ANALYSIS OF TSUNAMI EVACUATION ROUTE PLANNING IN KULON PROGO REGENCY

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Abstract. Situated on the southern coast of Java Island, Kulon Progo Regency is prone to tsunami hazards since it directly faces the subduction zone of the Eurasian Plate and the Indo-Australian Plate. The road condition on the coast of Kulon Progo Regency, which extends from east to west, can be an obstacle in the evacuation process if there is no proper evacuation route planning. Therefore, it is essential to plan an evacuation route in the coastal area of Kulon Progo Regency. This study proposes the tsunami evacuation route and evaluates it with field conditions on the coast of Kulon Progo Regency. The evacuation route was built using the Least-cost path analysis. The Least-cost path analysis for determining the evacuation route was carried out in two scenarios: A and B. The results of the Least-cost path analysis of scenario A are considered less suitable because the results are more through land use and away from the road network. The results of scenario B are better able to represent conditions in the field because the path is adjacent to the road network that can be passed either by vehicle or pedestrian.

Keywords: *tsunami, evacuation route, Least-cost Path , Kulon Progo Regency, scenario*

1 INTRODUCTION

Indonesia is prone to tsunamis because it is located at the confluence of three tectonic plates: the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate. These are subduction zones between the continental and oceanic plates (Koshimura, 2019). Kulon Progo Regency is in the southern part of Java Island. It is directly adjacent to the Indian Ocean, facing the subduction zone of the Eurasian Plate and the Indo-Australian Plate. The morphology of the coast in Kulon Progo Regency tends to be flat because it is a landform alluvial plain. Therefore, when the high wave occurs, water will enter the mainland far away and make a wide overflow area which can threaten the society of Kulon Progo Regency. Based on historical data by Badan Nasional Penanggulangan Bencana (2012) of tsunami events in South Java, there have been two massive tsunamis: the Banyuwangi tsunami and the 2006 Pangandaran tsunami. Approximately 90% of the estimated population at risk from the tsunami survived due to a rapid evacuation to higher ground (Mas et al., 2013). Therefore, tsunami evacuating route map preparation is needed to be one of the non-physical tsunami disaster mitigation efforts (Sudaryatno et al., 2022).

The success of the evacuation depends on the effectiveness of the evacuation route, so it is necessary to compile an evacuation route map. Then it can be evaluated related to the evacuation route on the coast of Kulon Progo Regency. Thus, the negative impact of the tsunami disaster can be minimized. The determination of evacuation routes is based on a tsunami hazard map and more parameters (Kitamura et al., 2020). The decision of evacuation routes needs to consider hazard areas and evacuation routes' conditions. A Hazard area is required to reference the dangerous and safe areas. Whereas evacuation routes must be secure, in good conditions, and easy to pass, evacuation routes outside buildings must be broad enough and can be passed by at least two vehicles.

The determination of evacuation routes can be carried out using the integration of remote sensing technology and geographic information systems (GIS). GIS, with the spatial multi-criteria evaluation, can be used to identify the actual leadership procedure utilizing the geo-reference information (Febrina et al., 2020). The Least-cost path analysis algorithm considers the value of surface cost to generate the least cost between source and destination. The Least-cost path analysis can generate an evacuation route with no or poor road network conditions in an evacuation scenario.

Most minor Cost Path Analysis is a geospatial analysis method related to modeling the area of conformity (Gustas & Supernant, 2017). It is used to find the optimum route on raster data; it starts with making a cost surface using a weighted overlay, usually the Multi-Criteria Decision Analysis method, then followed by the process of making cost distance, cost backlinks, and cost path analysis. The parameters used in this analysis are land use to be the base of the roughness coefficient, the slope for assessment movement through the mountainous regions of the highlands, and the road to measure the road width and reflect the road capacity (BSN, 2019; Gowen & de Smet, 2020; Putri & Maryono, 2018). Those parameters are related to the affordability of evacuation points that are easier to reach.

Previous literature on tsunami evacuation routes was conducted by Grumbly et al. (2019) with the research site in Aberdeen, Washington. The study combined evacuation maps using the Least-Cost Path and participating maps to determine the evacuation route based on their local knowledge can then be used to determine clearance time (minimum time needed to reach safety). The Least-Cost Path evacuation route indicates that pedestrian simulation tends to overestimate the ability of pedestrian populations to evacuate before the arrival of a tsunami wave safely. Meanwhile, evacuation routes based on community participation are classified as requiring a long clearance even though the line made is a straight line because the route is made without considering land use, so it is less effective. In Kulon Progo Regency, the main road, called Jalur Lintas Selatan (JLS), is parallel to the shoreline, which is ineffective as an evacuation route. The Least-cost path analysis used in this paper determines evacuation points perpendicular to the coastline. Further, the result of the evacuation route map is evaluated to the field condition.

In Kulon Progo, no evacuation maps cover all the districts. Habibi & Khakim (2017) conducted a study to determine tsunami evacuation routes in Wates District using the Network Analysis method; the survey results produced three evacuation routes with three different gathering points. These results were considered poor because the evacuation route was parallel to the coastline, and the evacuation was ineffective. So it is necessary to have an evacuation route planning that improves the limitations of the previous evacuation route.

2 MATERIALS AND METHODOLOGY

2.1 Study Area

This research location is in the Kulon Progo Regency's coastal area. These areas include the sub-districts of Temon, Wates, Panjatan, Galur, Kokap, Pengasih, and Lendah. The reason for choosing this area is because the coast of Kulon Progo is directly adjacent to the Indian Ocean. This causes this area to have the potential for a tsunami. In addition, it is also supported by the existence of the Indo-Australian Plate, whose movement is often the cause of earthquakes, where earthquakes are one of the causes of tsunamis. This is supported by the existence of YIA Airport in Kapanewon Temon, Kulon Progo Regency. This airport was built in the coastal area of Kulon Progo Regency which can increase the rate of population growth in the vicinity, either temporarily or permanently. Based on data released by BPS in 2022, the total population in the study area reached 149,574 people. This study area was selected considering the hazard map made by the Indonesia-German Working group on Vulnerability Modeling and Risk Assessment, which was coordinated by LIPI and DLR. The areas potentially affected by the tsunami hazard can be seen in the (German-Indonesia Cooperation of a Tsunami EWS, n.d.) The research area can be shown in Figure 2-1.

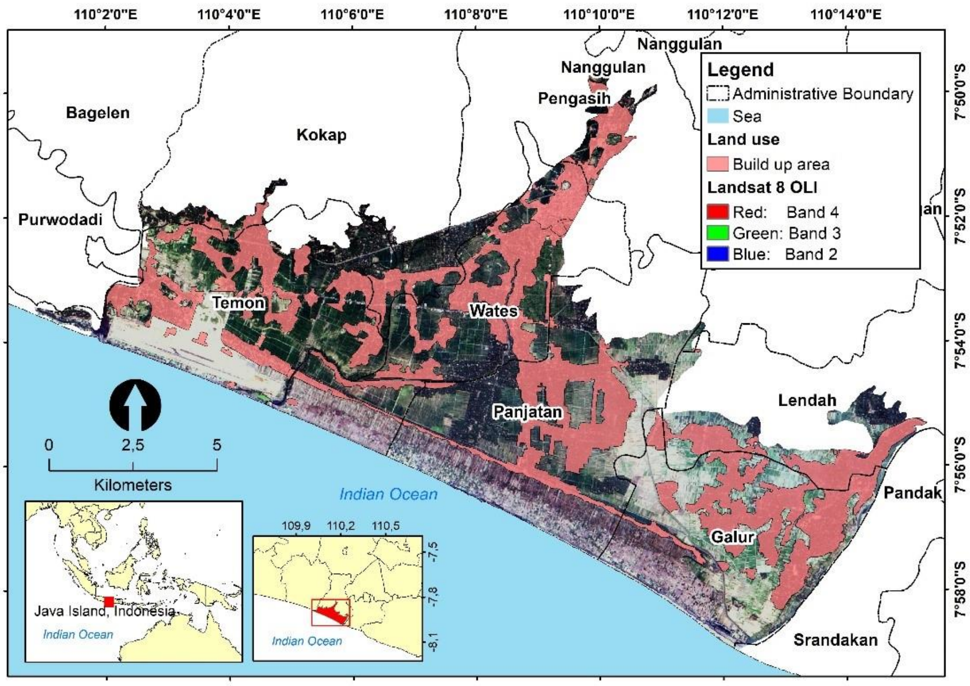

Figure 2- 1 Study area

2.2 Data Collection

The data used in this study consisted of Landsat 8 OLI imagery, ALOS PALSAR DEM with a vertical accuracy of 2.0×10^{-4}, and road network data. Data collection is shown in Table 1. For all data, the clipping process occurs at the boundary of the study area shapefile. From Landsat 8 OLI imagery, information extraction is done through visual interpretation to obtain land use information. ALOS PALSAR DEM was visually interpreted to identify terrain, then the slope information from this terrain information. The road network data is rasterized and converted from vector to raster data.

Table 2-1: Data sources.

Data	Source
Landsat 8 OLI imagery Accusation date July, 7th 2021	United States Geological Survey (USGS) in website https://earthexplorer.usgs.gov/
DEM ALOS PALSAR	//search.asf.alaska.edu/#/
Road network	https://tanahair.indonesia.go.id/portal-web

Further, the workflow of this research can be shown in the flow chart in Figure 2-2.

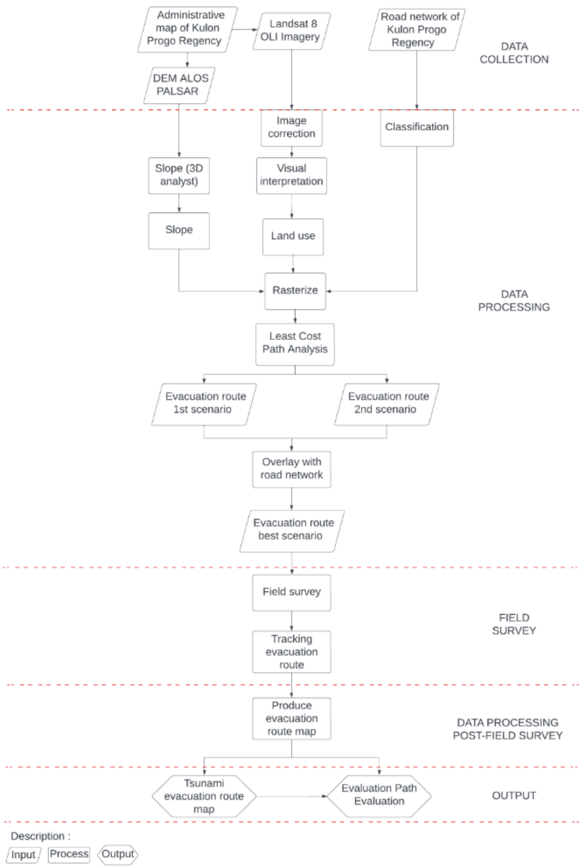

Figure 2-2: Study workflow

2.3 Data Processing

Data processing is done by raster-based analysis, namely, Least-cost path analysis. The parameters used in this analysis are land use, slope, and road network. Each parameter will be given a weight according to its accessibility to be traversed by either vehicles or pedestrians. The Least-cost path algorithm will determine the best route for the evacuation route. The Least-cost path analysis begins with making a cost surface. The next process is the creation of cost distance and cost backlinks. The results of cost distance and cost backlinks are used to generate cost path analysis.

2.4 Evacuation Route Map

The Least-cost path analysis is used to determine the evacuation route from several points in the coastal area of Kulon Progo Regency to the evacuation point. Least-cost path analysis is a GIS-based method that focuses on landscape characteristics, such as slope and land cover to obtain the most efficient path from the hazard zone location (Wood & Schmidtlein, 2012). The approach that can be done is the isotropic approach. An isotropic approach is an approach that combines aspects of land use and slope to make evacuation trips more quickly and efficiently. The route is determined by the weight given to each parameter. From the Least-cost path analysis results, field validation (by tracking) was done to test the resulting route's accessibility.

Evacuation route planning is carried out by processing cost path analysis. The analysis requires field validation to find out the most logical evacuation route that can be passed. The results of field validation indicate that cost path analysis considering land use is the most logical evacuation route. Said to be logical because there is continuity between the results of the analysis and field validation. This conformity can be validated from the figure below. That the results of tracking in the field are not much different from the results of the cost path analysis.

2.5 Least-cost Path Analysis

The Least-cost path analysis method is applied for pedestrian and vehicle evacuation simulations. These two simulations can be done by calculating the Least-cost path using two different scenarios. Within these two scenarios, they have different parameter weights. The first scenario is called scenario B, which uses land use as the main parameter. The distribution of a selection of this scenario considers the distance that is not too far away dan free from the hazard zone. This is because this scenario is made so that residents can pass during a tsunami disaster by running without using a vehicle. This choice of this scenario is to avoid road damage due to tsunamis such as earthquakes (Marfai et al., 2021). In contrast, the scenario created for the second scenario, called scenario A makes the road network parameter the main parameter. This considers the road network's ability on the Kulon Progo to accommodate residents who save themselves during a tsunami disaster. Therefore, this evacuation route is made from the coastline and is safe from the danger zone. Referring to SNI 7766:2012, it is necessary to consider several things, such as

1. Far from shorelines, river estuaries, river bodies, waterways, or industrial areas, as well as across rivers or over bridges, near lakes, lakes, swamps or lakes,
2. Create several alternative evacuations to avoid the accumulation of refugees, create a block system for evacuation routes in residential areas, where a river body perpendicular limits each block to the shoreline,
3. Create a temporary safe area system for sloping to flat areas in the form of buildings or artificial hills,
4. Find the shortest and safest path, which is equipped with evacuation signs to the assembly point. The gathering point is a field or open space.

The Least-cost path analysis parameters are land use, slope, and road. The parameters can be seen in table 2-2.

Table 2-2: Parameters used.

Parameters	Description
Land use	Build up area
	Forest
	Moor/field
	Open land
	Plantation
	Pond
	Ricefield
	Sand
	Shrubs
	Waterbody
Slope	Flat
	Sloping
	Slightly tilted
	Crooked
	Steep
	Very Steep
Road	Arteri road
	Collector road
	Local road

One starting point can be made by several evacuation points to avoid a buildup of refugees. The evacuation point chosen is the result of consideration of the applicable regulations regarding tsunami hazard evacuation. Based on the SNI regulations that have been mentioned, evacuation points are sought that meet the best criteria for locations that can be used as evacuation sites for tsunami hazards. The evacuation points are scattered in several Kapanewon locations, as shown in table 2-3.

The least-cost path analysis must prepare starting points as areas considered prone to tsunami events. This point is divided into four points scattered along Kulon Progo. These points are Glagah Beach, Karangwuni Village Coast, Baitullah Mosque (located near Bugel Beach and Gumukwaru Beach), and Trisik Beach Lagoon. These four starting points are used for two different simulations. The points used as material for starting checks in the field operating vehicles are the Glagah Beach point, Karangwuni Village Coast, Baitullah Mosque (located near Bugel Beach and Gumukwaru Beach), and the starting point for pedestrian simulation using the point from Trisik Beach Lagoon.

Table 2-3: Evacuation point plan.

Kapanewon	**Evacuation Point**
Kokap	Sibogor Field
	Kokap Kapanewon Office
Pengasih	Banaran Field
	Pengasih 2 Junior High School
Wates	Univesitas Negeri Yogyakarta
	Wates Sport Centre
	The Wates Square
	Giripeni Low-cost Flat
	Cangkring Stadium
Panjatan	Panjatan 1 Junior High School
Sentolo	Demangan Field
Galur	Sewugalur Field

3 RESULTS AND DISCUSSION

3.1 Least-cost Path Analysis

The best cost path analysis can be done by trial and error with the best results from each scenario used. The Least-cost path analysis using scenario A is emphasized on road network parameters of 80%, land use parameters and slope gradients are given a value of 10%. The results of this evacuation route can be seen from the image below. The four starting points resulted in evacuation routes leading to several evacuation points. The first point resulted in an evacuation route to Sibogor Field, Kokap Kapanewon Office, and Banaran Field. Of these three routes, the evacuation route to Sibogor Field is the shortest evacuation route resulting from the first point, while the farthest point is at Banaran Field. At the second point, it produces an evacuation route that leads to three evacuation points, namely Wates Sport Center, The Wates Square, and Universitas Negeri Yogyakarta. The evacuation route resulting from scenario A is perpendicular to the coastline. The third point of the evacuation route using vehicle simulation resulted in five lanes leading to five different evacuation points. Of these five evacuation routes, the longest route is the evacuation route to Compassionate 2 Junior High School, while the shortest route is the evacuation route to Panjatan 1 Junior High School. Evacuation routes that use vehicle routes simulation are still not suitable. This is because the paths or roads that are made are not in the existing road network. The road network that is formed passes through land uses that tend to be impassable. In contrast to the results of the evacuation route with a pedestrian route simulation away from the river and past the use of paddy fields and residential blocks that are still passable.

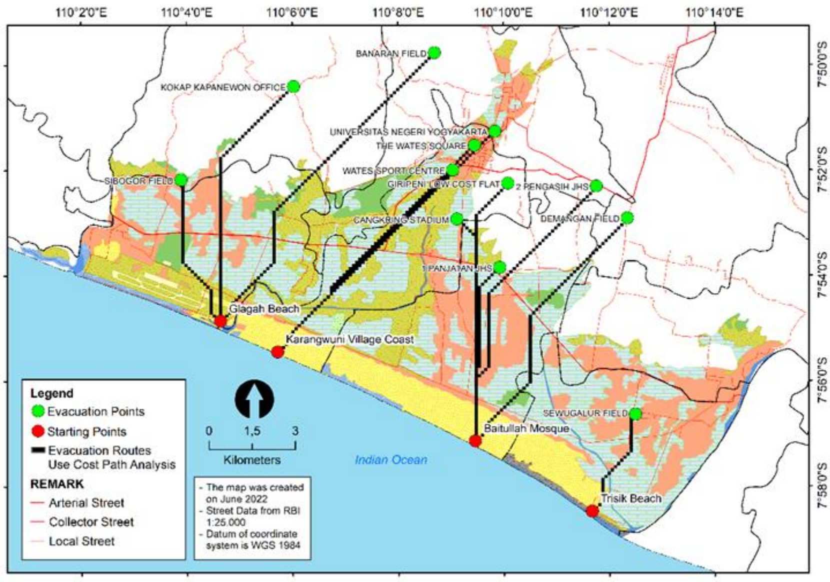

Figure 3-1: Cost Path Evacuation Route Map using Scenario A

The Least-cost path analysis with scenario B is emphasized on the land use parameter by 50%, the slope parameter by 40%, and the road network parameter by 10%. The results of the evacuation route for the scenario B can be seen in Figure 3-2. The resulting evacuation route of scenario B has a different evacuation route than scenario A. At the first point leading to the evacuation point which is similar to the result of the evacuation route of scenario A. However, both have different forms of evacuation routes. The second point resulted in four evacuation routes leading to Cangkring Stadium, Wates Sport Center, The Wates Square, and Universitas Negeri Yogyakarta. From the four evacuation routes produced, it can be known that the evacuation route to Cangkring Stadium is the shortest route for the second point. At the third point, there are also four evacuation points, namely Panjatan 1 Junior High School, Demangan Field, Compassionate 2 Junior High School, and Giripeni Low Cost Flat. This figure shows that the evacuation route built is much more representative. This is because three lanes for vehicles are formed near the road network. This result can be said to be able to represent conditions in the field and can be used as a reference in checking in the field. Meanwhile, the path for the pedestrian route simulation does not have much difference from the evacuation route using scenario A.

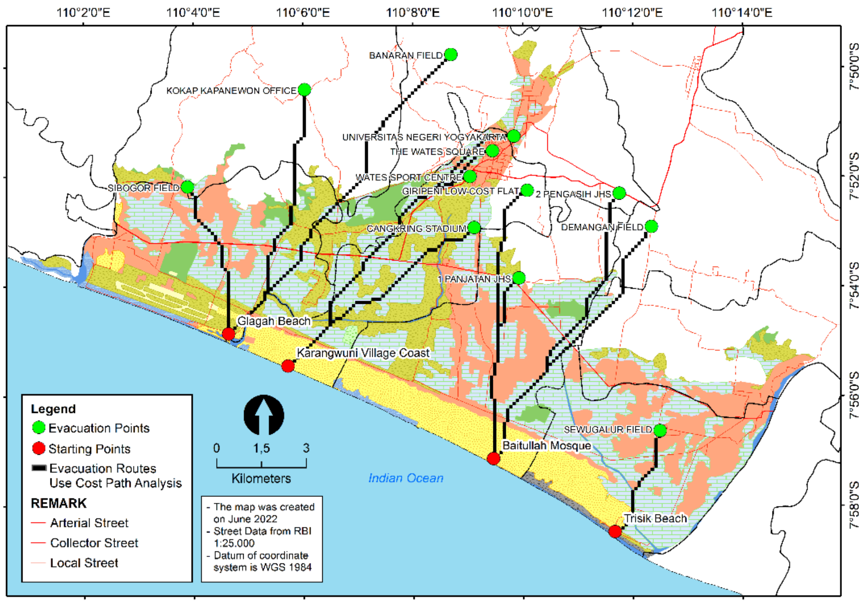

Figure 3-2: Cost Path, Evacuation Route Map, using Scenario B

3.2 Evacuation Route

Based on the two scenarios that have been made, one scenario is chosen, namely scenario B, to be checked in the field. This check was done from the four points selected from as

The evacuation route's initial location. Three points were chosen for the travel simulation to the evacuation point using a four-wheeled vehicle. One other point is selected for the walking simulation.

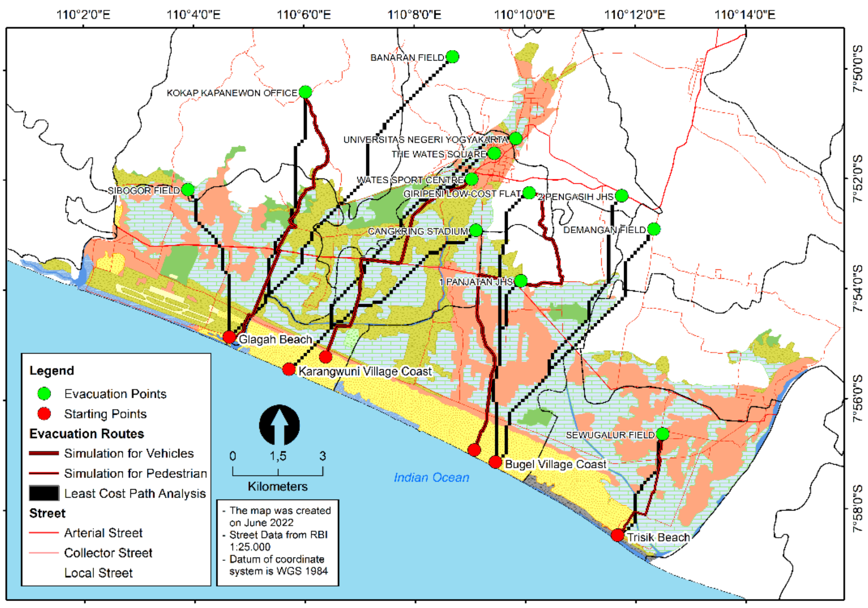

Figure 3-3: Evacuation Route Map using Best Scenario (Scenario B)

Three of the four evacuation starting points have different evacuation routes. Based on these results, the most representative evacuation route for each point is one. At point one, the most effective and representative evacuation route is the evacuation route from Glagah Beach to Kapanewon Kokap Office. This line is formed in a residential area with a wide road network. However, during point 1 fieldwork, control lies in road repairs, which can be an obstacle in evacuations.

The second chosen point was in Karangwuni Village, which was in an inaccessible mining area. Therefore, the second point was moved to the north, which is in a settlement area. This relocation considers the vulnerability of the residential area to the tsunami hazard. Checking the accessibility of evacuation routes in the field starts from the starting point, which goes straight to the footpath. The choice of this path is due to its direction which is perpendicular to the coastline. However, this road is relatively narrow if you use a four-wheeled vehicle. It is lucky because this evacuation route can be continued in a broader road network, so it does not hinder the evacuation process from going to Wates Sport Centre.

The third point is a point that is along the path on the coast, precisely Bidara Beach. From the four evacuation routes generated by the cost path analysis, Junior High School 1 Panjatan and Rusunawa Giripeni were selected as evacuation points. These two evacuation points were chosen because the two locations were close together. The results of tracking the evacuation route in the field from the starting point of the Baitullah Mosque need to pass the Trisik Beach Off-Road Road, whose road is damaged and can hinder the evacuation process. Therefore, the starting point of this area was shifted to Bidara Beach. This point is chosen due to the exit route that leads to the north with better road conditions. The third point above is the starting point for the tsunami hazard identification route using the vehicle route simulation.

Another point on Trisik Beach is used as a point for pedestrian simulation. This is because the results of the cost path analysis to this point lead to the Sewugalur Field, where the handling's accessibility can still be reached easily. Unlike the other three evacuation routes, this fourth line focuses on the ability of land use for pedestrians to pass through. The starting point in the field is also changing due to the difficulty of accessibility to the selected starting point for the path cost path. Therefore, this evacuation route starts from Trisik Beach. The path taken is a road that is in the settlement area that can still be passed until later it enters the rice field area that leads perpendicular to the coastline. Even though it is included in the rice field area, this evacuation route can still pass through a path that can be passed on foot. Not only passing through the rice field area, but the evacuation route with a pedestrian simulation also passes through the yard area. However, for pedestrian simulations, the evacuation route chosen passes through the rice field area with the hypothesis that rice fields can be passed when there is a tsunami. The ability of land use can be seen from the water content, which can complicate the evacuation process.

3.3 Evaluation of Evacuation Routes

The evacuation route intended for pedestrians produces an evacuation route that passes through the river network. This is because the weight of the slope is 40%. The relief with high accessibility is flat, while the river network tends to have a flat relief. With this result, then tracking in the field tend not to follow the path but to adjust the conditions in the area. Adjustments are made by considering whether land use can be passed.

As a result of the field survey, it was seen that the road signs leading to the evacuation site were still not directed. Many pieces of the road do not have evacuation point directional signs. These road signs are more often found on major roads that are often passed. Road signs should be given on every road leading north. This can help the evacuation process more effectively and efficiently. There are also broken road boards that are still not repaired. In general, Kulon Progo Regency still needs to improve regarding the procurement of evacuation route road boards. They were supported by good road conditions and following regulations related to good evacuation routes.Some roads leading to beach attractions in Kulon Progo have damaged, rocky, and narrow road conditions . The situation of this road is quite tricky for tourists or residents to carry out the evacuation process. There must be continuity between the opening of the attraction and the good road condition.

4 CONCLUSION

Least-cost path analysis from the scenario A and scenario B produced routes with the same distribution of evacuation points. The scenario created resulted in a different evacuation route. If a comparison is made, then scenario B has a result that better represents the conditions in the field than the parameters used. This result relates to evacuation routes that are almost parallel or are on a road network in the field. Based on the results of this processing, a field survey was carried out for several evacuation routes by selecting one from several evacuation points at each starting point so that one lane was formed leading to the evacuation point at each starting point. Basically, the Least-cost path analysis produced by this study is still not perfect. Based on the results of tracking in the field, the results obtained tend not to follow the path of the Least-cost path analysis results. The path resulting from field tracking is the result of adjustments to road conditions in the field. However, the results of the Least-cost path analysis adjusted to the simulation in the field can be taken into consideration in making evacuation routes in Kulon Progo. However, the condition of the road perpendicular to the coastline tends to be narrow and some roads have been damaged so it cannot be said to be good for the evacuation process. Supported by the fact that the road leading perpendicular to the coastline is not much to pass by vehicle. The streets that lead north are trails that can only be reached by pedestrians. It is important to have road board facilities on every small road so that people can evacuate quickly during a tsunami. In addition, the lack of roadboard facilities along the coastal tourism is a concern in the creation of evacuation routes. The creation of evacuation routes needs to be supported by socialization and simulation to the community so that the evacuation process can run smoothly.

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