Susceptibility Investigation of Debris Flow Hazard Using Topographic Index in Phang-nga province, Southern Thailand

Aksara Kulsilrak and Santi Pailoplee*

Earth Science Program, Department of Geology, Faculty of Science,
Chulalongkorn University, Bangkok 10330, Thailand

* Corresponding author e-mail: Pailoplee.S@gmail.com

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Abstract

Phang-nga, a province in Southern Thailand, is highly susceptible to geohazards such as debris flows and flooding, both of which pose significant risks to human life and property. Several topographic factors contribute to the potential for debris flow, including: i) steep mountain slopes and ii) the presence of multiple mountain-front outlets. In this study, the Frequency Ratio (FR) method was used to identify and generate a map of debris flow susceptibility across Phang-nga. Topographic indices related to debris flow activity were analyzed using terrain data obtained from a 30-meter resolution Digital Elevation Model (DEM). The FR was computed by integrating ten parameters that characterize areas prone to debris flow, including: i) slope, ii) elevation, iii) aspect, iv) lithology, v) vegetation cover, vi) land use, vii) topographic wetness index, viii) terrain ruggedness index, ix) rainfall, and x) profile curvature. The findings indicate that debris flow susceptibility in Phang-nga can be categorized into five levels. The high and very high susceptibility classes are concentrated in the valley directions, near the streamlines. The most prevalent class in the region is the moderate susceptibility class. Meanwhile, the eastern and southern parts of Phang-nga have been found to have low and very low susceptibility (Class 1 and Class 2, respectively), located in the direction of the mountain range and areas with lower average rainfall.

Keywords: Phang-nga, Debris Flow, Topographic Index, Mass Wasting

1. Introduction

Mass wasting is a geological process that refers to the downward movement of rocks, soil, mud, and snow along a slope. From a geological perspective, mass wasting can be classified into several categories based on: i) the type of material involved, such as rocks, soil, snow; ii) the amount of water present; and iii) the movement patterns, including fall, collapse, avalanche, slip, and flow. These three factors influence the different patterns of mass movement in terms of speed, size, and the extent of the potential hazard, which may include rock falls, landslides, rockslides, debris avalanches, and debris flows, among others.

Phang-nga is one of the provinces in Southern Thailand, covering an area of approximately 4,171 square kilometers. It is located at a latitude of 8° 27′ 52.3″ North and a longitude of 98° 32′ East, on the western coast of southern Thailand. The province has a coastline approximately 239.25 kilometers in length. Its boundaries are as follows:

Ranong province lies to the north, Surat Thani and Krabi to the east, Phuket province to the south, and the Andaman Sea to the west.

In the past, Phang-nga province has frequently been affected by flash floods, as reported by various online news sources in Thailand. Flash floods and debris flows often occur simultaneously, as the flowing water aids in the transportation of rocks and debris. As a result, it can be anticipated that Phang-nga may experience debris flows in the future. This serves as the foundation for the present research study, which aims to analyze the results in terms of susceptibility.

To assess the debris-flow hazard areas in Phang-nga, this study utilized topographic analysis, remote sensing, and GIS to identify and delineate the potential risk zones. The Frequency Ratio (FR) method, which is widely used for debris flow assessment, will be applied, as demonstrated in the research by Polat and Erik (2020).

To analyze areas susceptible to debris flow (Figure 1), the base data used was a Digital Elevation Model (DEM) with a resolution of 30 meters. Subsequently, ten topographic index factors were spatially analyzed across Phang-nga, including:

slope, elevation, aspect, lithology, vegetation coverage, land use, TWI (Topographic Wetness Index), TRI (Terrain Ruggedness Index), rainfall, and profile curvature. These parameters were analyzed using ArcGIS software, while SAGA software was employed to calculate the Topographic Wetness Index (TWI) and Terrain Ruggedness Index (TRI).

After analyzing all topographic indices for debris flow identification, the Frequency Ratio (FR) approach was applied to calculate scores for each index. Following this, the FR values were classified according to their susceptibility to debris flows. As shown in **Table 1**, the FR values in this study were divided into five categories: very low, low, moderate, high, and very high. Finally, the debris flow susceptibility was mapped following the method outlined by Polat and Erik (2020).

The maps generated in this study were validated against historical landslide events in Phang-nga, as recorded in the Department of Mineral Resources database, which is illustrated in Figure 2.

Table 1 Classification of debris flow susceptibility in this study

Class of debris flow susceptibility	Interval of debris flow susceptibility
Very low	4.83 to 8.56
Low	8.57 to 9.79
Moderate	9.80 to 10.86
High	10.87 to 13.63
Very high	13.64 to 18.24

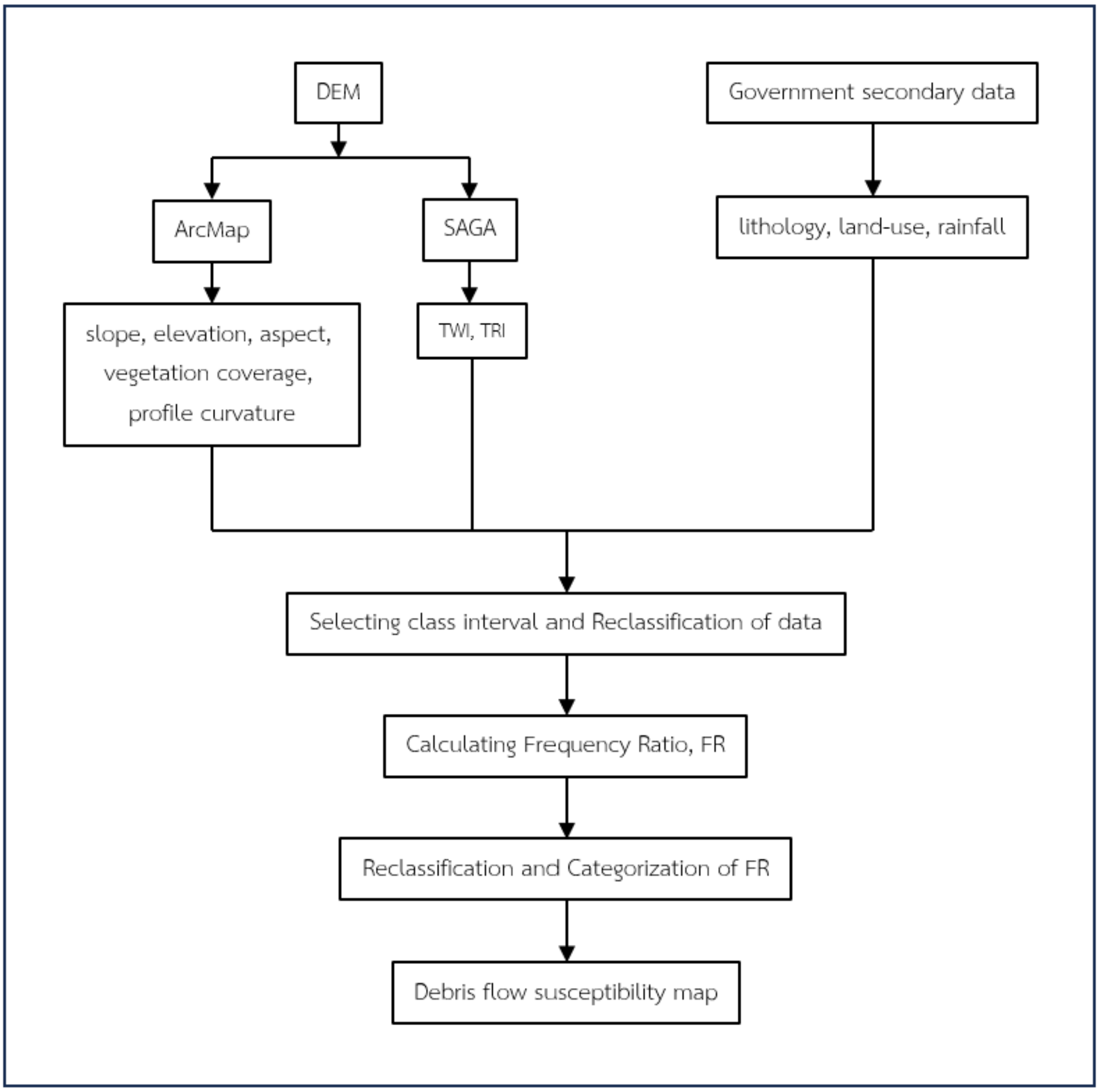

Figure 1 Flowchart showing methodology to analyze debris flow susceptibility in this study

2. Topographic index

2.1. Slope

Slope angle is a key factor commonly used in debris flow susceptibility modeling. The slope of Phang-nga (Figure xx) ranges from 0° to 78°. The average gradient in most regions is between 0° and 15°. The maximum slope values are found in the lower-right part of the province, along the fault line of the Phuket mountain range, which continues from the Tanaosri mountain range, with slopes ranging from 40° to 78°. Before calculating debris flow susceptibility, this study divides the slope gradient into five classes: Class 1 (0° - <15°), Class 2 (15° - <22.5°), Class 3 (22.5° - <30°), Class 4 (30° - <40°), and Class 5 (>40°). Class 1 is primarily located in the western and southern parts of the Phang-nga region, while the other classes are distributed throughout the entire area

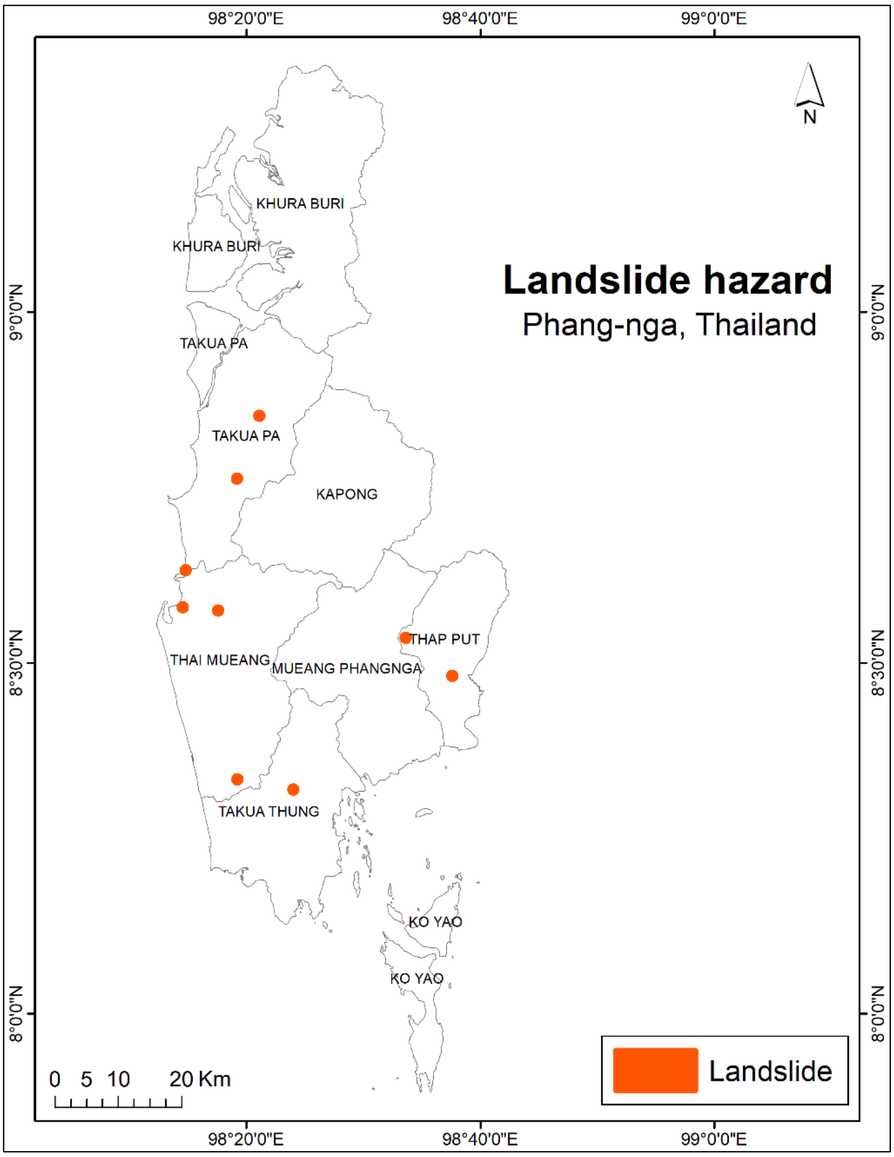

Figure 2 Map of Phang-nga showing the location of historical landslide hazard (orange do) obtained from the Department of Mineral Resources (DMR)

2.2. Elevation

The elevation of Phang-nga ranges from -21 to 1,332 meters, with an average elevation of less than 80 meters in most regions. The highest elevations are found in the right, central, and upper parts of the province, within the boundaries of Khura Buri, Kapong, and Mueang Phang-nga districts, which are part of the Phuket Mountain range. This value gradually decreases in the surrounding areas, with more than 59% of the region having an elevation of less than 80 meters. Before calculating debris flow susceptibility, this study divides elevation (in meters) into five classes: Class 1 (<80), Class 2 (80 - <250), Class 3 (250 - <400), Class 4 (400 - <600), and Class 5 (>600). Class 1 is primarily located in the western and southern parts of the Phang-nga region.

2.3. Aspect

The overall flow direction mostly slopes westward toward the coast of the Andaman Sea. Before calculating debris flow susceptibility, this study divides aspect according to the flow direction into 9 classes: Class 1 (flat), Class 2 (north), Class 3 (northeast), Class 4 (northwest), Class 5 (east), Class 6 (southeast), Class 7 (south), Class 8 (southwest), and Class 9 (west).

2.4. Lithology

The majority of the area consists of sedimentary rock (about 41%) and sediment (37%), with both occurring in approximately equal proportions, followed by igneous rock and carbonate sedimentary rock, respectively. Sedimentary rocks are found in the central and eastern parts of the province, while sediments are located in the western and southern regions. Igneous rocks are distributed in the western, eastern, and northern parts of the province, and finally, carbonate sedimentary rock is found in the eastern part of the province. Before calculating debris flow susceptibility, this study divides lithology into four classes: Class 1 (sedimentary rocks), Class 2 (sediment), Class 3 (igneous rock), and Class 4 (carbonate sedimentary rock).

2.5. Vegetation coverage

Almost the entire area, or 94.98% of the province, is covered by healthy vegetation. The remaining areas consist of land, shrubs, and water in roughly equal proportions. Land areas (1.29%) are distributed across every district, particularly near streams and coastlines. Shrub areas (1.89%) are also distributed throughout all districts. Water areas (1.84%) are found in seven districts, mostly near the coastlines.Before calculating debris flow susceptibility, this study divides vegetation coverage into four classes: Class 1 (healthy vegetation), Class 2 (shrubs), Class 3 (land), and Class 4 (water).

2.6. Land use

Almost half of Phang-nga Province is covered by forest and agricultural land, accounting for 46.42% and 42.34%, respectively. Miscellaneous, urban and built-up, and water areas each make up approximately 3-4%. Forest land is distributed across all districts, primarily located in areas with high elevation (above 250 meters). Agricultural land is found throughout all districts, typically near low-elevation areas. Miscellaneous land accounts for approximately 3.15% and is scattered across every district. Urban and built-up land covers about 3.69%, distributed across all districts. Water areas make up around 4.40%, spread throughout the districts near streams and coastlines, predominantly in areas with an elevation below 80 meters and a slope of less than 15 degrees. Before calculating debris flow susceptibility, this study divides land use into five classes: Class 1 (agricultural land), Class 2 (forest land), Class 3 (miscellaneous), Class 4 (urban and built-up land), and Class 5 (water).

2.7. Topographic wetness index

The Topographic Wetness Index (TWI) values ranged from -21.64 to 10.80. The highest TWI values were found along streamlines and near coastal areas. These high TWI values were primarily observed in slope classes 2 (15° to <22.5°) and 3 (22.5° to <30°), with most of these areas located in the eastern part of the province. The high TWI values in these areas indicate an increased potential for landslides, which may trigger debris flows into the basin. Furthermore, areas with the highest TWI values are more likely to become saturated and contribute to surface runoff during dry periods when soil moisture storage is low. Before calculating debris flow susceptibility, this study divides TWI into five classes according to the Jenks Natural Breaks classification: Class 1 (-21.64 to -16.68), Class 2 (-16.67 to -13.37), Class 3 (-13.36 to -9.30), Class 4 (-9.29 to -4.98), and Class 5 (-4.97 to 10.80).

2.8. Terrain roundness index

The Terrain Ruggedness Index (TRI) values ranged from 0 to 13.80. The highest TRI values were found in areas with elevations ranging from 400 to 600 meters, corresponding to elevation classes 4 and 5, with most of these areas located in the eastern part of the province. The high TRI values in these areas indicate an increased potential for landslides that may trigger debris flows into the basin. This increased potential is especially notable in lower elevations, where TRI values rise significantly above 80 meters. Before calculating debris flow susceptibility, this study divides TRI into five classes according to the Jenks Natural Breaks classification: Class 1 (0 to 3.1166), Class 2 (3.1167 to 8.0141), Class 3 (8.0142 to 13.8021), Class 4 (13.8022 to 28.4946), and Class 5 (28.4947 to 113.5333).

2.9. Rainfall

The rainfall values in this study were estimated using the Frequency Magnitude Distribution (FMD) method, based on data from six rainfall stations across five provinces: i) Ranong Meteorological Station – Ranong, ii) Surat Thani Meteorological Station – Surat Thani, iii) Phra-saeng Meteorological Station – Surat Thani, iv) Phang-nga Meteorological Station – Phang-nga, v) Southern Meteorological Center (West Coast) – Phuket, and vi) Krabi Meteorological Station – Krabi. The rainfall data used in this study spans a total of five years from the meteorological stations. The FMD calculation was performed using the MATLAB program. Once the Mmax values for the five years were obtained, they were used to create a map

displaying the rainfall data, as shown in Figure 3.11, by applying interpolation using the IDW method. Before calculating debris flow susceptibility, this study divides rainfall into five classes: Class 1 (<145), Class 2 (145 to <160), Class 3 (160 to <175), Class 4 (175 to <190), and Class 5 (>190).

2.10. Profile curvature

The proportions of concave and convex areas in Phang-nga province are nearly equal, with concave (Class 1) regions having 2,076,995 pixels with positive values, and convex (Class 3) regions having 2,026,067 pixels with negative values. The planar (Class 2) areas, on the other hand, have the smallest proportion, with 242,521 pixels. These areas are associated with flow speeds ranging from slow to fast, with both positive and negative values.

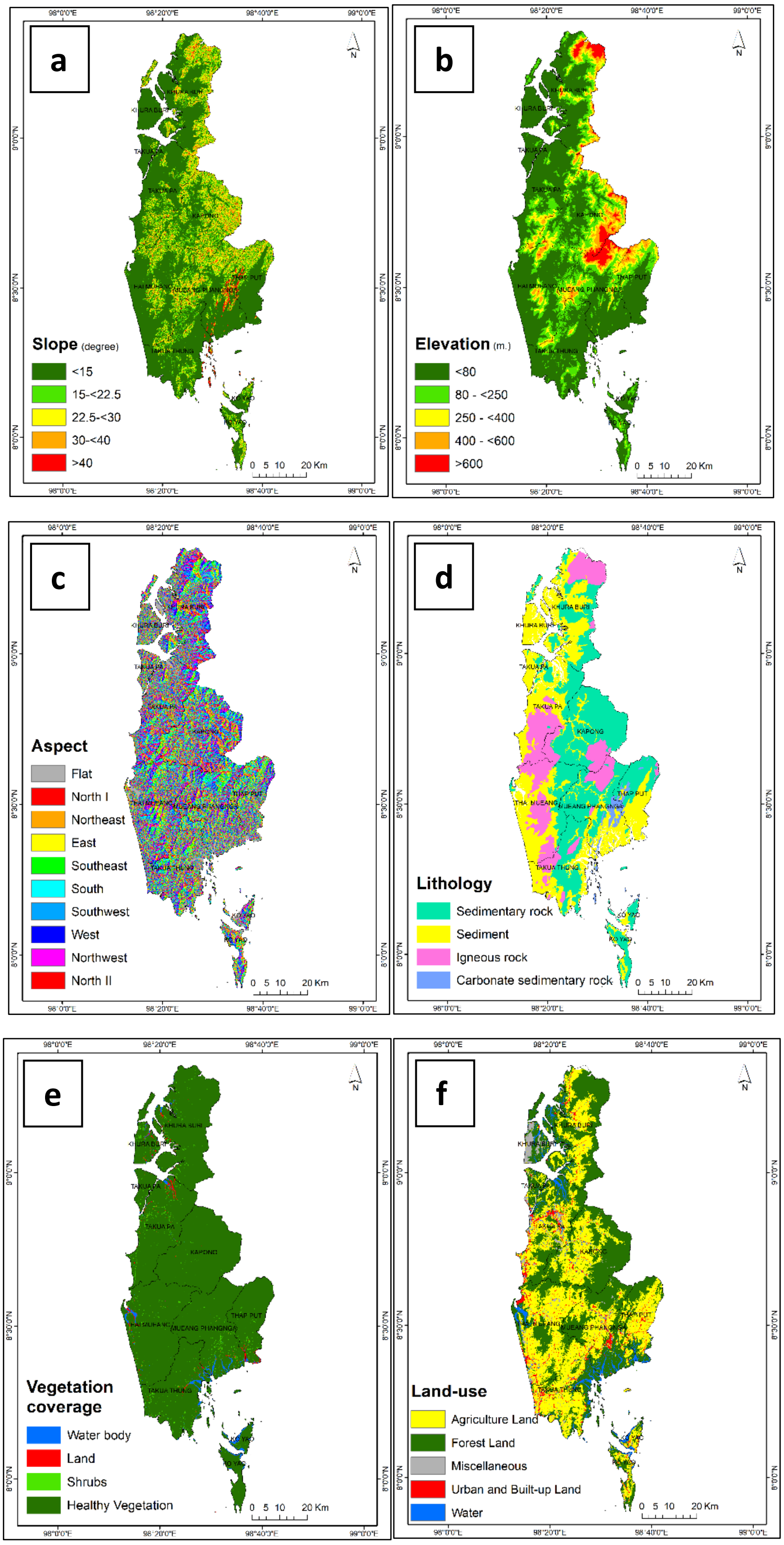

Figure 3 Map of Phang-nga showing the topographic index related to the debris flow susceptibility. (a) slope, (b) elevation, (c) aspect, (d) lithology, (e) vegetation coverage, and (f) land use, respectively.

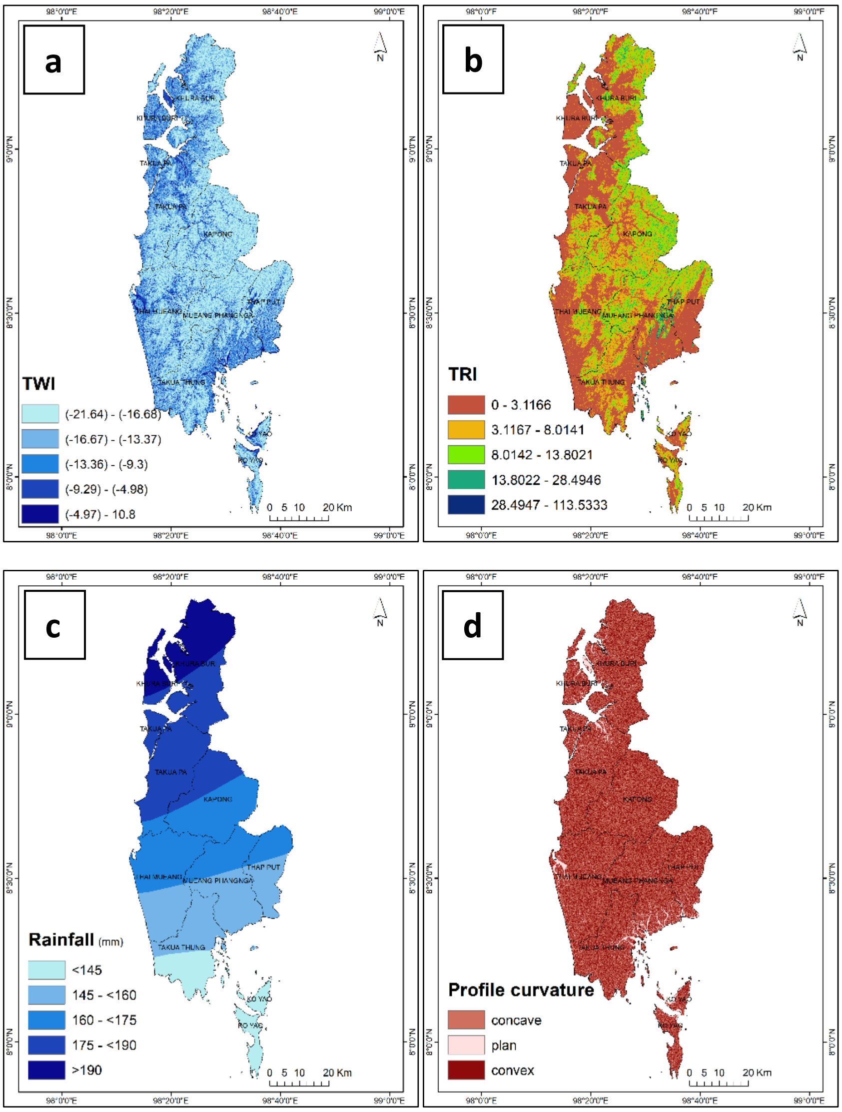

Figure 4 Map of Phang-nga showing the topographic index related to the debris flow susceptibility. (a) TWI, (b) TRI, (c) rainfall, and (d) profile curvature, respectively.

Table 2 Debris flow susceptibility of 10 parameters in this study

Index	class	Area (pixel)	Landslide in class (pixel)	FR
Slope	< 15	2831990	5482	1.13
	15 - 22.5	651845	1023	0.92
	22.5 - <30	503841	537	0.62
	30 - <40	273510	314	0.67
	>40	55557	39	0.41
Elevation	<80	2574561	5370	1.22
	80 - <250	950067	1865	1.15
	250 - <400	422158	185	0.26
	400 - <600	262594	0	0
	>600	136203	0	0
Aspect	Flat	98476	23	0.14
	North I	251712	512	1.19
	Northeast	447406	656	0.86
	East	499487	720	0.84
	Southeast	563505	845	0.88
	South	544130	1059	1.14
	Southwest	554136	987	1.04
	West	573956	998	1.02
	Northwest	558048	1095	1.15
	North II	225887	500	1.29
Lithology	Igneous rock	789053	2670	1.98
	Sedimentary-rock	1712059	1980	0.68
	Carbonate sedimentary rock	1571728	0	0
	Sediment	79638	2446	0.91
Vegetation coverage	Water body	84093	18	0.13
	Land	59035	22	0.23
	Shrubs	86158	157	1.12
	Healthy vegetation	4333784	7223	1.02
Land use	Agriculture land	1840841	3474	1.11
	Forest land	2018140	1622	0.47
	Miscellaneous	136849	471	2.02
	Urban and Built-up Land	160374	1727	6.32
	Water	191397	116	0.36
TWI	1	2040161	2959	0.85
	2	1343029	2439	1.06
	3	450474	844	1.10
	4	359916	779	1.27

	5	152003	399	1.54

Index	class	Area (pixel)	Landslide in class (pixel)	FR
TRI	1	2095021	4126	1.15
	2	1299197	2238	1.01
	3	773505	870	0.66
	4	164160	186	0.66
	5	13700	0	0
Rainfall	<145	387309	0	0
	145 - <160	1055042	2937	1.63
	160 - <175	1271774	2861	1.31
	175 - <190	1131028	1679	0.87
	>190	523591	0	0
Profile curvature	concave	2076995	3759	1.06
	Plan	242521	256	0.62
	convex	2026067	3405	0.98

3. Debris Flow susceptibility

3.1. Frequency Ratio (FR)

The FR model was used to calculate the weighting factors for debris flow susceptibility, with ten parameters: i) slope, ii) elevation, iii) aspect, iv) lithology, v) vegetation coverage, vi) land use, vii) TWI, viii) TRI, ix) rainfall, and x) profile curvature. The FR method has been widely used for debris flow susceptibility assessment (Qin et al., 2017) based on the observed relationship between the distribution of debris and individual debris flow-related variables. This method demonstrates the relationship between the location of the debris flow and the variables in the study area. The FR can be calculated using the equation below (1).

$$F_r = \frac{N_i}{N} / \frac{S_i}{S} \qquad \text{Equation (1)}$$

Where S is the total number of pixels, N is the number of pixels where debris occurs, Si is the number of pixels for a specific study variable, and Ni is the number of pixels for the i-th variable. A value greater than one indicates a stronger correlation, while values less than one indicate weaker correlations on average (Lee et al., 2004a, 2004b). The FR values for each factor were summed for each pixel. Consequently, the higher the FR, the higher the sensitivity. Conversely, the smaller the FR, the more sensitive the debris flow is (Das and Raja, 2015). The computed FR values can be divided into five categories using the natural Jenks classification: very low, low, medium, high, and very high susceptibility (Das and Raja, 2015). The AUC (Area under the ROC Curve) method was used to assess the accuracy of the FR results. It evaluates the accuracy of the model's predictions regardless of the classification threshold used. In this study, the AUC was 42.96% (Figure 5).

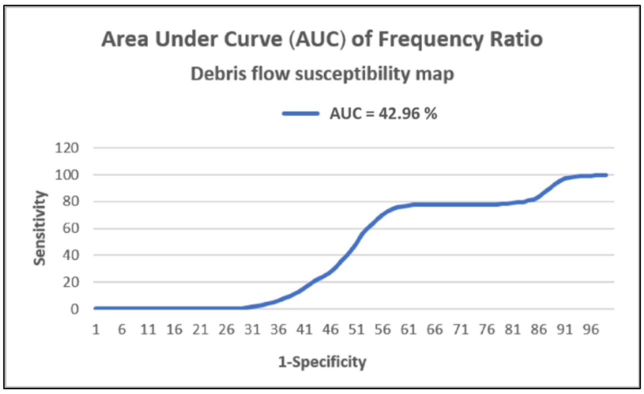

Figure 5 Showing area under curve (AUC) of frequency ratio

3.2. Susceptibility Mapping

The result of the debris flow susceptibility in Phang-nga is shown in Figure 5, with color classification based on the sensitivity level: i) dark green indicates a very low debris flow susceptibility area, ii) green indicates a low debris flow susceptibility area, iii) yellow indicates a medium debris flow susceptibility area, iv) orange indicates a high debris flow susceptibility area, and v) red indicates a very high debris flow susceptibility area. The levels of debris flow susceptibility can be divided into five groups, as shown in Table 1: Class 1 (very low: 4.83 to 8.56), Class 2 (low: 8.57 to 9.79), Class 3 (moderate: 9.80 to 10.86), Class 4 (high: 10.87 to 13.63), and Class 5 (very high: 13.64 to 18.24).

The area quantities can be sorted in descending order as follows: Class 3 covers 1,613.05 km², Class 2 covers 1,370.18 km², Class 1 covers 735.08 km², Class 5 covers 103.90 km², and Class 4 covers 40.22 km², as shown in Table 3. According to the results of the analysis, a large portion of Phang-nga has been designated as a moderate susceptibility area. The other areas not mentioned above are considered to be very high susceptibility areas. Furthermore, these high susceptibility areas were discovered along the Phuket mountain range and Tanaosri mountain range.

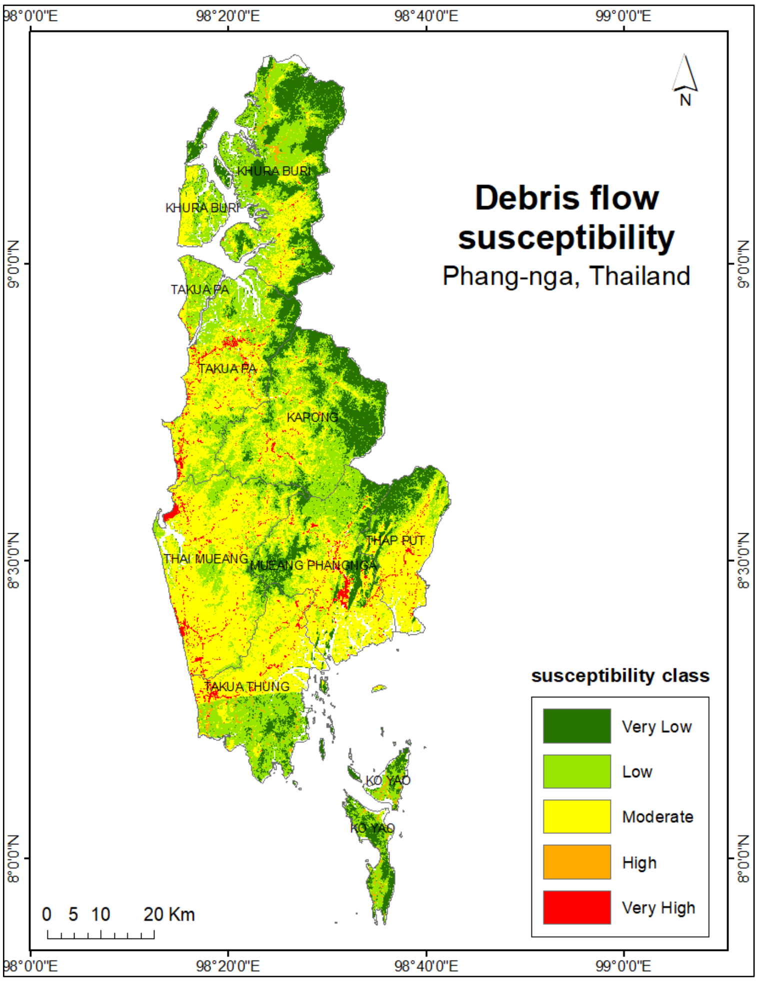

Figure 5 Map of The Phang-nga showing debris flow susceptibility map (green means very low susceptibility and red means very high susceptibility) obtained from this study.

Table 3 The total area for each class of the debris flow susceptibility map.

Class of debris flow susceptibility	Area (sq.km.)
Very low	735.08
Low	1370.18
Moderate	1613.05
High	40.22
Very high	103.90

4. Discussion

According to the results (Figure 5), the most prevalent class identified in Phang-nga province is moderate susceptibility. This concentration is primarily found in areas directly adjacent to the coastline, typically at elevations not exceeding 80 meters. Based on the analysis of the sensitivity map, it was found that the severity level of susceptibility corresponds with the area, as regions along drainage paths exhibit severity levels ranging from moderate to very high. If a disaster event were to occur, these areas would be directly affected. However, this also depends on the slope of the land in those areas. The relatively low AUC value from the validation process is due to data limitations, as the available comparison data only includes the point locations of landslide occurrences. This study may contain some inaccuracies due to calculations based on different parameters. The results from the map can be used, but they must be evaluated with caution and in conjunction with other factors, as there are challenges in confirming the accuracy of the map. Nevertheless, the use of the frequency ratio method to assess susceptibility is widely accepted in this field and continues to yield reliable and accurate results across various applications.

5. conclusion

Geomorphological indices are effective tools for assessing the impact of debris flow hazards. This method is useful for disaster mapping by Phang-nga. The relative active topography was assessed using DEM data with resolutions of 30 meters.

The frequency ratio (FR) method evaluated and weighted ten parameters that influence debris flow occurrences: slope, elevation, aspect, lithology, vegetation coverage, land use, TWI, TRI, rainfall, and profile curvature. These values are known as debris flow sensitivity values, and they are classified into five categories based on the degree of sensitivity.

The high and very high classes (Class 4 and Class 5) of debris flow susceptibility have been identified in the valley direction, located near the streamlines, and are areas where sediments can accumulate, predominantly in the western and southern parts of the province. Meanwhile, the eastern and southern parts of Phang-nga have been found to have low and very low classes (Class 1 and Class 2, respectively), which are located in the direction of the mountain range and areas with lower average rainfall.

The receiver operating characteristic (ROC) curve method can be used to assess the prediction accuracy for debris flow susceptibility, which plots the true positives rate (i.e., sensitivity) versus the false positives rate (i.e., 1-specificity). The AUC (Area under the ROC Curve) evaluates the accuracy of the model's predictions regardless of the classification threshold used.

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