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Planning Evacuation Routes as Tsunami Disaster Mitigation in Coastal Makassar City

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Abstract. The recent series of earthquakes can trigger tsunamis. Coastal areas are highly dynamic and therefore potentially subject to tsunami threats. Makassar City is a coastal area. Therefore, Makassar City is vulnerable to hit by tsunami, as the increasing stress at the ends of the active plates around Sulawesi Island, which increases the potential for seabed earthquakes, which in turn can cause tsunamis. The absence of a tsunami disaster mitigation concept in the southern coastal area of Makassar city increases the chances of huge losses in the event of a tsunami. The purpose of this research is to map the tsunami disaster mitigation in the southern coastal area of Makassar City. The research method is observational spatial data input and direct observation in the field. All coordinate data and the latest earthquake became the main input in the SiTProS program, while spatial data used ArcGIS Map. The research study area is from The Rinra Hotel (Phinisi Point Mall) to Barombong Stadium. The path along this route will be the location of the proposed Temporary Evacuation Site (TES) route, with the scenario that there are 15 building units that are higher than the maximum wave height at the coastline of 4.29 meters that can be recommended for vertical evacuation. The simulated tsunami propagation time to reach a tsunami detection device (buoy) was 30.586 minutes after a potential tsunami occurred in the Sulawesi Sea at an earthquake of 5.8 SR, and the time to reach the coastline was at 41.44 minutes. The best shortest path for evacuation during a tsunami is away from the Barombong bridge and the Jeneberang River estuary. This study concluded three evacuation routes, namely: (I) the route after Barombong bridge towards the south up to Barombong Stadium; (II) the route after Barombong bridge towards the north up to the bridge after GTC Mall; (III) the route from CPI towards the south up to the bridge before GTC Mall (Danau Tanjung Bunga road). In these evacuation routes, the ones that can be used as alternative routes are route I and route III because they go beyond the coastal boundary. Meanwhile, route II is not recommended as it exceeds the coastal boundary.

Keywords: Planning, Evacuation Routes, Disaster Mitigation, Tsunami, Makassar Coastline

1 Introduction

Makassar City is the biggest coastal city in South Sulawesi, also in Eastern Indonesia (Marfai, 2014). This Metropolitan City consist of 15 subdistrict inhabited by 1.4 mil-

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lion people (Pemerintah Kota Makassar, 2021).Makassar's territorial boundaries is the coastal area stretches along approximately 35 kilometers from the north to west and south coast of the city. Based on the recapitulation of the tsunami hazard assessment shown in the Table 1.1 and Figure 1.1. We can be see that there are 11 sub-districts that have potential to be hit by the high level tsunami and 4 sub-districts in moderate level.

Table 1. Potential Area Affected by The Tsunami Disaster in Makassar City in 2020

No	Sub-districts	Moderate level tsunami potential		High level tsunami potential		Total Wards	Total Area (Ha)
		Wards	Area (ha)	Wards	Area (ha)		
1	Biringkanaya	-	-	3	364.86	3	364.86
2	Mamajang	-	-	1	3.96	1	3.96
3	Mariso	-	-	7	91.75	7	91.75
4	Panakkukang	1	2.79	1	238.68	2	241.47
5	Sangkarrang Islands	-	-	3	154.00	3	154.00
6	Tallo	1	0.90	5	280.22	6	281.22
7	Tamalanrea	1	0.18	4	1,436.67	5	1,436.85
8	Tamalate	-	-	4	572.55	4	572.55
9	Ujung Pandang	-	-	4	39.87	4	39.87
10	Ujung Tanah	1	3.06	5	43.74	6	46.80
11	Wajo	-	-	5	33.75	5	33.75
Grand Total		4	6.93	42	3,260.05	46	3,266.98

(Source: Makassar City Government, 2021)

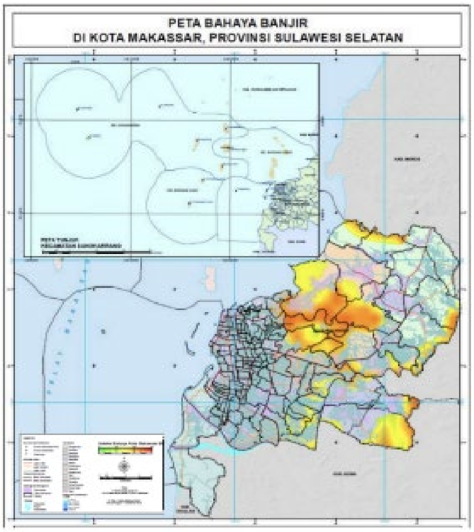

Fig. 1. Tsunami Hazard Map in Makassar City in 2020

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Tsunami waves are generated by earthquakes, volcanic eruptions, or underground landslides that can destroy coastal areas. Time gap between the earthquakes and tsunami can be used to provide early warning to the community to avoid disaster. That describes tsunami disaster mitigation (Baeda et al., 2024). Mitigation is a series of efforts to reduce disaster risk, either through physical development or through awareness in increasing the ability to face the threat of disaster (Pemerintah Republik Indonesia, 2007). Tsunami mitigation is one form of emergency response to disasters. Disaster emergency response is the series of activities that carried out immediately at the time the disaster occurs. It must have been carried out immediately to deal with the negative impacts caused by the disaster, which includes Search and Rescue (SAR) activities and evacuation, properties, fulfillment of basic needs, protection shelter, management of refugees, and restoration of infrastructures and facilities (Pemerintah Republik Indonesia, 2007). It means, when the threat of tsunami occurs, for example caused by earthquakes, the SAR activities in vulnerable areas can be carried out as soon as possible before causing more damage so it is necessary to establish evacuation routes as part of tsunami disaster mitigation (Bestari & All Exis Vernando Salmon, 2023). Evacuation route is a oath or route to evacuation spot, where become the gathering point of disaster victims until the they evacuated to shelter or safe place (Susilorini et al., 2020). Mitigation act can be described by the characteristics, such as: (1). Passive mitigation dan (2). Active mitigation. Preventive measures that are included in active mitigation include several things, are: making and placing warning danger warning signs, prohibition on entering disaster-prone areas, relocation of people from disaster-prone areas to safer areas, planning of Temporary Evacuation Site (TES) (Baeda et al., 2016). There are two common methods, which are horizontal evacuation and vertical evacuation. Horizontal evacuation methods is evacuating people from the hazard area to safe far place. Vertical evacuation method executed by relocating people to a strong multi-storey buildings located around the disaster location (Kurniawan et al., 2019).

Makassar City has planned as an implementation of waterfront city concept[1] and also one of the coastline which directly faces the southern part of the Makassar Strait (Baeda et al., 2016). Therefore mitigation map in the form of evacuation path and evacuation procedures are required, in case a seabed earthquake occurs at the southern part of Makassar Straits. In this research area, further research is required regarding the direction of wider tsunami waves, consist the southern part of Metro Tanjung Bunga Street which is densely populated area (Baeda et al., 2016). Here are the importance of this research lies, because recently the series of earthquakes around the globe occur, is feared can trigger tsunami. The problems formulations are: how the tsunami disaster mitigation mapping in the southern part of Makassar Coastal Areas and how are the evacuation map resulted by spatial analysis and numerical simulation of tsunami inundation.

2 Data Sources and Research Methodology

2.1 Data and Research Area

Research method start with collecting primary data by input the spatial datas and direct observation on site. While secondary data gained from internet browsing, private

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documentation and interpretation. The whole coordinate and recent earthquakes data become main input in SiTProS application software. SiTPros (Siam Tsunami Propagation Simulator) is an application software included math modelling for predicting tsunami, the propagation, real-time simulation and visualization. It is an application to get the modelling of artificial tsunami waves visualization on research location (Bulawan, 2024), while spatial data used to form pattern, processed by ArcGIS Pro and ArcGIS Map. This is applied to identify the threat from tsunami and tsunami detector response to an earthquake events. The following complement of evacuation map/mitigation which is evacuation route are:

1. Collect range data on the time span of running, walking, climbing stairs activities in research area with the certain range of age
2. Collect data about buildings height and inventorying which building that are worthy of being Temporary Evacuation Site (TES) around the research area
3. Input wave’s height and impact time data
4. Input digital data of site topography and land use
5. Input the coordinate point of the research area

Those secondary data included: boundaries latitude and longitude in southern Makassar Coastal City, slope data, land use datas, time span of community activities. The research route start from The Rinra Hotel (Mall Phinisi Point) to Barombong Stadium. Pathway along the route become the proposed location of Temporary Evacuation Place. The lane marking using ArcGIS Pro application.

Fig. 2. Research Location Map (Source: Data Processing, 2024)

Tsunami Simulation using SiTPROS application software. First, determine the coordinate location of research site. Earthquake events data support taken from the nearest coordinate which is in latitude -3.44° and longitude 118.12° in 2008 at Sulawesi Sea, the source was from www.globalcmt.org. The minimum Magnitude set in 5. From this application, recent earthquakes data around research site taken in 5.8 SR

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magnitude, the marking set by Google Earth Pro. SiTPros application also used to plan the buoy placement (tsunami wave detector).

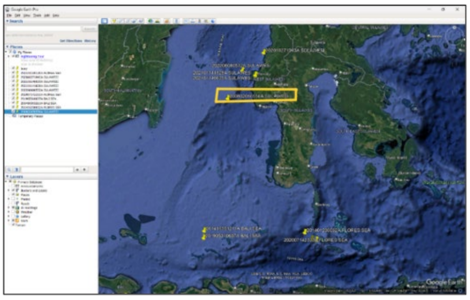

Fig. 3. Earthquake Spot Tak to Magnitude (Mw) Input (Source: Google Earth input, 2024)

Buoy placement is approach the coastline. From tsunami propagation simulation, obtained that the time of tsunami reach the buoy are 30,586 minutes.

Fig. 4. Time of tsunami reach the buoys's simulation (Source: SiTPros simulation, 2024)

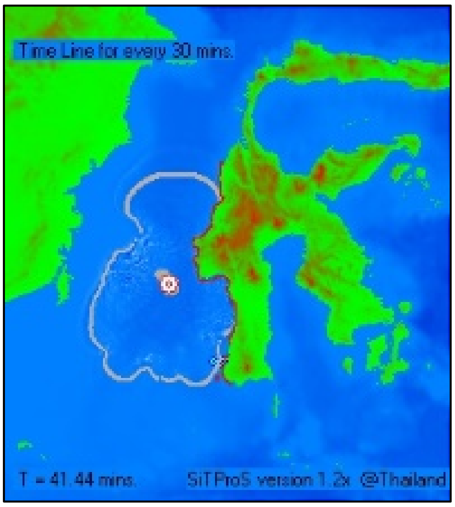

Fig. 5. Tsunami propagation reach coastline simulation at minute 41,44 (Source: SiTPros simulation,2024)

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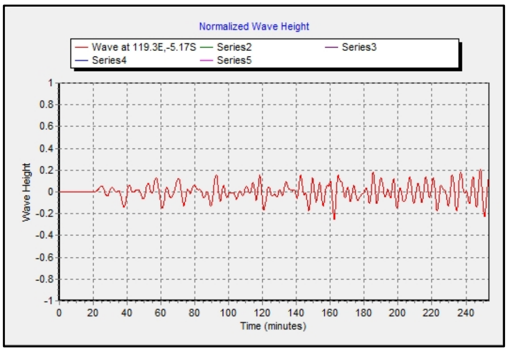

Fig. 6. Shortest Time of Tsunami's Impact in minutes (Source: SiTPros simulation,2024)

From resulting figures of tsunami wave reach the buoys simulation, is taken the time where the Coastline color start to change to red color. That is the time of critical events, where the tsunami waves already reach along the coastline. And from the figure result is taken at a minute 41,44 since the earthquakes that potentially turn into tsunami waves occurs.

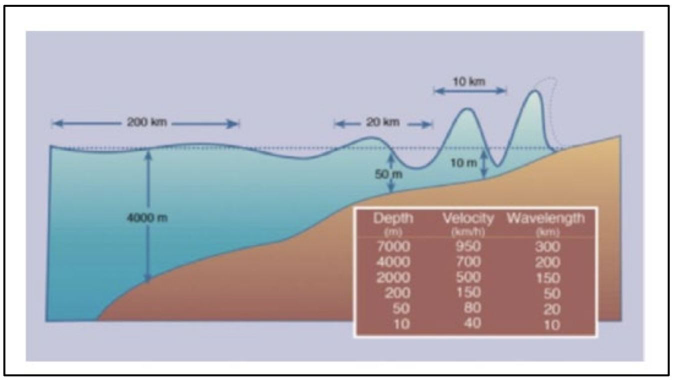

Fig. 7. Propagation of tsunami to the coastline, whose wave height rises as it runs towards shallower waters (run-up). (Source: IOC – UNESCO (2016) in (Bulawan, 2024))

The next step is calculated the wave's height with Aydan Formula (Bulawan, 2024):

Hm = A x Mw x exp (b x Mw);

ΔHr = B x Hm

Hr = Hm + □Hr

Where:

A, b and B is a constant number. For tsunami in Indonesia's area, the constant number for A = 0,004; b = 0,9; dan B = 2,5

Mw = magnitude

Hm = maximum height of wave at the coastline

ΔHr = run-up height of tsunami wave

Hr = run-up height, counted from average water surface

The run-up is the first wave of tsunami. Run-up is not always constitutes of the highest wave because the height and damage level caused by tsunami also can be affected by factors such as water depth, coast geometric, earthquake magnitude which triggers the tsunami destruction wave (Baeda & Namiruddin (2019) in Bulawan, 2024).

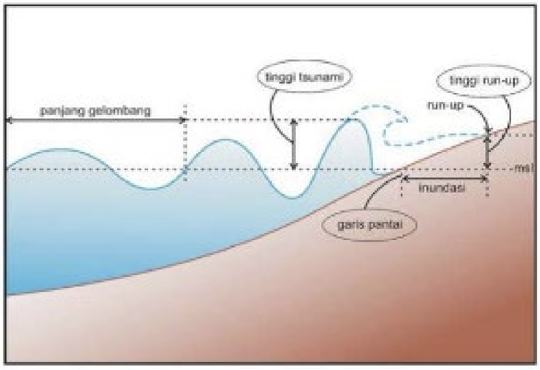

Fig. 8. Run-up Tsunami (Source: Puspito (2010) in Bulawan, 2024)

In evacuation route planning, spatial analysis required to determine the slope, land use and road network map for the making of evacuation roadmap as tsunami disaster mitigation (Badan Standardisasi Nasional, 2017). The slope classification is listed at the Table 2.1.

Table 2. Slope classification

Class	Slope (%)	Classification
I	0 – 8	Flat
II	>8 – 15	Sloping Steep
III	>15 - 25	Slightly Steep
IV	>25 – 45	Steep
V	>45	Extremely Steep

(Source: Guidelines for Preparing Land Rehabilitation and Soil Conservation Patterns (1986) in Bodro Setyoko et al.(2019))

2.2 Methodology

The following method to complete the information in the range of analysis's compilation according to Kurniawan et al.(2019), are:

Analysis of Regional Spatiality.
Analysis of Regional Spatiality is an analysis using ArcGIS Map 10.3.1 software based on Digital Elevation Model (DEM) data to being applied in Cost Weighted Stance (CWS) analysis. Cost Weighted Stance (CWS) analysis commonly using to create accessibility modelling with different value for every land use and every steep of slope. The values are Cost Weighted Distance (CWD) between initial cell and the nearest destination point. The truth is by Spatial Analysis, we weighted the slope

using the existing land use according to Table 2.2. Cost weighted converted into raster format with one cell represents one meter(ESRI, n.d.). Every data detail has value which describe type of land use and the slope to affect the speed of refugee walking or running or climbing stairs activities.

Table 3. The required time to across every cell based on the certain slope range

Val-ue (%)	Slope (%)	Speed (m/sec) = 1.34*new grade	Inverse Speed (sec/m)
85	0 – 9	1.34	0.87796313
45	9 – 15	0.603	1.65837479
35	15 – 27	0.469	2.13219616
20	27 – 36	0.268	3.73134328
12	36 – 48	0.1608	6.21890547

(Source: Asian Disaster Preparedness Center (ADPC), 2007)

Speed conservation valued 100 (in %). In this study, the average evacuation speed are set in 1,34 mps based on the slowest speed from unassisted elder people. Inverse speed formula are: $\frac{1}{\frac{Land\ use\ Value}{100}\times\frac{Slope\ Value}{100}\times 1.34\ (average\ speed)}$ (Kurniawan et al., 2019). The folowing table about the required time to accross every cell based on land use class describes in following table.

Table 4. Required Time to Across every cell based on Land Use Class

Value (%)	Land Use	Speed (mps)	Speed (spm)
5	Settlements	0.067	14.92537
60	Fields	0.804	1.243781
50	Rice Fields	0.67	1.492537
100	Bridge	1.34	0.746269
90	Coast	1.206	0.829187
95	Open Land	1.273	0.785546
1	Swamps	0.0134	74.62687
80	Open vege-tation	1.072	0.932836
1	Canals, Rivers, Lakes, Ponds	0.0134	74.62687
50	Shrubs	0.67	1.492537
100	Arterial roads	1.34	0.746269
100	Collector roads	1.34	0.746269
90	Local roads	1.206	0.829187

(Source: Widyaningrum (2009) in Kurniawan et al. (2019))

This research can only be obtained using surface modelling by Google Earth Pro Satellite Figure. This is because the free downloaded DEM Data from internet for Makassar or Sulawesi Island are not complete so that it was difficult to be processed in the available ArcGIS Map software. For Satellite Figure taken from SAS Planet which the output saved as Google Maps version. DEM data resulted the coastline contour along the research pathway, topographic map whose shown the height of site's contour, slope map, land use map and boundaries space map. Meanwhile, environmental parameters that explain tsunami vulnerability can be seen in Table 2.2.

Table 5. Environmental parameters that explain tsunami vulnerability

Parameter	Range	Description	Score	Weight %
Elevation (m)	<10	Very high	5	25
	>10 – 25	High	4	
	>25 – 50	Medium	3	
	>50 – 100	Low	2	
	>100 – 350	Very low	1	
Slope (%)	0-2	Very high	5	20
	2-5	High	4	
	5-15	Medium	3	
	15-40	Low	2	
	>40	Very low	1	
Land Use	Resettlements, Ricefields, Swamps, Rivers	Very high	5	15
	Gardens/Vegetations	High	4	
	Fields	Medium	3	
	Lakes, Grasslands, Savanna, Shrubs	Low	2	
	Forests, Rocks, Steep Slopes, Limestones	Very low	1	
Distance from coastline (m)	0-500	Very high	5	20
	>500-1000	High	4	
	>1000 – 1500	Medium	3	
	>1500 – 3000	Low	2	
	>3000	Very low	1	
Distance from river	0 – 100	Very high	5	20
	>100 – 200	High	4	
	>200 – 300	Medium	3	
	>300 – 500	Low	2	
	>500	Very low	1	

(Source: Mujani (2024) in Baeda et al.(2024))

The appearance of speed inversion in the following maps are in land use which the shapefiles formed in polygon, which are resettlements, rice fields, swamps, fields, and vegetations. In arterial roads, collector roads, local roads and bridge were not appeared because of the shapefiles formed in polyline, while in coast and river boundaries although the shapefiles are in polygon has only shown in table based on the necessity that the locals are required to leave the place as soon as the tsunami potential warning announced.

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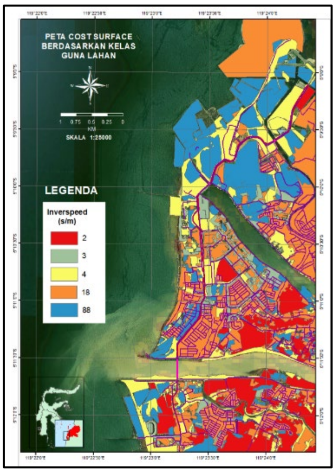

Fig. 9. Cost *Surface* Maps based on Land Use Classification (second per meters) (Source: Analysis, 2024)

Table 6. Required time to across every cell based on land use class

Land USE	Land Use Value (%)	Slope Val-ue (%)	Slope (%)	Invers Speed (second per meter)
RESETTLEMENTS	5	85	0 - 8	17.559
FIELDS	60	45	8-15	2.764
SWAMPS	1	85	0 - 8	87.796
RICE FIELDS	50	85	0 - 8	1.756
VEGETATIONS	50	35	15 - 25	4.264
COAST	90	85	0 - 8	0.976
BRIDGE	100	35	15 - 25	2.132
RIVER	1	85	0 - 8	87.796
ARTERIAL ROAD	100	85	0 - 8	0.878
COLLECTOR ROAD	100	85	0 - 8	0.878
LOCAL ROAD	90	85	0 - 8	0.976

(Source: Kurniawan et al. (2019))

Suggestion Temporary Evacuation Site (TES) Analysis.

Suggestion Temporary Evacuation Site (TES) Analysis in research area based on Tsunami height scenario that the topography of the study area is relatively low. This will determine the type of evacuation in the event of a tsunami disaster. Building height must exceed the maximum wave height at the shoreline (Hm) and the criteria set are according to Budiarjo (2008), Mück (2008), and Widyaningrum (2009), in Kurniawan et al.(2019), which are:

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1. Located outside the coast boundary (200 meter) and the river boundary (100 meter);
2. Preferably located on a main road for easy visibility;
3. Near or in a residential area

For consideration, the buildings public area are easily accessible for many people (the public) to enter in a short time and has proper spacious, strong construction, slope and land use function are included.

Least Cost Path (LCP) Analysis.
It is an evacuation route that can be accessed to the location of the Temporary Evacuation Site (TES) within the time period provided. The analysis of evacuation roadways carried out GIS (Geographic Information System) from ArcGis software. Then the land use value and slope illustrate the speed reduction assumptions for each class. Previously, modeling was made in the Arc Tool Box that entered sequentially: Spatial Analyst Surface (Slope) - Surface Reclass (Reclassify) - Spatial Analyst Overlay (Weighted Overlay) - Spatial Analyst Distance (Cost Distance and Cost Backlink) - Spatial Analyst Distance (Cost Path). In weighting, the variables taken only slope and land use because the path of the research location determined is already in the range 0 - 500 in Table 2.2., where the tsunami vulnerability is very high. The modeling results will show the Least Cost Path, or the closest path in determining evacuation routes, then create a series of tsunami disaster mitigation maps. This means that the creation of evacuation route maps is based on descriptive spatial analysis of the region and numerical simulations of tsunami propagation analysis results.

3 Results and Discussion

The calculated wave height at 41.44 minutes is 0.009790839 meters as a graphical output from the SiTPros Application. With A is 0.004; b is 0.9; B is 2.5; and the magnitude (Mw) used is 5.8. Maximum wave height at the shoreline (Hm) = 0.004 x 5.8 x exp(0.9 x 5.8) = 4.29047307 meters. Tsunami wave run-up height (ΔHr) = 2.5 x 4.29047307 = 0.105018324 meters. The run-up height calculated from the mean water level (Hr) is 0.147025654 meters. The maximum normalized wave is 0.04200733 meters. Meanwhile, the tsunami evacuation map is as follows:

3.1 Spatial Analysis of the Region

The next analysis conducted is the analysis of slope, land cover and road network that will be used as a consideration in making evacuation maps as tsunami disaster mitigation at the Research Site which is located on the south coast or more precisely in the southwest of Makassar City. Figure 3.1 shows the topographic map of the research location.

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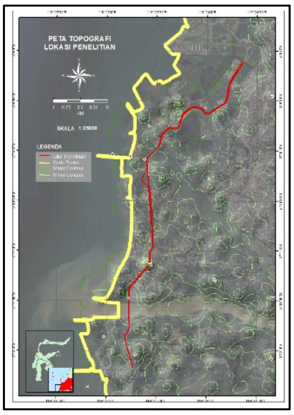

Fig. 10. Site's Topographic Map (Source: Analysis, 2024)

From Figure 3.1 Slope Map, it can be seen that the slope at the research site is dominated by dark green (Flat), light green (Sloping) and yellow (Slightly Steep).

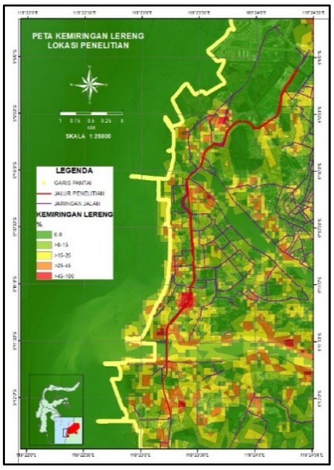

Fig. 11. Slope Map (Source: Analysis, 2024)

Since the map is sourced from Google Satellite Imagery taken through SAS Planet 210409.10126 Nightly, the imaged areas with steep slopes (Orange) and very steep (Red), but in reality on the ground there is no slope in question, it can be concluded that the results of the slope analysis based on this satellite image also refer to the height of the surrounding buildings.

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Fig. 12. Rows of Three-Story Shophouses at the Research Site (Source: Field Observation, 2024)

The placement of TES was carried out with considerations as described earlier, namely choosing public places with wide openings and on relatively flat slopes, exceeding the coastal boundary distance (200 meters), exceeding the river boundary distance of 100 meters, building construction that is strong enough, and having enough space for vertical evacuation beyond the maximum wave height when the Tsunami reaches the coastline.

3.2 Least Cost Path (LCP) Analysis

From the Barombong Stadium - Rinra Hotel path, there are three bridges crossed by the River. Therefore in determining the Least Cost Path (Shortest Distance) the point of origin is divided into three points to represent areas that are heavily inhabited or traveled by vehicles. From this point of origin, Weighted Cost Modeling (Cost Distance, Cost Backlink and Cost Path) will be carried out to fifteen Temporary Evacuation Sites (TES). The three Shortest Evacuation Route (Least Cost Path) modeling scenarios are as follows:

If residents or drivers have passed the Barombong bridge to the south (away from Makassar City), it means that when the announcement of a potential Tsunami is issued, they are urged to immediately evacuate vertically to TES 2 (Homwell Store) and TES 1 (Barombong Stadium). The shortest routes (LCP01_1 and LCP01_3) have exceeded the coastline (200 meters) and can be used as alternatives. It is expected to avoid the Barombong bridge and stay away from the Jeneberang River estuary.

If residents or drivers have passed the Barombong bridge to the north (entering Makassar City), meaning that when the announcement of a potential Tsunami is issued, they are urged to immediately evacuate the farthest vertical before the second bridge after the Barombong bridge, which is to TES 7 (GTC Mall). Along this northbound route, vertical evacuation can also be carried out by heading to TES 3 (Grand Toserba Metro Tanjung), TES 4 (Inalum Store), TES 5 (Warkop Phoenam) and TES 6 (Colonial Hotel). However, the shortest distances on these evacuation routes (LCP02_1 and LCP02_3) fall within the coastal boundary, so it is recommended to follow the normal route, i.e. the research route (in Figure 3.5 shown in red).

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If residents or drivers have just entered the Tanjung Bunga area to the south (pass the CPI), this means that when the announcement of a potential Tsunami is issued, they are advised to immediately evacuate the farthest vertical after the third bridge (after the Barombong bridge, is to TES 8 and 9 (Rolling Hills Shophouse and Ocean Drive Shophouse). Along this route there are also nearby TES, namely TES 15 (Rinra Hotel), TES 14 (Gammara Hotel), TES 13 (Upper Hills Convention), TES 12 (Honda Metro Tanjung) and TES 10 (Trans Mall / Mega Bank). The Shortest Evacuation Routes (LCP03_1 and LCP03-3) are outside the coastal boundary so they can be used as alternative evacuation routes in addition to the research route.

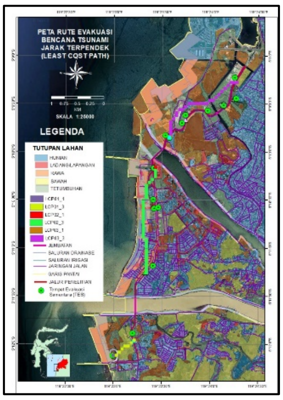

Fig. 13. Least Path of Tsunami Disaster Evacuation Route (Least Cost Path) (Source: Analysis, 2024)

4 Conclusion

If an earthquake occurs in an area located at latitude -3.44° and longitude 118.12° in the Sulawesi Sea with an earthquake magnitude of 5.8 SR, the time for tsunami waves to reach buoys (tsunami early warning tools) which commonly placed close to the coastline is approximately 30.586 minutes. If the buoys are functioning properly, this time can be used to immediately warn residents to evacuate both horizontally and vertically. The time for tsunami waves to reach the coastline is about 41.44 minutes. From the run-up calculation, the run-up height of tsunami waves reaching the shoreline at the research location is 0.105018324 meters or about 10.5 cm. While the average water level is 0.147025654 meters or about 14.7 cm. The best shortest path for evacuation during a tsunami is away from the Barombong bridge and the Jeneberang River estuary. This study concluded three evacuation routes, namely: (I) the route after Barombong bridge to the south up to Barombong Stadium; (II) the route after Barombong bridge to the north up to the bridge after GTC Mall; (III) the route from CPI direction to the south up to the bridge before GTC Mall (Danau Tanjung Bunga road). In these evacuation routes, the ones that can be used as alternative routes are route I and route III because they go beyond the coastal boundary. While route II is not recommended. It can be replaced with this research's route, which is Metro Tanjung Bunga Street as arterial roads.

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A suggestion from this research is that research can be continued with a of a potential tsunami disaster event scenario with the earthquake's magnitude is greater than 5.8 SR. It is also possible to model evacuation routes that continue further to south. Also possible to model evacuation routes further away from the coastline.

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