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LANDSLIDE SUSCEPTIBILITY INDEX AND NETWORK MAPPING FOR SPOTTING THE AFFECTED AND ALTERNATIVE PLANNING ROUTES

Abdul Rauf Abdul Rasam[1], Dorisin Mardie[2], Mohd Shahmy Mohd Said[3], Nurhanisah Hashim[4], & Rosmadi Ghazali[5*]

[1,2,3,4,5]*School of Surveying Science and Geomatics, College of Built Environment,*
UNIVERSITI TEKNOLOGI MARA UITM SHAH ALAM, SELANGOR, MALAYSIA

Abstract

Millions of people were harmed by landslides, and many have lost their lives. Instead of widening the access road during a landslide, an alternative or new road should be introduced accurately. This study was conducted to determine an appropriate GIS-based alternative planning route during landslides in Ranau, Sabah, Malaysia. For determining the criteria weights of the landslide, a GIS-based Multi-Criteria Decision Making (GIS-MCDM) technique was utilised with the extension of the Analytical Hierarchy Process (AHP). The Landslide Susceptibility Index (LSI) map was created using lithology, slope, aspect, rainfall, land use or land cover (LULC), and proximity to a stream. The map was compared with the NASA-landslide historical data for the verification. The study found that lithology, slope, and aspect were the most contributing factors to the local landslide occurrences. The route from Pinausuk to the destination position of Kundasang is the most appropriate choice. An alternative planning route map is a helpful tool for the authorities and it might be also made available to the public, so they will know which path can be taken for more secure alternative access during landslides.

Keywords: Landslide Susceptibility Index (LSI), GIS Network Analysis, Alternative Routes

[1] Corresponding author Email: rauf@uitm.edu.my

INTRODUCTION

Landslides are large-scale movements of soil triggered by earthquakes, volcanic eruptions, falling boulders, shallow debris flows, or slope collapses. They can also be brought on by human activity, especially regarding development. Landslide is mainly caused by physical/built up environment such as slope, road networks, elevation, faults, curvature, land cover, lithology, hydrology and streams (Bacha et al., 2018; Basharat et al., 2016; Kanwal et al., 2015; Khan et al., 2018; Rahim et al., 2018). Forests and slope regions were cleared for development purposes such as logging, road construction, and building construction.

In Malaysia, high-intensity and extended rainstorms are the leading causes of landslides. This scenario is because Malaysia receives much rain—about 3000 mm annually and led to the monsoon system. This system reveals that this nation is prone to landslides, particularly in mountainous and sloping places. However, landslides can occur not only in mountainous areas but also in plane areas. In general, the country is not considered mountainous, but, a specific region has hilly landforms, such as the Tahan Range in Peninsular Malaysia and Crocker Range in East Malaysia. The Tahan Mount rises to 2187 metres, while the Kinabalu Mount is the highest peak at 4095 metres.

Landslides affected millions and caused deaths in particularly vulnerable landslide areas in Sabah. An earthquake phenomenon in Ranau Sabah occurred on 5 June 2015 at 6.0 Richter magnitude scale. This phenomenon led to massive landslides that killed 19 people, and most were caught by landslides (BBC, 2015). Based on BBC News, on 8 June 2015, 30 pupils and staff climbed the Kinabalu Mount for an educational trip, where a teacher and a student were missing. More than 130 people were rescued. Some climbers had made their way down with the help of tour guides and park ranges, as informed by the Straits Times in 2015. On 15 September 2021, the landslide recorded two lives lost and six families affected at Penampang-Tambunan Road. Three lives were lost on 15 September 2021 at Forest Hill construction quarters. The estimated damaged properties after ten days of landslide occurrence are RM174 million, as the Star Times-News reported in 2017.

One contributing factor to landslide occurrences in Kota Kinabalu Sabah is lithology. Lithology types include sandstone and shale, which are highly weathered and have high porosity. The high porosity of the layer has the potential to consist of high-water content (Zikiri et al., 2021). The slope angles class between >35°, slope aspect East and Southwest, lithology and soil types in Kundasang, Sabah are considered landslide-prone areas (Sharir et al., 2017).

Sabah Daily Express in 2013 reported that instead of widening the access route to Ranau, a new road is a better alternative. The new route runs from Telipok to Kampung Randagong in Ranau. Congenially, this new road is the second route which connects Kota Kinabalu and Ranau. This statement has suggested that the construction of new roads is more emphasised than widening the road due to geohazards such as landslides, including in the Kota Kinabalu and Tuaran. The more widening projects carried out, the more frequently landslides occur.

This study identifies a GIS-based alternative secure route planning during the landslides in Ranau. With the technology nowadays in Geographical Information System (GIS) field congenially, there are many efficient methods for obtaining geographical data from open-source internet websites, which leads to high probabilities for proposed alternative routes that are safe from landslide phenomena. GIS users can define the world differently by mapping the position and quantity of things, the density of people and objects, and any phenomenal changes. This geospatial technology used to acquire, manage, interpret, display, and analyse the related data of safe routes during landslide hazards. Previous studies have proven that the virtuous capabilities of the GIS-MCDM method utilised in environmental and natural disaster applications (Abdul Rasam et al., 2016; Mohd Zubir et al., 2022; Mohd Zaini et al., 2021; Mohamad Nor Sing et al., 2022; Rasam et al., 2017; Ridzuan et al., 2017; Saad et al., 2021).

RESEARCH METHODOLOGY

This study was conducted in the district of Ranau of Sabah, Malaysia. Ranau's geomorphology, which is hilly with artificial slopes, is a landslide-prone terrain. The altitude of Ranau is 1176 metres above mean sea level with 1663 mm of annual rainfall and 21.9°C of annual temperature. The estimated area of Ranau is 3609 km², with the latest total population being 118,092 in 2020. The study's research methodology was organised into four main sections, including the preliminary studies, data acquisition, data processing stages, and the result and analysis. **The preliminary study** consists of identifying the problem, literature search, selection of study area, and selection of software. The selected technique was AHP, Spatial Analyst, and Network Analyst carried out with ArcGIS 10.8 and Microsoft Excel 2019.

Data acquisition for the study was mainly collected from open-source websites such as OSM, Crudata, USGS, FAO, and ESRI. These datasets covered landslide historical data, satellite imageries such as Landsat 8, and DEM. DEM was used for deriving the slope, aspect and proximity data from the stream. The data were also collected from other spatial data sources: lithology, LULC, rainfall, road, and location. These spatial data were specifically used for identification of landslide-prone areas and the affected route. Landslide historical data were obtained from NASA in point shapefile format. A total of eleven cases of previous landslides were employed for the verification process.

ArcGIS mapping is used for processing landslide historical data in point features of affected route area in Ranau**. The data processing and analysis** stage involved evaluating the landslide criteria for analysing the affected route area as proposed by the literature review using AHP. The main criteria for landslide contribution were lithology, slope, LULC, and proximity to the stream. Image analysis and data management of seven satellite image bands were also processed with the software. For DEM, there are four GeoTIFF images, which were then combined by mosaic to new raster in data management tools in the raster part in ArcToolbox/ spatial analyst tools for slope and aspect mapping. The stream network was created in the hydrology part where the fill was created first, followed by flow direction, and finally, flow accumulation. In flow accumulation symbology, the classes were classified into two classes which are 0 to 30.000 and 30,000 to above, using a raster calculator in map algebra. Next, the stream link was created in raster before converting to a polygon using a stream feature known as stream networks. To process proximity from the stream through the stream network, the multiple ring buffer was applied in the analysis tool with five different distances: less than 300, 600, 900, 1200, and more than 1500.

Identifying the shortest route and the closest facility was also conducted using Network Analyst Extension in ArcGIS. The route in the network analyst toolbar showed four feature layers: stops, routes, point barriers, line barriers, and polygon barriers. The techniques were used to determine the weight of criteria in AHP. The criteria were calculated using M. Excel 2019 and then analysed using LSI in AHP extension in ArcMap. Next, the process applied the weighting of the criteria using AHP. The process of weighting the criteria used is to express the importance of each criterion namely lithology, slope, aspect, LULC, rainfall, and proximity from the stream.

Table 1 indicates the scores based on the literature review on the relative importance between criteria. The matrix calculation was performed to obtain the weights for each criterion used. The value in the normalised matrix was acquired by dividing the score value by the column total. The result of this study is the landslide-prone areas and affected routes in the study area. Next, the analysis was focused on the landslide prone-areas map, landslide susceptibility index map, and a map of alternative safe route planning during a landslide from Pinausuk to Kundasang, Ranau. The closest facility was also discussed in the result and analysis.

Table 1: AHP Calculation

Criteria/ Factors	**Lithology**	**Slope**	**Aspect**	**Rainfall**	**LULC**	**Proximity from Stream**
Lithology	1.000	2.000	2.000	6.000	7.000	4.000
Slope	0.500	1.000	5.000	7.000	5.000	6.000
Aspect	0.500	0.200	1.000	2.000	3.000	2.000
Rainfall	0.167	0.143	0.500	1.000	3.000	2.000
LULC	0.143	0.200	0.333	0.333	1.000	2.000
Proximity from Stream	0.250	0.167	0.500	0.500	0.500	1.000
Total	2.560	3.710	9.333	16.833	19.500	17.000

RESULT AND DISCUSSION

Identifying the Affected Route Area of the Landslides

The areas of the impacted route were examined using the AHP approach to determine the landslide causes. The lithology and slope of the affected route areas were divided into two types: Orthic Acrisols and Orthic Luvisols. Orthic Luvisols is the predominant soil type in the affected route region. The slope was analysed into four ranges which are Class 1 (0-15), Class 2 (15-250, Class 3 (25-35), and Class 4 with more than 35° of contour height. The highest number of lithology or soil types was Orthic Acrisols, while the highest number of slope angles in the study area was 74° (>35). However, in the affected route areas, the lithology is Orthic Acrisols. For slope, the 0-15° were mostly in the affected route area.

The map of the aspect and LULC of the affected route area was analysed into nine flat ranges (-1), North (0-22.5), northeast (22.5-67.5), east (67.5-112.5), southeast (112.5-157.5), south (157.5-202.5), Southwest (202.5-247.5), west (247.5-292.5), and northwest (292.5-337.5) in degree unit. The aspect in the affected route area mainly occurred in the Southwest where the rainfall and wind intended in this aspect. LULC was analysed into nine classes: water bodies, vegetation cover, grass, flooded vegetation, agriculture, scrub or shrub, built area, bare ground, and cloud. LULC in the affected route area mainly was the vegetation cover. However, the affected route is located in the built areas of LULC.

The rainfall map was analysed into six ranges: less than 2880, 2880-2900, 2900-2930, 2930-2960, 2960-2990, and more than 2990 in millimetres per year. The proximity from the stream was analysed into five ranges, namely less than 300, 600, 900, 1200, and more than 1500 metres. The rainfall in the affected route areas mainly occurred at 2900 to 2930 mm/year, which was a moderate pattern. The proximity to the stream was more than 1500 metres, meaning the roads were far from the stream.

Based on the criterion's map in the affected route area, the lithology was a criterion that affected all areas in the route area prone to landslides. The landslide phenomena can occur at any time in the affected route areas where several places are involved, namely Kundasang, Pinausuk, Mohimboyon, Semuruh, Kauluan, Dumpiring, Noluoh, Koporingan, and Tambiau. The following analysis on the slope affected several areas, such as Mesilau, Liposu and Tamalang. The aspect also affected the areas such as Kundasang, Mesilau, and Ruhukon. The rainfall affected forest areas at Ranau near the Trus Madi Forest Reserve and the Sinua Village. LULC and proximity from the stream are the criteria less affecting the area to the occurrence of landslides.

Based on AHP-MCDM result with considerations to the selected criteria, the finalised pairwise matrix was prepared as shown in Table 2. The normalised matrix was based on the weighted criterion score value—the normalised matrix results from dividing the score value and column total.

Table 2. Finalised Pairwise Matrix

Normalise Matrix								
	Litho-logy	**Slope**	**Aspect**	**Rainfall**	**LULC**	**Proximity from Stream**	**Row Total**	**Weight**
Lithology	0.391	0.539	0.214	0.356	0.359	0.235	2.095	0.349
Slope	0.195	0.270	0.536	0.416	0.256	0.353	2.026	0.338
Aspect	0.195	0.054	0.107	0.119	0.154	0.118	0.747	0.124
Rainfall	0.065	0.039	0.054	0.059	0.154	0.118	0.488	0.081
LULC	0.056	0.054	0.036	0.020	0.051	0.118	0.334	0.056
Proximity from Stream	0.098	0.045	0.054	0.030	0.026	0.059	0.310	0.052
	1.000	1.000	1.000	1.000	1.000	1.000	6.000	1.000

The finalised pairwise matrix generating the criterion priorities is shown in Table 3. The criterion priorities in affected route areas as the most contributing landslide occurrences were lithology (34.9%), secondly was slope (33.8%), thirdly was aspect (12.4%), then was rainfall (8.1%) and LULC (5.6%), and the lowest contributing factor of the landslide occurrences was proximity from the stream (5.2%). Therefore, based on this finalised pairwise matrix calculation result, the consistency ratio is 0.078 or 7.8%, accepted as the consistency ratio is not more than 0.1 or 10% (Saaty, 1987). The consistency ratio was obtained from Eigenvalue and random index (RI).

Table 3: Criterion priorities

No.	Criteria	Priority	Rank
1.	Lithology	0.349 or 34.9%	1
2.	Slope	0.338 or 33.8%	2
3.	Aspect	0.124 or 12.4%	3
4.	Rainfall	0.081 or 8.1%	4
5.	LULC	0.056 or 5.6%	5
6.	Proximity from Stream	0.052 or 5.2%	6

The final result of the AHP technique was a LSI map, in which the index value varied from 149.8 to 216.2 for low-susceptibility areas and very high-susceptibility areas, respectively (Figure 1). However, for straightforward interpretation and visual of the areas, the result of the LSI map was classified into four classes which were low, moderate, high, and very high. The low susceptible areas were Kundasang and Pinausuk, Himbaan, and Purak Pogis. The highly susceptible areas were the Mesilau, Kundasang, Kiwawoi, and Ranau. These susceptible areas of the landslide occurrences were due to the criteria: lithology, slope, aspect, rainfall, LULC, and proximity from the stream, potentially influencing the landslide phenomena.

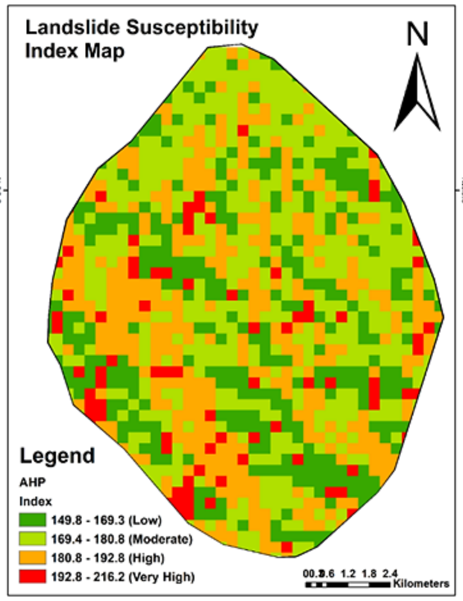
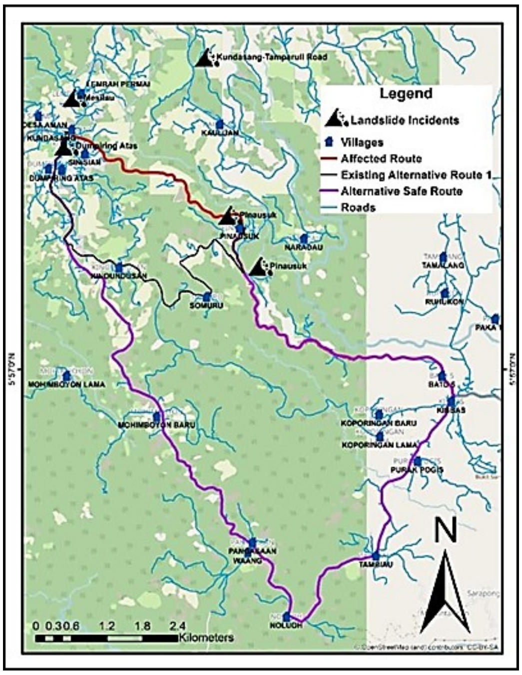


Figure 1: Landslide Susceptibility Index Map (LSI) of the Affected Route Areas

Alternative Routes during Landslides

Figure 2 indicates the map of alternative safe routes during landslides in Ranau, mainly from Pinausuk to Kundasang. The existing Alternative Route 2 was selected as the safer alternative route since this road was safer than the existing Alternative Route 1, as shown in the image of the existing Alternative Route 1 and the comparison of both alternative routes in Table 4. Compared to the alternative route, the existing Alternative Route 1 during landslides in Ranau is from the Tamparuli-Ranau route to the Semuruh-Kinoundusan road and to the Kibbas- Mohimboyon road for going to the destination location (Kundasang). The existing Alternative Route 1 is used regularly by drivers during landslides for access due to the short distance.

However, this road is an unpaved and small road where cars have difficulty passing. In short, this road may be pretty risky and unsafe. The existing Alternative Route 2 was safer because the road was paved and could be accessed by two cars, as shown in Table 4. Table 4 indicates the comparison of existing Alternative Route 1 and existing Alternative Route 2 in terms of an average driving distance, time, and road conditions.



Existing Alternative Route 1 used regularly by drivers-Semuruh-Kinoundusan Road

Existing Alternative Route 2 is rarely used by drivers- Kibbas-Mohimboyon Road.

Figure 2: Alternative Route from Pinausuk to Kundasang, Ranau during Landslides

Table 4: Comparative Existing Alternative Route 1 and Existing Alternative Route 2

Comparison	Existing Alternative Route 1	Existing Alternative Route 2
Driving Distance	7.9 km	22 km
Driving Time	30 minutes	44 minutes
Paved Road	No	Yes
Safer	No	Yes

Verification of the Alternative Safe Routes during Landslides

The verification map of the landslide susceptibility index and an alternate safe path was also conducted for the result practicality as the actual situation. Verification is necessary to determine whether the map's outcome is appropriate for usage. The verification data used was the landslide historical data acquired from NASA where 8 locations and 11 cases were reported. The data overlapped with the LSI and alternative safe route maps during landslides from Pinausuk to Kundasang, Ranau. Based on the LSI map, the location along the affected route was low susceptibility to landslides. However, the route near the Pinausuk village was identified as highly susceptible to landslides. The existing Alternative Route 1 from Pinausuk through Semuruh-Kinoundusan was identified as having low and moderate landslide susceptibility.

Most of the identification of new alternative routes is high susceptibility to landslides. In contrast, the existing Alternative Route 2 from Pinausuk through Kibbas-Mohimboyon was found to have an as high susceptibility to landslides. However, there is no landslide occurrence along this alternative safe route.

Regarding the proposal of new alternative safe route accesses during landslides, another safe alternative road is better to facilitate drivers moving to their destination, especially from the Pinausuk village to Kundasang, where roads in the Pinausuk village area were often affected due to landslide occurrences. The new alternative roads must be built in areas identified as low susceptibility landslide areas, or at least in areas with medium susceptibility landslides and have a suitable soil structure and soil type (lithology), as well as take into consideration of the slope and aspect. In addition, the many alternative routes would help reduce traffic congestion in the area as well as help reduce the land surface load in the area because drivers will use more than one road to their destination. The local agencies can assist in estimating the cost of proposed route development and maintenance.

This study also suggests that the result of the susceptibility index can be enhanced by integrating the holistic setting risk criteria (Sim et al., 2022), such as social vulnerability, climate change, and other disaster risk factors, for providing a significant cost estimation of the route development and maintenance (Nor Diana et al., 2021). Furthermore, a geospatial real-time monitoring system (Mohd Mokhtar et al., 2021; Shankar et al., 2018) can be further explored for better route planning during natural disasters (Mohd Zahari et al., 2020) in the district.

CONCLUSION

Landslides have killed and injured millions of people, with Sabah in Malaysia being particularly at risk. The present state government stated that building a new road rather than expanding an existing one is the best option for the access route to Ranau. Consequently, GIS technology was implemented in this study to gather geographic data from open sources, which increases the likelihood of the recommended alternate safe path from the landslide danger in the district. The affected route area analysed using the GIS-AHP technique based on the six selected parameters showed that the landslides' most contributing factors were lithology, slope, aspect, rainfall, LULC, and proximity from the stream. The LSI map included four classes of landslide susceptibility index, namely low, moderate, high, and extremely high; the landslide prone-areas map indicated that eleven landslide incidents were also recognised. These maps are beneficial to identify the risk susceptibility of landslides, as the Mesilau, Kundasang, Kiwawoi, and Ranau were recognised as very highly susceptible areas. The main findings of the network analysis have suggested that the safest route and the closest facility is the route from the Pinausuk village (source location) to

Kundasang (destination location) through the Tamparuli-Ranau route and Kibbas-Mohimbayan, Kundasang route, with the length of 22 kilometres and 44 minutes of driving time. The public should be aware of the alternative safe route map to know which path may be utilised for safer option access during landslides. The result of the study was constrained by the use of available data input and occurs only at a specific time.

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