Flood Hazard and Risk Assessment of Lower Magat River Basin Using Geospatial Technologies: Basis for Developing Flood Hazard Map

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ABSTRACT

This study provides a comprehensive geospatial assessment of flood susceptibility in the Lower Magat River Basin, focusing on the municipalities of Solano, Bayombong, Quezon, and Bagabag in Nueva Vizcaya. The study addresses the escalating threat of inundation by utilizing the Analytic Hierarchy Process (AHP) to evaluate and weight six critical parameters: distance to rivers, precipitation, elevation, slope, soil type, and land use/land cover (LULC). Results indicate that Distance to Rivers (36.1%) and Precipitation (25.4%) are the primary drivers of flood hazard in the region. The integration of these factors through weighted overlay analysis reveals a heterogeneous distribution of risk, with Solano exhibiting the most pervasive vulnerability, as 71.72% (48.04 sq.km) of its land area is classified as high susceptibility. In contrast, Bayombong and Quezon harbor the most extreme localized risks, with Barangays Casat, Darubba, and Runruno emerging as critical "Very High" hazard hotspots. The findings demonstrate that high-risk zones are concentrated within a 600-meter buffer of the Magat River, particularly where low-gradient slopes (0–5.8%) and heavy clay soils impede drainage. The study achieved a high consistency ratio (CR < 0.10), validating the model's reliability for land-use planning. It is recommended that local government units integrate these susceptibility maps into their Comprehensive Land Use Plans (CLUP), enforce strict river easement zones, and implement nature-based solutions like reforestation to mitigate runoff. This research serves as a critical baseline for disaster risk reduction, providing a data-driven framework for enhancing community resilience against future flooding events.

Keywords – flood susceptibility mapping, analytic hierarchy process (AHP), weighted overlay analysis, Nueva Vizcaya, disaster risk reduction (DRR), land use planning

INTRODUCTION

Flooding is one of the most recurrent and destructive natural hazards in the Philippines, primarily due to the country's geographic location within the Pacific typhoon belt and its exposure to intense monsoon rainfall and strong tropical cyclones. Each year, flooding causes significant damage to lives, infrastructure, agriculture, and local economies, particularly in river basin areas where settlements are concentrated near waterways. Effective flood hazard assessment and mapping are therefore essential tools for disaster risk reduction, land-use planning, and sustainable development, especially in flood-prone regions.

The Lower Magat River Basin, located in Nueva Vizcaya, is one of the areas frequently affected by flooding during the rainy season and periods of intense typhoon activity. Several municipalities within the basin, namely Bagabag, Solano, Bayombong, and Quezon are traversed by tributaries such as the Nangalisan River, Lamut River, Sta. Cruz River, Bayombong River, as well as various creeks and seasonal rivers. These water systems, combined with low-lying topography and varying land cover conditions, contribute to increased flood susceptibility in the area. As population growth and land-use changes continue, the potential impacts of flooding are expected to intensify, highlighting the need for accurate and up-to-date flood hazard information.

Geospatial technologies, particularly Geographic Information Systems (GIS), have become vital tools in flood hazard assessment due to their ability to integrate, analyze, and visualize spatial data from multiple sources. GIS allows for systematic evaluation of physical and environmental factors that influence flooding, such as elevation,

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slope, precipitation, land cover, soil type, and proximity to river systems. By combining these parameters, flood hazard maps can be generated to identify areas with varying levels of flood risk. These maps serve as valuable references for local government units, planners, and disaster management agencies in formulating mitigation strategies and emergency preparedness plans.

However, despite the availability of flood hazard maps for the Lower Magat River Basin, a critical gap exists in terms of the timeliness and relevance of the geospatial data being used. Information obtained from the Provincial Disaster Risk Reduction and Management Office (PDRRMO) and the Provincial Planning and Development Office (PPDO) indicates the most recent authoritative dataset is the 2015 MGB Hazard Map. Given the dynamic nature of flood-related factors including land-use changes, urban expansion, river morphology alterations, and climate variability these datasets may no longer accurately reflect present conditions on the ground. The continued reliance on outdated spatial information may lead to misinformed planning decisions, inefficient allocation of resources, and reduced effectiveness of flood mitigation strategies.

This gap underscores the need for an updated and more comprehensive flood hazard assessment that incorporates recent and higher-resolution spatial data. Addressing this limitation is crucial to improving the accuracy and reliability of flood risk identification and to ensuring that local government units are equipped with relevant and evidence-based tools for disaster preparedness and land-use planning.

This study utilized GIS-based techniques to develop a contemporary flood hazard map for the tributaries of the Lower Magat River Basin. Updated secondary data, including digital elevation models, rainfall data, land use, and soil information, were processed using ArcGIS software and the Analytic Hierarchy Process (AHP). The analysis focuses on low-lying areas characterized by high susceptibility due to their topographic features and proximity to river networks. By bridging the gap between the 2015 baseline and present-day conditions, this research provide a scientifically grounded spatial assessment essential for improved flood risk management in Nueva Vizcaya.

A. Objective of the study

To assess the flood susceptibility of Nueva Vizcaya using GIS by identifying flood hazard zones, determining the key environmental and physical factors influencing flood risk, and developing a GIS-based flood hazard map.

METHODS

A. Research Design

This study employed a quantitative-evaluative research design using Geospatial Multi-Criteria Decision Analysis (MCDA) to assess flood hazard levels in the Lower Magat River Basin, Nueva Vizcaya. This design was appropriate as it allowed for the systematic integration of six key environmental and physical drivers, elevation, slope, land use/land cover, soil type, precipitation, and distance from rivers which collectively governed the hydrological response of the basin. To ensure high-resolution accuracy, secondary datasets were sourced from verified repositories: IfSAR or SRTM-DEM for topographic derivatives (elevation and slope), Sentinel-2 imagery for land cover mapping, CHRS Data Portal for rainfall data, and FAO/UNESCO for soil parameters.

The core of the methodology utilized the Analytic Hierarchy Process (AHP) to determine the relative influence of each parameter. Through a pairwise comparison matrix, weights were assigned to each factor for instance, prioritizing high precipitation and low elevation as dominant drivers of inundation while ensuring a Consistency Ratio (CR) of less than 0.10 to maintain mathematical rigor. These parameters were processed as standardized thematic layers in ArcGIS and integrated using the Weighted Linear Combination (WLC) method. This process calculated a Flood Susceptibility Index for every pixel in the study area, which was then categorized into low, moderate, and high hazard zones using the Natural Breaks (Jenks) classification method.

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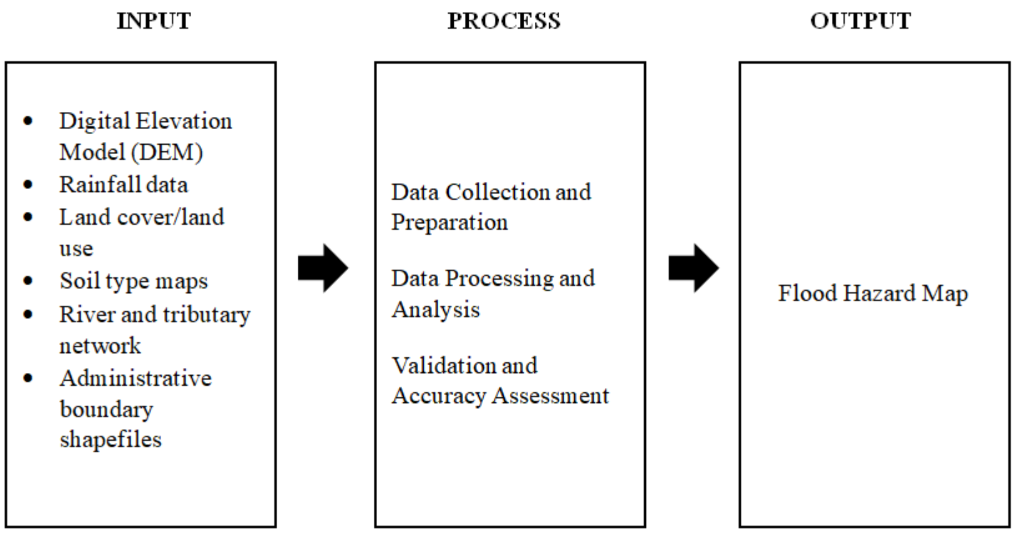
To validate the model's reliability, the research design incorporated a spatial verification phase where the generated hazard map was cross-referenced with historical flood footprints and GPS-tagged disaster records from the PDRRMO of Nueva Vizcaya. This evaluative approach ensured that the "Basis for Developing Flood Hazard Map" cited in the title was scientifically grounded. The final output was designed as a high-resolution decision-support tool for local government units and disaster management agencies, providing an evidence-based framework for land-use zoning, infrastructure prioritization, and sustainable disaster risk reduction strategies within the Lower Magat River Basin.

B. Conceptual Framework

Figure 1 shows the conceptual framework of the study. This research adopted the Input–Process–Output (IPO) Framework to illustrate the development of a GIS-based flood hazard map for Nueva Vizcaya. The input consists of six flood-conditioning factors: elevation, slope, precipitation, land use/land cover (LULC), soil type, and distance from rivers, derived from various geospatial and remote sensing data sources. These datasets were processed using Geographic Information System (GIS) techniques, including raster conversion, reclassification, and standardization. The Analytical Hierarchy Process (AHP) was then employed to assign weights to each factor, followed by the weighted overlay analysis in ArcGIS 10.3 to integrate the thematic layers. The output of the study is a GIS-based flood hazard map that classifies the Province of Nueva Vizcaya into low, moderate, and high flood susceptibility zones.

Figure 1: Conceptual Framework of the study



C. Research Respondents and Sampling Procedures

The population of this study consists of the entire Lower Magat River Basin, covering the municipalities of Bagabag, Solano, Bayombong, and Quezon in the province of Nueva Vizcaya. This population includes all geographic areas, river systems, and environmental features within the basin that may influence flood occurrence and susceptibility. As the study focuses on spatial and environmental analysis rather than human respondents, the population is defined in terms of geographic extent and environmental units rather than individuals.

D. Statistical Tools and Analysis

Flood susceptibility was assessed using a Geographic Information System (GIS)-based Multi-Criteria Decision Analysis (MCDA) integrated with the Analytic Hierarchy Process (AHP). Six flood-conditioning factors, elevation, slope, precipitation, land use/land cover (LULC), soil type, and distance from rivers were standardized and processed in ArcGIS 10.3 through raster conversion, reclassification, and spatial analysis.

The relative importance of each factor was determined using AHP through pairwise comparison matrices. The consistency of the assigned weights was evaluated using the Consistency Index (CI) and Consistency Ratio (CR), with a CR value of less than 0.10 indicating acceptable consistency. The validated weights were then applied using the Weighted Linear Combination (WLC) method through the ArcGIS Weighted Overlay tool to compute the Flood Susceptibility Index (FSI).

The resulting continuous FSI raster was classified into low, moderate, and high flood hazard zones using the Natural Breaks (Jenks) classification method, which identifies optimal class boundaries by minimizing within-class variance and maximizing between-class variance. The final GIS-based flood hazard map served as the primary output for identifying flood-prone areas in Nueva Vizcaya.

E. Validation of the Flood Susceptibility Map

The reliability of the generated flood susceptibility map was evaluated through field validation using historical flood occurrence data provided by the Provincial Disaster Risk Reduction and Management Office (PDRRMO) of Nueva Vizcaya. Historical records identifying flood-affected barangays were compared with the GIS-generated flood susceptibility map to assess the spatial correspondence between documented flood events and the predicted flood susceptibility classes.

To further verify the results, field visits were conducted in selected barangays with documented historical flooding, during which photographic evidence of flood-prone locations was collected. These photographs served as qualitative evidence to verify that the mapped high-susceptibility areas corresponded to locations with a history of flooding. The combined use of historical flood occurrence records and field photographs provided qualitative validation of the GIS-AHP flood susceptibility map and enhanced confidence in its ability to identify flood-prone areas within the Lower Magat River Basin.

RESULTS AND DISCUSSION

A. Spatial Assessment of Flood Hazard Susceptibility Across Nueva Vizcaya Municipalities

Quezon contains the largest overall physical area susceptible to flooding, with a combined 172.55 sq.km across moderate to very high levels. This is followed closely by Bagabag with 164.73 sq.km. However, Solano faces the most pervasive threat relative to its size, with 99.91% of its territory classified within moderate and high hazard zones. This comparison underscores that while Quezon and Bagabag deal with the largest absolute scale of flooding, Solano is the most universally vulnerable municipality, and Bayombong and Quezon harbor the most dangerous "Very High" risk pockets.

Table 1: Summary of areas affected by floods in the Lower Magat Basin

Category	**Solano**		**Bayombong**		**Bagabag**		**Quezon**	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Very Low	0	0	1.34	0.94 %	0	0	0	0
Low	0.06	0.09 %	20.16	14.16 %	1.02	0.62 %	1.23	0.71%
Moderate	18.88	28.19 %	81.40	57.15 %	67.67	40.83 %	106.64	61.36 %
High	48.04	71.72 %	39.23	27.55 %	97.06	58.56 %	65.68	37.79%
Very High	0	0	0.29	0.20 %	0	0	0.23	0.13 %

B. Flood-Conditioning Factors and Criteria Weights

As indicated in Table 2, Each factor’s sub-criteria were assigned a rating from 1 (Very Low) to 5 (Very High) based on their relative influence on flood hazard. For instance, areas within 0-609.18 meters of the river system and regions receiving 2,450-2,506 mm of annual precipitation were assigned the maximum rating of 5, reflecting their critical role in inundation.

Table 2: Flood Susceptibility Criteria and Sub-criteria Ranges

Flood Causative Criterion	Unit	Class	Susceptibility Class Ranges and Ratings	Susceptibility Class Ratings	Weight
Elevation	m	0-94	Very High	5	0.06
		94-140	High	4	
		140-170	Moderate	3	
		170-200	Low	2	
		200-250	Very Low	1	
Slope	%	0-5.8	Very High	5	0.10
		5.9-13	High	4	
		14-20	Moderate	3	
		21-30	Low	2	
		31-70	Very Low	1	
Land Use Land Cover	Level	Water	Very High	5	0.16
		Flooded Vegetation	High	4	
		Built Area	Moderate	3	
		Bare Ground	Low	2	
		Trees/Crops/Range Land	Very Low	1	
Soil Type	Level	Heavy Clay	Very High	5	0.06
		Stable Clay	High	4	
		Clay/Loam	Moderate	3	
Precipitation	mm/year	2,221-2,278	Very Low	1	0.25
		2,279-2,335	Low	2	
		2,336-2,392	Moderate	3	
		2,393-2,449	High	4	
		2,450-2,506	Very High	5	
Distance to rivers	m	0-609.18	Very High	5	0.36
		609.19-1,218.35	High	4	
		1,218.36-1,827.53	Moderate	3	
		1,827.54-2,436.71	Low	2	
		2,436.72-3,045.89	Very Low	1	

The relative importance of the six flood-conditioning factors was determined using the Analytic Hierarchy Process (AHP) through a pairwise comparison matrix. The resulting normalized weights assigned the highest influence to Distance to Rivers (36.1%) and Precipitation (25.4%), followed by Land Use/Land Cover (16.1%), Slope (10.0%), Soil Type (6.4%), and Elevation (6.0%). The consistency of the pairwise comparisons was evaluated using the Consistency Index (CI) and Consistency Ratio (CR), with the computed CR remaining below the acceptable threshold of 0.10, indicating reliable and consistent expert judgments. The validated weights were subsequently integrated with the reclassified spatial layers using the Weighted Overlay technique in ArcGIS to generate the final GIS-based flood susceptibility map.

Table 3: Pairwise comparison of five flood factors

	E	**S**	**LULC**	**Soil**	**P**	**DR**
E	1	1/2	1/3	1	1/4	1/5
S	2	1	1/2	2	1/3	1/4
LULC	3	2	1	2	1/2	1/2
Soil	1	1/2	1/2	1	1/4	1/5

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P	4	3	2	4	1	1/2
DR	5	4	2	5	2	1

Table 4: Normalized pairwise comparison matrix and calculated criteria weight for each factor

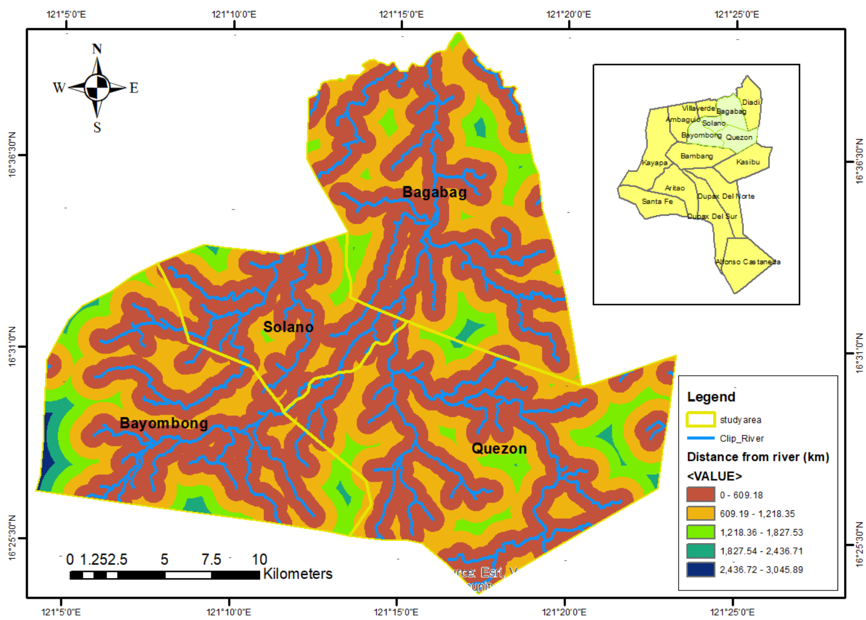
	E	**S**	**LULC**	**Soil**	**P**	**DR**	**Row Avg (Weight)**	**Percentage (%)**
E	0.063	0.045	0.053	0.067	0.058	0.075	**0.060**	**6%**
S	0.125	0.091	0.079	0.133	0.077	0.094	**0.100**	**10%**
LULC	0.188	0.182	0.158	0.133	0.115	0.189	**0.161**	**16%**
Soil	0.063	0.045	0.079	0.067	0.058	0.075	**0.064**	**7%**
P	0.250	0.273	0.316	0.267	0.231	0.189	**0.254**	**25%**
DR	0.313	0.364	0.316	0.333	0.462	0.377	**0.361**	**36%**

C. Cartographic Presentation and Analysis of Flood Thematic Layers

1. Distance from Rivers (Hydrographic Proximity)

Spatial analysis indicates that proximity to the drainage network is the primary determinant of flood vulnerability (AHP weight: 36.1%). As shown in Figure 3, the urban cores of Solano and Bayombong fall within the critical 0–609.18 m buffer zone. This low-lying terrain is subject to frequent overbank flow during peak discharge events along the Magat River's active floodplain, where historical inundation points confirm the mechanical dominance of riverine proximity.

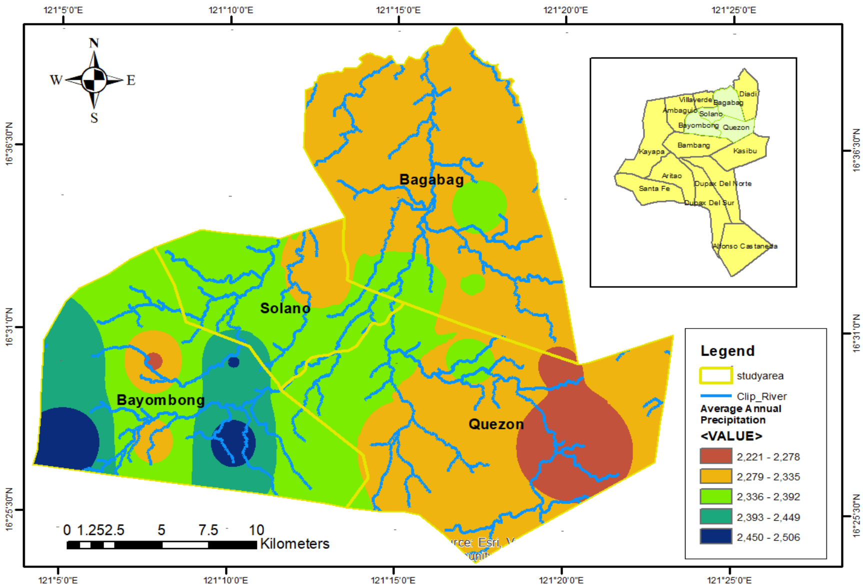
Figure 2: Distance from river Map of the Study Area



2. Average Annual Precipitation (Hydro-Meteorological Forcing)

Hydro-meteorological forcing acts as the primary atmospheric driver of flood dynamics (Figure 3). The central and southern sectors (Bayombong and Quezon) exhibit the highest precipitation gradients, reaching 2,450–2,506 mm/year. This intensive rainfall regime serves as the critical triggering mechanism that overwhelms natural channels and municipal drainage infrastructure during high-magnitude storm events.

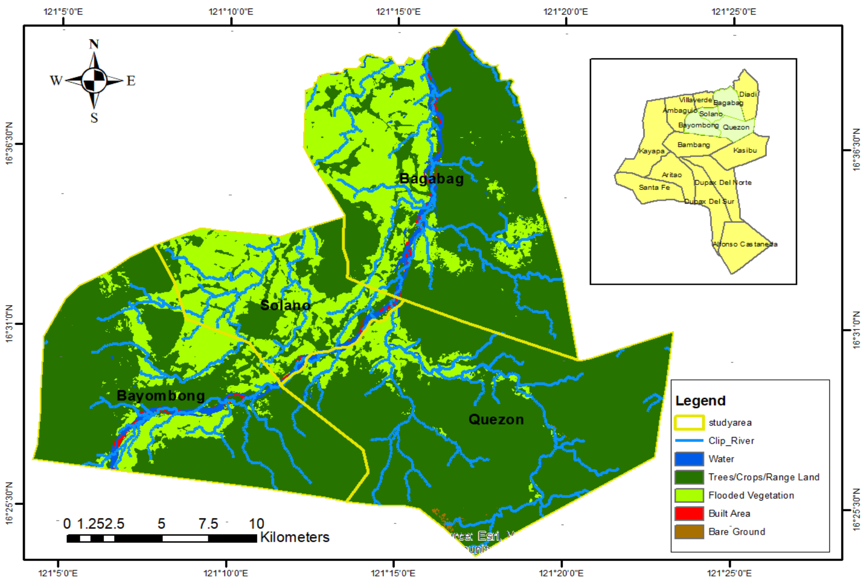
Figure 3: Average Annual Rainfall (mm) Map of the Study Area



3. Land Use and Land Cover (Surface Roughness and Infiltration)

The LULC map (Figure 4) shows that agricultural and urban development significantly alter regional runoff coefficients. While "Trees/Crops/Rangeland" offers moderate initial interception, urban expansion in Solano and Bayombong introduces extensive impermeable surfaces that accelerate overland flow. Additionally, "Flooded Vegetation" along the Magat River main stem indicates zones where natural drainage is chronically impaired by anthropogenic land use.

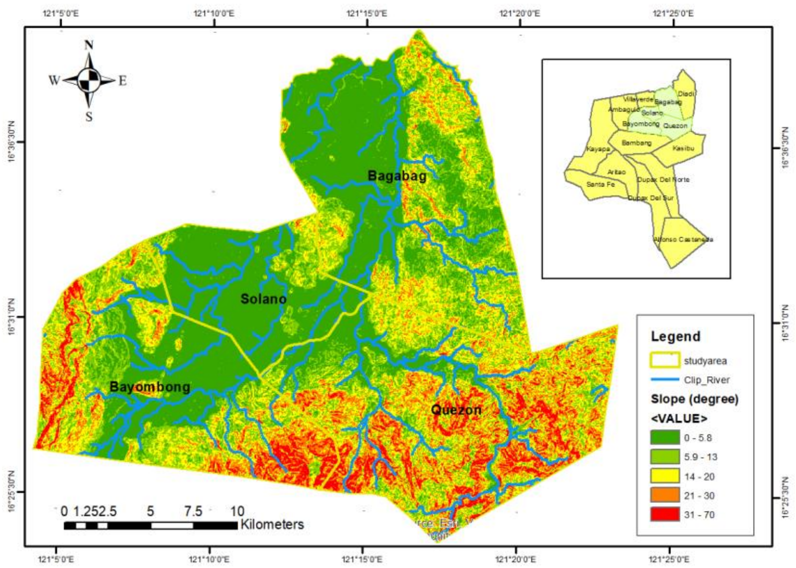
Figure 4: Land Use and Land Cover (LULC) Thematic Map of the Study Area



4. Topographic Slope (Terrain Gradient)

The Slope map (Figure 5) highlights the contrast between the rugged highlands and the flat valley floor. Solano and Bagabag are dominated by low-gradient slopes (0°–5.8°), acting as collection sinks for runoff from surrounding mountainous terrain. This lack of relief minimizes flow velocities, leading to prolonged floodwater residence times and drainage stagnation in commercial and residential districts.

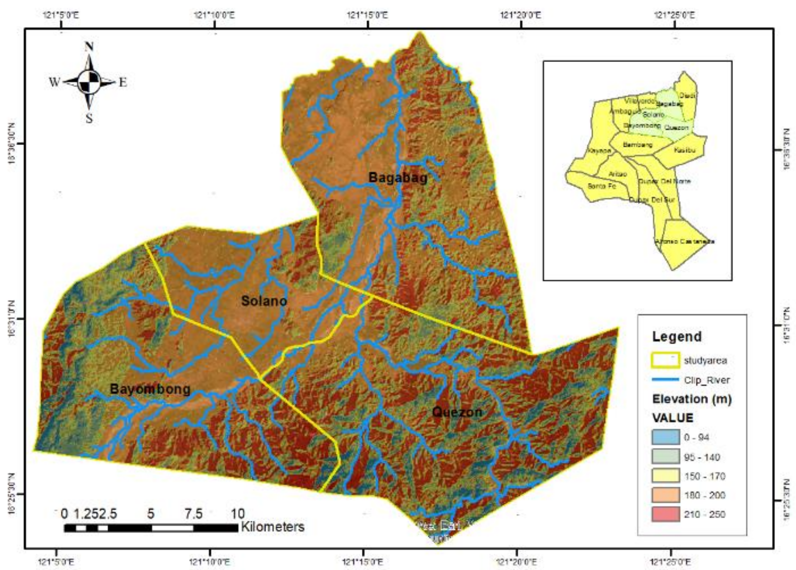
Figure 5: Topographic Slope (Degrees) Map of the Study Area



5. Elevation (Hypsometric Relief)

Hypsometric analysis (Figure 6) confirms that low-lying valley regions below 94 m are highly vulnerable to water accumulation. While flanked by high-elevation terrain that promotes rapid upland drainage, the basin floor functions as a primary topographic sink. This localized depression effect creates a natural trap for surface water during concurrent high-river stages and heavy monsoonal rainfall.

Figure 6: Elevation (Meters) Map of the Study Area



6. Soil Type (Pedological Permeability)

The soil distribution (Figure 7) indicates a significant presence of "Heavy Clay" and "Stable Clay" across Quezon and parts of Solano. These clay-dominated soils exhibit low hydraulic conductivity and high saturation potential. Once field capacity is reached, infiltration drops to near zero, triggering immediate surface runoff and limiting the earth's natural capacity to absorb excess water.

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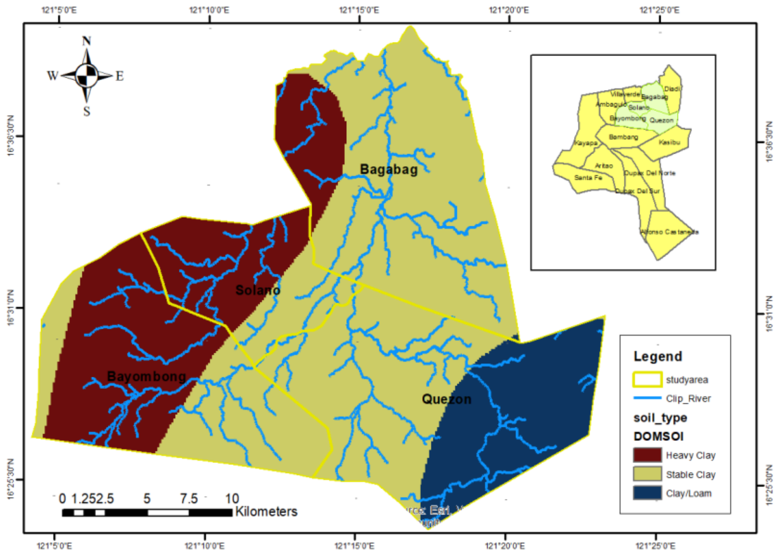
Figure 7: Soil Type Map of the Study Area

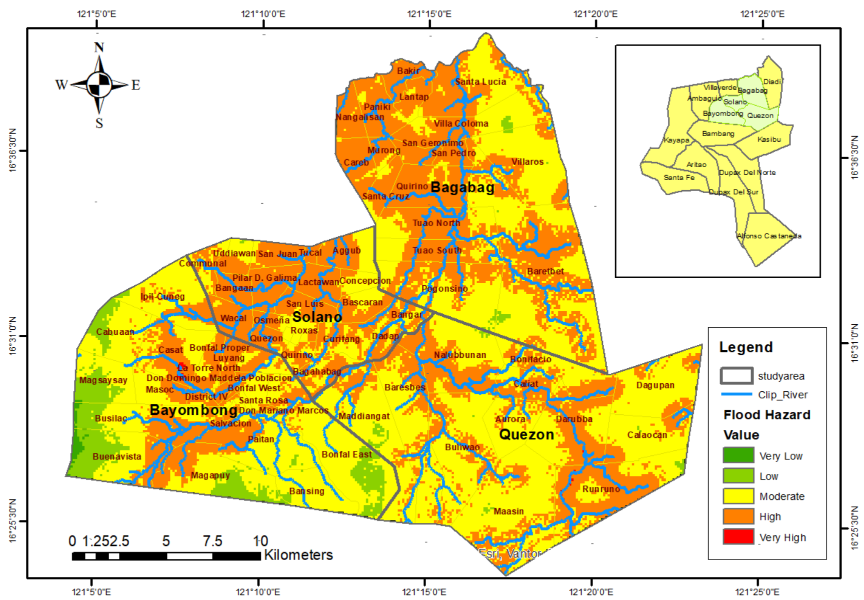


D. GIS-Based Flood Hazard Map of the Lower Magat River Basin

The GIS-based flood hazard map revealed varying levels of flood susceptibility across the Lower Magat River Basin. Among the four municipalities, Solano exhibited the highest proportion of high-susceptibility areas (71.72%; 48.04 km²), followed by Bagabag (58.56%; 97.06 km²), reflecting their low-lying terrain and proximity to major river systems. Quezon was predominantly classified as moderately susceptible (61.36%; 106.64 km²), while Bayombong displayed the most balanced distribution, with the largest extent of low and very low susceptibility areas (21.50 km²; 15.1%) due to its relatively higher elevations.

At the barangay level, Casat in Bayombong recorded a 100% very high susceptibility index, making it the most flood-prone area in the basin. Other highly vulnerable barangays included Darubba and Runruno in Quezon, Pilar D. Galima in Solano, Paitan in Bayombong, and Baretbet in Bagabag. Moderate flood susceptibility was concentrated in Aggub and Curifang (Solano), Bonfal East (Bayombong), Baretbet (Bagabag), and Maddiangat (Quezon). In contrast, safer zones were primarily located in Uddiawan (Solano), Buenavista and Magsaysay (Bayombong), Villa Coloma (Bagabag), and Maddiangat (Quezon), where higher elevations reduced flood susceptibility.

Figure 8: Flood Hazard Map of Lower Magat River



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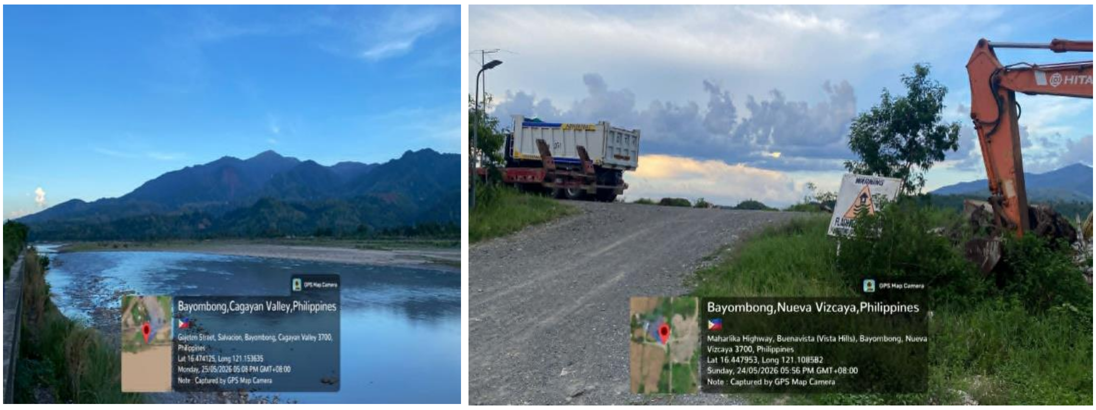
E. Field Validation of the Flood Susceptibility Map

The generated flood susceptibility map was qualitatively validated using historical flood occurrence records from the Provincial Disaster Risk Reduction and Management Office (PDRRMO) of Nueva Vizcaya and field photographs collected from selected flood-affected barangays in the municipalities of Bagabag, Bayombong Solano, and Quezon. The validation showed that areas classified as highly susceptible generally corresponded with locations that had experienced historical flooding. As shown in Figure 9, the field photographs provided visual evidence supporting the agreement between the mapped susceptibility classes and documented flood-prone areas, indicating that the GIS-AHP model reliably represents flood susceptibility within the Lower Magat River Basin.

Figure 9: Field validation of the GIS-generated flood susceptibility map using photographs from selected flood-affected barangays.

a)



b)

c)

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d)

CONCLUSION

Based on the results of this study, the following conclusion were drawn:

1. The GIS–AHP analysis identified distance to rivers (36.1%) and precipitation (25.4%) as the dominant factors influencing flood susceptibility in the Lower Magat River Basin.
2. High flood hazard areas are primarily located near the Magat River and in zones with high annual rainfall, highlighting the combined influence of hydrological and climatic conditions on flood occurrence.
3. Low-gradient terrain and heavy clay soils further increase flood susceptibility by limiting infiltration and promoting surface water accumulation.
4. The acceptable Consistency Ratio (CR < 0.10), together with the field validation results, confirms the reliability of the GIS-AHP approach and demonstrates that the generated flood hazard map provides a scientifically sound basis for flood hazard assessment and disaster risk reduction planning in the study area.

RECOMMENDATION

Based on the conclusion derived from the results of this study, the following are the recommendations:

1. Local government units (LGUs) should integrate the GIS-based flood hazard map into their Comprehensive Land Use Plans (CLUP) and Disaster Risk Reduction and Management (DRRM) plans to support evidence-based planning and flood risk mitigation.
2. Development within identified high-risk flood zones, particularly areas adjacent to major river systems, should be strictly regulated through the enforcement of river easements and appropriate land-use policies.
3. Nature-based solutions, including watershed reforestation and the expansion of urban green infrastructure, should be promoted to reduce surface runoff and improve water infiltration.
4. Future studies should integrate socio-economic indicators, such as population distribution, critical infrastructure, transportation networks, evacuation centers, and community preparedness, to develop a more comprehensive flood risk assessment that considers not only flood hazard but also community exposure and vulnerability.
5. Future research should compare the Analytic Hierarchy Process (AHP) with advanced approaches, including machine learning algorithms, hydrological simulation models, or hybrid geospatial techniques, to evaluate their predictive performance and further improve the accuracy and reliability of flood susceptibility mapping.

6. Future studies are encouraged to incorporate high-resolution LiDAR datasets, satellite-based remote sensing observations, hydraulic modeling, and climate change scenarios to further enhance flood hazard assessment, and improve the predictive capability of flood susceptibility maps under changing environmental conditions.

7. Community-based flood awareness and preparedness programs should be strengthened, particularly in highly susceptible barangays, to enhance disaster resilience and early warning response.

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