

Thematic Mapping of Landslide Susceptibility of Kayapa Nueva Vizcaya

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ABSTRACT

To properly manage the landslide threat and minimize property damage and fatalities, a landslide susceptibility map must be created. The municipality of Kayapa has seen landslides, just like many other hilly areas, which have caused lives, injuries, and property damage. Therefore, the purpose of this work was to use a Geographic Information System-based spatial multicriteria approach to create map of landslide susceptibility. For the current assessment, seven parameters were chosen, that include elevation, land cover, rainfall, slope, road distance, and river distance. Four susceptibility classes low, moderate, high and very high—were identified on the landslide susceptibility map that resulted from the integration of Analytical Hierarchy Process and Geographic Information System methodologies. The thematic maps provide a more detailed representation of the places that are susceptible. The data indicates that 7288.12 hectares are classified as low susceptible, 14138.65 hectares as moderate susceptible, 16525.27 hectares as highly susceptible, and 11618.47 hectares as very highly susceptible to landslides. The study also reveals that the Slope is the most influential factor affecting landslide vulnerability. Additionally, the field survey and geotagging validation provide positive findings, meaning that the verified spots match the susceptibility levels on the landslide susceptibility map. The visualization of landslide susceptibility is a useful tool for disaster preparedness since it allows local government agencies to put specific policies in place to reduce the danger of landslides, particularly in high-risk areas.

Keywords: landslide, map, parameters, susceptibility classes

INTRODUCTION

Landslide is a natural process that refers to the downslope motion of soil and rock materials under the influence of gravity (Kehew, 1988). Triggered by different factors including heavy or prolonged rainfall, earthquakes, volcanic eruptions, disturbance by human activities, or any combination of these factors (United States Geological Survey). Notably, landslides are most prevalent in regions with elevated or mountainous terrain which causes a significant injury, loss of human life, and extensive damages to properties and infrastructure.

According to the Mines and Geosciences Bureau (MGB), the Philippines rank as the fourth most exposed to landslide risk, after Indonesia, India and China. The combination of mountainous and hilly regions that experiences earthquakes as well as intense rainfall brought on by monsoons and/or typhoons, makes the terrain naturally susceptible to landslides as highlighted by the United Nations International Strategy for Disaster Reduction (UNISDR).

The Philippines has experienced several devastating landslides, the tragic event in Guinsaugon in St. Bernard, Southern Leyte on February 11, 2006, triggered by heavy rainfall from a tropical storm buried the entire village, claiming around 1,126 lives. Another catastrophic event occurred in Andap, New Bataan, Compostella Valley in November 2012, the heavy rains brought by Typhoon Pablo caused a massive debris flow that resulted in 128 fatalities and 450 individuals were reported missing. These cases illustrate the recurring threat of landslides in the Philippines, often amplified by the country's geographical characteristics and meteorological conditions. The northern part of Luzon like Nueva Vizcaya province is no exception. The province has experienced numerous landslides, resulting casualties, property damages and economic losses (Bishop et.al., 2007).

In Kayapa town in Nueva Vizcaya, a landslide buried a family of four in Barangay Banaw. In a statement, said the erosion took the lives of a 36-year-old father and his children: a 9-year-old boy, a two-year-old girl, and an eight-month-old baby. Landslides pose a significant threat in Kayapa, Nueva Vizcaya, with their potential loss of life, property damage, and environmental degradation. Hence, to mitigate these risks and enhance disaster preparedness, many researchers had utilized Geographic Information System (GIS) to generate landslide susceptibility map (Wright, 1997). However, despite advancements in landslide susceptibility mapping, a notable research gap exists in localized studies. Landslide susceptibility can change over time due to various factors. such as weather, construction activities and natural processes.

Therefore, this gap necessitates further and ongoing research of a landslide susceptibility to mitigate the evolving risks in the area. This research, titled “Thematic Mapping of Landslide Susceptibility of Kayapa Nueva Vizcaya” was conducted to reevaluate landslide prone areas within the municipality of Kayapa Nueva Vizcaya.

METHODOLOGY

INPUT	PROCESS	OUTPUT
<ul style="list-style-type: none"> Raster file (Slope, Precipitation, Digital Elevation Model) Shapefile or Vector file (Soil type, Landcover, Road networks, River networks) 	<ul style="list-style-type: none"> Generate thematic maps using GIS Relative Weight Assignment using AHP Validation 	<ul style="list-style-type: none"> Tabulated Total Area in hectares of susceptibility classes Thematic maps (Slope, Elevation, Precipitation, Soil type, Landcover, Distance from road, and Distance from river) Landslide susceptibility map

Figure 1. Conceptual framework of the study

Figure 1 shows the Conceptual Framework of the Study. The Input-Process-Output (I-P-O) is used to illustrate the scope of this study. The seven parameters that include slope, precipitation, elevation, soil type, landcover, distance from roads and rivers were considered in this study to determine the most influential factor of landslide susceptibility in terms of area in hectares per class categorized as low, moderate, high, and very high susceptibility, to generate thematic maps and landslide susceptibility map.

Geographic Information System (GIS) particularly the ArcGIS 10.8 (Developed by Esri) is the primary tool used for data processing, analysis, geospatial modelling and to create thematic maps. Individual maps for slope, elevation, precipitation, soil type, land cover, distance from river and distance from road are the thematic maps generated using that ArcGIS 10.8.

In this study, researcher applied the Analytical Hierarchy Process (AHP) as a suitable statistical tool to facilitate the decision-making and weighting process for accurately reflecting the influence of each causative factors in developing landslide susceptibility map through the application of Geographic Information System (GIS). The AHP developed by mathematician and operations researcher Thomas L. Saaty (1980) is a powerful multi-criteria decision analysis (MCDA) technique that enables the incorporation of multiple criteria in decision-making processes. Table 1 shows the Saaty’s proposed numerical scale. In the context of this study, where various factors such as slope, aspect, landcover, soil type, elevation, rainfall and distance from roads and rivers contribute to landslide susceptibility, the AHP were aid in prioritizing and weighting these factors according to their significance.

A pairwise comparison of all components of the variables that contribute to landslides is conducted to create a scale of the relative significance of each element; the outcomes are presented as a numerical rating on a rating scale. Pairwise comparisons in matrix form, when combined, will provide a priority scale for the key variables contributing to landslides. The weight analysis evaluation of utilizing the Analytical Hierarchy Process (AHP) was used, as presented in Table 1.

Table 1. Pairwise comparison matrix, normalized factor weights and consistency ratio of the data layers (Rahim et.al., 2018)

	1	2	3	4	5	6	7	Weights (%)
Slope (1)	1	2	3	4	5	5	6	35
Rainfall (2)	.5	1	2	3	4	4	5	23.563
Soil (3)	.333	.5	1	2	3	3	4	15.377
Landcover (4)	.25	.333	.5	1	2	2	3	9.749
Elevation (5)	.2	.25	.333	.5	1	2	3	7.205
Distance to Road (6)	.2	.25	.333	.5	.5	1	2	5.443
Distance to River (7)	.167	.2	.25	.333	.333	.5	1	3.663

CR (Consistency ratio) = 0.027, <0.1 acceptable

RESULTS

1. Total area in hectares for each susceptibility class to landslide based on the seven parameters

Table 2. Area coverage for each susceptibility class based on the Slope

Slope	Class	Area (Hectares)	Area (Percentage)
<18°	Low	1865.91	3.77
18°-30°	Moderate	6523.90	13.17
30°-50°	High	16412.24	33.13
>50°	Very High	24744.19	49.94

Table 3. Area coverage for each susceptibility class based on the Precipitation

Rainfall	Class	Area (Hectares)	Area (Percentage)
200.00-221.80	Low	34585.66	66.77
221.80 -238.67	Moderate	7858.08	15.85
238.67-260.12	High	5592.61	11.28
260.12-289.99	Very High	1531.17	3.09

Table 4. Area coverage for each susceptibility class based in Soil Type

Soil Type	Class	Area (has)	Area (%)
Annam clay loam	Low	4127.69	8.33

Sevilla clay	Moderate	8626.66	17.41
Guimbalaon clay loam, Guimbalaoan Annam Complex	High	18700.48	37.73
Mountain Soil, Sibul clay, Guimbalaon clay loam Eroded phase	Very high	18072.64	36.54

Table 5. Area category for each susceptibility class based on the Land Cover

Landcover Type	Class	Area (has)	Area (%)
Open /Close Forest	Low	17402.07	35.13
Brush/Shrubs	Moderate	8166.57	16.48
Annual/Perennial Crops	High	4947.41	9.99
Open/Barren, Built Up, Grassland, Inland Water	Very high	9032.68	18.23

Table 6. Area coverage for each susceptibility class based on the Elevation

Elevation (m)	Class	Area (has)	Area (%)
<500	Low	614.95	1.24
500-1000	Moderate	12145.68	24.51
1000-1500	High	25166.29	50.78
>1500	Very high	11629.62	23.47

Table 7. Area coverage for each susceptibility class based on the Distance from Road

Distance from road	Class	Area (has)	Area (%)
<100	Very high	1474.34	2.97
100-200	High	2754.09	5.56
200-300	Moderate	1841.43	3.72
>300	Low	43490.76	87.75

Table 8. Area coverage for each susceptibility class based on the Distance from River

Distance from river (m)	Class	Area (Hectares)	Area (Percentage)
<100	Very high	31179.04	62.92
100-200	High	6631.29	13.38
200-300	Moderate	7812.79	15.76
>300	Low	3932.48	7.94

Table 9. Synoptic table presenting the causative factors, their rating, susceptibility class and the weight assigned to each factor through AHP (Rahim et.al., 2018)

Causative factors	Rating	Susceptibility Class	Weights (%)
Slope			
<8°	1	Very low	35.00
8°-18°	2	Low	
18°-30°	3	Moderate	
>30°	4	High	
Rainfall			
170.00-174.54	1	Very low	23.563
174.54-178.66	2	Low	
178.66-182.58	3	Moderate	
182.58-187.60	4	High	
Soil			
Riverwash	1	Very low	15.377
Guimbalaon Clay Loam	1	Very low	
San Manuel Sandy Loam	1	Very low	
Unknown	1	Very low	
Quingua Silt Loam	2	Low	
Annam Clay Loam	3	Moderate	
Mountain Soils	4	High	
Landcover			
Closed/ OpenForest	1	Very low	9.749
Brush/Shrubs	2	Low	
Annual/Parennial crop	3	Moderate	
Open /Barren	4	High	
Built-up	4	High	
Inland water/Fishpond	4	High	
Grassland	4	High	

Elevation (m)			
<250	1	Very low	7.205
250-500	2	High	
500-1000	3	Moderate	
>1000	4	High	
Distance to Road (m)			
<100	1	Very low	5.433
100-200	2	Low	
200-300	3	Moderate	
>300	4	High	
Distance to River (m)			
<100	1	Very low	3.663
100-200	2	Low	
200-300	3	Moderate	
>300	4	High	

2. Thematic maps of the seven parameters

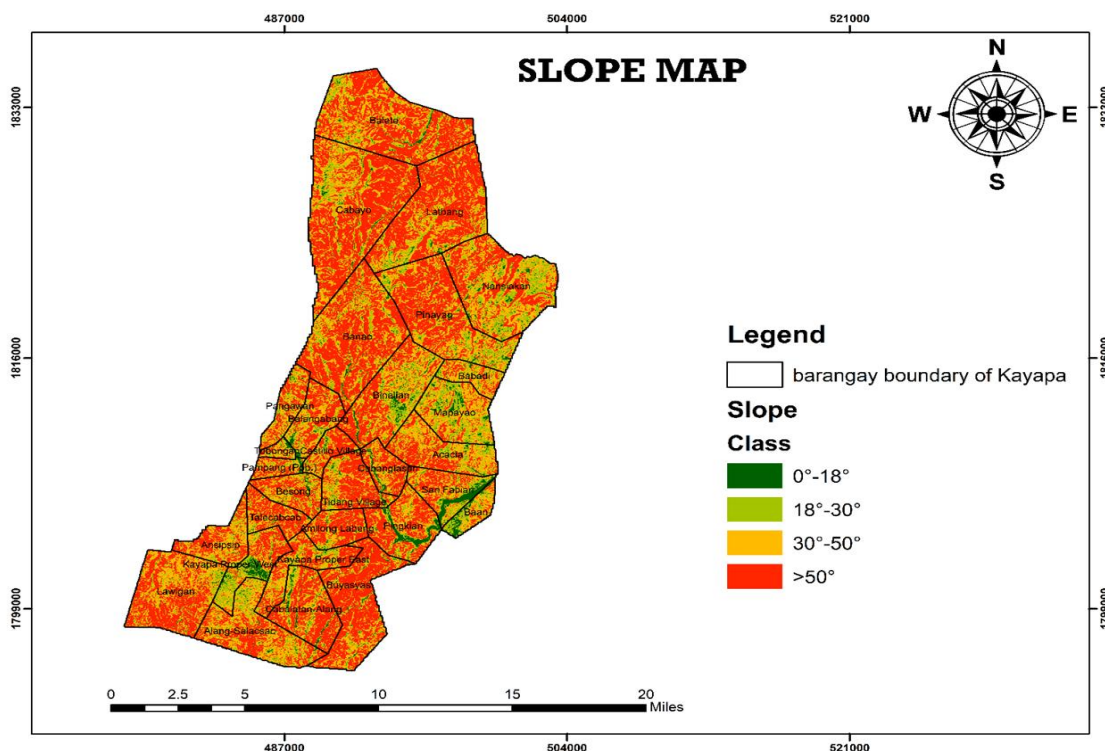


Figure 2. Slope Map of Kayapa Nueva Vizcaya

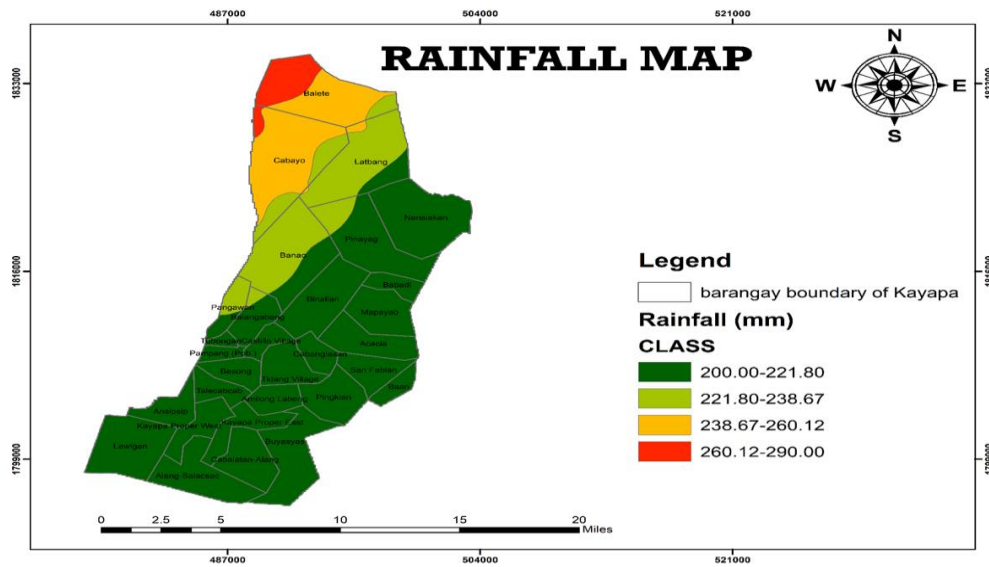


Figure 3. Rainfall Map of Kayapa Nueva Vizcaya

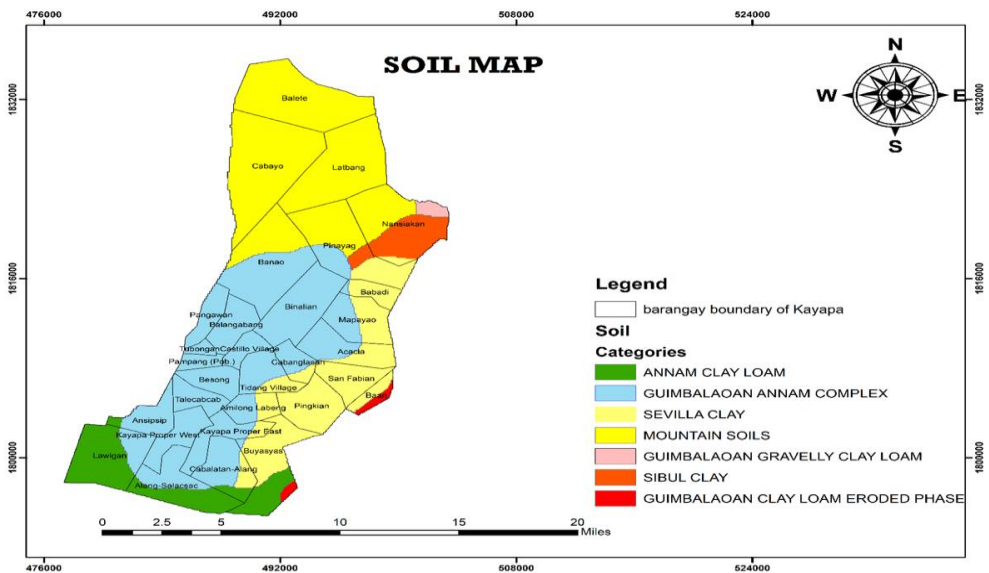


Figure 4. Soil Map of Kayapa Nueva Vizcaya

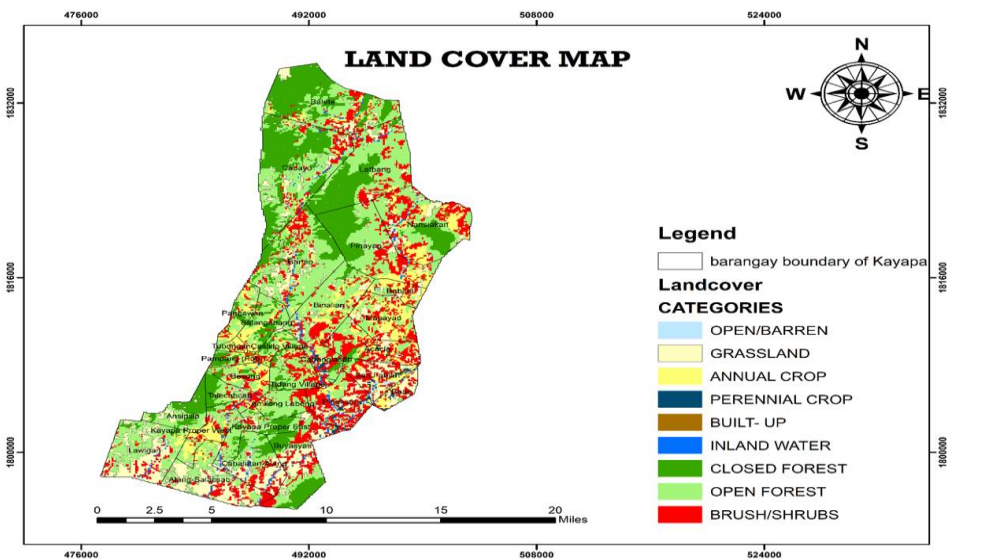


Figure 5. Land Cover Map of Kayapa Nueva Vizcaya

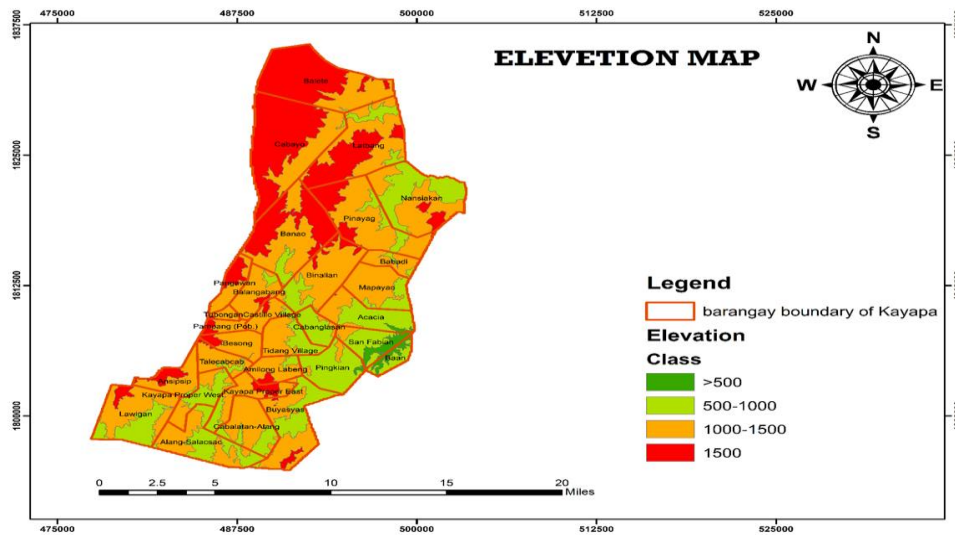


Figure 6. Elevation Map of Kayapa Nueva Vizcaya

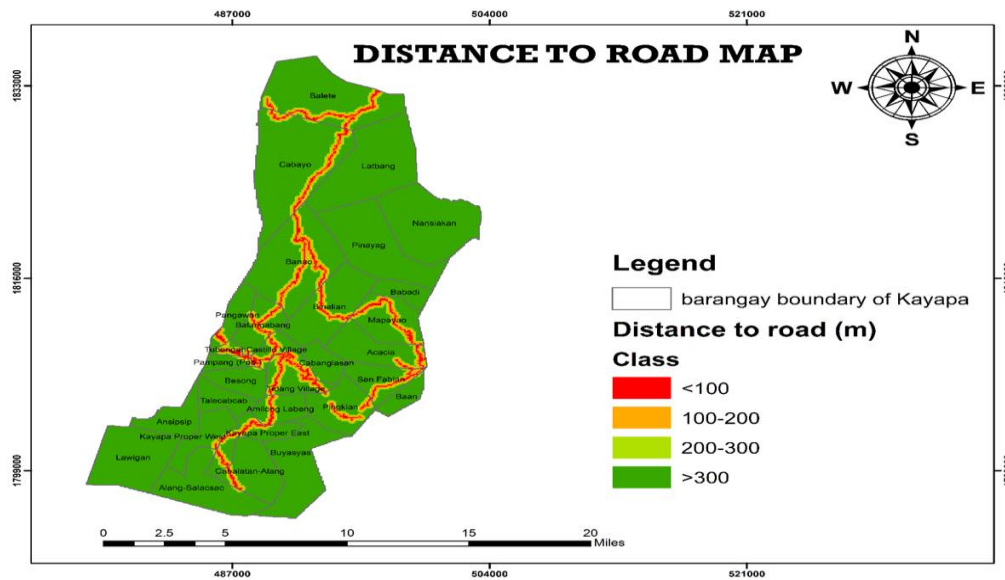


Figure 7. Distance to Road Map of Kayapa Nueva Vizcaya

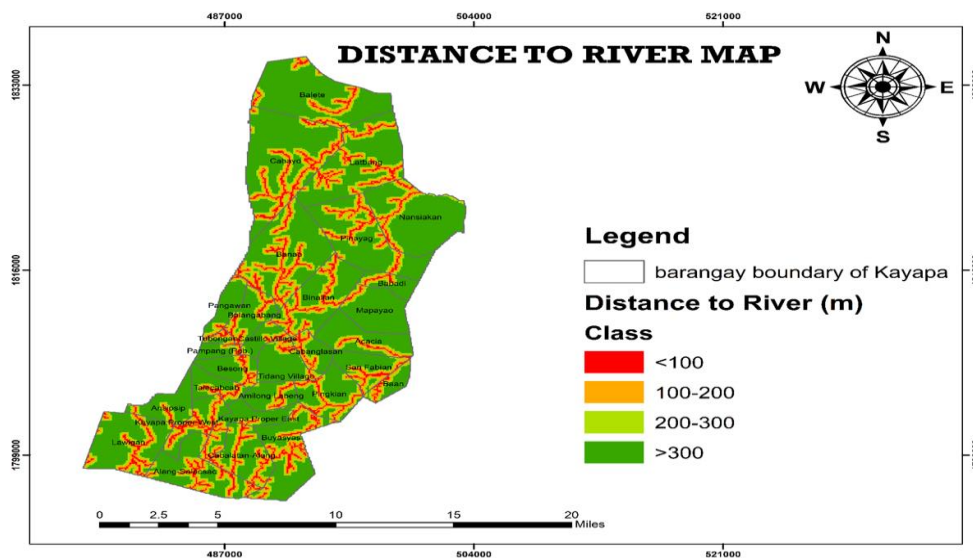


Figure 8. Distance to River Map of Kayapa Nueva Vizcaya

3. Visualization of Landslide Susceptibility of Kayapa Nueva Vizcaya

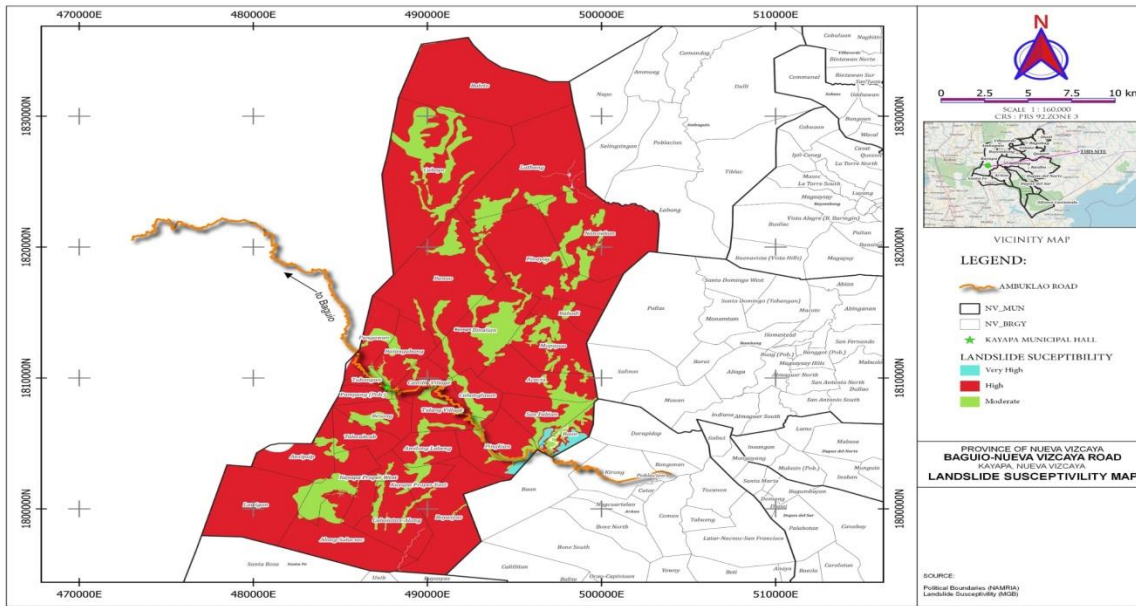


Figure 9. Landslide Susceptibility Map of Kayapa Nueva Vizcaya

4. Validations to support the landslide susceptibility map

Table 10. Field Survey for validation of points

Points	Validation Rating
1	Low
2	High
3	Low
4	High
5	High
6	High
7	High
8	High
9	High
10	High
11	Moderate
12	High
13	High
14	High

15	Moderate
16	Low
17	High
18	High

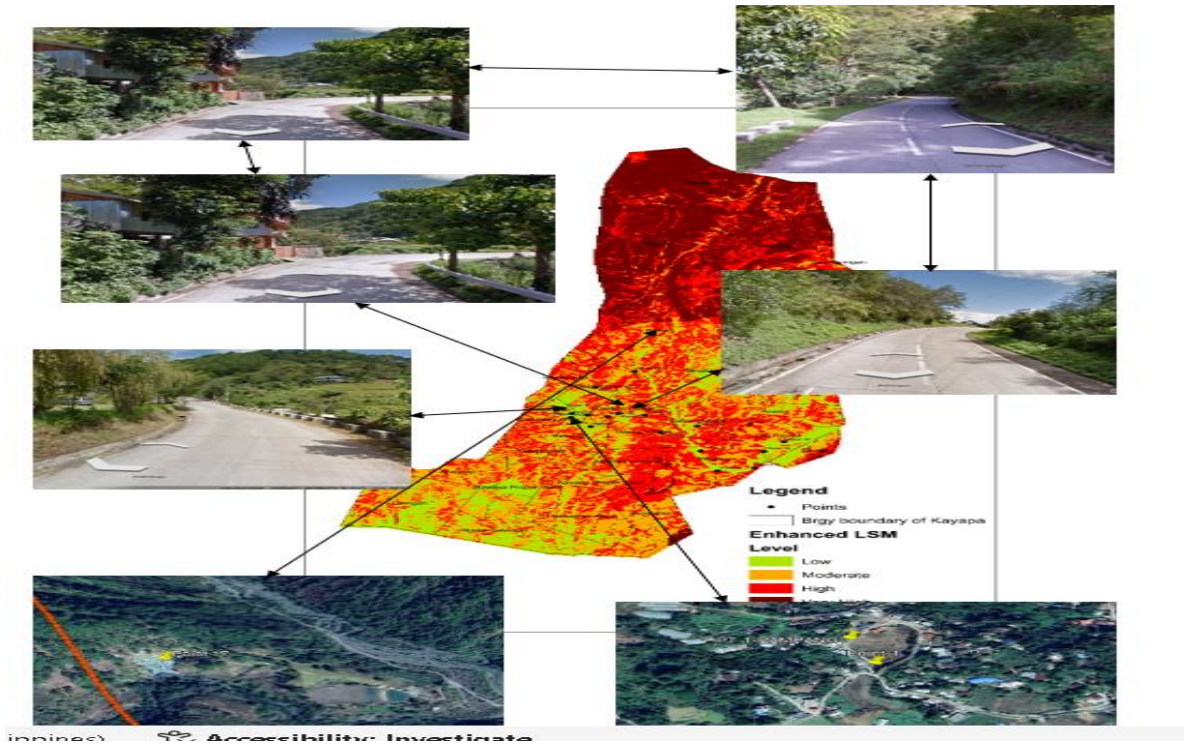


Figure 10. Overlaying of Points Validated in Enhance LSM of Kayapa Nueva Vizcaya

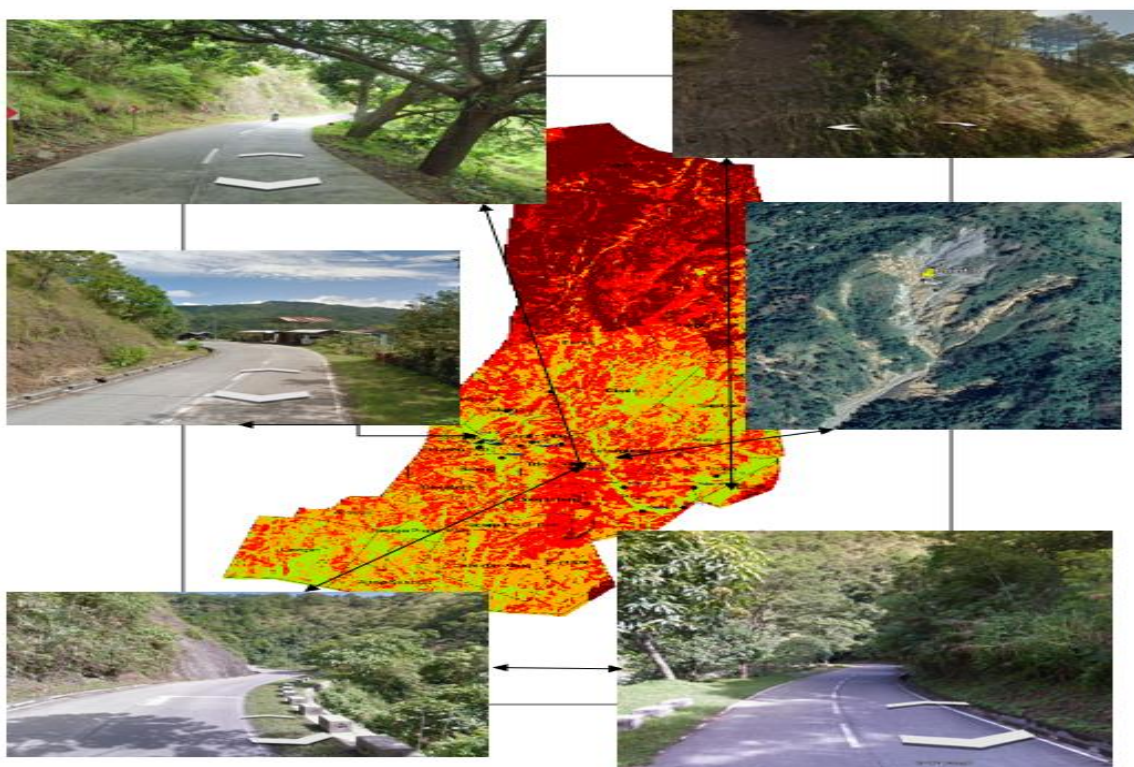


Figure 11. Overlaying of Points Validated in Enhance LSM of Kayapa Nueva Vizcaya

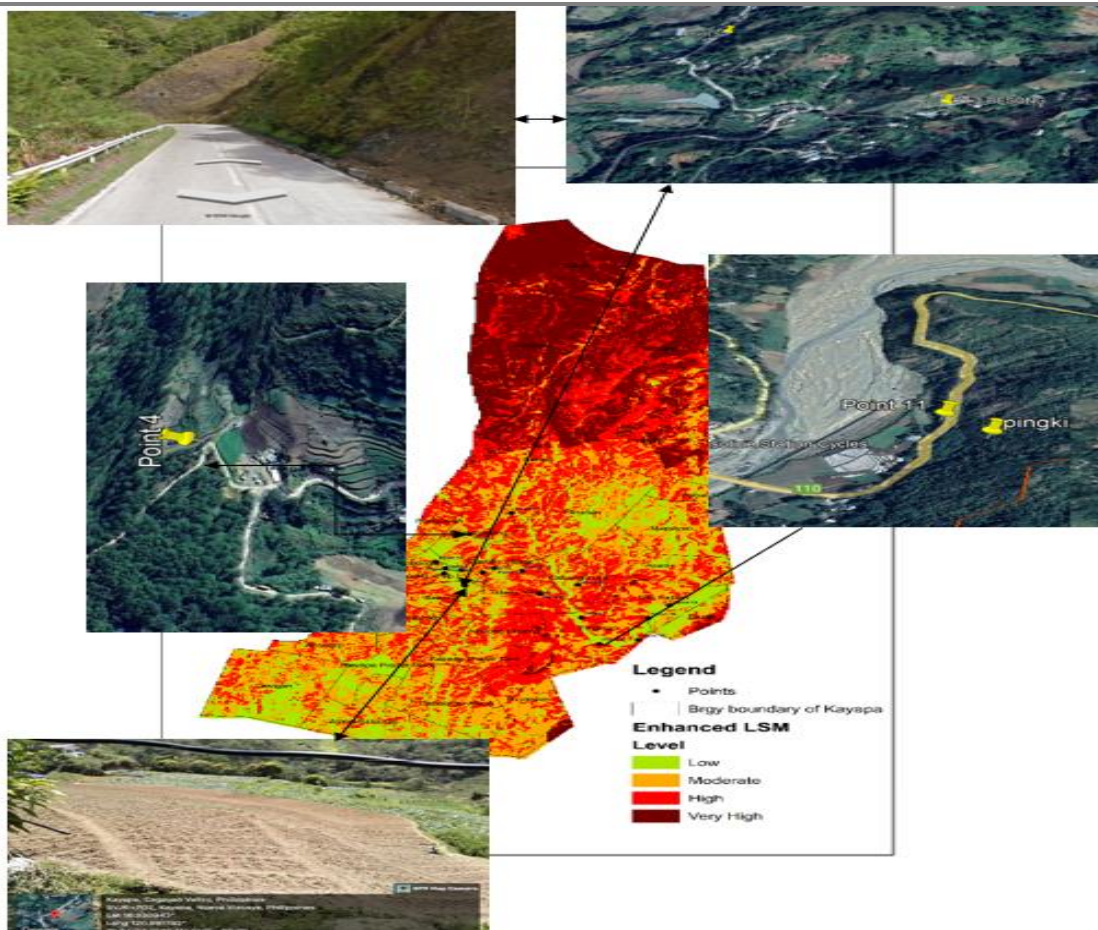


Figure 12. Overlaying of Points Validated in Land SM of Kayapa Nueva Vizcaya

DISCUSSION

Slope angle emerged as the most influential factor among other causative factors, with a relative weight of 35%. Table 2 and Figure 2 illustrates that slopes above 50 degrees and 30 to 50 degrees are classified as having a very high and high level of susceptibility to landslides and have the largest area, covering 24744.19 hectares (49.94%) and 16,412.24 hectares (33.13%).

Table 3 shows the distribution of rainfall with its corresponding classes and emerged as the second most influential factor among other causative factors, with a relative weight of 23.56%. Based on Figure 3, the study revealed that most of the total area under study were received 200- 221 average rainfall per year.

Soils and landslides are closely related, especially for shallow landslides that occur in soil or weathered bedrock (Temme 2021). Table 4 and Figure 4 depict that mountain soil, sibul clay, guimbalaon clay loam eroded phase, guimbalaon clay loam, and guimbalaon annam complex is categorized as very high and highly susceptible to landslides, having a vast area of 11,412.26 hectares (53.77%) and 18700.48 hectares (37.73%) of the total area of Kayapa.

Land cover influences landslide susceptibility by affecting soil stability and water infiltration. As shown in Table 5, open/barren, built-up, grassland, inland water, annual/perennial crops are considered to be very highly and high susceptible to landslides but have the smallest area, encompassing 9,036.68 hectares (35.13%) and 4,947.71 hectares (9.99%) of the total area of Kayapa.

Elevation is a parameter frequently used in landslide susceptibility analysis and is regarded as a vital factor for susceptibility mapping (Anthuwaynee et al., 2022). As shown in Table 6, a very high and high level of susceptibility is attributed to elevations exceeding 1000 meter and 1000 to 1500 meters above datum, but they have the largest area, covering 11,629.62 hectares (23.47%) and 25,166.29 hectares (50.78%) of the total area of Kayapa.

Proximity to roads can influence landslide susceptibility due to disturbances and slope destabilization during construction. As shown in Table 7 and Figure 7, places within 0 to 100 meters from the roads are considered to have a very high susceptibility to landslides and consist of only 1,474.34 hectares (2.97%) of the total area of Kayapa.

Distance from rivers emerged as the last influential factor, with a relative weight of 3.66%. Table 8 revealed that areas within 0 to 100 meters from rivers are classified as having a high susceptibility to landslides, covering only 2447.06 hectares (11.53%) of the total area. Moreover, areas falling within 100 to 200 meters and 200 to 300 meters are classified as having low to moderate levels of susceptibility to landslides, with the smallest portion encompassing 1643.89 hectares (7.75%) and 1784.71 hectares (8.41%).

To validate the results, the researchers employed geotagging on areas identified to exhibit disparities or differences in susceptibility class between the existing landslide susceptibility map and the updated version. Thereafter, a field survey was carried out to further assess the accuracy and the reliability of the latter, using GPS Camera to capture numerous georeferenced photographs. Furthermore, photos online from reliable sources that illustrate landslide cases in the area were geotagged. This method was identified to yield positive result.

The verified locations are shown in Figures 10 to 12, together with the associated geotagged photos. The points 1 in Pampang (points 2 and 4), Balangabang (points 6, 7, 8, and 9), Pingkian, and (points 9) Cabanglasan were identified as being extremely vulnerable to landslides in the current landslide susceptibility map. Validation revealed that the spots are located 500 to 1000 meters above the datum and have slopes between 18 and 30 degrees, which indicates that they are not very susceptible to landslides. Moreover, the average annual rainfall in these regions is somewhat low. While there are some sections with quite steep slopes, most of the land is not.

Furthermore, points 10 and 13 and points 11 and 16, San Fabian, are situated in Tidang Village. These locations were identified as having a high landslide susceptibility in both the updated susceptibility map and the current one. It has been evaluated and proven by field studies that certain places are in fact extremely sensitive. The geotagged photographs taken with the GPS camera show that these regions have high elevations and steep slopes and received more precipitation in this area.

Moreover, the geotagged images of landslide cases at points 12, 13, 14, 15, 16, and 18 were obtained from reputable online sources, and locals were contacted to verify their positions. After comparing the results with these points were categorized as very sensitive on the susceptibility map because of their high altitudes and steep slopes. In overall results of the validation, based from table 10 as presented, the study area is highly susceptible to landslide.

CONCLUSION

The result demonstrated a strong relationship between the contributing variables in the municipality of Kayapa particularly along the road the vulnerability to landslides. The data shows a definite increase in susceptibility levels with increasing slope steepness. A total of 24,744.19 hectares (49.94%) is categorized as extremely prone to landslides, especially those with slopes higher than 50 degrees. Rainfall is also crucial factor, with areas experiencing intense or prolonged rainfall being more susceptible to landslides. Landslides are most likely to affect areas above 1500 meters above the datum, which total 11629.62 hectares (3.09%). Additionally, the distance to highways and rivers had an impact on susceptibility; regions that were closer to these features—that is, less than 100 meters away—showed a greater chance to landslides.

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