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INTEGRATING SPATIAL COST PATH AND MULTI-CRITERIA ANALYSIS FOR FINDING ALTERNATIVE ROUTES DURING FLOODING

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Abstract

Route accessibility is essential infrastructure, facilitating more convenient transit for individuals. Nonetheless, the seasonal monsoon can lead to flooding and impair the accessibility of local transportation, especially in hilly-lowland areas. This study aims to investigate an alternative route access for safe travel from Kota Marudu to Kota Kinabalu, Sabah, during the floods with GIS path analysis and MCDA method. The slope, rainfall, land cover /land use (LULC), distance from the river and river density were utilized to construct the flood susceptibility map using Analytic Hierarchy Process (AHP), while path analysis was applied to find the accessible and safe routes. There are two other routes in the study region, one of which may be utilized as a suitable route. A new route should be considered to create roads in the higher area. The alternate route map suggested in the study is a beneficial tool as caution during the rainy season. As the flood's extent is simply an estimate, it is only possible to forecast the event, and sometimes can result in unexpected tragedy.

Keywords: Cost Path Analysis, GIS-MCDA, Alternative Routes, Flood Vulnerability, Transportation Accessibility

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INTRODUCTION

Floods are situations where water overflows onto ordinarily dry ground. In Malaysia, the main pattern of floods is a seasonal monsoon event. Flooding can occur as a consequence of an overflow of water from a water body, such as a river, lake, or ocean, where the water overtops or breaks levees, allowing some of the water to escape its regular limits, or as a result of rainwater accumulating on a wetland in a flood area. Human environmental alterations or land use changes can cause flooding, including deforestation and the removal of wetlands in the low-lands.

Floodings are not unusual events that can be predicted in a particular area due to many factors and effects facility damages. It includes the accessibility of a particular area's roads that have increased the number of infrastructural danger in recent decades (Suarez et al., 2005). The factors are predicted to influence road infrastructure significantly (Kalantari et al., 2019). Regarding alternative safe routes during flooding, it can facilitate people with more convenient mobility, which also contributes to more vigorous activities, indirectly helping the economic growth of a country. However, the seasonal monsoon and erratic weather may carry the rain that causes water overflow in low-land areas.

Roads submerged in floodwaters will restrict the movement of people. Several examples have been reported in the local news and media over the years, with claims that numerous victims were stranded on the road after being unable to reach their destinations. Some victims were carried away by the flood current as they tried to cross the flood. Thus, with the current IT and software development, it is now easier to analyze data, especially Geographical Information System (GIS) spatial data from many open-source data or related departments.

A GIS is a spatial system capable of creating, managing, analyzing, and mapping various forms of data, especially for natural disasters such as floods (Adnan et al., 2014). By merging location data with other types of descriptive data, GIS connects the data to a map. This process creates the spatial framework for mapping and analysis of flood events in conducting cost path analyses in perspective of today's growing urbanization and the resulting need for better surface transportation options. Traffic-influencing events and demand must be considered while building a road network (Vonderohe et al., 1993). GIS was also used to construct a road information management system, as Thlakma et al. (2015) studied, especially for resolving complicated road network issues.

In order to provide an alternative safe route access, it may be feasible to identify alternative paths that may not be affected by flood by utilizing the GIS technique. Ultimately, a path map showing a safe access route during a flood may be utilized as a detour in Sabah. Two main objectives were set in the study: i. to identify the areas impacted by flooding in the study area, and ii. to examine the proposed or new suitability of route access during flooding in the study area.

GIS PATH ANALYSIS AND AHP TECHNIQUES FOR LOCATING ALTERNATIVE PLANNING ROUTES

Flooding has a terrible impact on people's lives and socioeconomic situations, posing a severe threat to civilization (Qi & Altinakar, 2011). A flood occurs when the channel's capacity fills, and the water flows out of the channel (Huang et al., 2008). The natural cause of flood disasters is due to intense precipitation, prolonged rainfall, snow melt and storm surges. Floods have devastating consequences in underdeveloped countries such as Malaysia. In Sabah, the risk factors that increase flood susceptibility include land use, manufactured structures, and climate change. Land use changes such as dense urbanization and poor dam/drainage construction can trigger flood severity. Floods harm traffic by limiting vehicle movement and disrupting overall road network connectivity, as some impacted roads have become impassable and must be closed. Studying traffic route choice as an alternative for road users is crucial to overcome the spatial network problem.

The definition and concept of "alternative route "route" is a path taken to get from a starting point to a destination. Concerning that, "road" has the common concept defined as a long path extending from one location to another, particularly one having a specifically prepared surface that vehicles may use, which in other words is a long, narrow strip of the road having a smoothed or paved surface used for transport by motor vehicle, carriage, between two or more locations. While "alternative" emphasizes a proposal or scenario that provides a choice between two or more options in which something can be chosen instead. Moreover, it can also be another plan to make something feasible. Thus, an "alternative route" begins at a point where it diverges from the main numbered route and may travel through specific cities and towns and then re-joins the main route some miles later or improve a route for better convenience, as suggested by the Dunn Engineering Associates for U.S.A Department of Transportation (2006).

Mapping flood vulnerability is critical for identifying flood risk zones and developing mitigation strategies (Swain et al., 2020). Prior to selecting an alternative route, it is crucial to identify the affected part of the flood hazard area for alternative route risk assessment. Floods are complex dynamic occurrences; hence the flood vulnerability assessment can be done by using Analytical Hierarchy Process (AHP). AHP is a multi-perspective, multi-objective decision-making paradigm that enables users and planners to extract a quantitative scale of preference from a collection of choices (Ayalew & Yamangishi, 2005). By employing a ranking scale, Saaty (1987) presented a pair-wise comparison matrix (PCM) approach for constructing weighting factors for a particular criterion.

The criteria are then used to create a flood susceptibility map to indicate the severity of a flood in a particular area. The factors can include rainfall distribution, slope, river density, land use, and the distance from the river. The study chose these criteria based on their importance and relevance to flood mapping from various references in previous publications and expert opinions. It will give the rate from the most significant to the minor factor of flood occurrences.

AHP-MCDM is carried out using well-known GIS tools such as ArcGIS and QGIS. It makes completing analytical tasks considerably more straightforward and provides visual aids for problem-solving purposes of environmental matters (Abdul Rasam et al., 2016; Misni et al., 2017; Rasam et al., 2017; Zubir et al., 2022). The collected data may be merged, altered, and displayed to see the projected outcome. As a result, it generates ideas for issue solutions, such as flood mitigation and finding a safe way through the event. GIS and remote sensing (RS) data have mainly been utilized to determine the extent of flooded areas. Flood monitoring in real-time is critical for mitigating floods and limiting their impact (Notti et al., 2017). The combination of flood hazard identification with environmental degradation and climate change characteristics linked with LU/LC variations improved monitoring capabilities (Jalil et al., 2021).

Apart from this, spatial cost path analysis is also conducted. This spatial analysis is the process of modelling problems geographically, computing the findings, and exploring and examining a particular location. The path analysis in GIS allows for the efficient movement of commodities, the efficient coordination and organization of vehicles, and the intelligent analysis of transportation networks. Developing strategic routing strategies may assist in making better judgments and gaining a better understanding of the overall network of spatial scenarios (Jalil et al., 2018; Zain Rashid, 2019; Lokhman et al., 2012; Satti et al., 2022). Optimal route planning is another analysis in GI for traffic route selection based on road network modelling that can help prevent and mitigate traffic congestion during disasters. Genuine road conditions during flooding are recreated using road network modelling to produce a response plan for road users to evacuate depending on the roadways' natural hazards and status.

Network-based problems, such as planning alternate routes, sending emergency vehicles, estimating trip times, and locating facilities, can be managed using a GIS network or path analysis programmes. The programmes can forecast and present to road users with available alternatives using a GIS when specific access routes or links need to be closed due to catastrophic disasters such as floods. It is possible to create an appealing alternative way to display available traffic route options and a transportation network plan by utilizing GIS's ability to display spatial and attributive information as conducted at Jalan P. Ramlee in Penang (Othman & Abdul, 2014). Other research previously also conducted by

Vaishali et al. (2019) showing the capability of GIS for optimum route selection. The study integrated non-spatial (travel time, volume count, location of trip) and spatial data (boundary of city, road network shape file, GPS location of trip, land use shape file) for finding the optimum route path under different conditions. It aims to choose the best route planning for a city involving mitigating traffic problems.

RESEARCH METHODOLOGY

The research procedure consisted of four steps: a preliminary analysis, data gathering, data processing, and a flood vulnerability map. **In the preliminary study**, this research was based on the reference from many papers of previous studies that were conducted as guidance on alternative routes and analysis of the flood-prone, including the topic of the GIS-based Path and AHP method, flood vulnerability factors and risk map. The study area covers Kota Marudu to Kota Kinabalu, Sabah. The existing roads from Kota Marudu to Kota Kinabalu will pass Kota Belud District before reaching Kota Kinabalu, and vice versa. The Kota Belud District is a flood-prone area where the road access is frequently inundated, especially the main road to Kota Kinabalu. Kota Kinabalu is a capital city in Sabah is both an attraction as well as a busy city bursting with people. Thus, the Kota Belud District is an important study area, providing the main roads from Kota Marudu to Kota Kinabalu Road access.

This research's primary type of **data collection** was obtained from open sources. The data included several data classifications: satellite, topography, and hydrological data. Some of the data were selected based on the criteria from previous studies on flood occurrences located in Malaysia, as shown in Table 1. ArcGIS Pro software is the selected platform for manipulating DTM/DEM data and creating a flood extent map. The criteria, including the slope, rainfall, distance from the river, LULC, and river density, were also processed using ArcGIS Pro. Using the produced criteria visualization, the AHP take place to determine the most influencing factor causing floods in the flood extent area (Saaty, 1987). AHP is a multi-criteria decision analysis (MCDA) analytical approach that provides mathematical metrics to mathematically detect the inconsistency of judgments. The primary data processing and analysis chosen for the study is a GIS-AHP and path analysis technique.

Table 1: Data Required in the Study

Types of Data	Data Required	Sources
Satellite	Land Use DEM	Esri STRM satellite (USGS)
Topography map	Road Network River Network	https://extract.bbbike.org/ https://www.hydrosheds.org/
Hydrological Data	Rainfall Data	CRU TS v4.05
Reason	Integrate the data to do a relationship analysis between the data	

The AHP technique was used to determine the significance or usefulness of a set of paired criteria. Each criterion was paired and assigned a score ranging from 1 to 9 based on significance. The criterion closer to 1 suggested that the two criteria were considered equally significant, whilst the criterion closer to 9 indicated that one of the criteria in the pair was much more essential than the other. The preference values for AHP are shown in the study conducted by Saaty (1987). AHP gave the final weighted values valid to create a flood vulnerability map. The flood vulnerability visualizes the progress that could continue to select the alternative route access of the study area. The path analysis was also applied to find the shortest path and generate directions with the routes.

RESULT AND DISCUSSION

The Flood Vulnerability Index (FVI) Map

Five influential flood criteria in the study area include (a) slope; (b) rainfall; (c) LULC; (d) distance from the river; and (e) river density. It was established that these five criteria are crucial to the occurrence of floods, and as a result, their importance was prioritized for predicting flood vulnerability zones. These criteria were used to evaluate which factor influences the most when all are overlaid with the study area's flood-prone area with GIS-AHP method. For example, the slope with the lower value indicates that the land has a lower elevation, thus having more influence on the land inundated by flood.

Figure 1 shows the local flood vulnerability of the study area using MCDM (AHP and PCMs). The area affected by the flood is indicated, with the Pair-wise Comparison Matrix (PCM) and Consistency Ratio (CR) for flood vulnerability. The AHP method was applied to estimate the relative importance value for each criterion of causing flood in the flood-prone area. The weight overlay tool in ArcGIS Pro and the result of AHP were used to create the flood vulnerability map. The resulting layer was then clipped with the flood boundary map as this only focuses on the area in the flood extent. Pair-wise Comparison Matrix (PCMs) was the mathematical operation used for AHP techniques to decide the final weight of each criterion. As for the Consistency Ratio (CR), the inconsistency is acceptable if the value is smaller or equal to 10%. An automatic AHP calculator was utilized to run the calculations to produce the vulnerability map.

The vulnerability map visualizes the place-dependent level of risk resulting from floods within the affected part. The main road access majority falls in the medium and high risk of flood vulnerability zone. Using the route during the rainy season is hazardous for the public. The rating decision of each criterion was based on the data visualization processed in the ArcGIS software. The slope factor was higher within the flood-affected area than the annual precipitation. Lower elevation tends to accumulate water and cause inundation in the area. The slope versus LULC, distance from the river and river density had equal importance of flood factor in the affected area.

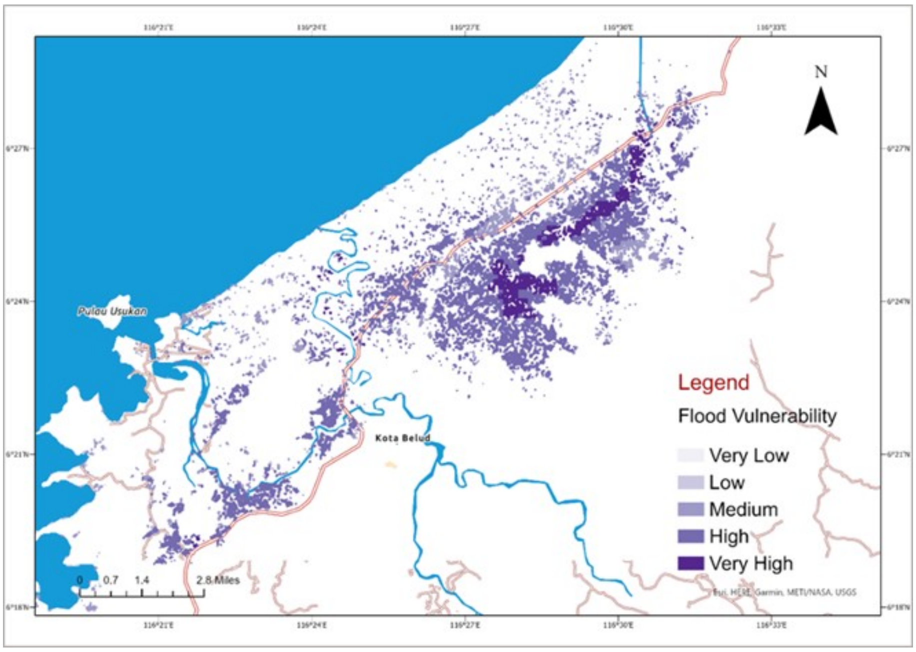

Figure 1: The Affected Areas of the Flood Vulnerability

LULC and distance from the river were more influencing in causing flood in the area than the precipitation. LULC were mostly crops and rangeland that could not penetrate water causing high water runoff. The area was also near the river, bringing water flow from the hills/mountains with a high risk of water overflow. However, the precipitation factor was more important than river density. Although the area is near the river, its density is low. Apart from that, LULC has equal importance with the distance from the river but a higher rating in a pair with river density. Finally, the distance from the river was rated more than the river density.

Table 2 displays the final weights for criteria chosen for flood vulnerability. The flood factor in the hotspot area affected by flood in the scope area ranking 1 was LULC and distance from the river. Both were equally important factors, thus, resulting in the same rank, which was 24.8% resulting weight. The second rank was the slope which was 22.3% weight. The third was the precipitation (15.0%), and the fourthly was the river density, which had the least important factor of flood occurrence in the hotspot area. The percentage value of all the criteria was used to overlay all the criteria layers shown in Figure 2 into one layer to produce the flood vulnerability. The resulting new layer was clipped with the identified flood-affected part polygon layer to analyze its susceptibility level. This process produces the final flood vulnerability, as shown in Figure 2.

Table 2: Final Weights for the Flood Vulnerability Criteria

	Criteria	Priority	Rank	(+)	(-)
1	Slope	22.3%	2	6.0%	6.0%
2	Rainfall/Precipitation	15.0%	3	6.0%	6.0%
3	LULC	24.8%	1	2.7%	2.7%
4	Distance from River	24.8%	1	2.7%	2.7%
5	River Density	13.1%	4	5.2%	5.2%

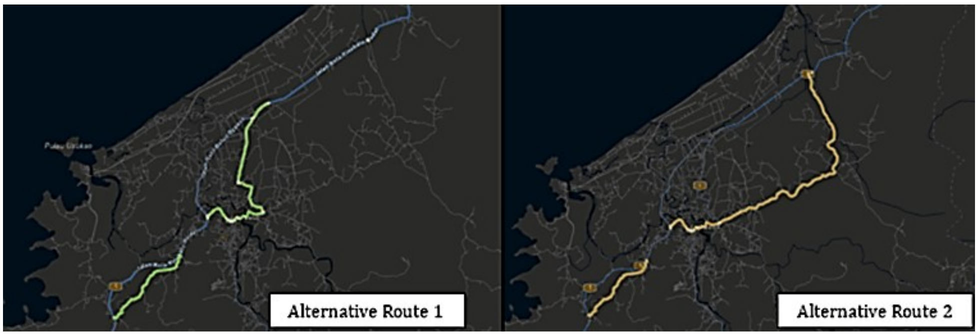

Figure 2. The Optimum Alternative Route 1 and 2 in Kota Marudu and Kota Kinabalu

Alternative Routes Accessibility during the Flooding

The purpose of the route selection only includes one highway facility, and the route will be rerouted away from the inundated region before re-joining the main road again after a short distance. Kota Belud provides several routes from Kota Marudu to Kota Kinabalu. In that way, a few alternative routes could be used for the public to pass between the nodes. The selection of new suitability of route access during the flood was performed. The best route was chosen from some other existing road connections. Apart from the existing roads, a new road proposal was also recommended.

To find the optimum alternative routes, the ArcGIS Pro Network Analysis Tool is used to identify the shortest route, its travel time, and its distance. Figure 2 shows Alternative Route 1 and Route 2 between Kota Marudu and Kota Kinabalu. Other than the primary connection route of Jalan Kota Belud Bypass Kudat/ Kota Marudu that can be used to travel from Kota Marudu to Kota Kinabalu (and vice versa), the connection of Jalan Tuaran-Kota Belud near Jalan Kampung Liwan - Jalan Pekan Kota Belud - Jalan Lama Kota Belud and Jalan Kawang-kawang - Jalan Botong Rosok - Jalan Lama Kota Belud can also be the alternative routes sequentially denoted as Alternative Route 1 and Alternative Route 2. Alternative Route 1 covers a shorter travel time of 49 minutes, while Alternative Route 2 has a longer travel time. It is also the shortest route and closer to the main road than the Jalan Alternative Route 2. Table 3 below shows some information on the criteria listed for the alternative routes.

Table 3: Alternative Routes Criteria in a Normal Situation

	Alternative Route 1	**Alternative Route 2**
Shorter travel time	49 min	1 hr 2 min
Distance	30 mi	32 mi
Closeness to the main road	Yes	No

For selecting the alternative safe route access during the flood, the flood risk map must also be considered in order to select the safe route access during the flood. Figure 3 indicates the alternative road layer overlaid with the final flood vulnerability layer. However, when overlaid with the final flood vulnerability layer, the connectivity of Alternative Route 1 (green) still was affected by the flood. Using the road was unsafe as it falls within the medium and high vulnerability flood area, and most of the road was affected. For example, the Jalan Tuaran - Kota Belud near Jalan Kampung Liwan, is one of the route connections of Alternative Route 1. As mentioned earlier, it was also near the river, which has the most influencing factor in causing floods in Kota Belud.

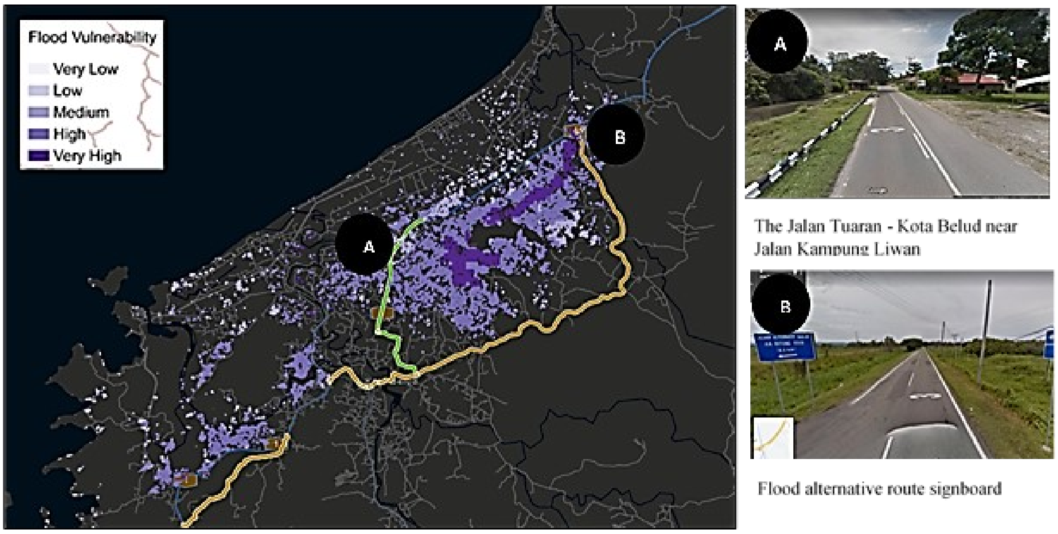

Figure 3: The Alternative Roads Layer during the Flooding

On that note, the Second Alternative Route (Orange) has a longer travel time and distance and is further from the main route, and it is safer to use this path. The flood risk of the path was lower when it connected again to the main road, and the remaining flood-affected part along the path was short and low risk. Alternative Route 2 (Orange) is the final alternative safe route access during the flood from Kota Marudu to Kota Kinabalu, Sabah. Additionally, even if it would be reconstructed for improvement of the road, it will require lower cost because of the shorter flood-affected area and lower risk. Furthermore, this route has been officially demarcated as an alternative path during flooding. The route has a signboard that is stated it as an alternative flood route, as illustrated in Figure 3.

Inclusively, providing infrastructure that is both secure and well-organized is crucial for growth and economic development. Two other roads are available and known to be accessible, but only one avoided being affected by the water that this analysis had forecasted. The second one, on the other hand, was safer to be used, but when it connected to the main road again, it still had a chance of being flooded since the results showed that a tiny portion of the road was still affected, despite being classified as having a low risk of flooding. Flood events can only be predicted and commonly affect low-land areas. There is still a possibility that other areas will also be affected when a very severe flood occurs.

As a result, putting up a proposal for a new road in the more elevated portion of the area would be a better idea. The other aspects that need to be considered in the future study are retrofitting existing infrastructures (Musolino et al., 2022), socioeconomic status, and social services analysis of the local community (Thapa et al., 2022; Loreti et al., 2022; Tsolmongerel & Margreth, 2021) for enhancing risk evacuation and access routes during the flood hazards.

Furthermore, GIS-based management preparations and proposed evacuation routes for flood disasters must be introduced in the state towards a better humanitarian aid distribution process during and after post-disaster (Mohamad et al., 2021; Mohd et al., 2018; Zahari et al., 2020).

CONCLUSION

Floods have threatened the social and economic infrastructure of the flooded region in Kota Belud District, which had a detrimental effect on the area's population development and living level. This exploratory study also affected the mobility of the people travelling from Kota Marudu to Kota Kinabalu through the District. GIS-AHP-Path analysis was used for the flood risk assessment and alternative safe routes during the flood in Kota Belud. The production of the flood vulnerability map using slope, precipitation, LULC, distance from the river, and river density helps identify the areas with high, high, moderate, low, and shallow risk for flooding, respectively. The two routes usually used as alternative routes apart from the main road from Kota Marudu to Kota Kinabalu are the road network connection of Jalan Lama Kota Belud - Jalan Pekan Kota Belud - Jalan Tuaran - Kota Belud and Jalan Lama Kota Belud - Jalan Botong Rosok - Jalan Kawang-kawang. Except for a tiny area impacted by flooding, which could be seen on the final alternative route, Alternative Route 2 was far safer than Alternative Route 1. In comparison, Alternative Route 1 had a shorter travel time and distance and was closer to the main road. However, when flood risk was included in the route selection criteria, Alternative Route 1 was still unsafe because its exposed part was almost along the way. The user may be advised to choose the safer path when the rainy season arrives by using this alternate route map as caution during the season. The current findings were limited by the use of only available data input at a specific time.

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