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Landslide Susceptibility Mapping in Quezon, Nueva Vizcaya Using GIS: An Enhancement

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ABSTRACT

Creating a landslide susceptibility map is imperative for effectively managing the landslide hazard, reducing property damage and loss of life. Like many other mountainous places, the municipality of Quezon has also experienced landslides, resulting in fatalities, injuries, and property destruction. Hence, this study was conducted to generate an enhanced landslide susceptibility map using a GIS-based spatial multicriteria approach. Seven causative factors, including slope, rainfall, soil type, land cover, elevation, distance from the road, and distance from the river, were selected for the present assessment. An enhanced landslide susceptibility map was generated by integrating AHP and GIS techniques and was categorized into four susceptibility classes: very low, low, moderate, and high. The result presented in the study illustrates that there was a disparity between the two maps. The enhanced map shows a more detailed representation of truly vulnerable areas. Specifically, 3589.64 hectares are identified as very low susceptible, 5690.36 hectares are low susceptible, while 5993.09 hectares and 5792.80 hectares are categorized as moderately and highly susceptible to landslides. The results presented in the study indicate that Barangay Maasin, Runruno, and Calaocan, and some parts of Maddiangat, Baresbes, Buliwao, and Darubba, are identified as at high-risk areas. On the other hand, Barangay Dagupan and Bonifacio are at moderate risk, while Barangay Nalubbunan, Caliat, and Aurora are at low risk. Furthermore, the validation conducted by geotagging and field survey yields positive results, indicating that the validated points aligned on the enhanced LSM. The enhanced LSM serves as a valuable tool for disaster preparedness and enables local agencies to implement targeted measures to mitigate landslide risks, especially in high-risk places.

Keywords: landslide, enhancement, factors, enhanced landslide susceptibility map, AHP, GIS, LSM

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

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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 were 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).

On November 11, 2020, heavy rains brought by Typhoon Ulysses triggered a landslide in Brgy. Runruno, Quezon, Nueva Vizcaya, claiming 10 lives including a two-month-old infant and several houses were destroyed. Moreover, in recent years, frequent heavy rains have triggered multiple landslides along the roads, leading to road closures causing transportation disruption to nearby municipalities.

Landslides pose a significant threat in Quezon, 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 "Landslide Susceptibility Mapping in Quezon, Nueva Vizcaya Using GIS: An Enhancement" was conducted to reevaluate landslide prone areas in the municipality of Quezon. Specifically, this study aims to enhance landslide susceptibility map and provide valuable information for risk mitigation and disaster management.

Objectives of the Study

This study aimed to generate an enhance landslide susceptibility map for the municipality of Quezon in Nueva Vizcaya using Geographic Information System. The specific objectives are as follows:

1. To determine the area in hectares for each susceptibility class to landslides based on the following causative factors:
   a. Slope
   b. Rainfall
   c. Soil Type
   d. Land Cover
   e. Elevation
   f. Distance from road
   g. Distance from river
2. To determine the area in hectares for each barangay falls within each susceptibility class based on the generated enhanced landslide susceptibility map.
3. To identify the significant difference between the existing susceptibility map and the enhanced version.
4. To provide effective mitigation measures that can be implemented to reduce landslide risks in the area.

MATERIALS AND METHODS

Research Design

This study utilized a quantitative research design to create an updated landslide susceptibility map for the study area. Geospatial data, such as the Digital Elevation Model (DEM), land cover, soil type, rainfall, road networks, river networks, and slope which was derived from the DEM, were collected as secondary data. Moreover, the detailed comparison between the existing and enhanced landslide susceptibility map and the recommendations for mitigation measures are descriptive and illustrative in nature.

Conceptual Framework

The conceptual framework illustrates the input, process, and output of the study. The chart shows that the inputs are; total area for each susceptibility class to landslide based on the following causative factors: slope, rainfall, soil type, land cover, elevation, distance from roads, distance from rivers, and rainfall; total area for each barangay falls within each susceptibility class based on the generated enhanced landslide susceptibility map; comparison between the existing susceptibility map and the enhanced version; and providing mitigation measures. Through a systematic process, seven thematic map layers were produced with the help of ArcGIS in preparation for analysis to reassess the landslide susceptibility of the area. Subsequently, weight assignment was employed using the Analytical Hierarchy Process (AHP) to create the final output, which was the enhanced landslide susceptibility map. Following this, geotagging was employed and field survey was carried out by the researchers to ground truth and validate the results generated by the GIS. Lastly, the researchers recommended mitigation measures that can be implemented.

INPUT	PROCESS	OUTPUT
• Total area in hectares for each susceptibility class to landslide based on the following causative factors: a) Slope b) Rainfall c) Soil type d) Land cover e) Elevation f) Distance from road g) Distance from river • Total area in hectares for each barangay falls within each susceptibility class based on the generated enhanced landslide susceptibility map • Comparison between the existing susceptibility map and the enhanced version • Provide mitigation measures	• Data Acquisition from PPDO • Data Acquisition from PAGASA • Creating thematic maps in ArcGIS 10.8 • Weight Assignment using AHP • Validation	• Enhanced landslide susceptibility map • Recommend mitigation measures to prevent and mitigate the risk involving landslide

Figure 1. Conceptual framework of the study

Research Locale

The Municipality of Quezon is situated at the Northeastern part of the province of Nueva Vizcaya. It is located 16°20' North and 121°25' East, bounded on the West by the municipality of Solano, on the North by the Municipality of Bagabag, on the Northeast by the Municipality of Diadi, on the East by the Municipality of Diffun, Province of Quirino, on the Southeast by the Municipality of Kasibu, and on the Southwest by the Municipality of Bayombong and Bambang. It covers a total land area of approximately 21225.26 hectares, or about 5.14% of province's total land area. The municipality of Quezon consist of 12 barangays namely; Runruno with its vast territory of 4180.37 hectares or about 19.70% of the municipal's total area, Calaocan spanning 1,808.96 hectares or about 12.85% of the municipal's total area, Dagupan covering a total area of 2,711.06 hectares or about 12.77% of the municipal's total area, Maasin encompassing a total area of 2147.50 hectares or about 10.12% of the municipal's total area, Bonifacio extending over a total of 1808.96 hectares or about 8.52% of the municipal's total area, Maddiangat covering a total area of 1,758.10 hectares or about 8.28% of the municipal's total area, Nalubbunan extending over a total of 1,391 hectares or about 6.56% of the municipal's total area, Buliwao encompassing a total area of 1,205.19 hectares or about 5. 68% of the municipal's total area, Baresbes covering a total area of 1,160.54 hectares or about 5.47%, Caliat covering a total area of 908.26 hectares or about 4.28% of the municipal's total area, Aurora occupying a total of 659.22 hectares or about 3.11%, and Darubba with the least total covered area of 566.16 hectares or about 2.67% of the municipal's total area.

Research Instrument

In this study, the researchers utilized ArcGIS 10.8 as a primary tool for data processing, analysis, geospatial modeling, and map production. Interviews with local authorities and residents were employed to gather valuable information regarding areas with a history of landslides. Furthermore, geotagging was employed to tag areas identified to have disparities in the existing landslides susceptibility map and the enhanced version. A field survey was also carried out to ground truth and validate the results generated by the GIS, using GPS Camera application to capture georeferenced photographs.

Data Gathering Procedure

The data gathering procedure entails acquiring geospatial data for analysis. In this study, the causative factors were selected based on various case studies (Arizapa et al., 2015; Jazouli et al., 2019) and on the available data in the study area. The factors considered were elevation, slope, rainfall, land cover classification, soil type classification and distance from roads and rivers.

A letter was sent to the Provincial Planning and Development Office (PPDO) requesting the following data in shapefile format including the 2019 landslide susceptibility map, DEM, soil type, land cover, road and river networks, as well as Quezon Administrative Boundary to delineate the area. Slope was derived from DEM. Furthermore, another letter was sent to NVSU PAGASA Agromet requesting the rainfall map of the province of Nueva Vizcaya from the year 2019 to 2023.

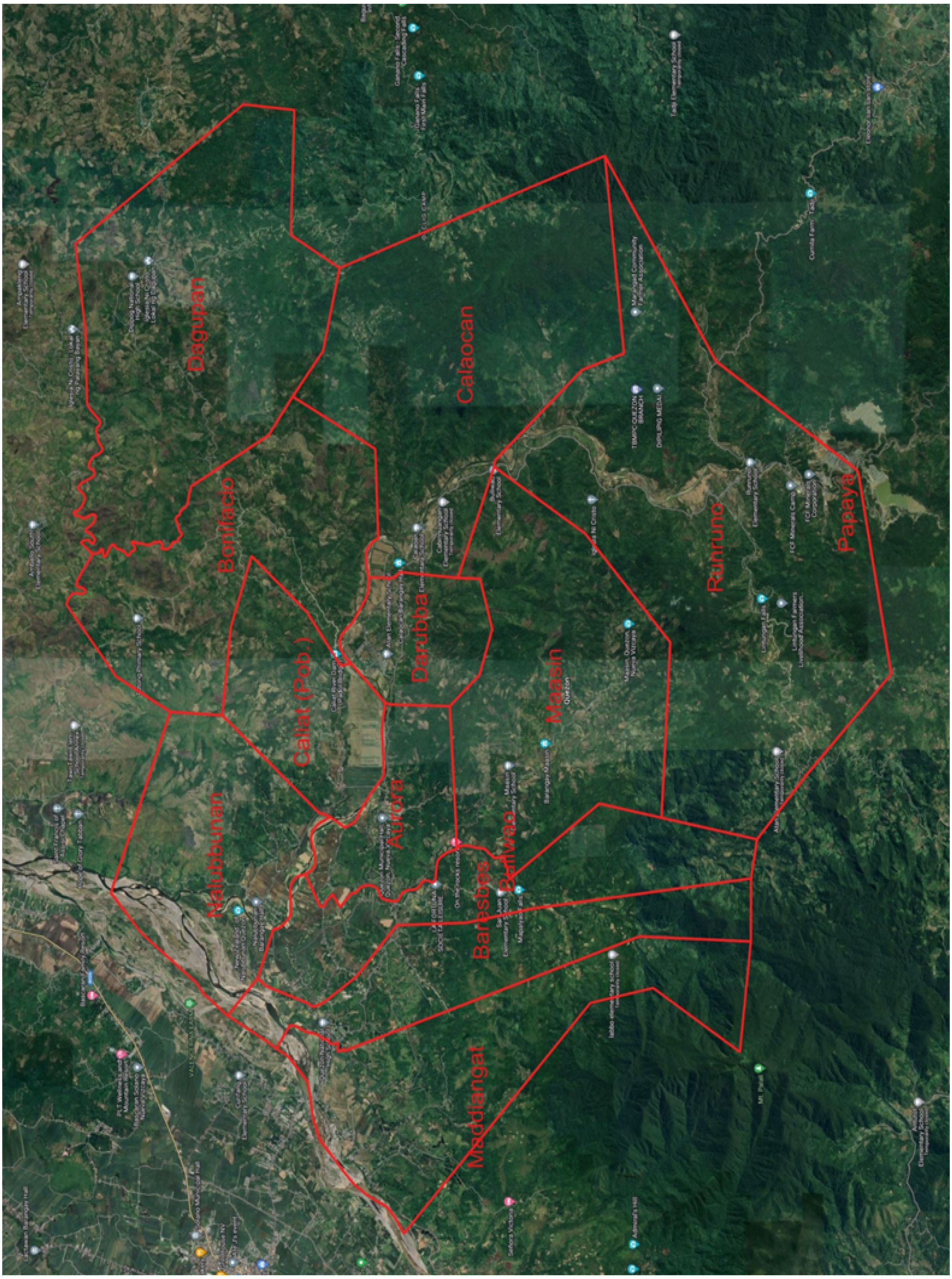


Figure 2. Satellite Map of the Study Area

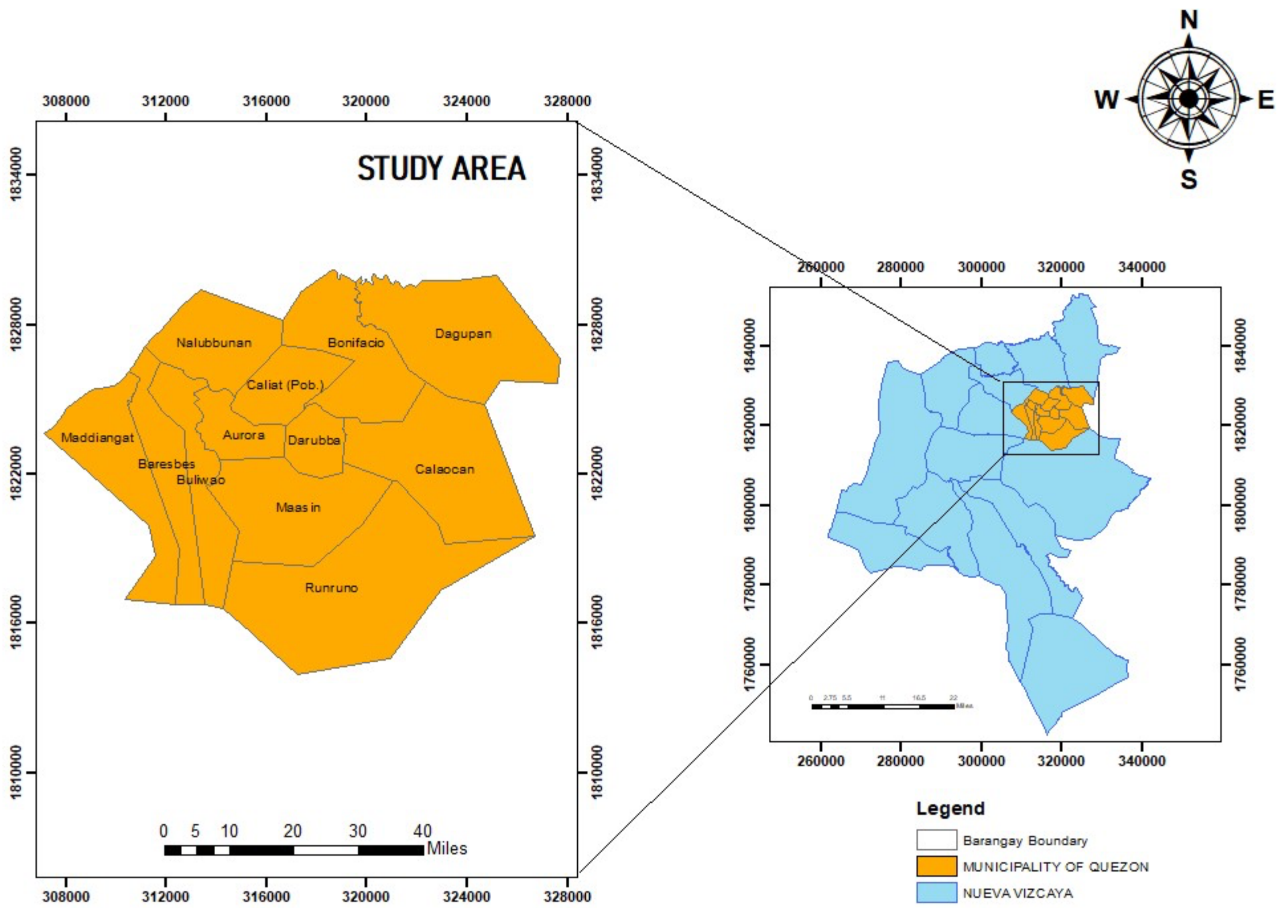


Figure 3. Location Map of the Study Area

Statistical Tool

In this study, researchers 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 enhanced 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 2 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.

For Problems 1 and 2, the researchers adopted the weight assignment of using AHP in the study of Rahim et al. (2018) entitled "GIS Based Landslide Susceptibility Mapping with Application of Analytical Hierarchy Process in District Ghizer, Gilgit Baltistan Pakistan." Table 3 shows the Pairwise comparison matrix, normalized factor weights and consistency ratio of the data layers of the study.

For Problem 3, field surveys and geotagging were conducted to validate and ground truth points that illustrate disparities between the existing and enhanced landslide susceptibility maps to give the present study a more reliable edge.

In Problem 4, the researchers relied on their observations and knowledge to propose mitigation measures for reducing landslide risks aimed at safeguarding communities and the environment from the potential impacts of landslides.

RESULTS AND DISCUSSION

Total Area in Hectares for Each Susceptibility Class to Landslide based on the Following Causative Factors

a. Slope

Slope angle emerged as the most influential factor among other causative factors, with a relative weight of 35%. Table 1 and Figure 4 reveals that slopes above 30 degrees are classified as having a high level of susceptibility to landslides but have the least area coverage, encompassing 3,517.57 hectares (16.58%). Meanwhile, slopes between 18 and 30 degrees are classified as moderately susceptible to landslides, with 6,816.60 hectares (32.13%) covering the largest portion. Moreover, slopes below 8 degrees and 8 to 18 degrees are classified as very low and low susceptible to landslides, encompassing an area of 4,424.58 hectares (20.86%) and 6,454.90 hectares (30.43%), respectively.

Table 1. Area coverage for each susceptibility class based on the Slope

Slope	Class	Area (has)	Area (%)
<8°	Very low	4424.58	20.86
8°-18°	Low	6454.90	30.43
18°-30°	Moderate	6816.60	32.13
>30°	High	3517.57	16.58

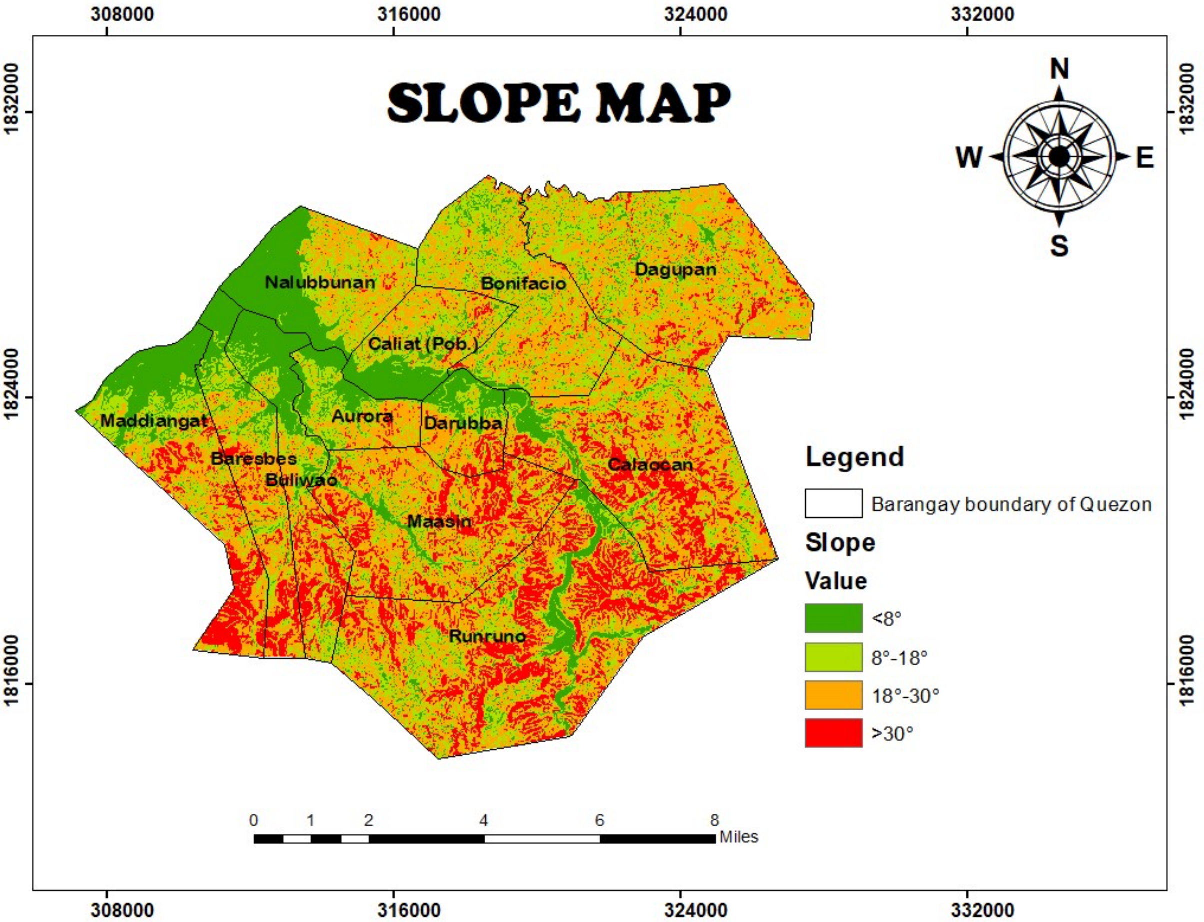


Figure 4. Slope Map of Quezon

b. Rainfall

Rainfall emerged as the second most influential factor among other causative factors, with a relative weight of 23.56%. Table 2 and Figure 5 shows that places experiencing an average annual rainfall of 182.58–187.60 mm are classified as highly susceptible to landslides but have the least area coverage, encompassing 2897.80 hectares (13.65%) of the total area. Meanwhile, places with an average annual rainfall of 178.66–182.58 mm are categorized as moderately susceptible, covering the largest portion with an area of 9,526.17 hectares (44.88%). Lastly, places experiencing an average annual rainfall of 170.00–174.54 mm and of 174.54–178.66 mm are categorized as having very low and low level of susceptibility to landslides, covering an area of 4,578.16 hectares (21.57%) and 4,221.59 hectares (19.89%), respectively.

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

Rainfall (mm)	Class	Area (has)	Area (%)
170.00-174.54	Very low	4578.16	21.57
174.54 -178.66	Low	4221.59	19.89
178.66-182.58	Moderate	9526.17	44.88
182.58-187.60	High	2897.80	13.65

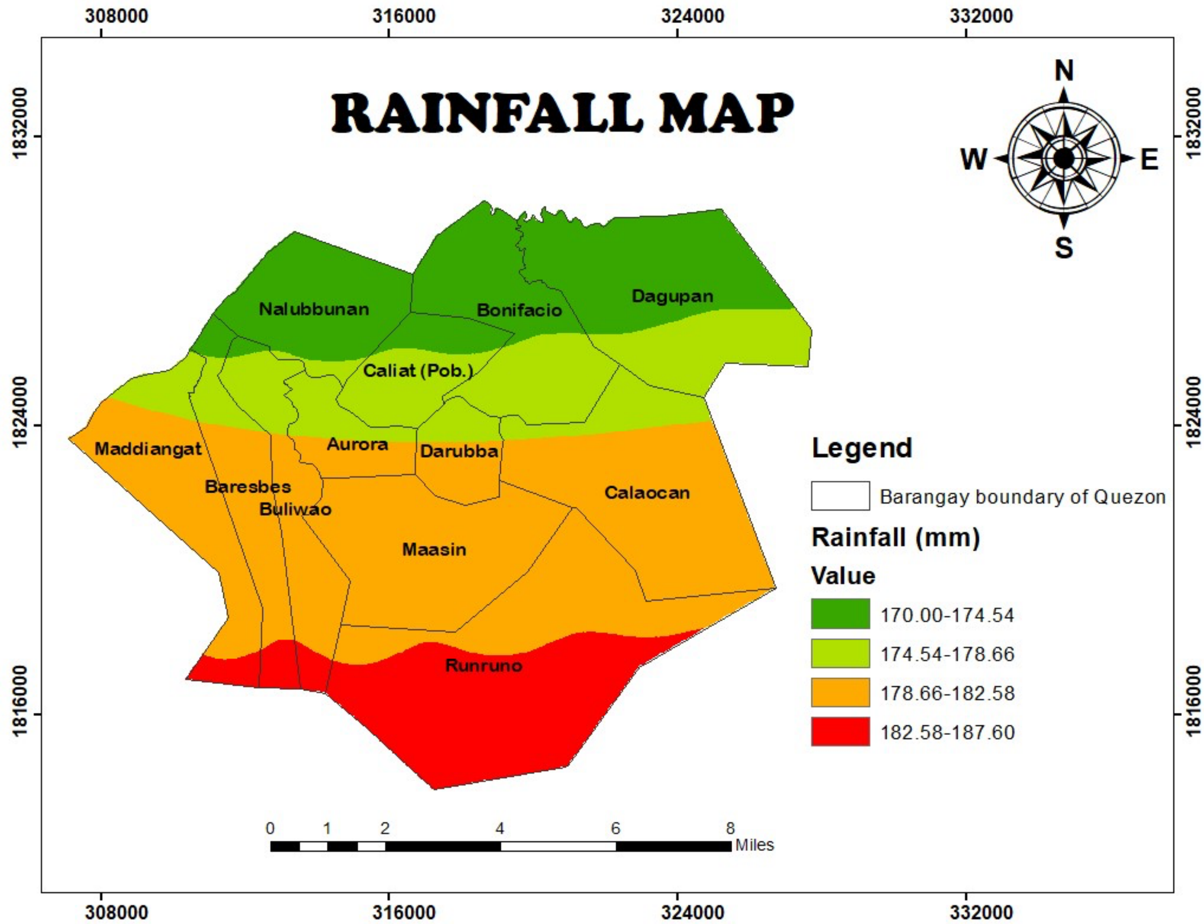


Figure 5. Rainfall Map of Quezon

c. Soil Type

Soils and landslides are closely related, especially for shallow landslides that occur in soil or weathered bedrock (Temme, 2021). Table 3 and Figure 6 reveals that mountain soil is categorized as highly susceptible to landslides, having a vast area of 11,412.26 hectares (53.77%) of the total area. Subsequently, annam clay loam and quingua silt loam are categorized as having low and moderate level of susceptibility to landslides, covering 8,110.65 hectares (38.22%) and 1,420.28 hectares (6.69%), respectively. Lastly, riverwash, san miguel sandy loam, guimbaolaon clay loam, and unknown are classified as very low susceptible to landslides, constituting the smallest portion with an area of 281.62 hectares (1.32%).

Table 3. Area coverage for each susceptibility class based on Soil Type

Soil	Class	Area (Has.)	Area (%)
Riverwash, Unknown, San Miguel Sandy Loam, Guimbalaon Clay Loam	Very Low	281.62	1.32
Quingua Silt Loam	Low	1420.28	6.69
Annam Clay Loam	Moderate	8110.65	38.22
Mountain Soil	High	11412.26	53.77

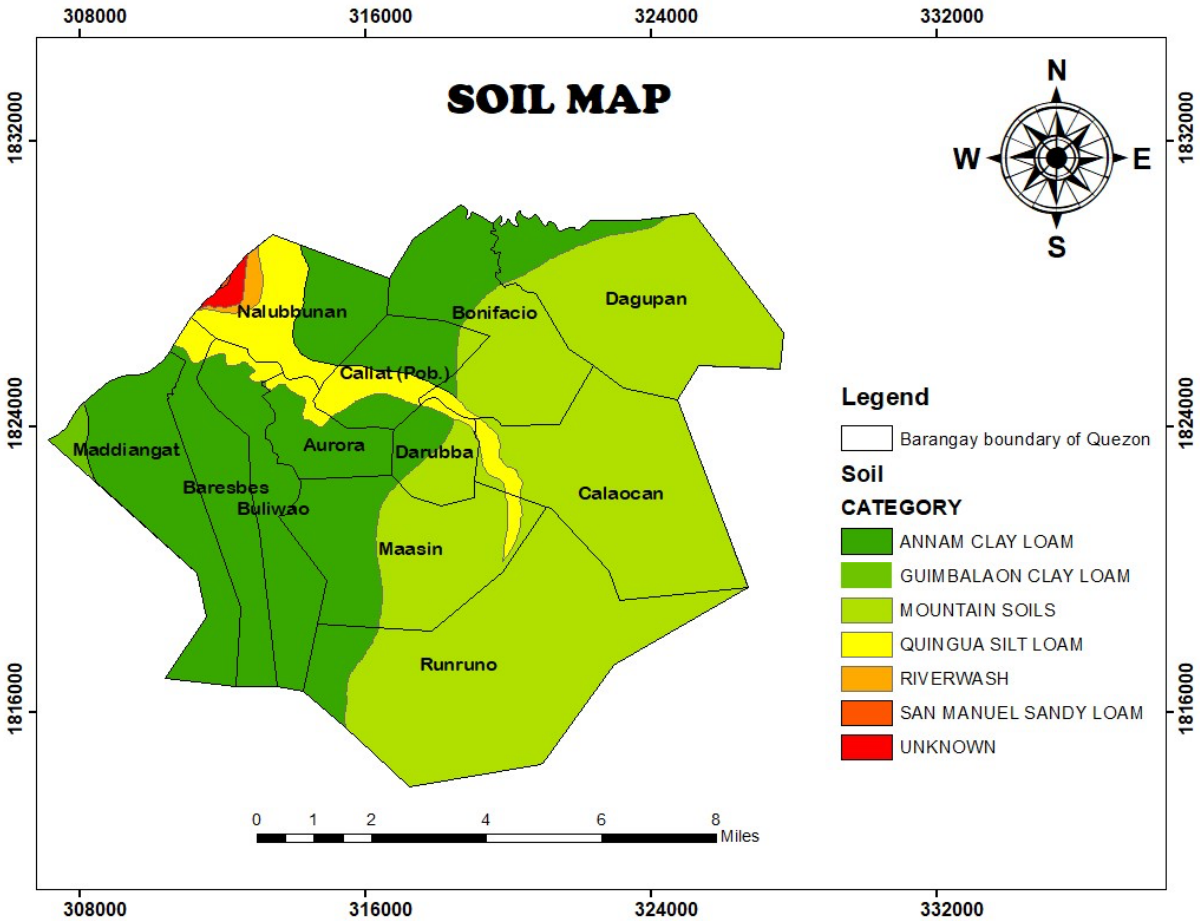


Figure 6. Soil Map of Quezon

d. Land Cover

Land cover influences landslide susceptibility by affecting soil stability and water infiltration. As shown in Table 4 and Figure 7, open/barren, built-up, grassland, and inland water are considered highly susceptible to landslides but has the least area coverage, encompassing 3,050.48 hectares (13.47%). Moderately susceptible, on the other hand, is attributed to annual/perennial crops covering 4,418.61 hectares (20.83%) of the total area, while brush/shrubs are classified as having low susceptibility to landslides encompassing 6,738.55 hectares (31.75%) of the total area. Moreover, open and closed forests are considered to have a very low susceptibility to landslides, with 7,017.59 hectares (33.06%) constituting the least area coverage.

Table 4. Area category for each susceptibility class based on the Land Cover

Land Cover	Class	Area (Has.)	Area (%)
Open/Closed Forest	Very Low	7017.59	33.06
Brush/Shrubs	Low	6738.55	31.75
Annual/Perennial Crop	Moderate	4418.61	20.83
Open/Barren, Built-up, Grassland, Inland Water, Fishpond	High	3050.48	14.37

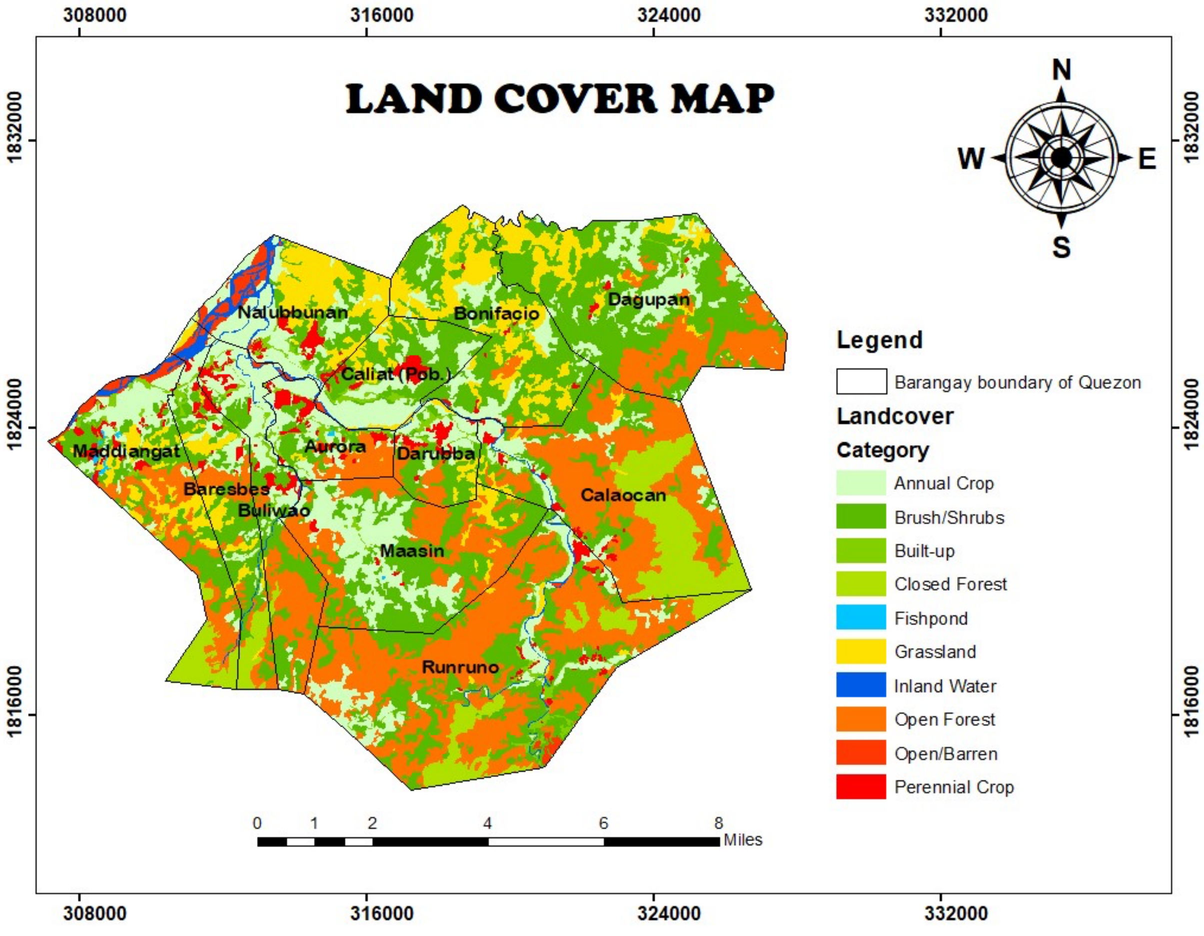


Figure 7. Land Cover Map of Quezon

e. Elevation

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 5 and Figure 8, highly susceptible is attributed to elevations above 1000 meters above datum, with 374.79 hectares (1.77%) covering the smallest area. On the other hand, 250 to 500 meters above datum are categorized as having a low level of susceptibility to landslides with 10,819.13 hectares (50.98%) covering the largest area. Moreover, less than 250 meters and 500 to 1000 meters above datum are considered very low and moderately susceptible to landslides covering 1575.66 hectares (7.42%) and 8454.10 hectares (39.83%), respectively.

Table 5. Area coverage for each susceptibility class based on the Elevation

Elevation (m)	Class	Area (has)	Area (%)
<250	Very low	1575.66	7.42
250-500	Low	10819.13	50.98
500-1000	Moderate	8454.10	39.83
>1000	High	374.79	1.77

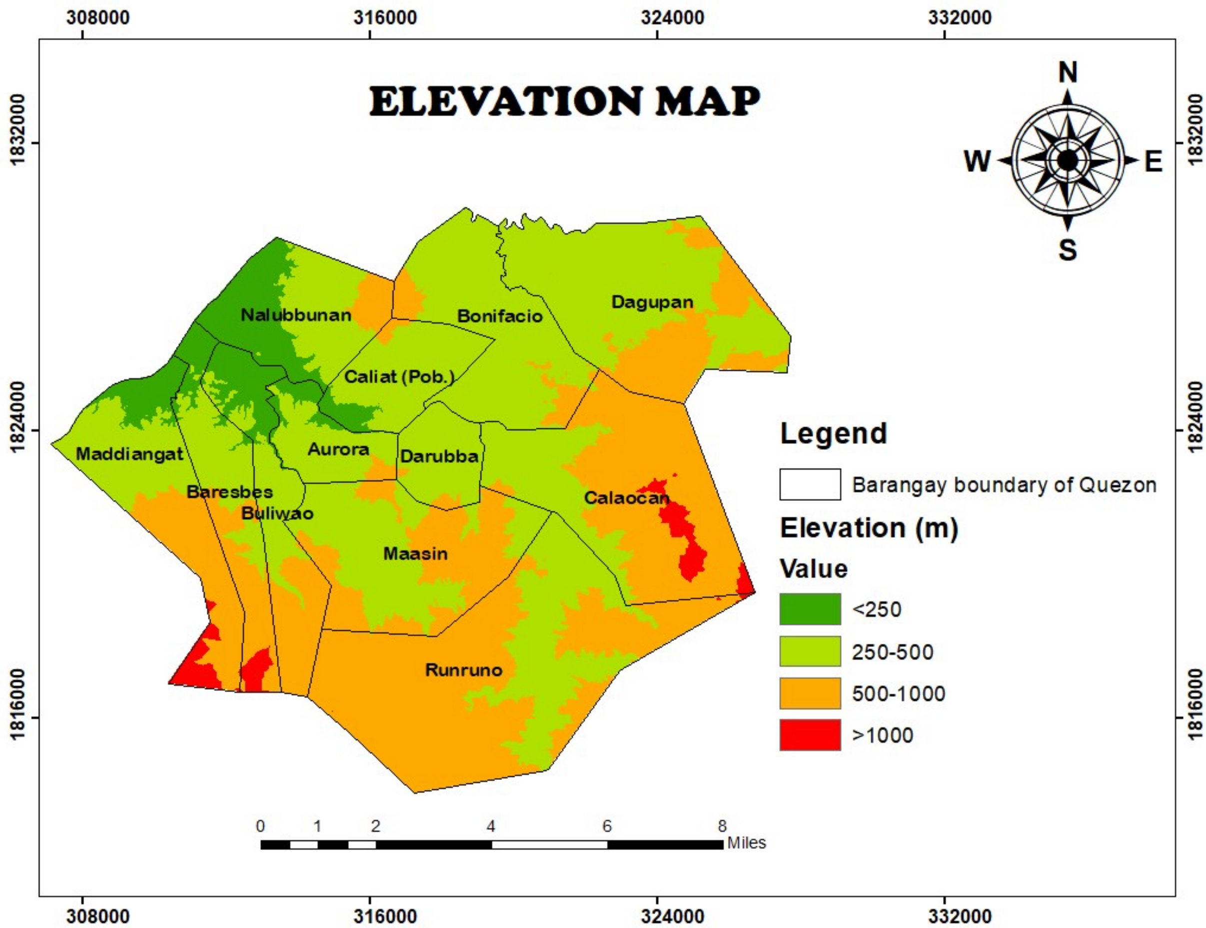


Figure 8. Elevation Map of Quezon

f. Distance from roads

Proximity to roads can influence landslide susceptibility due to disturbances and slope destabilization during construction. The analysis reveals that places situated within 0 to 100 meters from the roads are considered to have high susceptibility to landslides. Places falling within the range of 100 to 200 meters from roads are considered moderately susceptible. Those within the range of 200 to 300 meters from roads are classified as having low susceptibility, while places more than 300 meters from the roads are considered to have very low susceptibility to landslides.

Table 6. Area coverage for each susceptibility class based on the Distance from Roads

Distance to road (m)	Class	Area (has)	Area (%)
<100	High	1461.16	6.88
100-200	Moderate	1168.92	5.51
200-300	Low	1067.91	5.03
>300	Very low	17525.21	82.58

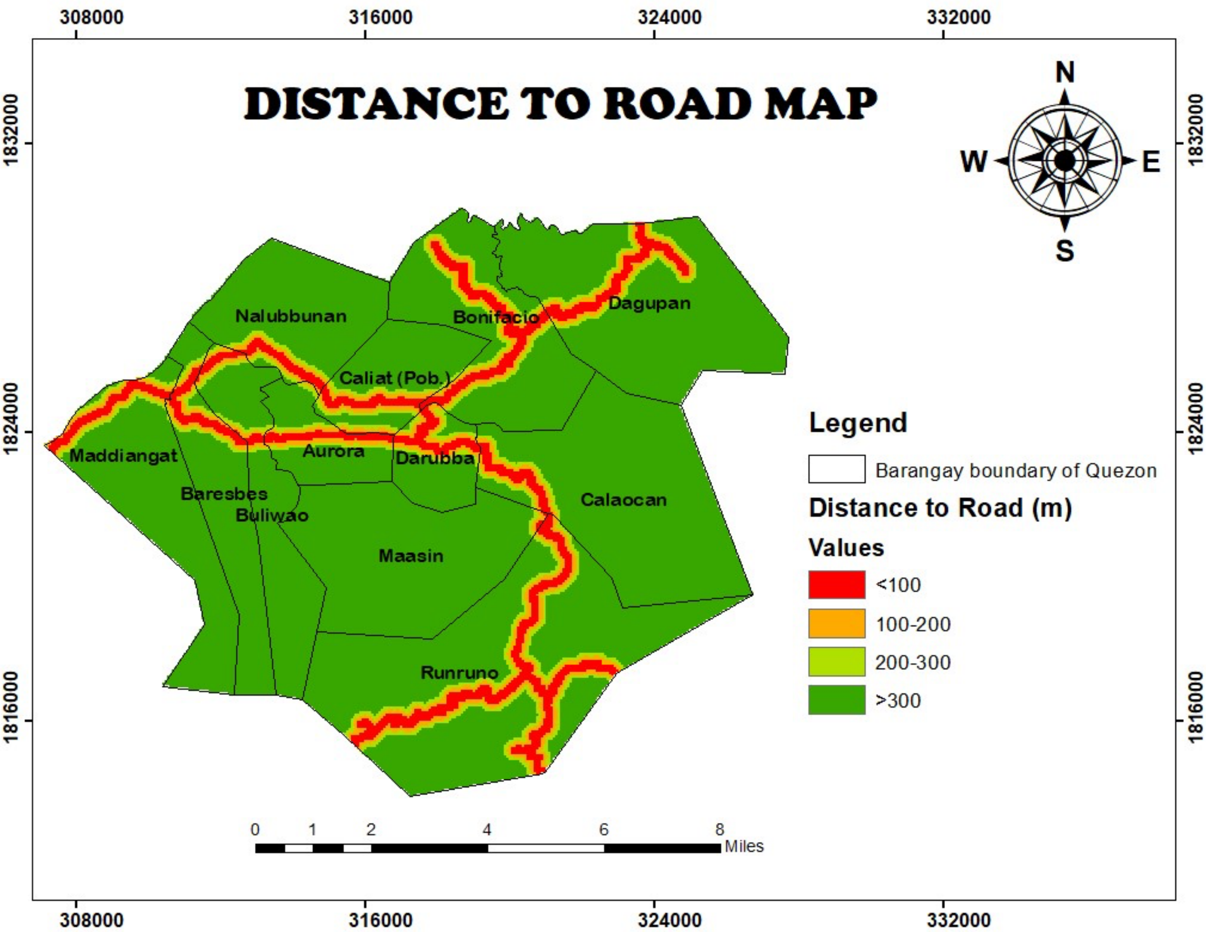


Figure 9. Distance to River Map of Quezon

g. Distance from rivers

Distance from rivers emerged as the least influential factor, with a relative weight of 3.66%. Table 10 shows that places within 0 to 100 meters away from rivers are classified as having a high susceptibility to landslides, covering 2447.06 hectares (11.53%) of the total area. Places falling within 100 to 200 meters away from rivers are classified as moderately susceptible to landslides with an area of 1784.71 hectares (8.41%), while places 200 to 300 meters are classified as moderately susceptible to landslides, with the smallest portion encompassing 1643.89 hectares (7.75%). Lastly, places situated more than 300 meters away from rivers are considered to have very low susceptibility to landslides and were found to have a vast area of 15,344.80 hectares (72.31%).

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

Distance to river (m)	Class	Area (has)	Area (%)
<100	High	2447.06	11.53
100-200	Moderate	1784.71	8.41
200-300	Low	1643.89	7.75
>300	Very low	15344.80	72.31

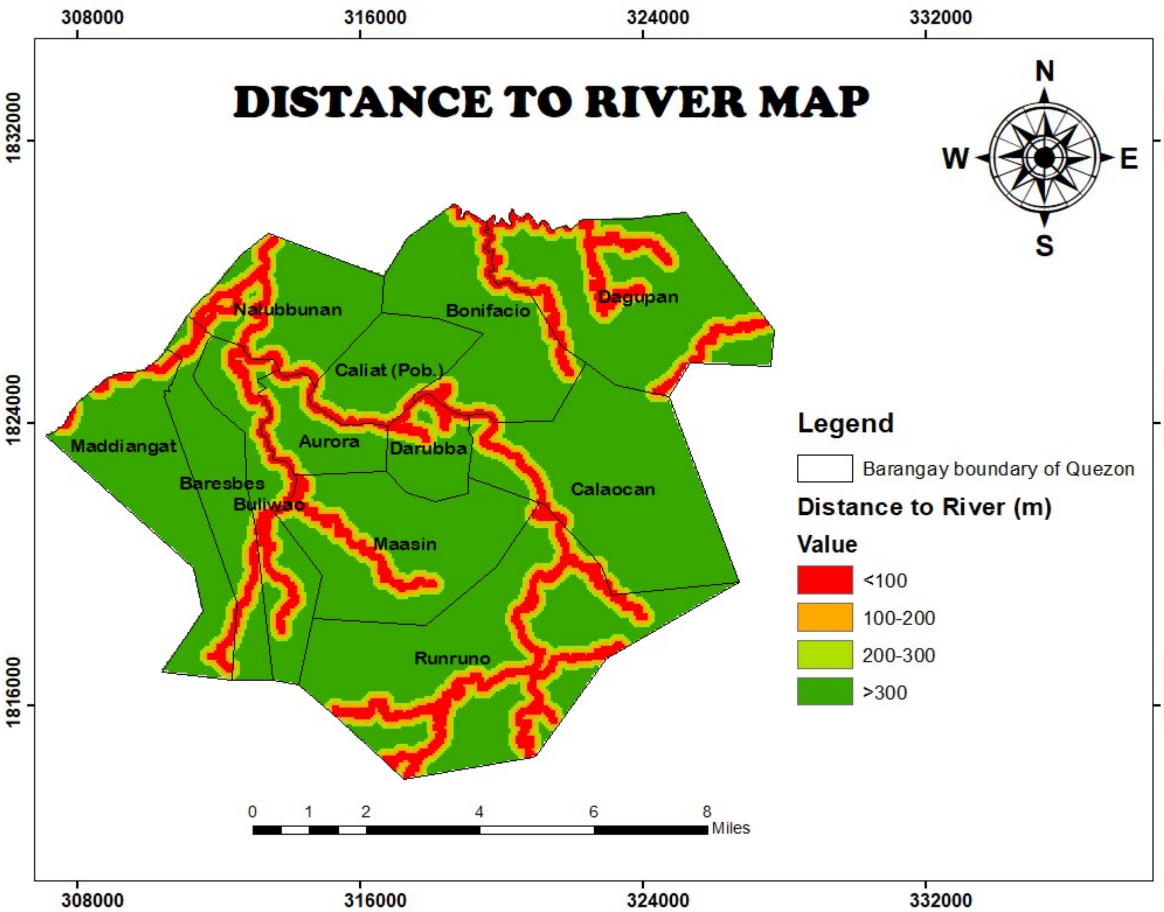


Figure 10. Distance to River Map of Quezon

Table 8. 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	35.000
8°-18°	2	Low	
18°-30°	3	Moderate	
>30°	4	High	
Rainfall			
170.00-174.54	1	Very low	
174.54-178.66	2	Low	23.563
178.66-182.58	3	Moderate	
182.58-187.60	4	High	
Soil			
Riverwash	1	Very low	
Guimbalaon Clay Loam	1	Very low	
San Manuel Sandy Loam	1	Very low	
Unknown	1	Very low	15.377
Quingua Silt Loam	2	Low	
Annam Clay Loam	3	Moderate	
Mountain Soils	4	High	
Landcover			
Closed/ OpenForest	1	Very low	
Brush/Shrubs	2	Low	
Annual/Parennial crop	3	Moderate	
Open /Barren	4	High	9.749
Built-up	4	High	
Inland water/Fishpond	4	High	
Grassland	4	High	
Elevation (m)			
<250	1	Very low	
250-500	2	High	
500-1000	3	Moderate	7.205
>1000	4	High	
Distance to Road (m)			
<100	1	Very low	
100-200	2	Low	
200-300	3	Moderate	5.433
>300	4	High	
Distance to River (m)			
<100	1	Very low	
100-200	2	Low	
200-300	3	Moderate	3.663
>300	4	High	

Area in Hectares for Each Barangay Falls within Each Susceptibility Class based on the Generated Enhanced LSM

Barangay Aurora

Table 9 and Figure 11 presents the distribution of susceptibility classes in Barangay Aurora. It shows that high level of susceptibility constitutes the smallest area, covering 10.52 hectares (1.60%) of the total area. Conversely, very low level of susceptibility has the largest area, covering 237.80 hectares or 36.07% of the total area. Additionally, moderately susceptible places cover 185.27 hectares (28.10%), while places with low susceptibility to landslides cover 225.63 hectares (34.23%).

Table 9. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Aurora

Level	Area (Hectares)	Area (%)
Very Low	237.80	36.07
Low	225.63	34.23
Moderate	185.27	28.10
High	10.52	1.60

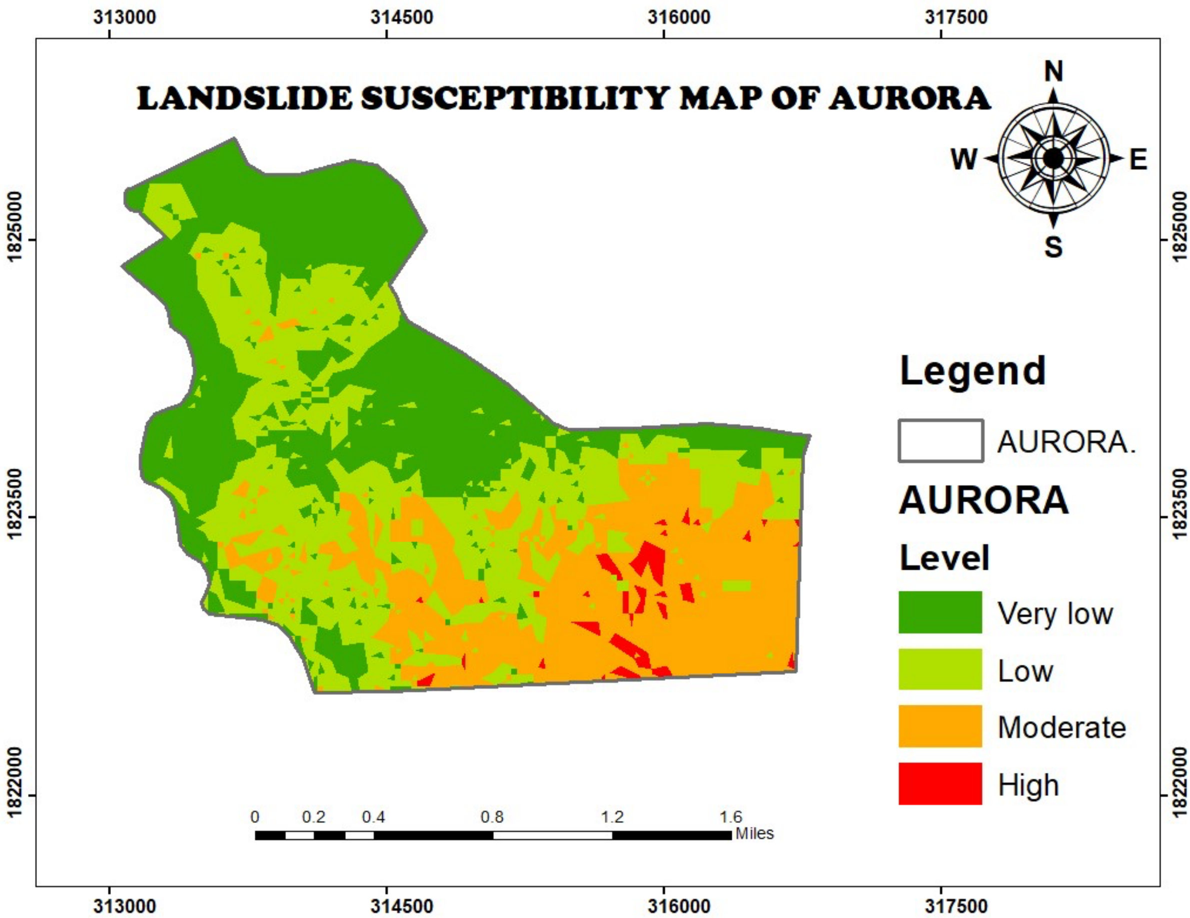


Figure 11. Landslide Susceptibility Map of Aurora

Barangay Baresbes

Table 10 and Figure 12 shows the area coverage for each susceptibility class of Barangay Baresbes. It reveals that 253.84 hectares (21.97%) are classified as having a very low susceptibility to landslides, while another 362.91 hectares (31.41%) are categorized as low susceptible, representing the largest portion. Additionally, 362.36 hectares (31.36%) of the total area are classified as moderately susceptible, and the smallest portion of Baresbes is classified as highly susceptible to landslides, covering 176.32 hectares (15.26%) of the total area.

Table 10. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Baresbes

Level	Area (Hectares)	Area (%)
Very Low	253.84	21.97
Low	362.91	31.41
Moderate	362.36	31.36
High	176.32	15.26

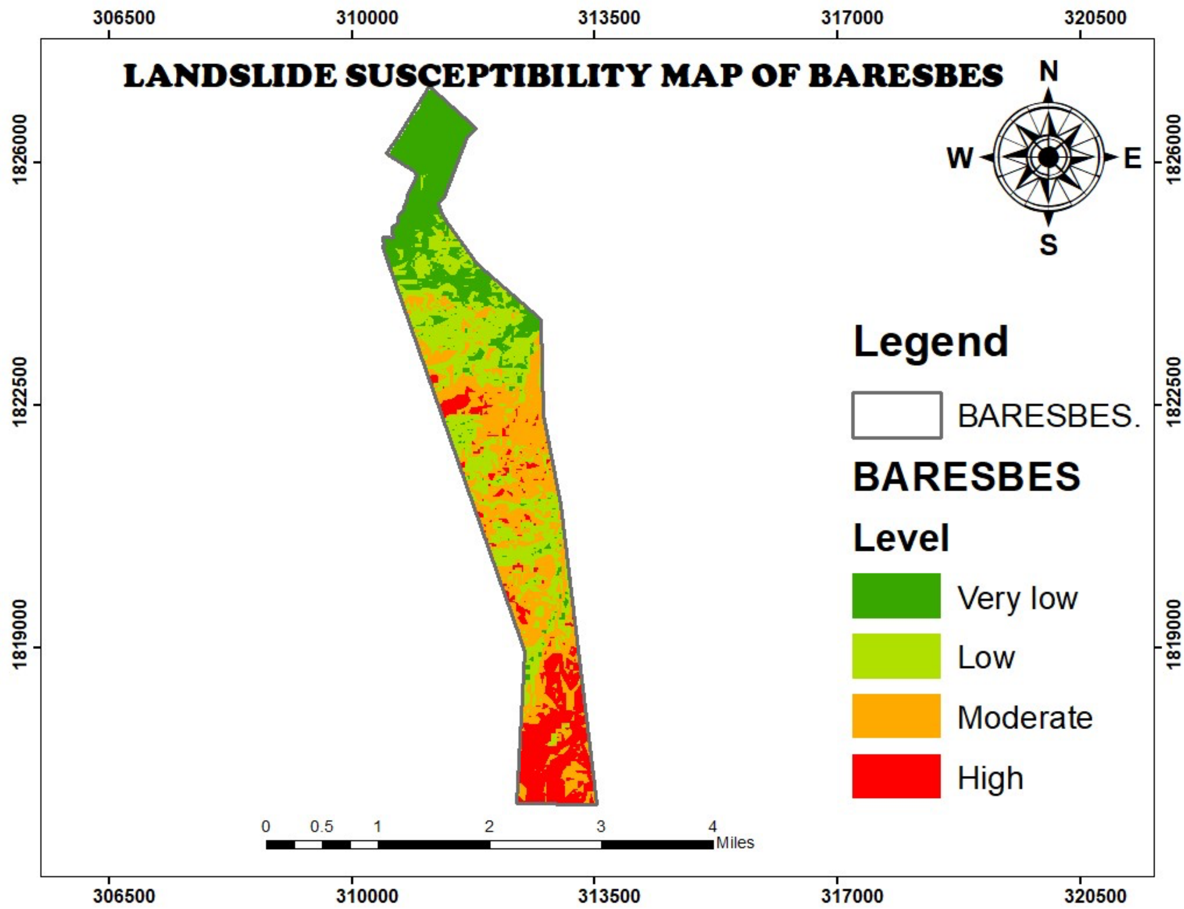


Figure 12. Landslide Susceptibility map of Baresbes

Bonifacio

In Barangay Bonifacio, as shown in Table 11 and Figure 13, the low a level of susceptibility constitutes the largest portion, covering 946.31 hectares (52.63%). In contrast, places classified as highly susceptible to landslides covers an area of 20.76 hectares (1.15%), constituting the smallest portion. Moreover, the moderate level of susceptibility encompasses 376.77 hectares (20.95%), while very low level of susceptibility encompasses an area of 454.22 hectares (25.26%).

Table 11. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Bonifacio

Level	Area (Hectares)	Area (%)
Very Low	454.22	25.26
Low	946.31	52.63
Moderate	376.77	20.95
High	20.76	1.15

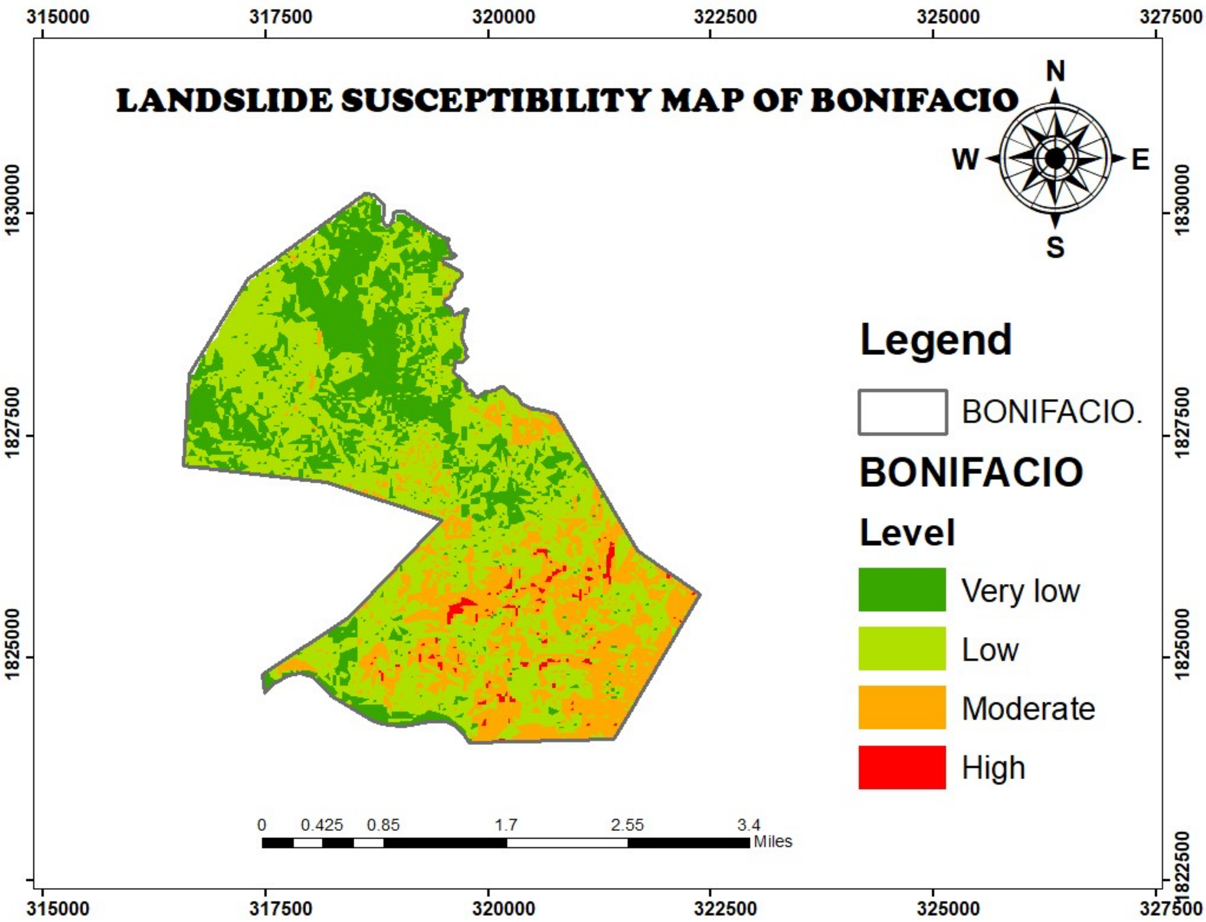


Figure 13. Landslide Susceptibility Map of Bonifacio

Barangay Buliwao

Table 12 and Figure 14 reveals the distribution of susceptibility to landslides within Buliwao. The largest portion, comprising 405.84 hectares (33.72%), falls under the category of very low susceptibility, while the smallest portion, with an area of 176.50 hectares (14.67%), is highly susceptible to landslides. Additionally, 224.22 hectares (18.63%) are classified as having low susceptibility, whereas 396.92 hectares (32.98%) are moderately susceptible to landslides.

Table 12. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Buliwao

Level	Area (Hectares)	Area (%)
Very Low	405.84	33.72
Low	224.22	18.63
Moderate	396.92	32.98
High	176.50	14.67

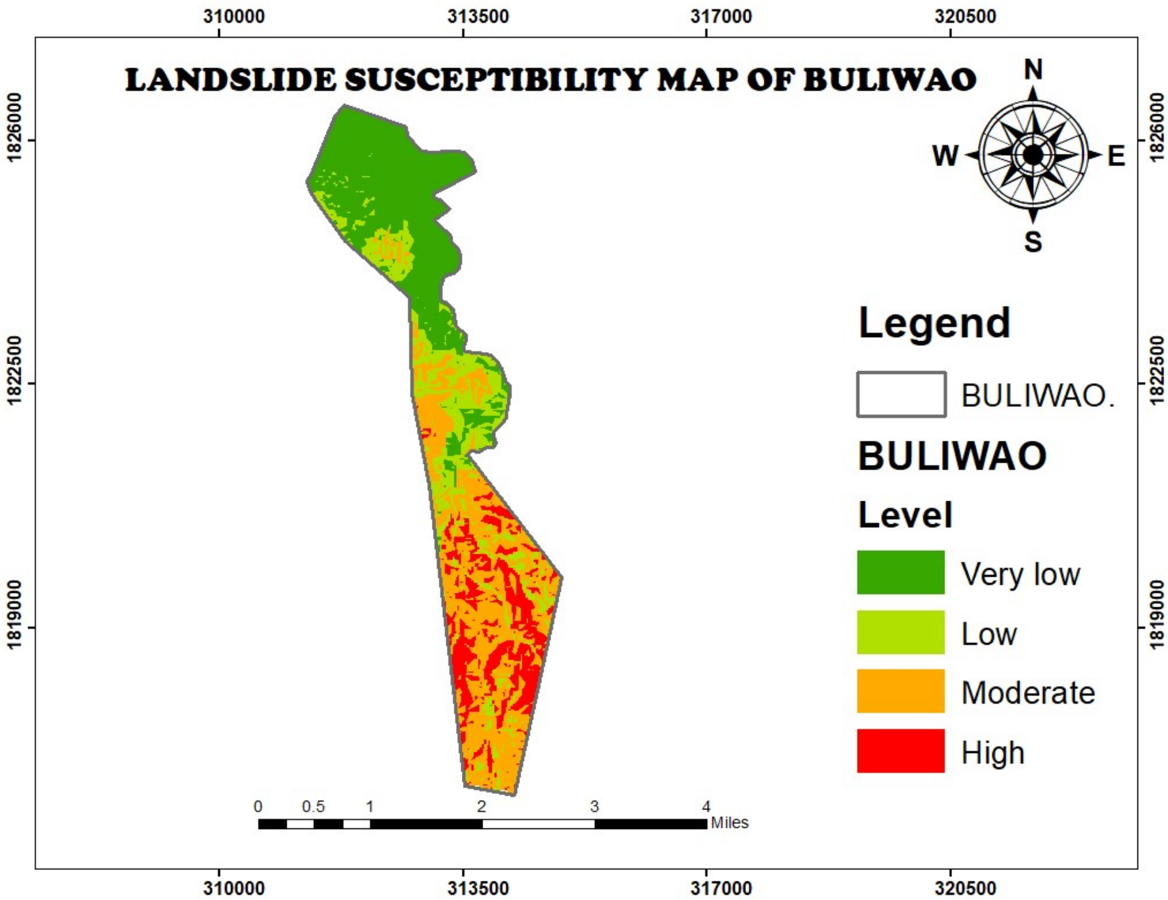


Figure 14. Landslide Susceptibility Map of Buliwao

Barangay Calaocan

Table 13 and Figure 15 presents the results of integrating GIS and AHP in creating a landslide susceptibility map, emphasizing Barangay Calaocan. The largest portion, covering 1502.83 hectares (55.37%), is highly susceptible to landslides, while the smallest portion, comprising only 71.83 hectares (2.65%) of the total area, exhibits a very low level of susceptibility. Moreover, moderately susceptible to landslides encompass 890.54 hectares (32.81%), and those with a low level of susceptibility cover 249.15 hectares (9.18%) of the total area.

Table 13. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Calaocan

Level	Area (Hectares)	Area (%)
Very Low	71.83	2.65
Low	249.15	9.18
Moderate	890.54	32.81
High	1502.83	55.37

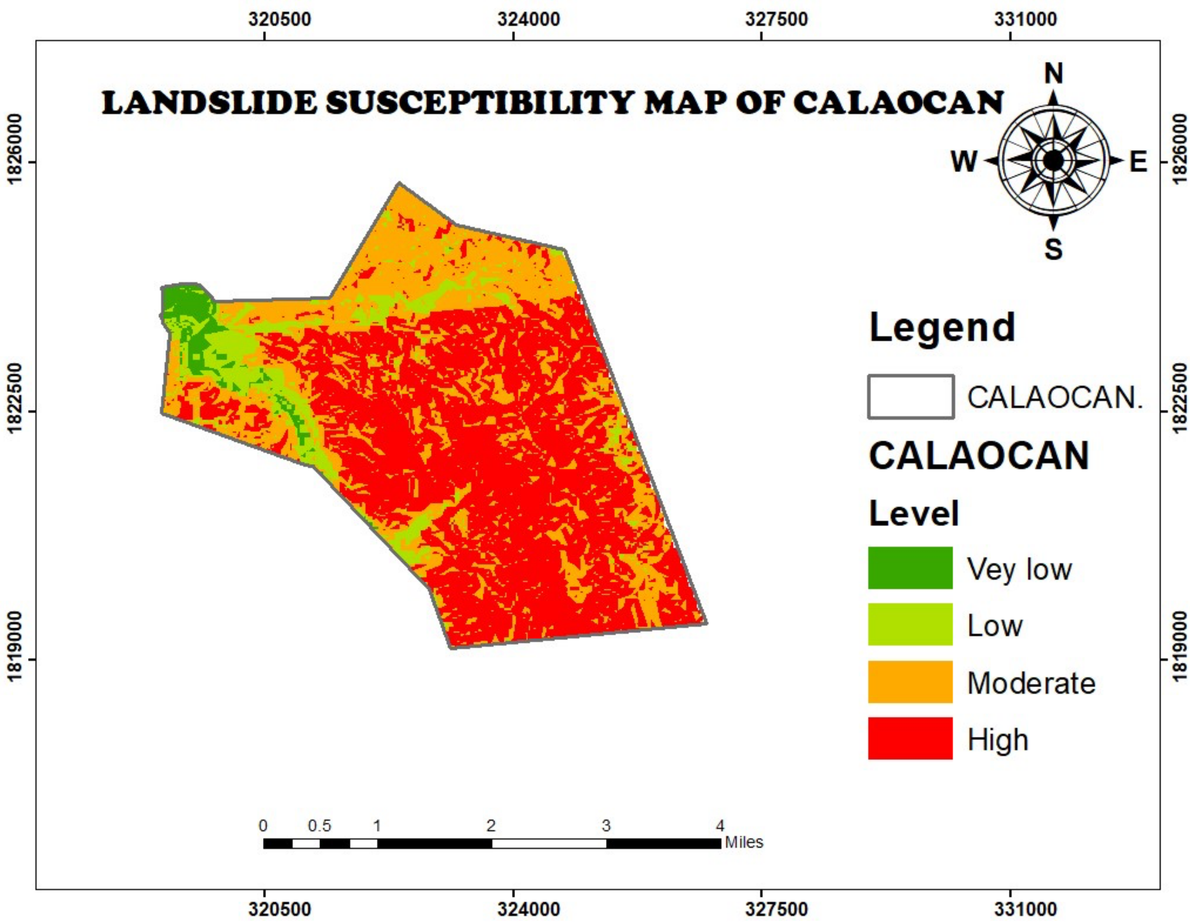


Figure 15. Landslide Susceptibility Map of Calaocan

Barangay Caliat

Table 14 and Figure 16 illustrates the distribution of susceptibility classes in Caliat, where the largest portion comprises 464.89 hectares (51.19%) classified as having low susceptibility to landslides. Furthermore, an area of 326.62 hectares (35.96%) and 116.75 hectares (12.85%) is classified as having a very low and moderate level of susceptibility, respectively. Notably, no highly susceptible areas are classified within the barangay.

Table 14. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Caliat

Level	Area (Hectares)	Area (%)
Very Low	326.62	35.96
Low	464.89	51.19
Moderate	116.75	12.85

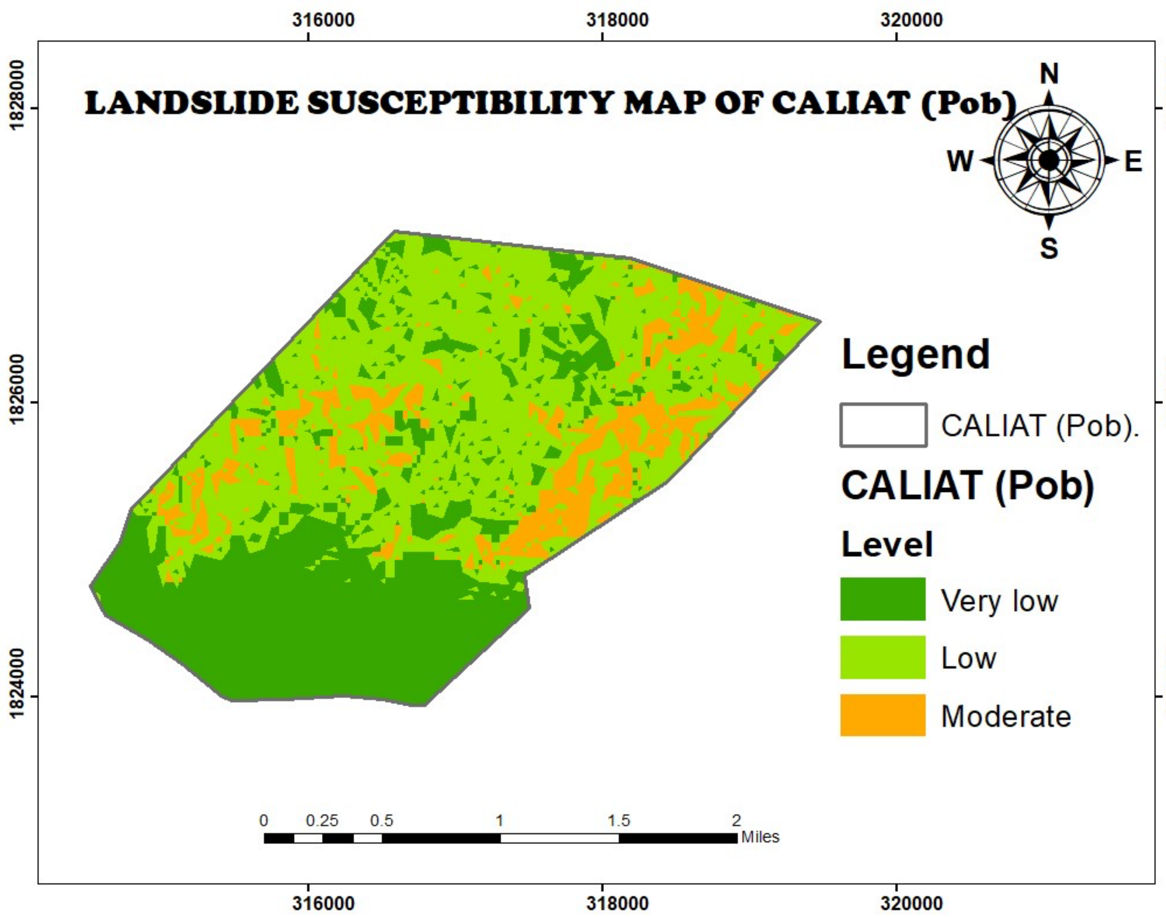


Figure 16. Landslide Susceptibility Map of Caliat (Pob)

Barangay Dagupan

In Table 15 and Figure 17, the distribution of susceptibility classes in Dagupan is presented. The largest area coverage, encompassing 1216.01 hectares (45.49%), is attributed to the low level of susceptibility, followed by the moderate level, which encompasses 1093.04 hectares (40.89%) of the total area. Conversely, the high level of susceptibility has the least area coverage, with only 93.95 hectares (3.51%), while the very low level covers 270.04 hectares (10.10%) of the total area."

Table 15. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Dagupan

Level	Area (Hectares)	Area (%)
Very Low	270.04	10.10
Low	1216.01	45.49
Moderate	1093.04	40.89
High	93.95	3.51

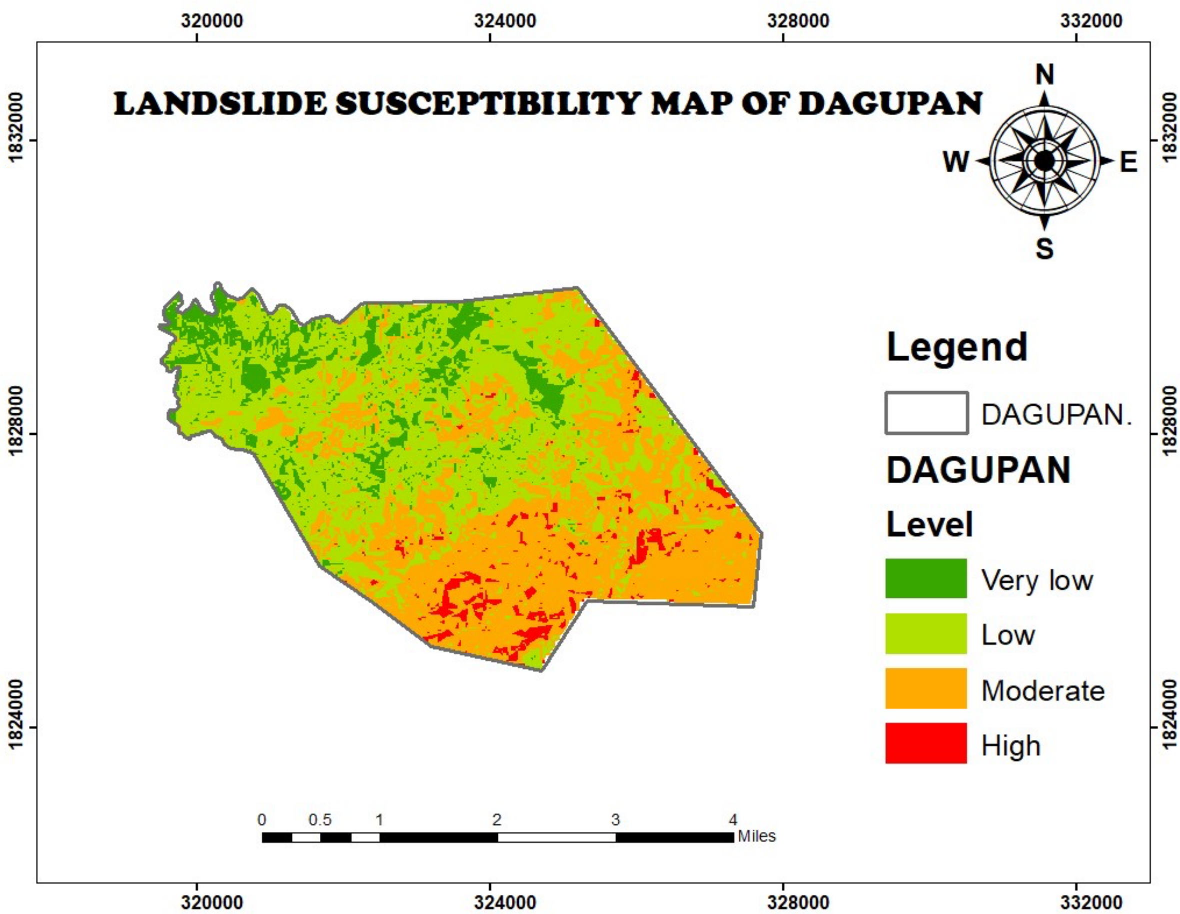


Figure 17. Landslide Susceptibility Map of Dagupan

Barangay Darubba

Table 16 and Figure 18 illustrates the distribution of susceptibility classes in Barangay Darubba. It reveals that the largest portion was classified with a moderate level of susceptibility, covering an area of 212.78 hectares (37.58%). Meanwhile, the smallest portion was attributed to a high level of susceptibility, encompassing an area of 83.68 hectares (14.78%) of the total area. Moreover, 166.33 hectares (29.38%) and 103.37 hectares (18.26%) are classified as very low and low susceptibility to slope failures, respectively.

Table 16. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Darubba

Level	Area (Hectares)	Area (%)
Very Low	166.33	29.38
Low	103.37	18.26
Moderate	212.78	37.58
High	83.68	14.78

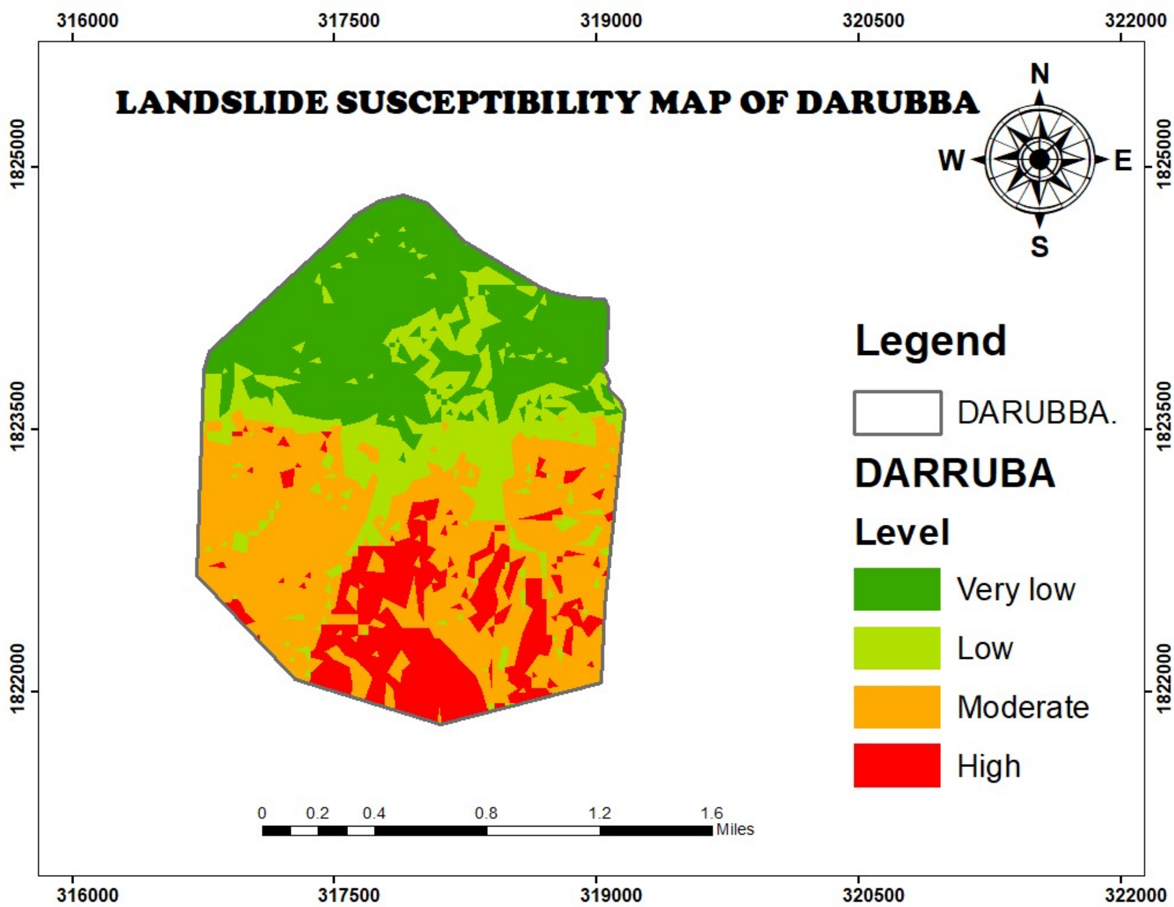


Figure 18. Landslide Susceptibility Map of Darubba

Barangay Maasin

Table 17 and Figure 19 displays the distribution of susceptibility levels, with the moderate level of susceptibility covering the largest area, having 874.67 hectares (40.73%) of the total area. Conversely, the very low level of susceptibility exhibits the least area coverage, comprising 57.06 hectares (2.66%). In addition, the low susceptibility level encompasses 467.70 hectares (21.78%), while the high level of susceptibility covers 748.07 hectares (34.83%) of the total area.

Table 17. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Maasin

Level	Area (Hectares)	Area (%)
Very Low	57.06	2.66
Low	467.70	21.78
Moderate	874.67	40.73
High	748.07	34.83

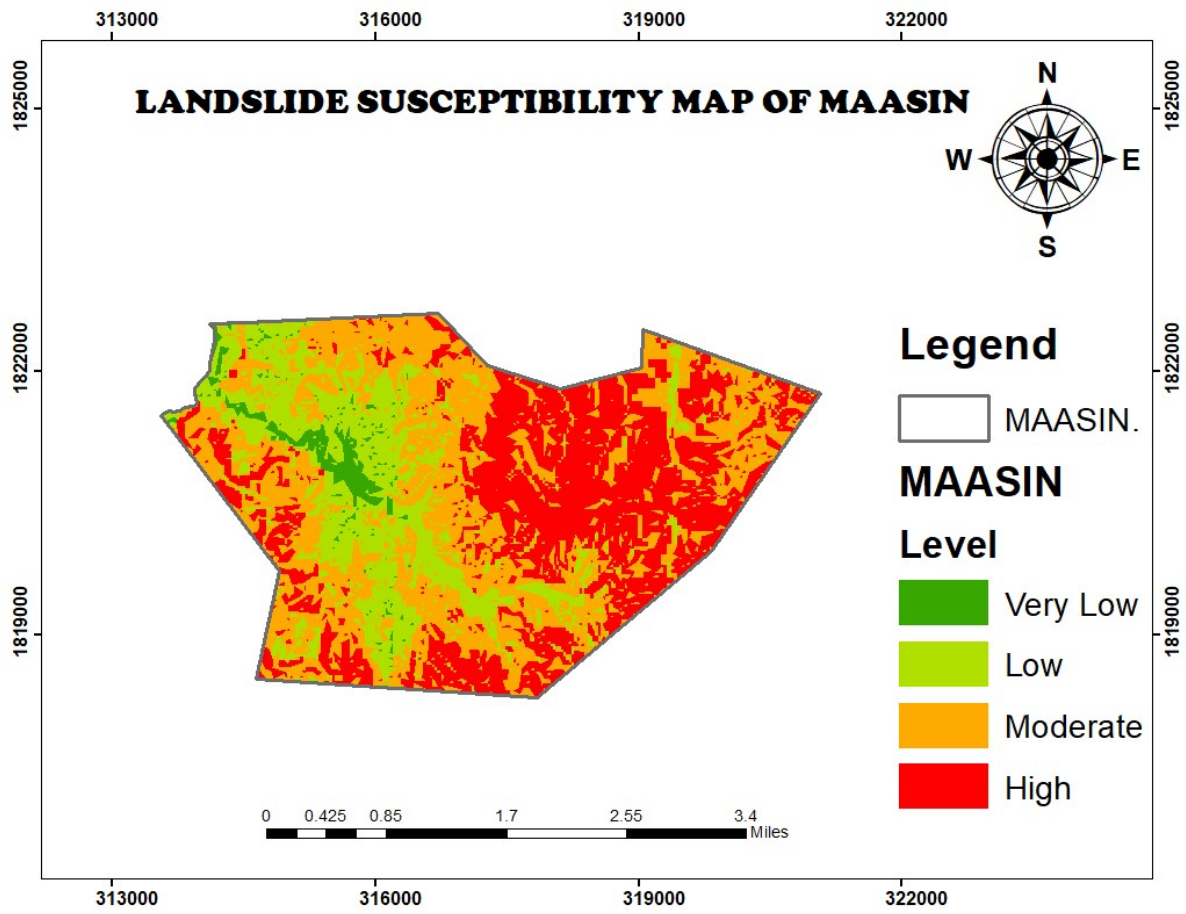


Figure 19. Landslide Susceptibility Map of Maasin

Barangay Maddiangat

Table 18 and Figure 20 presents the area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Maddiangat. It reveals that the majority of the area falls within the very low to low susceptibility category, comprising 415.63 hectares (24.14%) and 512.12 hectares (29.75%) of the total area, respectively. Meanwhile, the smallest area coverage is attributed to the high level of susceptibility to landslides, covering 313.54 hectares (18.21%) of the total area, while the moderate level of susceptibility encompasses 480.38 hectares (27.90%) of the total area.

Table 18. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Maddiangat

Level	Area (Hectares)	Area (%)
Very Low	415.63	24.14
Low	512.12	29.75
Moderate	480.38	27.90
High	313.54	18.21

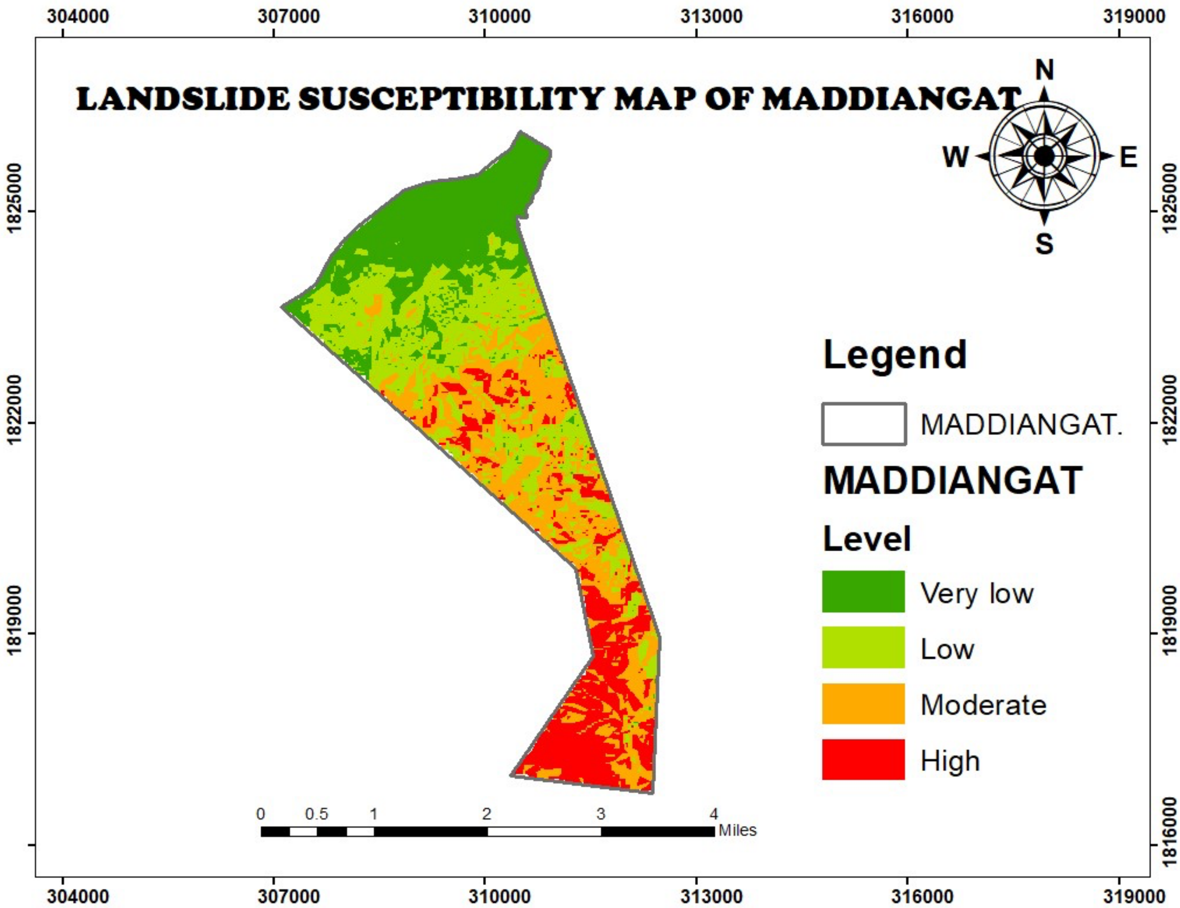


Figure 20. Landslide Susceptibility Map of Maddiangat

Barangay Nalubbunan

Table 19and Figure 21 indicates that the majority of Barangay Nalubban is characterized by very low to low susceptibility to landslides, covering a significant area of 849.08 hectares (61.62%) and 517.57 hectares (37.55%) of the total area, respectively. Conversely, moderately susceptible areas only cover a small area of 11.38 hectares (0.83%), and notably, no places are classified as highly susceptible to landslides.

Table 19. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Nalubbunan

Level	Area (Hectares)	Area (%)
Very Low	849.08	61.62
Low	517.57	37.55
Moderate	11.38	0.83

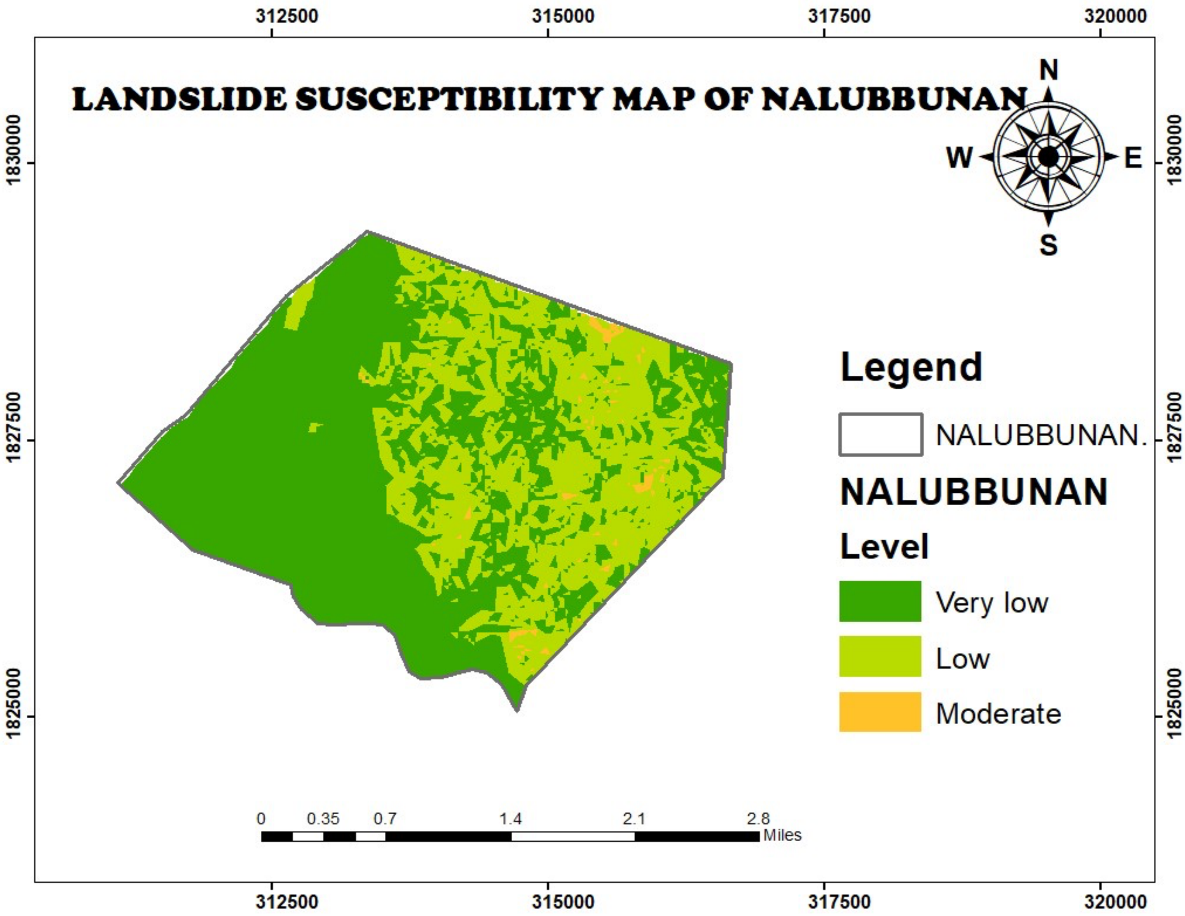


Figure 21. Landslide Susceptibility Map of Nalubbunan

Barangay Runruno

Table 20 and Figure 22 illustrates the distribution of susceptibility classes in Runruno. It reveals that a large portion of the barangay is highly susceptible to landslides, covering a vast area of 2666.61 hectares (64.40%) of the total area. Moderate susceptibility, on the other hand, accounts for 992.13 hectares (23.96%). Meanwhile, only a small portion of Runruno is considered to have very low to low susceptibility, covering an area of 81.27 hectares (1.96%) and 400.44 hectares (9.67%), respectively.

Table 20. Area coverage for each susceptibility class according to the enhanced landslide susceptibility map of Runruno

Level	Area (Hectares)	Area (%)
Very Low	81.27	1.96
Low	400.44	9.67
Moderate	992.13	23.96
High	2666.61	64.41

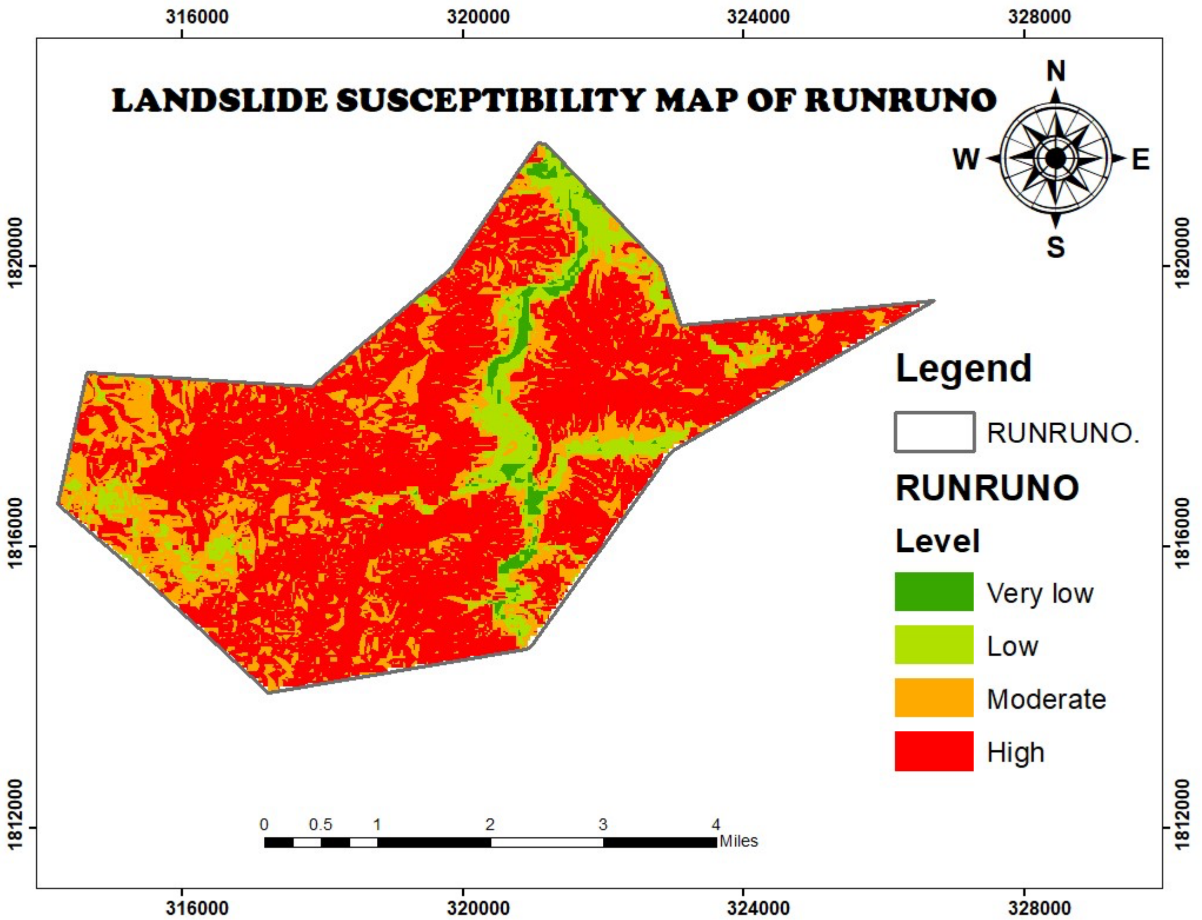


Figure 22. Landslide Susceptibility Map of Runruno

Significant Difference between the Existing Susceptibility Map and the Enhanced Version

The integration of AHP and GIS has revealed significant differences in the spatial extent and distribution of susceptibility classes between the existing landslide susceptibility map (LSM) and the enhanced version. Table 21 and Figure 23 presents the distribution of susceptibility classes of the 2019 LSM, indicating that 15,790.63 hectares (80.13%) of the study area were classified as highly susceptible, covering the largest area. Additionally, 1,524.92 hectares (7.74%) were categorized as moderately susceptible, 1,862.49 hectares (9.45%) as having low susceptibility, and 528.13 hectares (2.68%) as having very low susceptibility to landslides, covering the smallest area.

Table 21. Area coverage for each susceptibility class of the 2019 LSM

Level	Area (Hectares)	Area (%)
Very low	528.13	2.68
Low	1862.49	9.45
Moderate	1524.92	7.74
High	15790.63	80.13

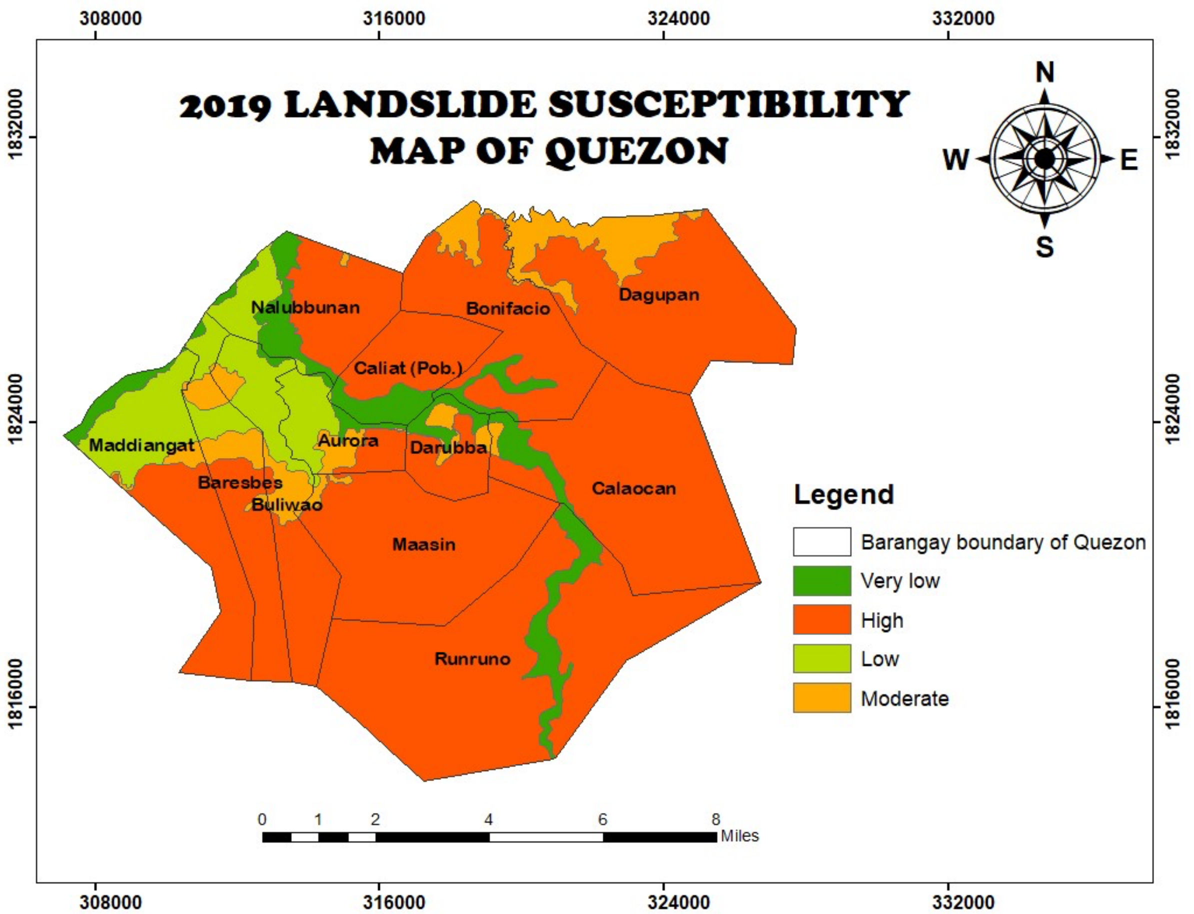


Figure 23. 2019 Landslide Susceptibility Map of Quezon

However, upon analysis of the enhanced version, significant changes in susceptibility classes are evident. Table 22 and Figure 24 illustrates the distribution of susceptibility classes in the enhanced map, with 5,792.80 hectares (27.50%) of the study area being highly susceptible. Moderately susceptible areas cover the largest area, encompassing 5,993.09

hectares (28.45%). Additionally, 5,690.36 hectares (27.01%) are categorized as having low susceptibility, while 3,589.64 hectares (17.04%) are classified as having very low susceptibility.

Table 22. Area coverage for each susceptibility class of the Enhanced LSM

Level	Area (Hectares)	Area (%)
Very Low	3589.64	17.04
Low	5690.36	27.01
Moderate	5993.09	28.45
High	5792.80	27.50

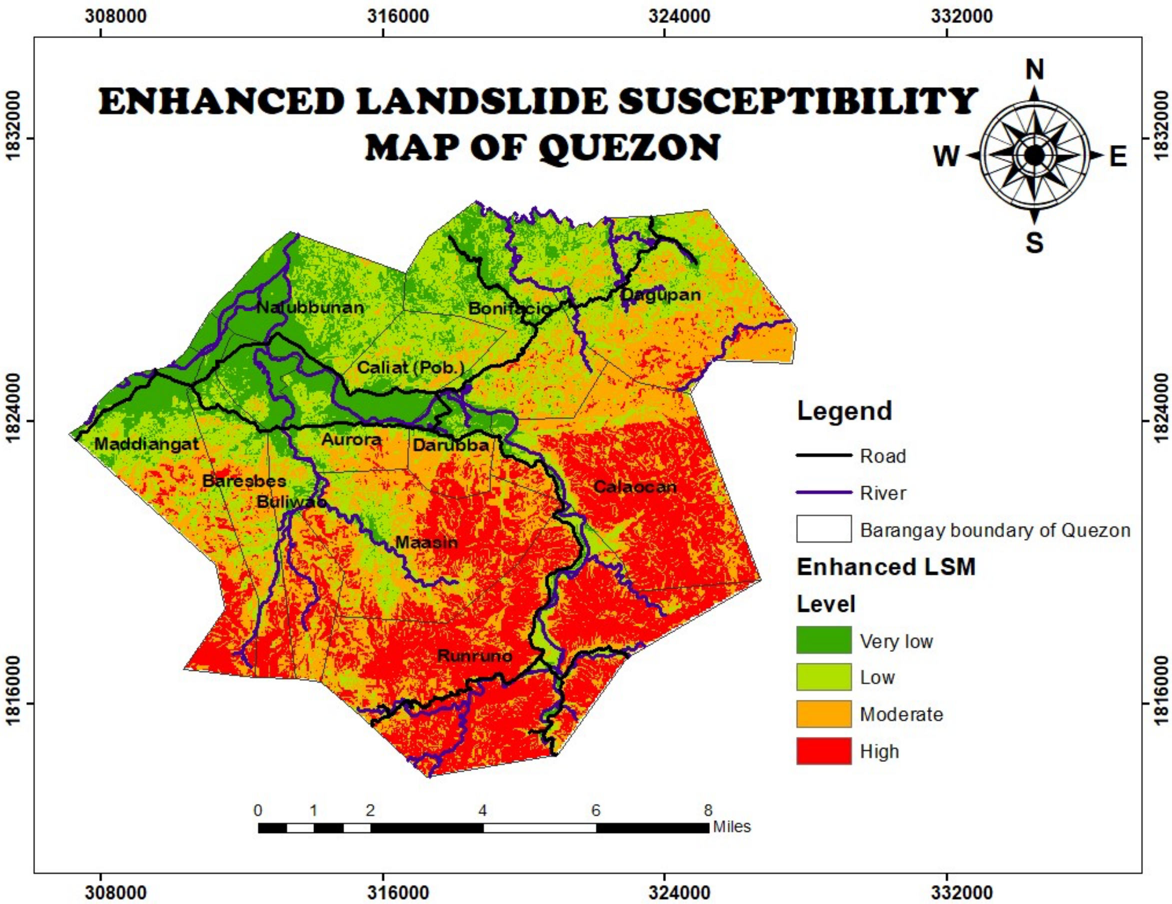


Figure 24. Enhanced Landslide Susceptibility Map of Quezon

Mitigation Measures that can be Implemented to Reduce Landslide Risks in the Area

Mitigation measures can reduce and pro-actively mitigate the risk of landslides in the area. Some strategies include:

1. Implementation of monitoring systems such as rainfall gauges can provide early detection of slope instability, enabling timely evacuation.
2. Implementation of zoning regulations to restrict development in landslide-prone areas to minimize risks.
3. Use stabilization technique such as retaining walls, gabion walls, rock bolts, and soil nails to stabilize slopes adjacent to roads.

4. Site-based assessments of critical facilities and infrastructure situated in areas highly susceptible to landslide to evaluate which are feasible for relocation, prevention, or protection strategies.
5. Thorough investigations including fieldwork, mapping, measuring possible deformation of the highly susceptibility area, and ground monitoring.

Validation

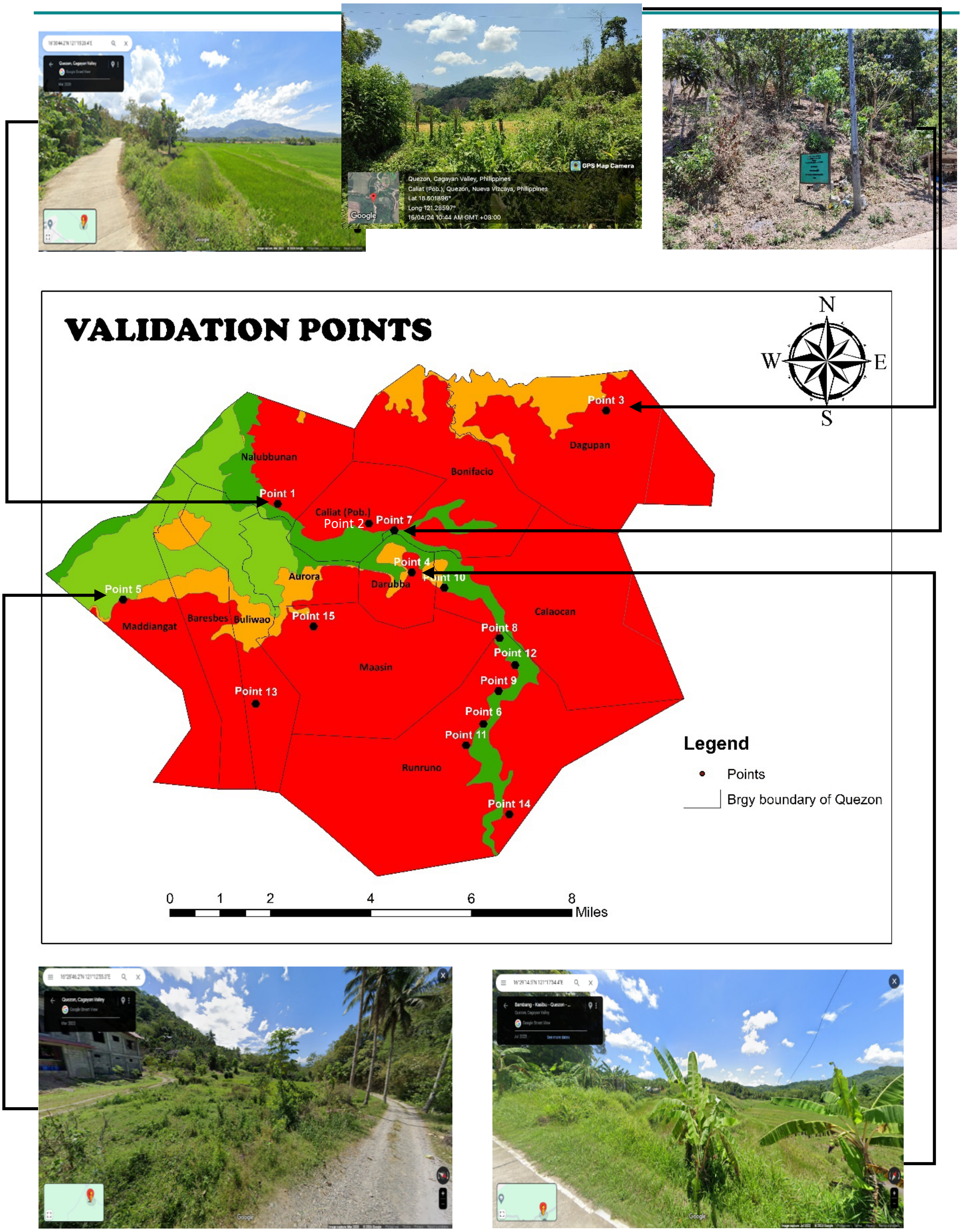
To validate the results, the researchers employed geotagging on areas identified to exhibit disparities or differences in susceptibility class between the existing landslide susceptibility map and the updated version. Thereafter, a field survey was carried out to further assess the accuracy and the reliability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

Table 26. Validated points and their validation ratings

Points	Existing Landslide Susceptibility Map Rating	Enhanced Landslide Susceptibility Map Rating	Validation Rating
1	High	Low	Low
2	High	Low	Low
3	High	Low	Low
4	High	Low	Low
5	High	Low	Low
6	High	High	High
7	Very low	Moderate	Moderate
8	High	High	High
9	High	High	High
10	High	High	High
11	High	High	High
12	High	High	High
13	High	High	High
14	High	High	High
15	High	High	High

Figures below present the validated points together with the corresponding geotagged images. In the existing landslide susceptibility map, points 1, 2, 3 ,4, and 5, located in Barangay Nalubbunan (points 1), Caliat (points 2), Dagupan (points 3), Darubba (point 4) and Maddiangat (5) were classified as highly susceptible to landslide. However, upon validation, said points are situated at low elevations ranging from 250 to 500 meters above datum, featuring slopes ranging from 0 to 18 degrees, which were classified as having low susceptibility to landslides. Although some places in these barangays exhibit hills particularly along the roads, these areas receive a low amount of average annual rainfall, thereby classified as low susceptible. In Table 26, these validated points conform with the susceptibility class on the enhanced L.

Furthermore, points 6,7, 8 ,9, 10, 11, 12, 13, 14 and 15 located in Barangay Runruno (points 6, 8, 9, 11, 12, and 14), Bonifacio (point 7), Calaocan (Point 10), Buliwao (point 13), and Maasin (point 15). In both the existing and enhanced susceptibility map, these points were classified as highly susceptible to landslides. Through field surveys, it was validated and confirmed that these places are indeed highly susceptible. As evidenced by the geotagged photos captured with GPS camera, although these places are predominantly covered with brush/shrubs and open/closed forests. They are characterized by steep slopes, high elevations, and located along the roads. Additionally, these places receive moderate to high amount of precipitation and the presence of mountain soils make these places vulnerable to landslides. Moreover, the geotagged photos at points 11, 13, 14, 15 illustrates landslide cases were sourced from reliable sources on the internet, and their locations were confirmed by asking local residents. Upon cross-referencing with the enhanced landslide susceptibility map, these points were classified as highly susceptible due to their high elevations and steep slopes. Therefore, these places are indeed susceptible to landslides.


VALIDATION POINTS
N
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Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
Point 7
Point 8
Point 9
Point 11
Point 12
Point 13
Point 14
Point 15
Nalubbunan
Bonifacio
Dagupan
Caliat (Pob.)
Aurora
Darubba
Calaocan
Maddiangat
Baresbes
Buliwao
Maasin
Runruno
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Points
Brgy boundary of Quezon
0
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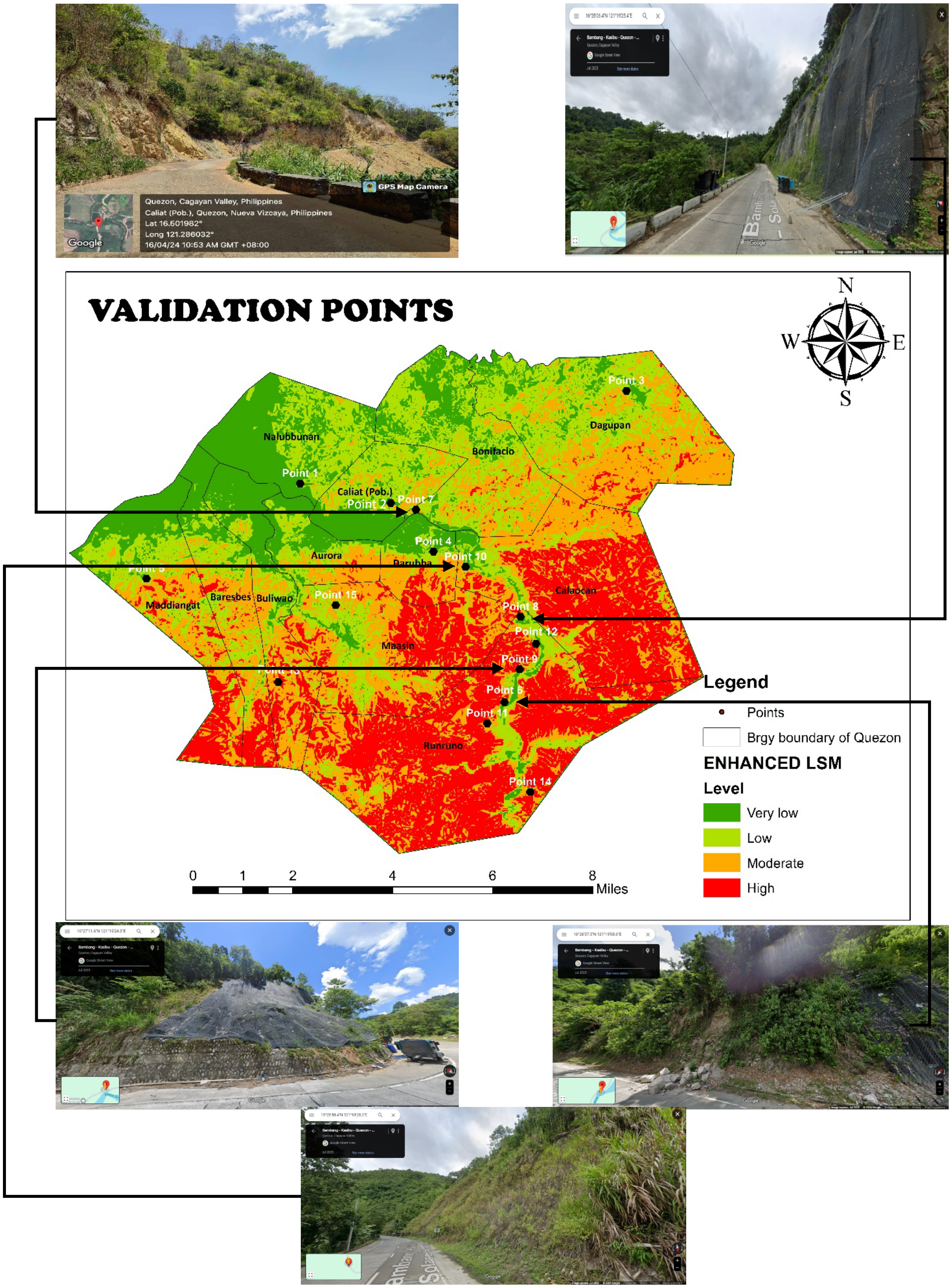
Miles
GPS Map Camera
Google


GPS Map Camera
Quezon, Cagayan Valley, Philippines
Caliat (Pob.), Quezon, Nueva Vizcaya, Philippines
Lat 16.501982°
Long 121.286032°
16/04/24 10:53 AM GMT +08:00
Google
VALIDATION POINTS
N
W
E
S
Point 3
Dagupan
Nalubbunan
Bonifacio
Point 1
Caliat (Pob.)
Point 2
Point 7
Point 4
Aurora
Darubba
Point 10
Maddiangat
Baresbes
Buliwao
Point 15
Calaocan
Point 8
Point 12
Maasin
Point 9
Point 6
Point 11
Runruno
Point 14
Legend
Points
Brgy boundary of Quezon
ENHANCED LSM
Level
Very low
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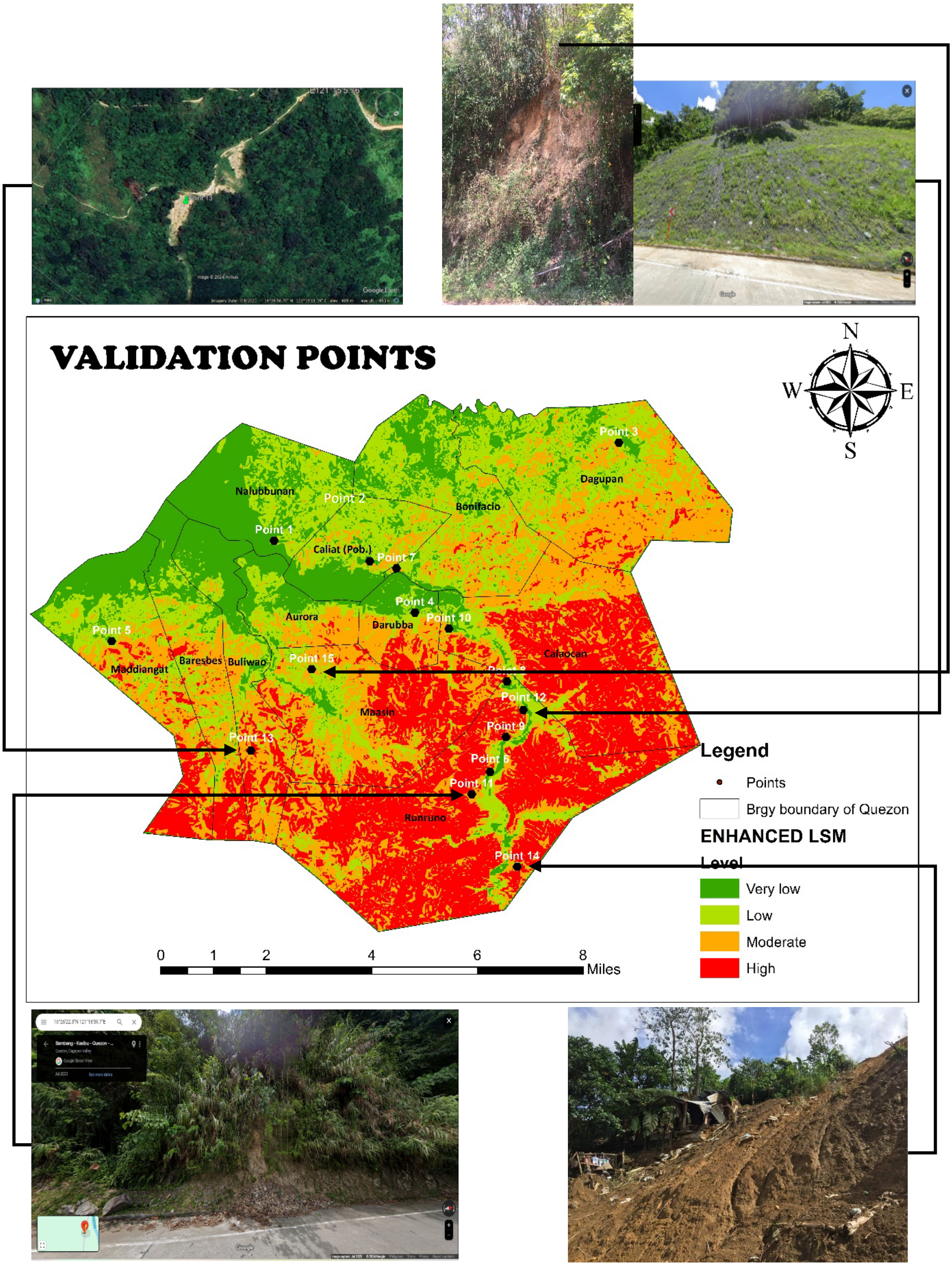
VALIDATION POINTS
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Caliat (Pob.)
Bonifacio
Dagupan
Aurora
Darubba
Calaocan
Maddiangat
Baresbes
Buliwao
Maasin
Runruno
0 1 2 4 6 8 Miles
Legend
Points
Brgy boundary of Quezon
ENHANCED LSM
Level
Very low
Low
Moderate
High

CONCLUSION

Landslide pose a significant risk to human lives, infrastructure and the environment. Predicting landslide susceptibility through mapping is crucial for effective risk management and mitigation strategies. However, landslide susceptibility can change over time due to various factors such as weather, construction activities and natural processes. Therefore, this study was conducted to generate an enhanced landslide susceptibility map for the municipality of Quezon by integrating the AHP and GIS. The study considered seven factors including slope angle, rainfall, soil type, land cover, elevation, distance from road and distance from rivers in generating the susceptibility map. Among the contributing factors, slope (35%) and rainfall (23.56%) had the highest relative weights, followed by soil type (15.38%), land cover (9.75%), elevation (7.21 %), while distance from road (5.43 %) and distance from river (3.66%) had the lowest relative weight. The enhanced landslide susceptibility map was categorized into four susceptibility classes namely, very low, low, moderate, and high.

The results presented in the study indicate that the municipality of Quezon is susceptible to landslides. As illustrated in the enhanced LSM, Barangay Maasin, Runruno, and Calaocan and some parts of Maddiangat, Baresbes, Buliwao, Darubba are identified as high-risk areas. Despite being predominantly covered with open/closed and brush/shrubs, these barangays are characterized by high elevations and slopes above 30 degrees. Furthermore, these barangays receive a moderate to high amount of rainfall and the presence of mountain soils significantly contribute to the vulnerability of these barangays to landslides. On the other hand, Barangay Dagupan and Bonifacio are at moderate risk; although they receive low amounts of annual average rainfall, they are characterized by a moderately steep slope and are composed of mountain soil, which is classified as highly susceptible, while Barangay Nalubbunan, Caliat, and Aurora are at low risk, as they are situated at low elevations, feature gentle slopes, and experience low precipitation.

Overall, in the study area, it was determined that 3589.64 hectares are very low susceptible, 5690.36 hectares are low susceptible, 5993.09 hectares are moderately susceptible, and 5792.80 hectares are highly susceptible to landslides. The distribution of area coverage for each susceptibility classes indicates a significant difference between the 2019 LSM and the enhanced version. In the validation of the enhanced version, 100% of the validated points align with the susceptibility levels indicated on the enhanced LSM. Therefore, the present study not only demonstrates a higher accuracy but also enhances the reliability of the landslide susceptibility map.

RECOMMENDATION

Based on the findings and conclusions presented, the following recommendations are suggested:

1. MPDO can use the results of the present study to re-evaluate facilities and infrastructure that are feasible for relocation, prevention, or protection measures.
2. The LGU can utilize the finding of the study to spread awareness and warn residents situated in highly susceptible areas. Thus, a landslide susceptibility map should be available to the public and posted in conspicuous places such as municipal halls and barangay halls.
3. The MDRRMC should develop landslide inventory map in the area to facilitate easier access to validate the results of the model.
4. For future researchers, conduct another landslide susceptibility assessment in the municipality using other statistical methods and techniques. Moreover, utilizing updated geospatial data will contribute to achieving more accurate and reliable results.

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