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MONITORING SPATIAL CONDITIONS AND ROAD TRAFFIC OF THE TSUNAMI EVACUATION ROUTE IN PADANG CITY USING GEOGRAPHIC INFORMATION SYSTEM

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ABSTRACT: The traffic of the tsunami evacuation route is an essential aspect of disaster mitigation. This relates to minimizing the possibility of fatalities and property damage as well as preparing communities to be resilient to disasters. This also refers to the accessibility of a body of water as measured by its length, type, and position along the coast. There are numerous roads that serve as evacuation routes for the earthquake and tsunami disasters in the present day, but their conditions are lacking. Furthermore, there has been no detailed research on the monitoring of the tsunami evacuation route in Padang City. Moreover, Padang City is extremely vulnerable to earthquakes and tsunamis based on its past and its possibility of future natural disasters. This research used a quantitative survey with scoring and analysis of Open Route Services (ORS) tools in the QGIS application. The results indicated that the road accessibility for cars was in priority 1 with a score of 28,02%, meanwhile the accessibility for motorbikes and pedestrian was in priority 1 with a score of100%. Therefore, it is not optimal for two vehicles to share the same road channel simultaneously. The tsunami-safe zone is located in the relatively elevated eastern area of Padang City. This study also identified and recommended which sections of the road must be enhanced for the tsunami evacuation route in priority 1.

Keywords: *Spatial Condition, Geographic Information System, Road Traffic*

1. INTRODUCTION

Padang City is located at 0° 44' 00"-1° 08' 35" south latitude and 100° 05' 05"-100° 34' 09" east longitude. The location is positioned in a tropical area near the equator. Padang has a variety of relief conditions. From west to east, the Padang City appears to have a flat relief, while the east coast, which is part of the Bukit Barisan Mountains, is steep [1]. This impacts the land use distribution of densely populated coastal communities. There were numerous types of services, including business, government offices, and education. On the eastern side, the Kerinci Seblat National Park still covers the natural forest of the Bukit Barisan Mountains.

The Padang City has a probability factor of 4 in the tsunami emergengy plan document, indicating that 60 to 80 % of the potential disaster is likely to occur. Padang is one of many Indonesian communities with a 60% chance of being impacted by an earthquake and tsunami. The Padang City is a coastal area that faces the Indian Ocean; alongside the city of Padang is a subduction zone that can cause destructive earthquakes and tsunamis [2].

Padang City is in close range to the Semangko great fault and the Mentawai megathrust fault lines, as seen on the Geological Map and Active Fault Map of Indonesia [3]. Therefore, it is more likely that seismic phenomena occur frequently. In 2009, a 7.6-magnitude earthquake occurred in Padang, Indonesia, and in 2010, a 7.7-magnitude earthquake in Mentawai, Indonesia, that triggered a tsunami. The Mentawai province experienced a magnitude 7.3 earthquake on April 24, 2013. This places Padang City prone to natural disasters, including earthquakes and tsunamis [4]. Based on the data mentioned earlier, Regional Disaster Management Agency (*Badan Penanggulangan Bencana Daerah* – BPBD) released in 2013 an index of seismic and tsunami vulnerability indicating a high level of vulnerability. According to seismicity data obtained from the United States Geological Survey (USGS), Padang City experienced 246 earthquakes in 2014, with magnitudes that extend from damaging to serious (magnitude 5 to 8 SR).

Earthquakes are one of the events that occur when the earth's plates move convergently, divergently, or transformatively due to an endogenous force. In addition to rock fractures,

cave collapses, and volcanic eruptions, tectonic deformation activities can also produce earthquakes. Seismicity in the Padang City is, however, primarily due to the presence of earthquake faults, as indicated by its historical occurrence. According to geologists, Padang City is also classified as an earthquake-prone region. Because it is located between two active earthquake sources, namely the meeting of the Australian and Eurasian tectonic plates and the Semangko Fault along the Sumatra island [5].

According to observational studies, several locations in Padang City have placed traffic signs with tsunami hazard warning information (evacuation road). Based on SNI 7743–2011 regarding Signs, evacuation information signs are equipment in a specific format that produces letters, symbols, numbers, and sentences to provide warnings of movement actions and rescue people from dangerous areas to safe areas [6]. These signs cover Dadok Tunggul Hitam disctric, Tabing disctric, Ampang area distric, and Andalas disctric. Areas included in the tsunami safe zone have also been designed to notify the public that the area is already a green zone (safe tsunami prediction). The signs can be seen at some location, including Simpang By Pass area, Dadok Tunggul Hitam area, Lubuk Minturun area, and Limau Manis area. The eastern area of Padang City is higher in elevation than the western area, as determined by spatial identification. Moreover, the majority of Padang City's coastline is less than 5 meters above sea level [7]. Community literacy should continue to be maintained using informational signs indicating tsunami-prone areas, tsunami evacuation routes, and tsunami-safe zones.

Geographic Information System (GIS) is one of the supplementary technologies in Geography. Using geographic analysis, geographic information systems are useful for mapping, planning, monitoring, and evaluating [8]. Geographic Information System (GIS) is currently gaining a lot of public interest. Because GIS is able to discover many objects that exist on the earth's surface [9]. Particularly in the fields of agriculture, forestry, urban planning, maritime, and many other fields.

GIS is frequently used in community development to assist in decision-making and creating policies [10], [11]. The findings in the field showed that there are still only a few roads that become highlights. It is not impossible that there are many roads that are incidentally important routes for evacuating tsunami safe areas, but are not treated as important roads to be improved as they are designated, considering that every disaster must refer to the quantity of loss of life and property (material). Therefore, the government of Padang City needs to utilize GIS to monitor the access of tsunami evacuation routes in order to increase regional resilience in the preparation of emergency plans for natural disasters, particularly earthquakes and tsunamis.

2. RESEARCH METHODS

This research is a descriptive survey research. The research methods used is spatial analysis and monitoring of road traffic in Padang. The research was conducted in Padang City using secondary data obtained from administrative maps, DEM data, Road Networks, and the Padang City Tsunami Vulnerability Map. QGIS used Network Analysis [12] on ORS (open route services) Tools [13] to process input data. In the field, primary data is obtained by measuring width samples and road class conditions. The collected data was analyzed with the QGIS application. Using cartographic principles, 3.27 is then displayed as a map

3. RESULTS AND DISCUSSION

3.1 Initial Study

Initial study was conducted to collect primary and secondary data, input data, and field observation data. The road conditions in the Dadok Tunggul Hitam, Ampang, and Tabing districts were observed in this study. The primary and secondary data collected refer to the Padang City's roads, DEM, and administration map. The following research flowchart provides further details.

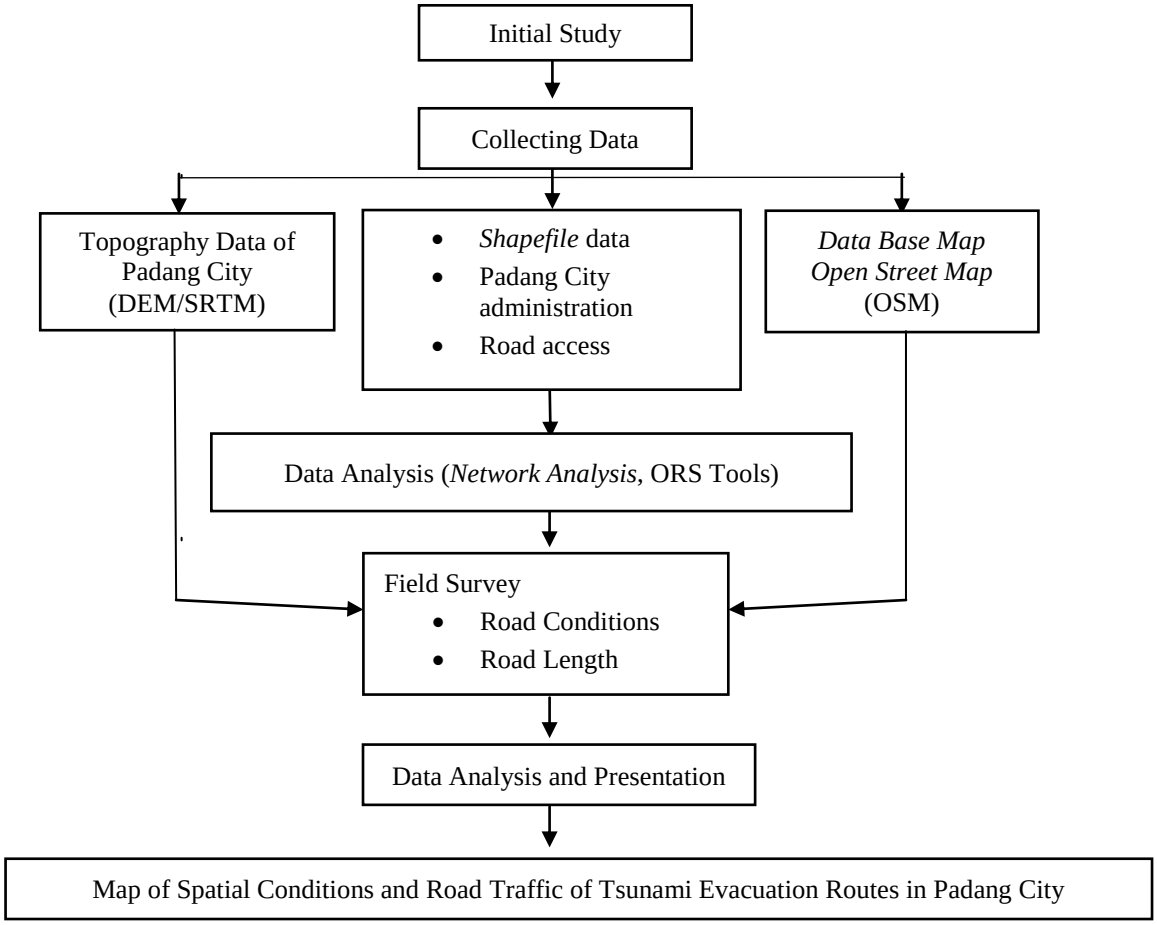

Fig 1 Research Flowchart

In the illustration above, the research process is shown from beginning to the end. Data analysis and presentation using scoring analysis and map data presentation using cartographic principles. The spatial conditions of Padang, particularly land use, were considered in the spatial study.

3.2. Evaluation of Road Traffic

The road is a type of infrastructure that serves as a link from one location to another. Traffic is the capacity of a road to facilitate passing loads. Road traffic is the capacity of a section of road to serve traffic flow requirements in accordance with its function, as measured by road service level standards [14]. According to the physical characteristics of the road, each road has a unique capacity to accommodate the load that passes it. Many factors influence road traffic, including the physical condition of a location, the population, the road's length, and its function. Therefore, evaluation and monitoring of road traffics are necessary. The 2011 earthquake and tsunami in Tohoku, Japan, demonstrated the significance of road traffic for evacuation in addition to their function as seawalls [15]. In this study, monitoring of road traffics is used to evaluate the tsunami evacuation route for various transportation facilities and vehicle types in Padang City.

It is essential to monitor road accessibility in order to assess the condition of the road itself. Several parameters, including road function/type, road length, and demographic activity along the road, are analyzed spatially utilizing a geographic information system when monitoring road accessibility.

Table 1. Monitoring Classification of Road Accessibility

No	Variable	Indicator	Scoring	Decsription
1	Road type	Path	1	Not accessible by vehicles, both cars and motorbikes.
		Local	2	It can be accessed smoothly by motorbikes, but can only accommodate a limited number of cars.
		Collector	3	It can be accessed smoothly by motorbikes and cars, but there are obstacles if they are passed simultaneously.
		Ring road	4	Can be accessed smoothly by motorbikes and cars.
2	Road length	< 3 m	1	Not accessible by vehicles, both cars and motorbikes.
		3 – 6 m	2	It can be accessed smoothly by motorbikes, but can only accommodate a limited number of cars.
		7 – 8 m	3	It can be accessed smoothly by motorbikes and cars, but there are obstacles if they are passed simultaneously.
		> 8 m	4	Can be accessed smoothly by motorbikes and cars.
3	Road Direction (towards the coastline)	Horizontal	1	This path is alongside to the coastline.
		Vertical	2	This path is opposite to the coastline.

Source: modified from [16] and [17]

Table 2. Monitoring Classification of Priority Road Traffic

No	Road Traffic	Score
1.	Priority 3	3-4
2.	Priority 2	5-7
3.	Priority 1	8-10

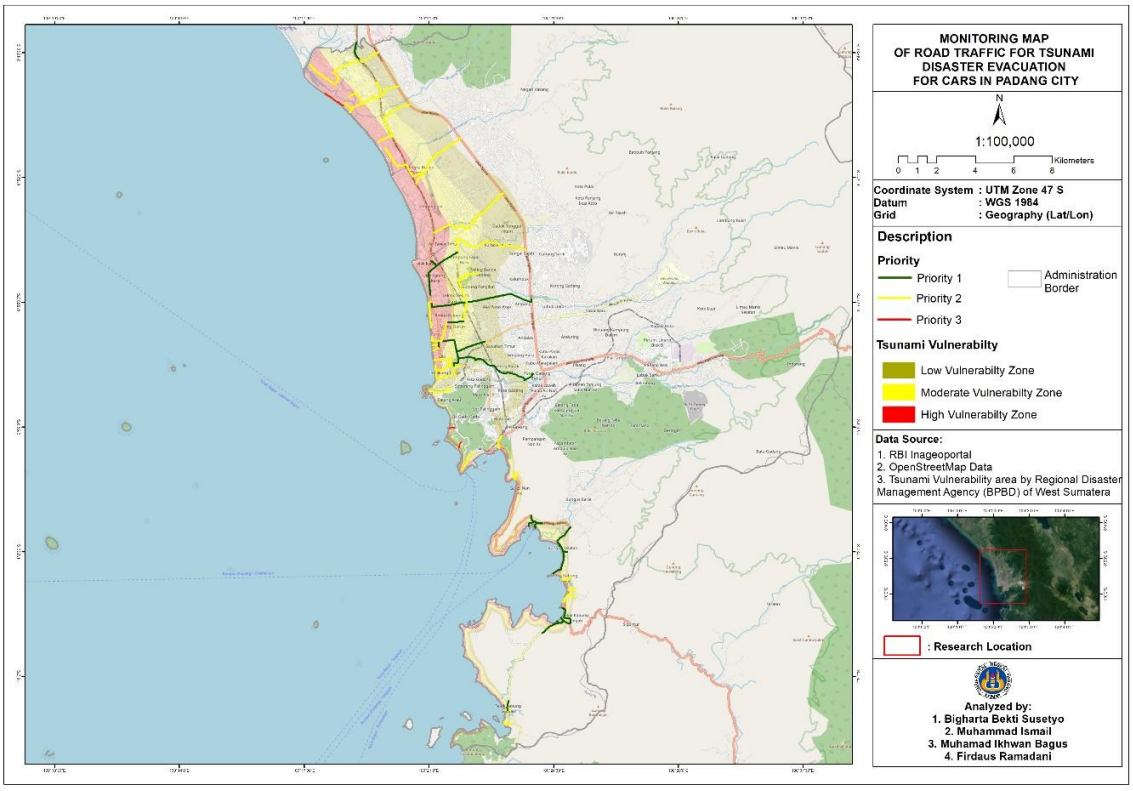

Fig 2 Monitoring of Road Traffic for Tsunami Disaster Evacuation for Cars

Table 3. Monitoring of The Road and Priority Scale for Cars

No	Road Monitoring					Priority Scale		
	Road's Name	Type	Length (m)	Road Direction (towards the beach)	Total Score	1	2	3
1.	S. Parman Street	Ring Road	9 m	Horizontal	8	✓		
2.	Jhoni Anwar Street	Collector	7 m	Vertical	8	✓		
3.	Raden Saleh Street	Ring Road	9 m	Vertical	10	✓		
4.	Khatib Sulaiman Street	Ring Road	9 m	Horizontal	9	✓		
5.	Ampang Raya Street	Ring Road	10 m	Vertical	10	✓		
6.	Adinegoro Street	Ring Road	9 m	Horizontal	9	✓		
7.	Ahmad Yani Street	Local	6 m	Vertical	6		✓	
8.	Sudirman Street	Collector	8 m	Horizontal	7		✓	
9.	Sawahan Street	Collector	8 m	Vertical	8	✓		
10.	Proklamasi Street	Collector	7 m	Vertical	8	✓		
11.	Air Camar Street	Collector	7 m	Vertical	8	✓		
12.	Padang-Painan Highway	Ring Road	8 m	Horizonal	8	✓		
13.	Bypass Street	Ring Road	10 m	Vertical	10	✓		
14.	Siti Nurbaya Street	Local	5 m	Vertical	6		✓	
15.	Tanjung Priok Street	Local	6 m	Horizontal	5		✓	
16.	Samudra Street	Collector	8 m	Horizontal	7		✓	
17.	HOS Cokroaminoto Street	Local	6 m	Vertical	6		✓	
18.	Robert Wolter Monginsidi Street	Local	6 m	Vertical	6		✓	
19.	Church Street	Local	6 m	Vertical	6		✓	
20.	Moh. Yamin Street	Local	6 m	Vertical	6		✓	
21.	Bundo Kanduang Street	Local	6 m	Vertical	6		✓	
22.	Karya Street	Local	5 m	Vertical	6		✓	
23.	Koto Marapak Street	Local	5 m	Vertical	6		✓	
24.	Damar 1 Street	Local	5 m	Vertical	6		✓	
25.	Olo Ladang Street	Local	5 m	Vertical	6		✓	
26.	Bandar Purus Street	Local	6 m	Horizontal	5		✓	
27.	Teuku Umar Street	Local	6 m	Horizontal	5		✓	
28.	Gadjah Mada Street	Local	6 m	Horizontal	5		✓	
29.	Penjernihan Street	Local	5 m	Vertical	6		✓	
30.	Siteba Highway	Local	6 m	Vertical	6		✓	
31.	Kemayoran Street	Local	5 m	Vertical	5		✓	
32.	Perjuangan Street	Local	5 m	Vertical	6		✓	
33.	Kurau Raya Street	Lokal	5 m	Vertical	6		✓	
34.	Bhayangkara Street	Local	5 m	Vertical	6		✓	
35.	Pasir Jambak Street	Local	5 m	Horizontal	5		✓	
36.	Ikur Koto Street	Local	6 m	Vertical	6		✓	
37.	Padang Sarai Street	Local	5 m	Vertical	6		✓	
38.	Evakuasi Street	Local	5 m	Vertical	6		✓	
39.	Setapak Street	Path	2 m	Horizontal	3			✓

Source: Results of data analysis, 2023.

Based on Figure 2 and Table 3, the priority scale for tsunami evacuation roads for cars is ranged from 1 to 3. This implied that not all roads leading to tsunami-safe zones are suitable for cars. Only 28.2% of the thirty-nine roads analyzed are included in priority 1. Furthermore, 69.23% are

categorized as priority 2 and 0.025% are categorized as priority 3. Due to the population density in the area, it is necessary to increase road traffic on priority 1, which is still below 50%. This requires a wide, paved road that is readily accessed by four wheels for one vehicle or two vehicles traveling simultaneously on two lanes to a tsunami safe zone.

According to field observations, the condition of the road was covered with asphalt/concrete. The elevation is also not a steep area. This condition is essential for facilitating or accelerating traffic flow on tsunami evacuation routes. The location and quantity of traffic signs and informational displays must always be evaluated. The community of Padang City must also know if there is information regarding the possibility of a tsunami, and if the road leading to a tsunami-safe location will be a one-way street.

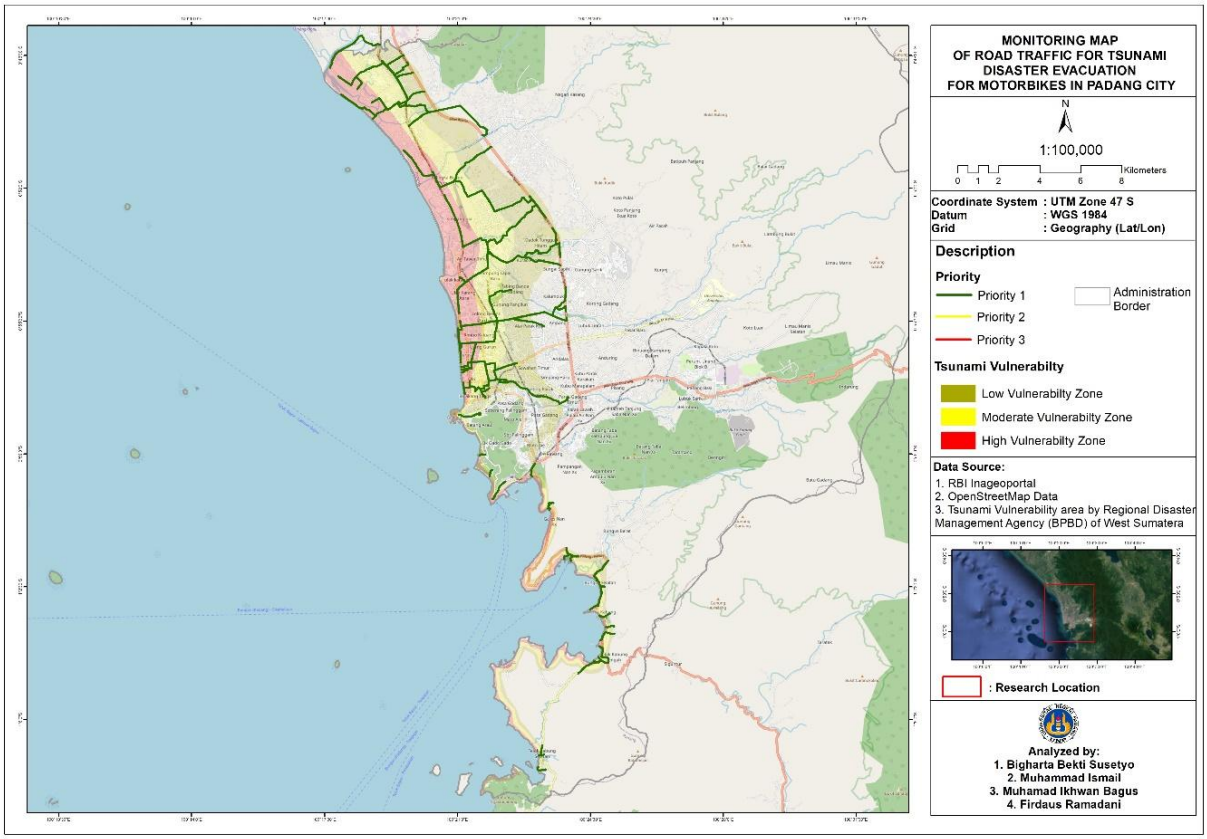

Fig 3 Monitoring of Road Traffic for Tsunami Disaster Evacuation for Motorbikes

Table 4. Monitoring of The Road and Priority Scale fo Motorbikes

No	Road Monitoring					Priority Scale		
	Road's Name	Type	Length (m)	Road Direction (towards the beach)	Total Score	1	2	3
1.	Adinegoro Street	Ring Road	9 m	Horizontal	9	✓		
2.	Padang Sarai Street	Local	5 m	Vertical	6	✓		
3.	Teritis Street	Local	5 m	Horizontal	5	✓		
4.	Evakuasi Street	Local	5 m	Vertical	6	✓		
5.	Bungo Tanjuang Street	Local	4 m	Vertical	6	✓		
6.	Bhayangkara Street	Local	5 m	Vertical	6	✓		
7.	Lubuk Gading Permai 3 Street	Local	4 m	Vertical	6	✓		
8.	Anak Air Street	Local	6 m	Vertical	6	✓		

9.	Kampung Jambak Highway	Local	6 m	Vertical	6	✓
10.	Pasia Nan Tigo Street	Local	5 m	Horizontal	5	✓
11.	Ikua Koto Street	Local	6 m	Vertical	6	✓
12.	Bronco Street	Local	4 m	Vertical	6	✓
13.	Taruko 4	Local	4 m	Vertical	6	✓
14.	Kemayoran Street	Local	5 m	Vertical	6	✓
15.	Kurau Highway	Local	5 m	Vertical	6	✓
16.	Siteba Highway	Local	6 m	Vertical	6	✓
17.	Lolong Karan Street	Local	6 m	Vertical	6	✓
18.	Jhoni Anwar Street	Collector	7 m	Vertical	8	✓
19.	Koto Marapak Street	Local	6 m	Vertical	6	✓
20.	Damar 1 Street	Local	6 m	Vertical	6	✓
21.	Olo Ladang Street	Local	6 m	Vertical	6	✓
22.	Bandar Purus Street	Local	6 m	Horizontal	6	✓
23	Prof Dr. Hamka Street	Ring Road	10 m	Horizontal	9	✓
24	Siti Nurbaya Street	Local	5 m	Vertical	6	✓
25	Tanjung Priok Street	Local	6 m	Horizontal	5	✓
26	Samudra Street	Collector	8 m	Horizontal	7	✓
27	HOS Cokroaminoto Street	Local	6 m	Vertical	6	✓
28	Robert Wolter Monginsidi Street	Local	6 m	Vertical	6	✓
29	Gereja Street	Local	5 m	Vertical	6	✓
30	M. Yamin Street	Local	6 m	Vertical	6	✓
31	Teuku Umar Street	Local	6 m	Horizontal	6	✓
32	Gadjah Mada Street	Local	6 m	Horizontal	6	✓
33	Penjernihan Street	Local	5 m	Vertical	6	✓
34	S. Parman Street	Ring Road	9 m	Horizontal	9	✓
35	Raden Saleh Street	Ring Road	9 m	Vertical	10	✓
36	Khatib Sulaiman Street	Ring Road	10 m	Horizontal	9	✓
37	Ampang Highway	Ring Road	10 m	Vertical	10	✓
38	Ahmad Yani Street	Local	6 m	Vertical	6	✓
39	Jendral Sudirman Street	Collector	8 m	Horizontal	7	✓
40	Sawahan Street	Collector	8 m	Vertical	8	✓
41	Proklamasi Street	Collector	7 m	Vertical	8	✓
42	Air Camar Street	Collector	7 m	Vertical	8	✓
43	Padang-Painan Highway	Ring Road	8 m	Horizontal	8	✓
44	Bundo Kanduang Street	Local	5 m	Vertical	6	✓
45	Karya Street	Local	5 m	Vertical	6	✓

Source: Results of data analysis, 2023.

According to Figure 3 and Table 4, all of the roads that served as tsunami evacuation routes in Padang City have a priority scale of 1 because they are influenced by road function type and road length, allowing motorbikes to cross. The infrastructure is good, and there are nearly no challenges because motorbikes can navigate even tight roads. The present roads in Padang City that serve as tsunami evacuation routes are therefore suitable for motorbikes.

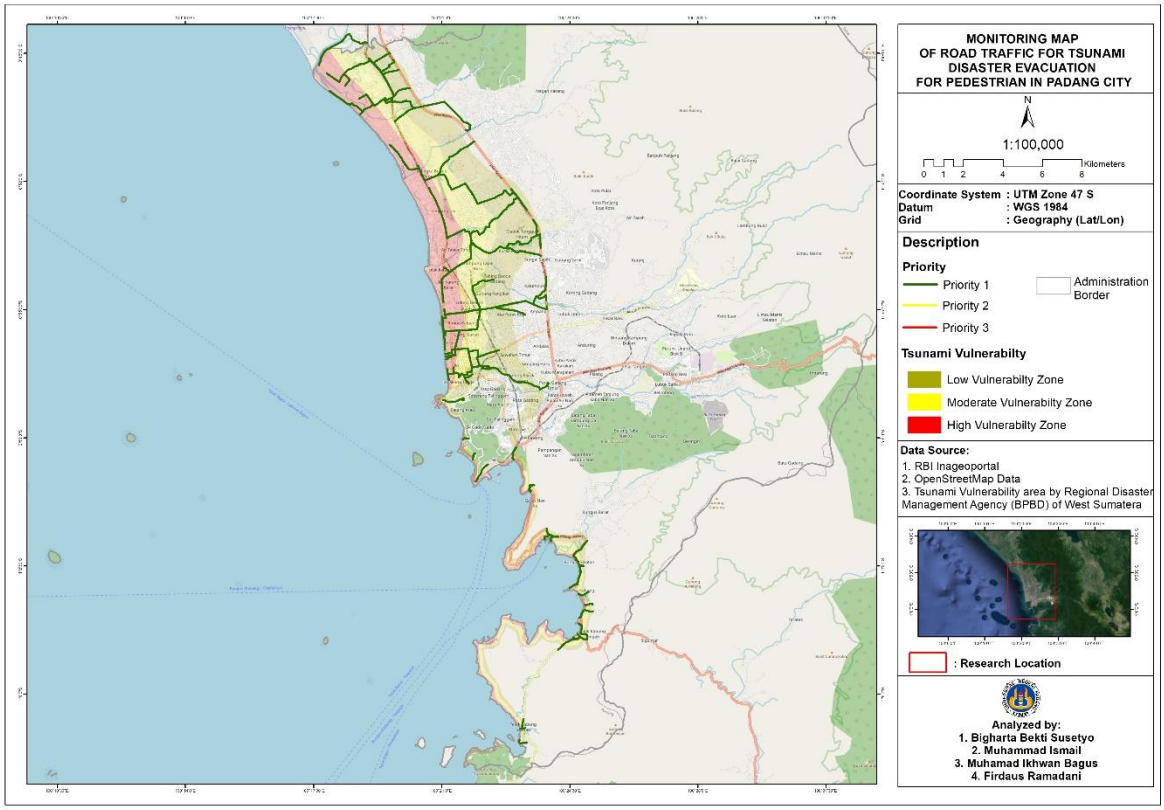

Fig 4 Monitoring of Road Traffic for Tsunami Disaster Evacuation for Pedestrian

Table 5. Monitoring of The Road and Priority Scale for Pedestrian

No	Road Monitoring					Priority Scale		
	Road's Name	Type	Length (m)	Road Direction (towards the beach)	Total Score	1	2	3
1.	Adinegoro Street	Ring Road	9 m	Horizontal	9	✓		
2.	Padang Sarai Street	Local	5 m	Vertical	6	✓		
3.	Teritis Street	Local	5 m	Horizontal	5	✓		
4.	Evakuasi Street	Local	5 m	Vertical	6	✓		
5.	Bungo Tanjuang Street	Local	4 m	Vertical	6	✓		
6.	Bhayangkara Street	Local	5 m	Vertical	6	✓		
7.	Lubuk Gading Permai 3 Street	Local	4 m	Vertical	6	✓		
8.	Anak Air Street	Local	6 m	Vertical	6	✓		
9.	Kampung Jambak Highway	Local	6 m	Vertical	6	✓		
10.	Pasia Nan Tigo Street	Local	5 m	Horizontal	5	✓		
11.	Ikua Koto Street	Local	6 m	Vertical	6	✓		
12.	Bronco Street	Local	4 m	Vertical	6	✓		
13.	Taruko 4	Local	4 m	Vertical	6	✓		
14.	Kemayoran Street	Local	5 m	Vertical	6	✓		
15.	Kurau Highway	Local	5 m	Vertical	6	✓		
16.	Siteba Highway	Local	6 m	Vertical	6	✓		
17.	Lolong Karan Street	Local	6 m	Vertical	6	✓		
18.	Jhoni Anwar Street	Collector	7 m	Vertical	8	✓		
19.	Koto Marapak Street	Local	6 m	Vertical	6	✓		

20.	Damar 1 Street	Local	6 m	Vertical	6	✓
21.	Olo Ladang Street	Local	6 m	Vertical	6	✓
22.	Bandar Purus Street	Local	6 m	Horizontal	6	✓
23	Prof Dr. Hamka Street	Ring Road	10 m	Horizontal	9	✓
24	Siti Nurbaya Street	Local	5 m	Vertical	6	✓
25	Tanjung Priok Street	Local	6 m	Horizontal	5	✓
26	Samudra Street	Collector	8 m	Horizontal	7	✓
27	HOS Cokroaminoto Street	Local	6 m	Vertical	6	✓
28	Robert Wolter Monginsidi Street	Local	6 m	Vertical	6	✓
29	Gereja Street	Local	5 m	Vertical	6	✓
30	M. Yamin Street	Local	6 m	Vertical	6	✓
31	Teuku Umar Street	Local	6 m	Horizontal	6	✓
32	Gadjah Mada Street	Local	6 m	Horizontal	6	✓
33	Penjernihan Street	Local	5 m	Vertical	6	✓
34	S. Parman Street	Ring Road	9 m	Horizontal	9	✓
35	Raden Saleh Street	Ring Road	9 m	Vertical	10	✓
36	Khatib Sulaiman Street	Ring Road	10 m	Horizontal	9	✓
37	Ampang Highway	Ring Road	10 m	Vertical	10	✓
38	Ahmad Yani Street	Local	6 m	Vertical	6	✓
39	Jendral Sudirman Street	Collector	8 m	Horizontal	7	✓
40	Sawahan Street	Collector	8 m	Vertical	8	✓
41	Proklamasi Street	Collector	7 m	Vertical	8	✓
42	Air Camar Street	Collector	7 m	Vertical	8	✓
43	Padang-Painan Highway	Ring Road	8 m	Horizontal	8	✓
44	Bundo Kanduang Street	Local	5 m	Vertical	6	✓
45	Karya Street	Local	5 m	Vertical	6	✓

Source: Results of data analysis, 2023.

Based on Figure 4 and Table 5, all of the roads that served as tsunami evacuation routes in Padang City have a priority scale of 1, indicating that all of the identified tsunami evacuation routes are suitable for pedestrian traffic. All of the roads can be utilized by pedestrians to move away from the coastline and towards the tsunami safe zone if the physical condition and function of the roads are maintained.

3.3 Discussion

Padang is one of the cities with a high level of vulnerability to tsunamis [18], as it is located in a plate subduction zone and thus has a high potential for oceanic earthquakes, which increase the probability of a tsunami [19]. The majority of Padang's populations live in coastal areas [20], so they require tsunami evacuation routes as a measure against natural disasters.

The road network plays a significant role in tsunami evacuation route planning [21]. The primary function of the road network, from a spatial perspective, is to connect one location to another. Effective tsunami evacuation routes can be identified through spatial network analysis [22], and the traffic of roads identified as tsunami evacuation routes can be evaluated further.

The spatial network analysis was conducted using a Geographic Information System (GIS) capable of calculating and estimating tsunami evacuation routes based on distance traveled [23]. Then, using the Open Route Services tool, which is linked to the Google Maps server, distance calculations and estimated travel time can identify effective tsunami evacuation routes, making them very useful for determining tsunami disaster mitigation policies in coastal areas [24].

Monitoring the road traffic to the tsunami evacuation route based on the types of transportation generally utilized by the community, namely: 1) four-wheeled vehicles (cars), 2) two-wheeled vehicles (motorbikes), and 3) pedestrian facilities [25]. Then, the function of the road [26], the length of the road [27], and the position of the road to the coastline are used to determine the priority route for road traffics in tsunami evacuation.

The results of the study indicated that transportation mode such as cars, have many

challenges, with ring road and collector road dominating the lanes with priority 1 for cars. This is because length of ring road and collector roads allows cars to cross when a tsunami warning is issued [28].

This regulation also applies to motorbikes because the weight and physical structure of motorbikes are lighter and more compact than cars [29], so that all tsunami evacuation routes in Padang City can be accessed entirely by motorbikes with a priority scale of 1.

Then, for pedestrian facilities, all identified tsunami evacuation routes are accessible to pedestrians with a priority scale of 1. In this research, routes to be accessed by pedestrians and vehicles are separated, i.e., road corridors are divided for pedestrians and motorbike drivers. Also considering the width of the current road[30], to minimize overcrowding of vehicles and population using the same route, so that every vehicle and pedestrian may move through the evacuation route without experiencing too much inconvenience.

4. CONCLUSION

In Padang City, road traffic for tsunami evacuation routes has different results for cars, motorbikes, and pedestrians. There are still many routes that have not become priority 1 for cars. Considering population density and the importance of mitigating or reducing fatalities, this is a recommendation for local governments to manage the road traffic. Priority 1 is assigned to the conditions of all motorbikes and pedestrian paths. The variable condition of road traffic has been met, and motoribikes and pedestrian traffic is sufficient to support road traffic for tsunami evacuation. This research suggests to maintain and improve the sidewalks, both for public facilities and for tsunami evacuation.

Padang City will need to inform the public in the future if there is a possibility of a tsunami caused by road traffic. This is to facilitate the mobility of self-evacuation, including whether or not two or more opposing lanes may become one-way lanes to a tsunami-safe location. The experience of the serious earthquake disasters in 2009 and 2010 should serve as a lesson in how to improve the efficient evacuation of population independently as disaster resilience for the community in Padang City.

5. REFERENCES

[1] D. Hermon, “Land stability model for sustainable spatial planning in Padang City-Indonesia based on landslide disaster,” *J. Geogr. Earth Sci.*, vol. 7, no. 1, pp. 19–26, 2019.

[2] F. Imamura, A. Muhari, E. Mas, M. H. Pradono, J. Post, and M. Sugimoto, “Tsunami disaster mitigation by integrating comprehensive countermeasures in Padang City, Indonesia,” *J. Disaster Res.*, vol. 7, no. 1, pp. 48–64, 2012.

[3] D. Arisa, B. Setiadi, and W. S. Priyanto, “Pre-and Coseismic Analysis of the Mw7. 6 Padang Earthquake 2009 from Geodetic Approach,” in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2021, p. 12069.

[4] H. Yue *et al.*, “Rupture process of the 2010 Mw 7.8 Mentawai tsunami earthquake from joint inversion of near-field hr-GPS and teleseismic body wave recordings constrained by tsunami observations,” *J. Geophys. Res. Solid Earth*, vol. 119, no. 7, pp. 5574–5593, 2014.

[5] D. H. Natawidjaja, “Updating active fault maps and sliprates along the Sumatran Fault Zone, Indonesia,” in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2018, p. 12001.

[6] Badan Standarisasi Nasional, *Rambu Evakuasi Tsunami*. Jakarta: Badan Standarisasi Nasional, 2011.

[7] A. Saputra, A. D. Saputra, D. Setiabudidaya, D. Setyawan, and I. Iskandar, “Validasi Areal Terbakar dengan Metode Normalized Burning Ratio Menggunkan UAV (Unmanned Aerial Vehicle): Studi Kasus,” *J. Penelit. Sains*, vol. 19, no. 2, pp. 66–72, Jun. 2019, doi: 10.26554/jps.v19i2.476.

[8] R. Febrina, D. K. Evan, L. Afriani, R. M. I. Retno, and H. A. Fitra, “The analysis of Tsunami evacuation route based on geographic information system: A case study in the coast of Lampung Bay,” in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, 2020, p. 12022.

[9] P. Debnath, “A QGIS-Based Road Network Analysis for Sustainable Road Network Infrastructure: An Application to the Cachar District in Assam, India,” *Infrastructures*, vol. 7, no. 9, p. 114, 2022.

[10] S. J. Carver, “Integrating multi-criteria evaluation with geographical information systems,” *Int. J. Geogr. Inf. Syst.*, vol. 5, no. 3, pp. 321–339, 1991.

[11] P. Jankowski, “Integrating geographical information systems and multiple criteria decision-making methods,” *Int. J. Geogr.*

Inf. Syst., vol. 9, no. 3, pp. 251–273, 1995.

[12] F. Lu and Y. Cao, "Three-Dimensional Modeling for Buildings Evacuation Management." 2012.

[13] QGIS, "ORS Tools," *Online Access*, 2019. https://plugins.qgis.org/plugins/ORStools/

[14] P. K. Bhuyan and M. S. Nayak, "A review on level of service analysis of urban streets," *Transp. Rev.*, vol. 33, no. 2, pp. 219–238, 2013.

[15] K. Kuribayashi, T. Hara, and S. Kuroda, "Study on seismic performance evaluation of road embankment along the coast," in *The 28th International Ocean and Polar Engineering Conference*, OnePetro, 2018.

[16] R. Indonesia, *Peraturan Pemerintah Republik Indonesia Nomor 34 Tahun 2006 Tentang Jalan.* 2006. [Online]. Available: https://jdihn.go.id/files/4/2006pp034.pdf

[17] A. Syukri, D. Hamid, L. Murdiansyah, A. Rozaan, and A. Roza, "Conceptual Design of Pedestrian Overpasses Bridge for Vertical Evacuation from Tsunami (POBET) in Padang City–West Sumatra," *J. Ilm. Rekayasa Sipil*, vol. 14, no. 2, pp. 1–10, 2017.

[18] F. Ai, L. K. Comfort, Y. Dong, and T. Znati, "A dynamic decision support system based on geographical information and mobile social networks: A model for tsunami risk mitigation in Padang, Indonesia," *Saf. Sci.*, vol. 90, pp. 62–74, 2016.

[19] N. Nofrion *et al.*, "SILENT SIMULATION: THE ABILITY OF GEOGRAPHY EDUCATION STUDENTS TO DO A HORIZONTAL EVACUATION TO A TSUNAMI SAFE ZONE IN PADANG CITY," *J. Geogr.*, vol. 13, no. 1, pp. 88–96.

[20] M. Di Mauro, K. Megawati, V. Cedillos, and B. Tucker, "Tsunami risk reduction for densely populated Southeast Asian cities: analysis of vehicular and pedestrian evacuation for the city of Padang, Indonesia, and assessment of interventions," *Nat. hazards*, vol. 68, pp. 373–404, 2013.

[21] M. J. Kurowski, N. Hedley, and J. J. Clague, "An assessment of educational tsunami evacuation map designs in Washington and Oregon," *Nat. hazards*, vol. 59, pp. 1205–1223, 2011.

[22] R. S. Dewi, "A-Gis based approach of an evacuation model for tsunami risk reduction," *IDRiM J.*, vol. 2, no. 2, pp. 108–139, 2012.

[23] F. Ashar, D. Amaratunga, and R. Haigh, "Tsunami evacuation routes using network analysis: a case study in Padang," *Procedia Eng.*, vol. 212, pp. 109–116, 2018.

[24] S. J. Scheer, V. Varela, and G. Eftychidis, "A generic framework for tsunami evacuation planning," *Phys. Chem. Earth, Parts a/B/C*, vol. 49, pp. 79–91, 2012.

[25] Y. Deng, Y. Chen, Y. Zhang, and S. Mahadevan, "Fuzzy Dijkstra algorithm for shortest path problem under uncertain environment," *Appl. Soft Comput.*, vol. 12, no. 3, pp. 1231–1237, 2012.

[26] F. Usman, K. Murakami, A. D. Wicaksono, and E. Setiawan, "Application of agent-based model simulation for tsunami evacuation in Pacitan, Indonesia," in *MATEC Web of Conferences*, EDP Sciences, 2017, p. 1064.

[27] F. Usman, S. Hariyani, and F. Shoimah, "Perencanaan Partisipatif Tanggap Darurat Bencana Tsunami Di Pesisir Selatan Watulimo, Trenggalek," *Tataloka*, vol. 23, no. 1, pp. 138–150, 2021.

[28] T. Takabatake, K. Fujisawa, M. Esteban, and T. Shibayama, "Simulated effectiveness of a car evacuation from a tsunami," *Int. J. disaster risk Reduct.*, vol. 47, p. 101532, 2020.

[29] Y. Goto, M. Affan, Y. Nurdin, and D. K. Yuliana, "Tsunami evacuation simulation for disaster education and city planning," *J. Disaster Res.*, vol. 7, no. 1, pp. 92–101, 2012.

[30] Z. M. Mayasari, M. Astuti, N. Afandi, and Y. Fauzi, "Vertical evacuation planning to reduce a risk of a tsunami disaster in teluk segara district, bengkulu city," in *Journal of Physics: Conference Series*, IOP Publishing, 2021, p. 12010.