusses the modes the community uses for evacuation, appropriate evacuation places and the feasibility of evacuation routes based on the road width and travel time road performance.

3.1 The transport mode for evacuation

The residents of Kuta Raja Sub-district used four types of vehicles: cars, pedicabs, motorcycles and foot, during the evacuation. The dominant mode of transport, chosen by the community to evacuate, was a motorcycle (72 %), followed by a car (9 %), pedicab (1%) and foot (18 %). Figure 3 illustrates the number of people using each type of transportation.

3.2 Safe location for evacuation

The evacuation site for the people of Kuta Raja Sub-district was a one to five-story building, whereas an evacuation site of empty fields and hills was unavailable in this area. The buildings selected for evacuation were government-owned, while private/personal-owned buildings were not used, although they were safe. These safe buildings for evacuation consisted of one to five-story buildings located within or outside Kuta Raja Sub-district. The buildings within Kuta Raja

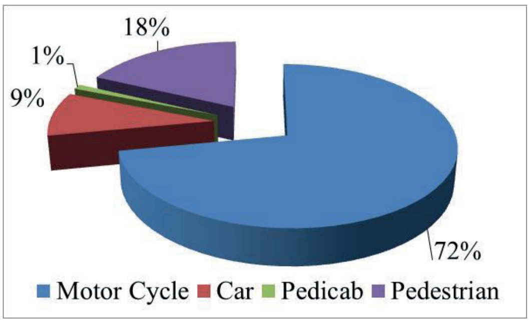

Figure 3 *Vehicle choices for evacuation*

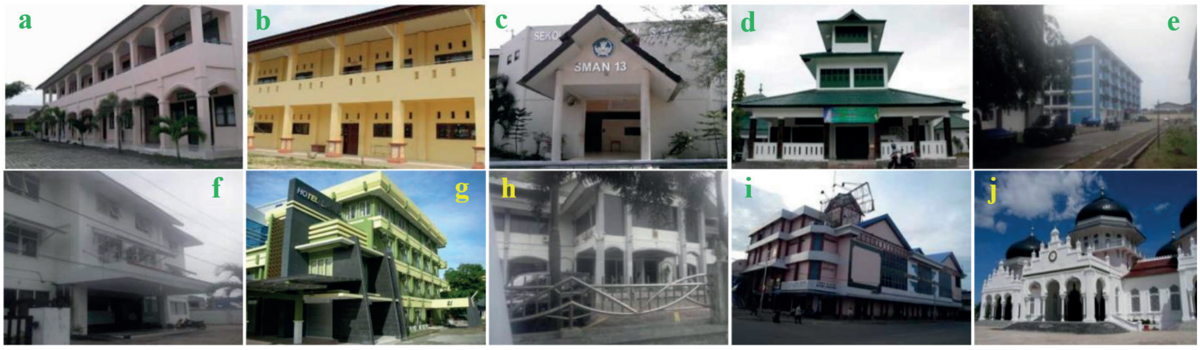

Figure 4 *(a) Public Elementary School 70 (SD), (b) Public Junior High School 12 (SMP), (c) Public Senior High School 13 (SMA), (d) Tgk. Dianjong Mosque, (e) Low-cost Rental Apartments, (f) Cut Mutia Hospital, (g) Hotel Lading, (h) State Electricity Company, (i) Pasar Aceh Building, (j) Baiturrahman Mosque*

Sub-district were Public Elementary School 70, Public Junior High School 12, Public Senior High School 13, Tgk. Dianjong Mosque and low-cost rental apartments. Meanwhile, the evacuation sites outside the Kuta Raja Sub-district were Cut Mutia Hospital, Hotel Lading, State Electricity Company (PLN), Pasar Aceh building and Baiturrahman Mosque located in Baiturrahman Sub-district. Safe locations for tsunami evacuation for the people of the Kuta Raja Sub-district are illustrated in Figure 4.

The one-story building was the Baiturrahman Great Mosque, which was safe for evacuation during the 2004 tsunami. Two-story (a, b, c, d, h), three-story (f), Four- story (g, i) and five-story (e). The location of the buildings was feasible due to the water height of the 2004 tsunami below the building floor height.

3.3 The feasibility of evacuation routes based on the width and travel time

According to SDC [15] the minimum width of the evacuation route for local roads is 4 m, while the evacuation time is 17 minutes of 43 minutes of the total Tsunami evacuation [9]. Meanwhile, the disaster evacuation time in Aceh was only 35 minutes, so the evacuation travel time was also reduced. This study assumed a travel time of 15 minutes, assuming the evacuation speed of 14 km/h for motor vehicles and 2.5 km/h for pedestrians [3]. The feasibility result of the evacuation route based on the travel time revealed that the safe points for evacuation could only be reached by motor vehicles and almost all the routes were not feasible for evacuation on foot. Therefore, the number of evacuation sites in the form of multi-story buildings needs to be added as they are reachable on foot. The safe points for evacuation in each village are as follows.

1) Gampong Jawa
The people in Gampong Jawa could evacuate to ten evacuation points, with three points located in the Gampong Jawa area and seven points situated outside Gampong Jawa. Based on the travel time of the evacuation route, the people of Gampong Jawa had 12 feasible routes for motor vehicles and two routes for pedestrians. The route for pedestrians was safe because the evacuation points were close, located in Gampong Jawa and a village next to it. It showed that people willing to evacuate on foot are unsafe if they choose a place of evacuation outside the location of the residence because it takes longer.
2) Gampong Pande
Gampong Pande had ten evacuation points with ten routes for motor vehicles. However, there was no proper evacuation route for pedestrians as the travel time to reach the evacuation point exceeded 15 minutes. Since the Gampong Jawa did not have evacuation buildings, people had to evacuate out of the village, which took > 15 minutes. Gampong Pande evacuation sites, which are safe according to the government, were similar to Gampong Jawa, including Public Elementary School 70, Public Junior High School 12, Public Senior High School 13, Tgk. Dianjong Mosque, low-cost rental apartments (Rusunawa), Cut Mutia Hospital, Hotel Lading, State Electricity Company (PLN) Banda Aceh, Pasar Aceh Building and Baiturrahman Mosque.
3) Gampong Peulanggahan
Gampong Peulanggahan had seven evacuation points with 11 feasible routes based on the travel time for motor vehicles and two routes for pedestrians. The feasible evacuation points for pedestrians were located in Gampong Peulanggahan. It means that their distance and travel time was shorter compared to other villages.
4) Gampong Keudah
Gampong Keudah had five evacuation points with eight routes for motor vehicles and no proper route for pedestrians. That was because the evacuation points were located outside the Gampong Keudah, as well.
5) Gampong Lampaseh Kota
Gampong Lampaseh Kota had two evacuation points with five routes suitable for motor vehicles, but there was no proper route for pedestrians. Both of these evacuation points were located outside the Gampong Lampaseh Kota.
6) Gampong Merduati
Gampong merduati had four evacuation points with six evacuation routes for motor vehicles and one evacuation route for pedestrians. The proper evacuation points for pedestrians were located in Gampong Merduati, so the travel time was shorter.

3.4 Routes feasibility based on the road performance

The calculation of the road capacity, traffic flow and degree of saturation was carried out to obtain the performance of the roads in the evacuation routes. The degree of saturation parameter was used to measure the performance of the road. The road performance calculation in this study assumes a one-way road. During a tsunami emergency, all the roads should be one-way and traffic flow to the red zone should be stopped. Traffic control points should be installed to prevent traffic flow to the red zone and direct it toward the evacuation site. The road feasibility, based on performance, was calculated by the degree of saturation parameter obtained by dividing the vehicle flows by the road capacity, the results are illustrated in Table 5.

1) Capacity of Road
The road capacity calculated was the roads the people went through to the planned evacuation site. The capacity was obtained by multiplying the basic capacity of the road segment (Co) with the Adjustment

factor values due to side frictions (FCsf), the city size adjustment factor (FCcs), the road width adjustment factor (FCw) and the road type adjustment factor (FCsp). This research assumed that the side frictions were very high and the roads type for evacuation were one-way and effective lane widths of 3-4 m. The Road Capacity on the Evacuation route can be seen in Table 4.

2) Degree of Saturation

The evacuation flows of Rama Setia Street and Diponegoro Street are not only from the Kuta Raja Sub-district, but from some villages in Meuraxa Sub-district as well, i.e. Gampong Lampaseh Aceh, Gampong Baro, Gampong Deah Teungoh and Gampong Deah Glumpang. These evacuation flows include motorcycles, cars and pedicabs (tricycles). IHCM considers it pedestrian side friction because it will inhibit the movement of evacuation flows due to low pedestrian speed. Side frictions are not only pedestrians but the parking vehicles and vehicles coming out from the left and right sides, as well. In this study, the side friction is assumed to be very high.

The survey found some roads with no traffic flow because no respondent chose those roads to the evacuation place: Krueng Geudong street segment 1, Raja Siuroe street, Tuanku Raja Keumala street and Panglateh street. Krueng Geudong street segment 1 is located in the swamp area, with no population. Though the Tuanku Raja Keumala street is located in a housing area and can be used to evacuate to Low-cost Rental Apartments, no respondent chose it as an evacuation site. The building is located near the sea, so the people feel unsafe to evacuate to the building. Some people were using the access routes for evacuation, as well.

The results of the road performance calculations, based on the degree of saturation (DS), can be seen in Table 5. The results showed that most of the main roads used for evacuation were very bad because the value was above 0.75 and exceeded 1.0 (Saturated/gridlock/vehicle cannot move). Poorly performing roads were not only arterial and collector roads, but the access roads, as well, such as Tgk. Dianjong street and T. Muda street. Tentara Pelajar street was safe because of the change of the two-way street into one direction when the evacuation widened the road and some communities evacuated to the PLN office (State Electricity Company) on that road. The road performance of Rama Setia street, Cut Mutia street and Diponegoro street was terrible (gridlock), with the DS ratio of the road segment reaching > 1.0 to 3.18. This shows that the roads are at the Service level F [21]. The gridlock increases when the flow is so high and vehicles get very close to each other. The total gridlock occurs when vehicles have to stop or move very slowly [30-31]. Improving the performance of roads can be done by widening some roads that still have space.

The result of DS shows that the existing roads cannot accommodate traffic flow during the evacuation. This study recommends the evacuation process by walking. Thus, developing the pedestrian routes, according to evacuation safety requirements, is strongly encouraged. Further, more escape buildings reachable within 15 minutes of evacuation time should be planned in the area. The pedestrian routes need to be designed separately from that of the traffic flow. Mixed traffic was hazardous in evacuation routes, as it causes accidents between pedestrians and motor vehicles.

According to SDC [15], the minimum width of the evacuation route for local roads is 4 meters. In the mixed traffic, the road capacity is divided by two, resulting in two 2-meter-wide lanes. According to Melkova [32] and

***Table 4** Road Capacity*

Street	Width (m)	Co	FCw	FCsp	FCsf	FCcs	Capacity
Jl. Krueng Geudong	4	1,650	1.08	1.00	0.73	0.90	1,170.77
Jl. Tgk. Dianjong	5	2,900	0.56	1.00	0.73	0.90	1,344.22
Jl. Pawang Hitam	5	2,900	0.56	1.00	0.73	0.90	1,344.22
Jl. Hamzah Yunus	4	1,650	1.08	1.00	0.73	0.90	1,170.77
Jl. Raja Siuroe	3.5	1,650	1.00	1.00	0.73	0.90	1,084.05
Jl. Bangka	4	1,650	1.08	1.00	0.73	0.90	1,170.77
Jl. Tuanku Raja Keumala	5	2,900	0.56	1.00	0.73	0.90	1,344.22
Jl. T. Muda	5	2,900	0.56	1.00	0.73	0.90	1,344.22
Jl. Cut Mutia	10	4,950	0.92	1.00	0.73	0.90	2,688.44
Jl. Tgk. Dikandang	6	3,300	0.92	1.00	0.73	0.90	1,994.65
Jl. Malem Dagang	5	2,900	0.56	1.00	0.73	0.90	1,344.22
Jl. Kamboja	4	1,650	1.08	1.00	0.73	0.90	1,170.77
Jl. Tentara Pelajar	14	6,600	0,96	1.00	0.73	0.90	4,336.20
Jl. Taman Siswa	5.5	2,900	0,56	1.00	0.73	0.90	1,430.95
Jl. Panglateh	5	2,900	0.56	1.00	0.73	0.90	1,344.22
Jl. Rama Setia	7	3,300	1.00	1.00	0.73	0.90	2,168.10
Jl. Diponegoro 1	8	3,300	1.08	1.00	0.73	0.90	2,341.55
Jl. Diponegoro 2	12	4,950	0.92	1.00	0.73	0.90	3,512.32

Table 5 *Degree of Saturation for Evacuation Routes*

Street	Capacity	Capacity (C)	Traffic Flow (Q)	Degree of Saturation
	Pcu/h	Pcu/15 min		Q/C
Jl. Kreung Geudong Segmen 1	1,170.77	292.69	0.00	0.00
Jl. Kreung Geudong Segmen 2	1,170.77	292.69	65.00	0.22 = A
Jl. Kreung Geudong Segmen 3	1,170.77	292.69	51.00	0.17 = A
Jl. Kreung Geudong Segmen 4	1,170.77	292.69	30.85	0.11 = A
Jl. Tgk. Dianjong Segmen 1	1,066.97	266.74	303.97	1.14 = F
Jl. Tgk. Dianjong Segmen 2	1,066.97	266.74	351.78	1.32 = F
Jl. Tgk. Dianjong Segmen 3	1,066.97	266.74	497.63	1.87 = F
Jl. Tgk. Dianjong Segmen 4	1,066.97	266.74	557.80	2.09 = F
Jl. Tgk. Dianjong Segmen 5	1,066.97	266.74	667.73	2.50 = F
Jl. Pawang Hitam	1,066.97	266.74	34.15	0.13 = A
Jl. Hamzah Yunus	1,170.77	292.69	20.56	0.07 = A
Jl. Raja Siuroe	1,084.05	271.01	0.00	0.00
Jl. Bangka	1,170.77	292.69	66.61	0.23 = A
Jl. Tuanku Raja Keumala	1,066.97	266.74	0.00	0.00
Jl. T. Muda Segmen 1	1,066.97	266.74	344.81	1.29 = F
Jl. T. Muda Segmen 2	1,066.97	266.74	193.96	0.73 = C
Jl. Cut Mutia Segmen 1	2,991.98	747.99	919.78	1.23 = F
Jl. Cut Mutia Segmen 2	2,991.98	747.99	758.70	1.01 = F
Jl. Cut Mutia Segmen 3	2,991.98	747.99	992.15	1.33 = F
Jl. Tgk. Dikandang Segmen 1	1,994.65	498.66	169.65	0.34 = A
Jl. Tgk. Dikandang Segmen 2	1,994.65	498.66	238.40	0.48 = B
Jl. Malem Dagang	1,066.97	266.69	225.97	0.85 = D
Jl. Kamboja	1,170.77	292.69	23.47	0.08 = A
Jl. Tentara Pelajar segmen 1	4,162.75	1,040.65	254.46	0.24 = A
Jl. Tentara Pelajar segmen 2	4,162.75	1,040.65	501.91	0.48 = B
Jl. Taman Siswa Segmen 1	1,066.97	266.69	200.20	0.75 = D
Jl. Taman Siswa Segmen 2	1,066.97	266.69	70.00	0.26 = A
Jl. Panglateh	1,066.97	266.69	0.00	0.00
Jl. Rama Setia Segmen 1	2,168.10	542.03	717.60	1.32 = F
Jl. Rama Setia Segmen 2	2,168.10	542.03	1,480.42	2.73 = F
Jl. Rama Setia Segmen 3	2,168.10	542.03	1,720.99	3.18 = F
Jl. Diponegoro Segmen 1	2,991.98	585.39	1,176.72	2.01 = F
Jl. Diponegoro Segmen 2	2,991.98	747.99	1,409.21	1.88 = F

Kramarova [33], the width of space needed for one person to walk is 0.85 meter, while the comfortable width for two people to walk ranges from 2.0 meters - 2.5 meters. Meanwhile, the 2-meter-wide lane for motorized vehicle mode is only sufficient for motorcycles. One motorbike requires width space of 1.3 meters [10], with details of the motorbike being 0.8 meter wide and 0.25 meter for the free space width on each side. For two motorcycles, it usually takes 2.1 meters. If the large space is available, pedestrian paths should ideally be on both sides of the road to minimize accidents between pedestrians and motorized vehicles due to people crossing the road.

According to Lawalata et al. [34], the width of small passenger vehicles ranges from 1.46 meter - 1.97 meter, excluding free space on both sides of the mode. Thus, cars are not recommended as an evacuation mode due to insufficient road width. In addition, cars tend to cause potential congestion during evacuation. Figure 5 illustrates the evacuation route map at the Kuta Raja Sub-district.

4 Conclusions

The research indicates that existing roads are unable to accommodate evacuation flow. Some of the DS ratios of the road segment reach 1.0 to 3.18, exceeding the recommended standard DS ratio value of 0.75. It is dangerous to public safety. Therefore, this study recommends that evacuation using a motorized vehicle should be minimized or avoided. Thus, the pedestrian route needs to be made by the evacuation

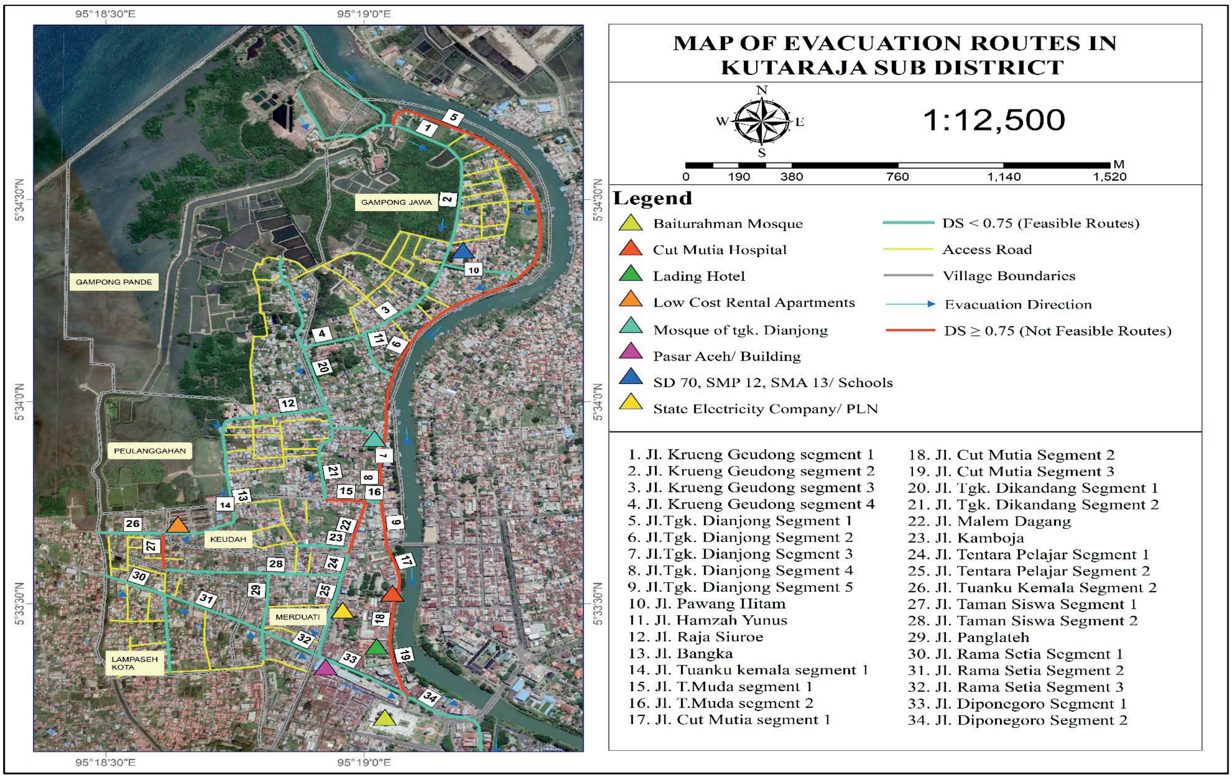

***Figure 5** Map of Evacuation Routes in Kuta Raja Sub-district*

safety requirements and the safe evacuation points in the form of buildings (vertical evacuation) need to be added by considering the evacuation travel time of 15 minutes. This pedestrian route also separates the pedestrians flow of evacuation from the motor vehicles' flow, to minimize the accident rate between pedestrians and motor vehicles.

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