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Landslide Vulnerability Map of Barangay Fatima, Pantabangan, Nueva Ecija

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ABSTRACT: Landslides are catastrophic geological risks that are unexpected. This study aims to develop a Landslide Vulnerability Map of Barangay Fatima, Pantabangan, Nueva Ecija. Landslide Mapping has been developed to mitigate the adverse effect of landslide. This study interprets and integrate landslide factors; elevation, slope, rainfall, soil classification, land cover, and proximity to road and fault lines to generate a landslide vulnerability map. The eigenvectors rendered by experts engaged are evaluated for consistency to obtain credible and acceptable findings using AHP. The results showed that rainfall had the largest eigenvector (32.66%), then slope (20.80%), soil texture (15.96%), proximity to fault line (14.02%), land cover (8.27%), proximity to a road (4.63%), and elevation (3.66%). This suggests that rainfall and slope are more important than the other factors. Moreover, monitoring of landslide occurrences in the area is advised so that future research can confirm the model's conclusions.

KEYWORDS: Landslide Vulnerability Map, Rainfall, Fatima, GIS, AHP

I. THE PROBLEM AND A REVIEW OF RELATED LITERATURE

A. Introduction

A landslide is defined by the Philippine Institute of Volcanology and Seismology (n.d.) as a gravity-driven mass movement of earth material, such as rock, soil, and debris, down a slope. When the pushing force overpowers the resisting force, a landslide occurs. It is a natural event that occurs on steep hills. The movement might be gradual or extremely quick. It has the potential to have a substantial impact on geographical areas both close to and far from the source.

Landslides are severe geological hazards that are cataclysmic and often unforeseeable. This phenomenon happens due to factors that make the slope unstable. As stated by the National Geographic Society (2022), landslides mainly occur because of the characteristics of the material, the structure of the land, and human activity. They are often triggered by heavy rainfall, weathering of rocks, earthquakes that cause shaking of soil, seismic activity from volcanoes, and other human-induced activities.

The Philippines is geologically situated on the Pacific Ring of Fire, henceforth, it is susceptible to disasters including typhoons, earthquakes, volcanic eruptions, and landslides. This archipelago of 7,640 islands is located along major tectonic plates. When these tectonic plates move, they can cause deadly landslides.

According to NASA (n.d.), on February 17, 2006, a large landslide buried an entire town in the southern Philippines. It has been confirmed that 85 individuals were killed, with 981 still missing and presumed dead. Days of torrential rain were most likely to blame for this devastating landslide. Accordingly, Pantabangan is considered prone to landslides and mudflow during rain.

Pantabangan is located in the northern part of the province of Nueva Ecija. It has 14 barangays and a land area of 392.56 square kilometers, according to PhilAtlas. It is a landlocked municipality. However, it has the famous Pantabangan Dam.

Pantabangan is a mountainous locality. It is situated near the Carranglan and Gabaldon fault lines, hence, it can be considered a landslide-vulnerable region. Geologists from Mines and Geosciences Bureau-Regional Office III (MGB-R3) conducted a geohazard assessment in municipalities in Nueva Ecija, including Pantabangan. Their analysis published in 2016 shows that Barangay Fatima is included in low landslide susceptible areas. However, the assessment was conducted on 2004. Hence, it should be updated because of the ever-changing environment. As the monsoon season approaches, the likelihood of future landslides increases. Severe rain and runoff, along with slopes destabilized by the earthquake and subsequent aftershocks, heightens the probability that steep and unstable valley slopes will collapse. Roads are at risk of being covered by landslides. Landslides on roadways obstruct and block traffic.

Landslides are a dangerous calamity as well as other natural disasters. Nevertheless, it has less research than other geological hazards. Landslide Susceptibility Mapping has been developed to mitigate the adverse effect of this natural calamity.

Landslides frequently occur in identified hazard zones and in locations where they have previously happened. Landslides in all likelihood will happen to existing ancient landslides, the bases of steep slopes, the bottoms of drainage channels, and developed hillsides with leach-field septic systems.

Various measures are used to reduce or eliminate the hazard of landslides and its repercussions. Landslide vulnerability mapping is one of these. Hence, an updated and proper landslide vulnerability assessment of Barangay Fatima is a must. Establishing a landslide vulnerability map is essential for dealing with the landslide threat and reducing property damage and loss of life. Preparing a landslide susceptibility map of a specific region is a valuable tool in landslide hazard management since it indicates the extent to which an area is susceptible to landslide occurrence. In risk management and urban planning, landslide detection and susceptibility mapping are significant. It may be used to help identify land regions most suitable for development by analyzing the risks of landslides.

This present study aims to develop a Landslide Vulnerability Map of Barangay Fatima, Pantabangan, Nueva Ecija using a Geographic Information System (GIS) and Analytic Hierarchy Process (AHP).

B. Conceptual Framework

The researchers constructed the figure below to represent the relationship among the variables used in the current study.

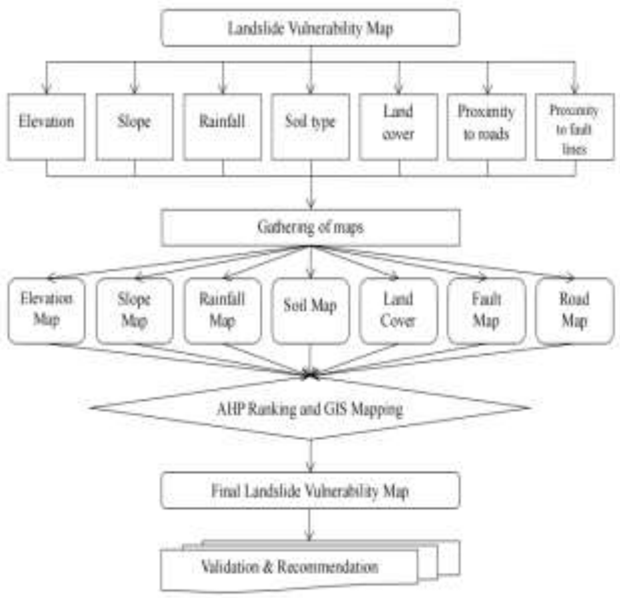

Figure 1-1. Conceptual Framework

The researchers considered and analyzed seven (7) biophysical factors that influence landslide occurrences; elevation, slope, rainfall, soil type, land cover, proximity to the road, and proximity to fault lines. Upon the determination of these factors, following previous research, maps of each criterion are gathered through requests from the LGU-Pantabangan and retrieving data from online sources and ArcGIS. Afterward, the maps are ranked, computed, and scrutinized through AHP and ArcMap, indicated in Fig. 1 as AHP ranking and GIS mapping. After these steps, the Landslide Vulnerability Map of Barangay Fatima, Pantabangan, Nueva Ecija is created.

C. Objectives of the Study

The primary focus of the study is on analyzing factors to create a Landslide Vulnerability Map of Barangay Fatima, Pantabangan, Nueva Ecija. Furthermore, the aims of the study are as follows:

1. To interpret various conditioning factors such as elevation, slope, rainfall, soil classification, land cover, proximity to fault line, and proximity to road which are necessary to design Landslide Vulnerability Map of barangay Fatima;
2. To integrate the maps of seven criteria considered in developing an updated landslide vulnerability model; and
3. To create Landslide Susceptibility Map of barangay Fatima, Pantabangan, Nueva Ecija.

D. Significance of the Study

This study was undertaken to investigate the factors that affects the probability of landslide and develop landslide vulnerability map of Barangay Fatima. Benefiting from the study are the various factors as follows:

The MDRRMO-Pantabangan. The map will be useful in landslide hazard management. Hence, the Municipal Disaster Risk Reduction and Management-Pantabangan will have an overview of places that have high, moderate, and low landslide vulnerability. It will be easier for them to create a landslide preparedness program and evacuation plan when a landslide strikes, considering that they can easily assess potential danger of a particular area in Pantabangan due to some geologic or man-made factors.

The LGU-Pantabangan. The Local Government Unit of Municipality of Pantabangan will be ready in terms of calamity.

The Students. Students will have broader knowledge on how to conduct a research on a similar topic. This will widen the scope of their understanding with regards to both Landslide Vulnerability Mapping and tools and technologies used to create such map. They will become equipped to deal with Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) that can be useful and applied to an academic paper with a concept related to the topic of this study.

E. Scope and Limitation of the Study

This study focuses on a hazard map, specifically, landslide vulnerability map of Barangay Fatima, Pantabangan, Nueva Ecija.

Only seven biophysical factors were considered namely, elevation, slope, rainfall, soil type, land cover, proximity to roads, and proximity to fault lines. The number of factors utilized in this modeling is comparable with the findings of Ozdemir (2005), who found that limiting the number of components used in pair-wise comparison to about seven produces a consistent and valid outcome in AHP.

F. Definition of Terms

There are terms used in this study that warrant further attention and clarification:

Analytic Hierarchy Process. Analytic Hierarchy Process (AHP) is a method for organizing and analyzing complex decisions, using math and psychology. It was developed by Thomas L. Saaty in the 1970s and has been refined since then. It contains three parts: the ultimate goal or problem you're trying to solve, all of the possible solutions, called alternatives, and the criteria you will judge the alternatives on. AHP provides a rational framework for a needed decision by quantifying its criteria and alternative options, and for relating those elements to the overall goal.

Biophysical Features. Biophysical feature is the characteristics that combine biological and physical features such as vegetation, hydrography, relief, climate, among others.

Geohazard. A geologic hazard is an extreme natural event in the crust of the earth that pose a threat to life and property, for example, earthquakes, volcanic eruptions, tsunamis (tidal waves) and landslides.

Geographic Information System. A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map, such as streets, buildings, and vegetation. This enables people to more easily see, analyze, and understand patterns and relationships.

Image Processing. Image processing is a method to perform some operations on an image, in order to get an enhanced image or to extract some useful information from it. It is a type of signal processing in which input is an image and output may be image or characteristics/features associated with that image.

Land Cover. Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other.

Landslide Vulnerability Map. A landslide vulnerability map indicates the possibility of landslide occurrences and highlights areas that are landslide vulnerable.

Pacific Ring of Fire. The Ring of Fire, also referred to as the Circum-Pacific Belt, is a path along the Pacific Ocean characterized by active volcanoes and frequent earthquakes. Its length is approximately 40,000 kilometers (24,900 miles). It traces boundaries between several tectonic plates—including the Pacific, Juan de Fuca, Cocos, Indian-Australian, Nazca, North American, and Philippine Plates.

Pair-wise Comparison Matrix. A Pairwise Comparison Matrix (PCM) is used to compute for relative priorities of criteria or alternatives and are integral components of widely applied decision-making tools: The Analytic Hierarchy Process (AHP) and its generalized form, the Analytic Network Process (ANP).

Vulnerability. Vulnerability is a measure of the extent to which a community, structure, service or geographical area is likely to be damaged or disrupted, on account of its nature or location, by the impact of a particular disaster hazard.

II. METHOLOGY

This chapter discusses the research design that are used in conducting this study. It presents the research design, locale of the study, instrument that are used, validation of instrument, data gathering procedure, and analysis and techniques of data.

A. Research Design

This study adopted an archival study and secondary data analysis research technique with a correlational research design. A correlational research design investigates relationships between variables without the researchers controlling or manipulating them (Bhandari, 2021). Furthermore, a correlational research is used to test the degree of connection between variables; variables that are not manipulated by the researchers. It is used to accurately compare identified factors to landslide occurrences. A correlational research design was considered appropriate for the topic under landslide susceptibility mapping, since this study determine the influences of various factors in landslide occurrences and subsequently developed a vulnerability map using a GIS (Geographic Information System) and AHP (Analytic Hierarchy Process).

LexisNexis (n.d.) defines archival research as 'the search for and extraction of information and evidence from sources. Archives are historical papers, records, and other materials about the activities and claims of persons, entities, or both. They exist to both conserves historically significant material and make it accessible for future use'. On the other hand, following Donnella, M., and Lucas, R. (2013), secondary data analysis is the evaluation of previously obtained data by others. Secondary data analysis allows academics to study research problems utilizing large-scale data sets, which are often inclusive of under-represented groups while conserving time and money. Archival research and secondary data analysis have immense potential as a tool for researchers because they offer relevant, updated, and credible data most economically and conveniently.

III. LOCALE OF THE STUDY

Pantabangan is located in Central Luzon, particularly in the northern part of the province of Nueva Ecija, with geographic coordinates of 15°48'41" N and 121°08'36" E. Pantabangan has a total land area of 39,256 hectares covering a total of 14 barangays (Figure 3-1), namely Cadaclan, Cambitala, Conversion, Fatima, Ganduz, Liberty, Malbang, Marikit, Napon-Napon, Poblacion East, Poblacion West, Sampaloc, San Juan, and Villarica. The elevation ranges from 103 to 552 meters above sea level.

Pantabangan is a locality neighboring the town of Rizal, near the epicenter of the 1990 Luzon Earthquake. Moreover, from a geological standpoint, Pantabangan is mountainous and close to fault lines which pose landslides.

Fatima (Figure 3-2) is a barangay in the municipality of Pantabangan, Nueva Ecija province. It has an area of 4,205 hectares. It is commonly known as "Kalayaan" and "Campsite". The population was 1,192 according to the 2020 Census. This accounted for 3.75% of Pantabangan's total population. Fatima is located on the island of Luzon at roughly 15.8122, 121.0963. At these coordinates, the elevation is calculated to be 295.4 meters (969.1 feet) above mean sea level. Fatima shares a boundary with the barangay(s) listed below:

Pantabangan, Nueva Ecija, San Juan
Nueva Vizcaya, Lukidnon, Dupax Del Sur
Pantabangan, Nueva Ecija, Conversion
Pantabangan, Malbang, Nueva Ecija
Pantabangan, Nueva Ecija, Poblacion West
Pantabangan, Nueva Ecija, Poblacion East

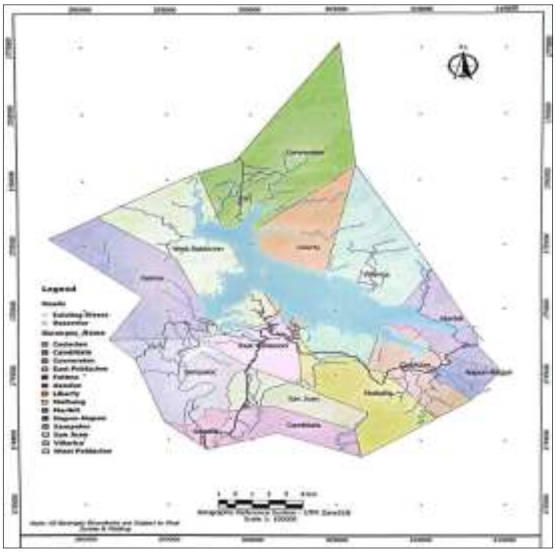

Figure 3-1. Municipality of Pantabangan Map

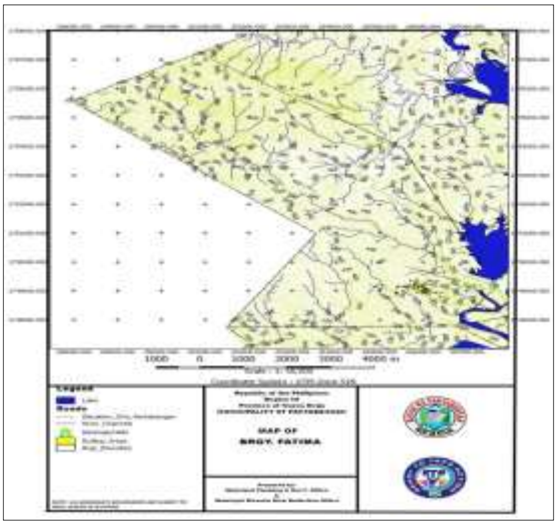

Figure 3-2. Brgy. Fatima Map

IV. RESEARCH INSTRUMENT

In this study, the researchers used maps of different aspects; elevation map, slope map, rainfall map, soil map, land cover map, road map, and fault map. Those data are gathered in the LGU (Local Government Unit) of Pantabangan, Nueva Ecija and credible online sources, and was analyzed through GIS (Geographic Information System) and AHP (Analytic Hierarchy Process) to obtain desired result.

In accordance with Passage Technology (n.d.), the Analytic Hierarchy Process (AHP) is a mathematics and psychology-based system for organizing and evaluating complicated choices. It was created in the 1970s by Thomas L. Saaty and has been enhanced since then. AHP provides a coherent framework for crucial decisions by quantifying its criteria and alternative possibilities and linking those components to the ultimate purpose.

A Geographic Information System (GIS), according to the National Geographic Society (2022), is a computer system that captures, saves, verifies, and displays data about places on the Earth's surface. By linking disparate data, GIS may help individuals and organizations better understand geographical patterns and relationships. This is useful for geologists, for example, when evaluating earthquake faults. GIS technology makes updating maps far easier than conventional mapping.

V. Data Gathering

The data collection technique requires second-hand data from the government and online sources. The researchers created a request letter for documents from the LGU of Pantabangan, Nueva Ecija, that was addressed to the Municipal Mayor, Hon. Roberto T. Agdipa. Upon authorization, the information and data were provided by the LGU and Municipal Disaster Risk Reduction Management Office. Furthermore, other necessary maps were retrieved from ArcGIS. The data gathered is subsequently compiled and analyzed.

VI. Data Analysis and Technique

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favor one over the other
5	Much more important	Experience and judgement strongly favor one over the other
7	Very much more important	Experience and judgement very strongly favor one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity.
2, 4, 6, 8	Intermediate values	When compromise is needed

The maps that are collected were interpreted to fulfill this study. Various factors influence the slope's stability. In this study, only the biophysical characteristics of the area were considered. These factors were elevation, slope, rainfall, soil type, land cover, and proximity to roads and fault lines (Fig. 4 to 10). Seven factors are the maximum to evaluate to obtain a valid and accurate result corresponding to Ozdemir (2005). A scale of 1 to 5 is used to determine the level of vulnerability for each factor, with one (1) being the least vulnerable and five (5) being the most vulnerable.

The elevations were classified using 200-m intervals. The slope was categorized as level to nearly level, gently sloping to undulating, undulating to rolling, rolling to moderately steep, and steep. The rainfall distribution of the whole Barangay Fatima is approximately 123.87 mm/year (ArcGIS). The soil map of Fatima was classified depending on surface soil texture; Annam clay loam. The land cover map was categorized into grassland/brush/shrubs, open barren/annual crop, open forest,

built up, and inland water. For fault lines and road networks, proximity analysis was used.

In data analysis, Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) were utilized. These tools have been used by Dolores, J., et al. (2020) in their study “Species-site Suitability Assessment of Native Species in Pantabangan-Carranglan Watershed Using Geographic Information System (GIS) and Analytic Hierarchy Process (AHP)” and by Arizapa, J., et al. (2015) in their study “Landslide Susceptibility Mapping of Pagsanjan– Lumban Watershed using GIS and Analytical Hierarchy Process” which uses the pair-wise comparison matrix that was accomplished through experts’ interview and has a result showing that slope and elevation have the highest and lowest influences to the occurrence of landslide, accordingly.

AHP is a semi-quantitative method that entails a comparison of selected variables to a pair of specific phenomena or incidents. In this instance, it was used in simulating a landslide's vulnerability of a municipality. AHP allocates values to the variables in the model based on their degree of effect on the occurrence of a landslide. This value assignment is often performed by several specialists.

AHP also employs a pair-wise comparison matrix that includes the comparison of one element to another element. The matrix was utilized to eliminate decision-making biases. This matrix's factors are being compared based on their respective significance or effect on landslides. The Saaty Rating Scale was used as a reference when comparing the various factors; as an input value in the matrix. It means that factors given higher value have a higher level of importance or influence on the occurrence of landslides.

Saaty (1980) suggested using a nine-point scale for evaluating the comparative significance or 'intensity' of each pair of criteria, with a '1' indicating equal importance between two criteria and a '9' indicating absolute importance of one criterion over another. The relative relevance scale and definitions for each intensity value are shown in Table VI-1.

Table VI-1. The Saaty Rating Scale

In this study, in conformance with Arizapa, J., et al. (2015), the pair-wise comparison matrix was achieved through interviews with experts. Experts are purposely chosen based on their experience, knowledge, and skills in hazard mapping on landslides. It is crucial to interview experts from various fields to obtain diversified opinions and perspectives.

For this study, six (6) experts were interviewed and consulted. However, only four (4) of them were ultimately chosen since the other two matrices went beyond the maximum consistency ratio value of 0.1. One municipal engineer, two MDRRMO-OICs, and one Assistant MDRRMO-OIC are among the remaining four experts consulted for this study.

After the matrix is completed, the data are analyzed and crucial variables are calculated. These variables are Eigenvectors and Consistency Ratio. Saaty's (1980) definition of Eigenvector relates to the relative weight, significance, or worth of the criteria, whereas the Consistency Ratio assesses the uniformity of the judgments made.

AHP's matrix has the following format: m x m matrix, where m is the number of variables scrutinized. Each value in the matrix, a_{jk}, shows the relevance of the j^{th} criterion relative to the k^{th} criterion, where j is the row factor and k is the column factor. The first step in manually computing the Eigenvector (E) and Consistency Ratio (CR) is to compute the nth root (X) of the product values by multiplying the entries in each row of the matrix together (eq. 1).

Equation 1: nth root of the product values

X of A = $\sqrt[n]{(a_{jk1})\,(a_{jk2})\ldots(a_{jkn})}$

where: X = nth root of the product value

A = factor of A

a_{jk} = values in the row of factor A

The sum of the X of A: X of n was determined and then utilized as the divisor for all the X obtained to normalize the eigenvector of factors. The eigenvector factor for each row is the result. The greater the eigenvector value, the greater the relative relevance or worth.

To measure the Consistency Index (CI), first solve the maximum vector (λ_{max}) using eq. 2 with the assumption that vector $A\omega = \lambda\omega$.

Equation 2: Maximum Vector (λ_{max})

$$\lambda\omega \text{ of } A = (a_{jk1} * E_A) + (a_{jk2} * E_B) + \ldots + (a_{jkn} * E_n)$$

where: ω = eigenvector of order n

λ = eigenvalue of matrix A

a_{jk} = values in the row of factor A

The equation simply states that the value entry a_{jk} is multiplied by the eigenvector of Factor A, and so on. There is a variation for Factor B and the remaining factors: where the first entry input jk for all remaining factors was multiplied to the eigenvector of Factor A and the rest remained the same: b_{jk1} was multiplied to the eigenvector of Factor A, and c_{jk1} was multiplied to E of A.

Based upon the AHP concept, $A\omega = \lambda_{max}\omega$. Therefore, to obtain an approximation of λ_{max}, divide each element of $\lambda\omega$ by the appropriate eigenvector. The average of these values is further calculated to get an approximation of λ_{max}. The estimate of $\lambda_{max}\omega$ should not be smaller than n, or else the computation will fail. The following step would be to compute the Consistency Index (eq. 3).

Equation 3. Consistency Index

$$CI = \frac{(\lambda_{max}\omega - n)}{(n-1)}$$

where: CI = Consistency Index

$\lambda_{max}\omega$ = eigenvalue of order n

n = number of criteria being compared

The last process is to compute the Consistency Ratio, which will indicate the consistency of the experts' assessment. Higher value indicates that expert has been less consistent, whereas lower number indicates that expert has been more consistent. CR greater than 0.1 is generally rejected since it indicates that there are some discrepancies in the assessments. However, judgments with CR > 0.1 are permitted in some instances - this implies that the judgments include minor inconsistencies - as long as they do not approach CR > 0.9 - which implies that the outcome has become random. The CR was calculated by dividing the calculated CI by the Random Index (RI) value in the table of inconsistencies for random judgments (eq. 4).

Equation 4. Consistency Ratio

$$CR = \frac{CI}{RI}$$

where: CR = Consistency Ratio

CI = Consistency Index

RI = Random Index

The eigenvector and CR are computed in the study using an excel template; rather than hand computation, which might lead to inaccuracies. The weights of the factors are compared to each other by choosing which factor had greater importance than the other; subsequently, the importance is compared to the Saaty Rating Scale.

AHP is utilized in this study to create Barangay Fatima landslide vulnerability map. Elevation, slope, rainfall, soil texture, land cover, distance to roadways, and distance to fault lines were all considered. AHP is used to assign relative importance to these variables. The relative weights are based on experts' assessment to establish the amounts of the effect of each factor using eigenvector computing. This refers to the relative weight of the effect of each element and is then used to calculate the landslide vulnerability index (LVI). Each parameter in the process is rendered into a map, and the LVI of the entire area is generated using GIS and a weighted overlay method. As indicated in eq. 5, the LVI of each pixel is calculated by adding the product of the class weights (P) and factor weights (W)

Equation 5. Landslide Vulnerability Index

$$LVI = \sum_{i=1}^{n} (Wi * Pi)$$

where: LVI = Landslide Vulnerability Index

Wi = factor weight

Pi = class weight

n = number of criteria being compared

Following the computation of the LVI, the spectrum is classified into five groups employing the Natural Breaks (Jenks) classification technique. This categorization approach is employed since it is based on inherent data and establishes limits based on large changes in data values (ArcGIS,n.d.).

Upon classifying and giving weight to each criterion, the maps gathered are rasterized. Then the data is organized and classified before processing to generate the Landslide Vulnerability Map of Barangay Fatima, Pantabangan, Nueva Ecija. through ArcMap.

Esri's ArcMap (also known as ArcGIS Desktop) is GIS software. ArcMap, as defined by Cornell University Library, is a full-fledged desktop GIS. It receives and produces a wide range of geographic data types, has a comprehensive set of processing and analytical capabilities, and may be used to generate detailed maps.

ArcGIS Desktop is a GIS software package that allows users to develop, analyze, manage, and distribute geographic data to ensure decision-makers may make rational choices. It allows users to develop maps, do geographical analysis, and organize data. For integrating maps, ArcGIS provides unique and flexible features.

The researchers used the Weighted Overlay feature of the ArcMap and typed in all the information gathered and needed to finish the process and create the landslide vulnerability map.

VII. PRESENTATION, ANALYSIS AND INTERPRETATION OF DATA

This chapter deals with the presentation and interpretation of maps and data that were gathered by the researchers through an interview with professionals and experts.

The researchers identified seven biophysical criteria that have influence on landslide occurrences; elevation, slope, rainfall, soil classification, land cover, proximity to road, and proximity to fault line. Subsequently, the researchers collected maps of aforementioned criteria. The maps have different colors which signifies their characteristics that are discussed below.

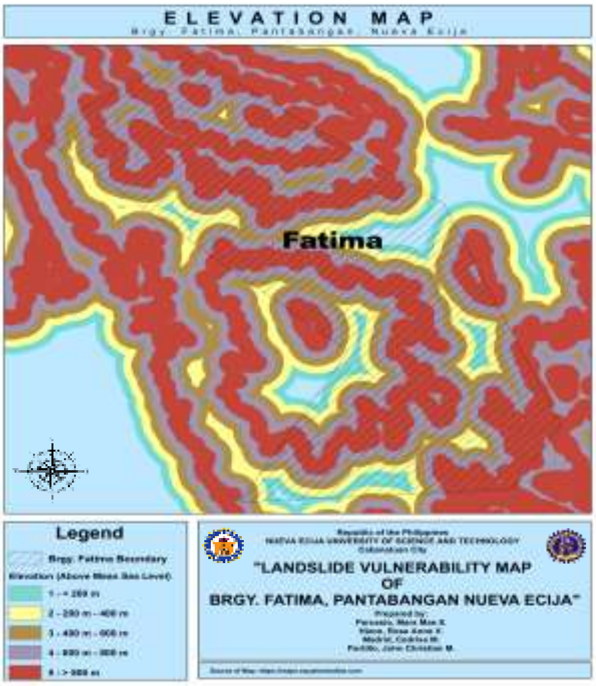

Figure 7-1. Elevation Map of Brgy. Fatima Pantabangan

Figure 7-1 demonstrates the elevation map of barangay Fatima. The elevation is classified using 200-meter intervals above mean sea level. The area that has <200m elevation is presented as blue, yellow means the area has 200m-400m elevation, brown means 400m-600m elevation, purple indicates 600m-800m elevation, and >800 is shown in color red. The map revealed that a large area has high elevation.

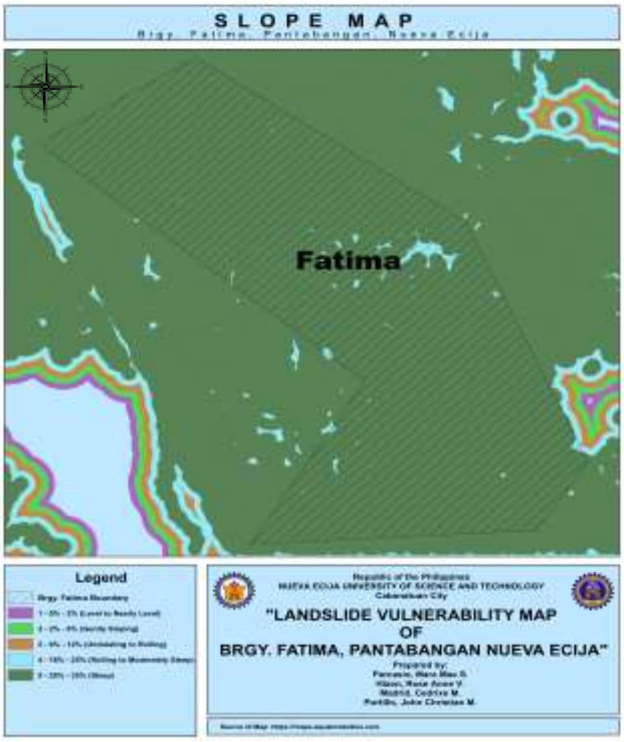

Figure 7-2. Slope Map of Barangay Fatima, Pantabangan

The slope map of Barangay Fatima is shown in Figure 7-2. The slope was classified as level to nearly level, gently sloping to undulating, undulating to rolling, rolling to moderately steep, and steep. It is evident that a steep slope is present in the barangay. Large area is color green which signifies 25% to 35% of slope and is classified as steep. Moreover, there are few regions that are colored blue which indicates rolling to moderately steep or that has 18% - 25% of slope.

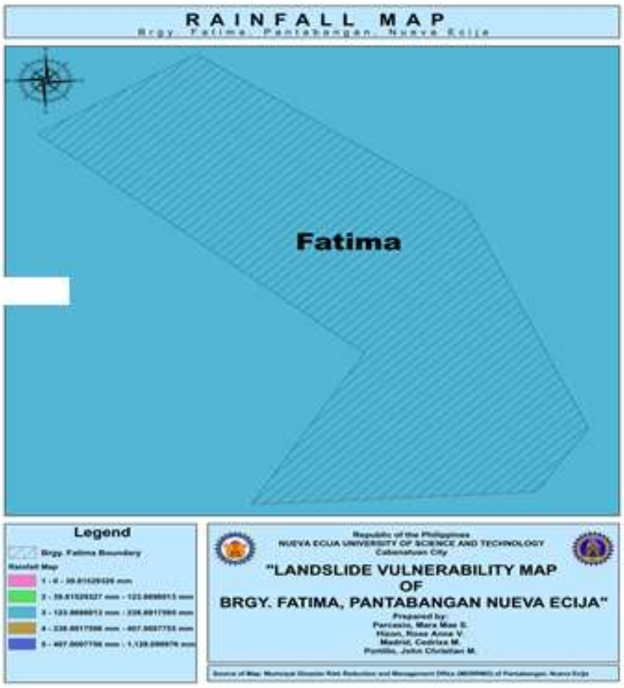

Figure 7-3. Rainfall Map of Barangay Fatima, Pantabangan

Fig. 7-3 displays the rainfall map of Barangay Fatima. The whole barangay is colored blue which signifies that there are an average of 123.87 millimeters to 238.89 millimeters per year or 4.88 inches to 9.41 inches per year of rainfall distribution in the entire area.

Soil texture is presented in Fig. 7-4. Soil texture is also regarded as soil classification and soil type. There is only one surface soil texture present in Barangay Fatima which is Annam clay loam. Hence, the figure only has red color.

Figure 7-5 shows the land cover map of Barangay Fatima. The land cover map was categorized into grassland/brush/shrubs (green), open barren/annual crop (neon green), open forest (red), built up (gray), and inland water (blue). The map shows that a large area of the barangay has either grassland, brush, or shrubs. In addition, the upper portion of the barangay has open forest.

Consecutively, Figure 7-6 below shows the Road Proximity Map of Barangay Fatima. On the road, proximity analysis is used. It has a 50-meters interval. Barangay Fatima only has a barangay road. The color indicates the distance of an area to the road; green symbolizes >200 meters vicinity to the road and royal blue denotes <50 meters vicinity.

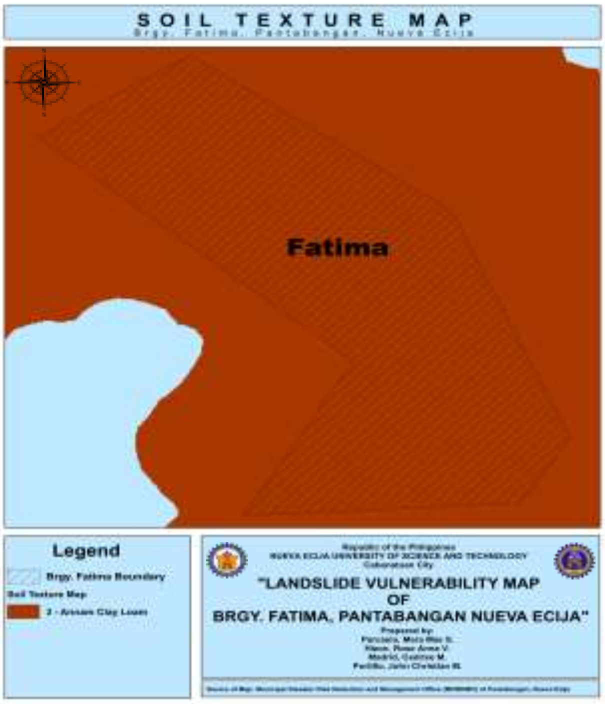

Figure 7-4. Soil Type Map of Barangay Fatima, Pantabangan

The seventh factor is presented in Figure 7-7. The Proximity to Fault Line Map also used proximity analysis. As mentioned above, the municipality of Pantabangan is located near a fault line. The map revealed that Barangay Fatima is in close proximity to Digdig fault and to an unknown fault. In the analysis, it has 2000 meters or 2 kilometers interval. The

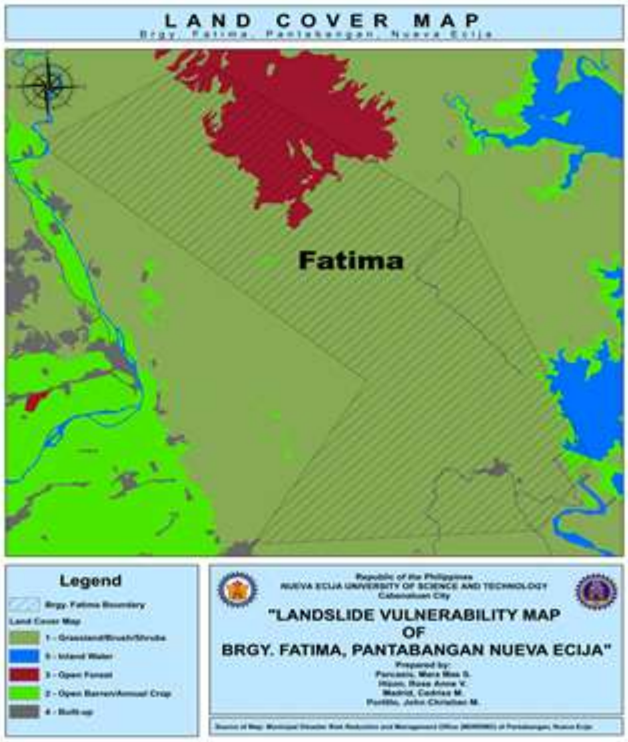

Figure 7-5. Land Cover Map of Barangay Fatima, Pantabangan

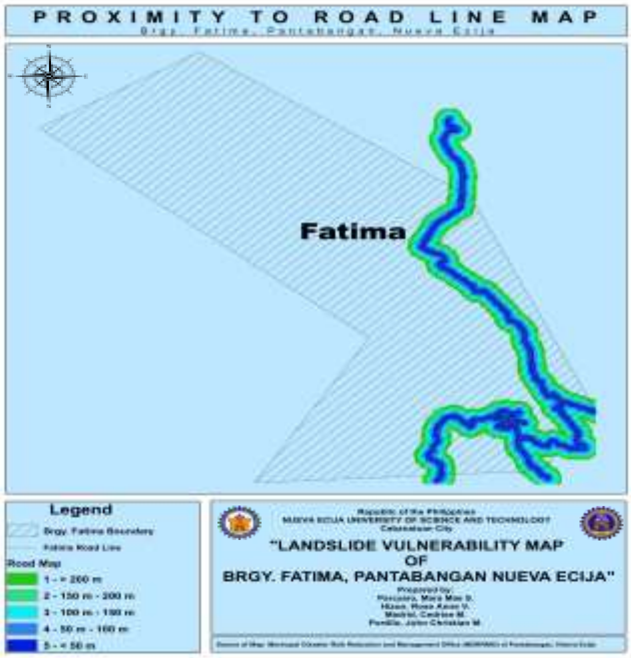

Figure 7-6. Proximity to Road Map of Barangay Fatima, Pantabangan

color red implies the distance of the area from the fault lines; the lighter the color, the farther it is from the fault.

These seven maps retrieved from MDDRMO-Pantabangan and ArcGIS are then ranked by the experts that are purposely chosen based on their knowledge, expertise, and skills.

The eigenvectors rendered by the experts engaged are evaluated for consistency to obtain credible and acceptable findings. The computed consistency ratio of the combined experts' judgment is 0.038, which is less than the Saaty threshold. Conforming to Saaty (1980), a consistent judgment should not exceed a consistency ration (CR) of 0.1. Furthermore, the integrated CR number is acceptable and all of the experts have relevant CR. Expert 1 has a CR value of 0.08, Expert 2 has a value of 0.09, Expert 3 has a value of 0.1, and Expert 4 has a value of 0.09. Hence, the results are guaranteed to be reliable and consistent.

The relative weights assigned to each landslide element in the use of AHP are established by expert judgment. As determined by the experts, the rainfall had the largest eigenvector (32.66%), followed by slope (20.80%), soil texture (15.96%), proximity to fault line (14.02%), land cover (8.27%), and proximity to road (4.63%), with the elevation factor displaying the lowest value (3.66%). These results are shown in Table VII-1.

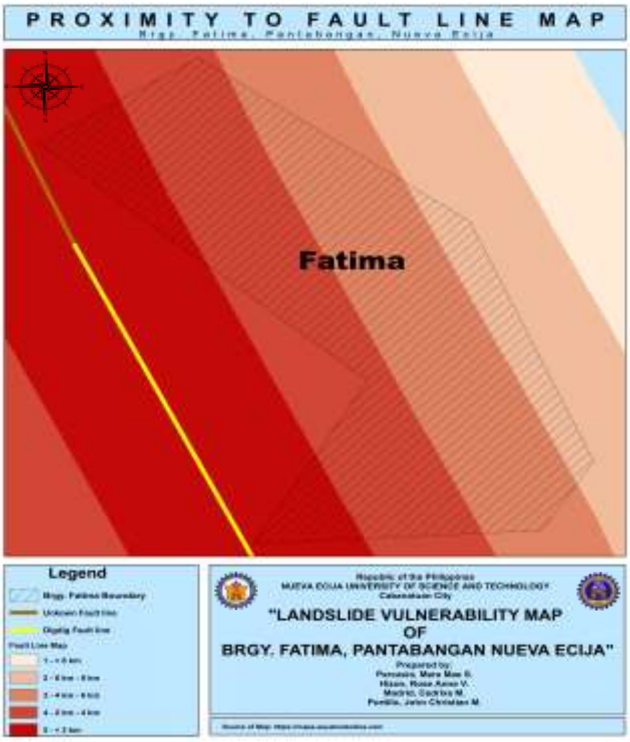

Figure 7-7. Proximity to Fault Line Map of Barangay Fatima, Pantabangan

Table VII-1. Consolidated results of Experts Judgments and Normalized Eigenvector

FACTORS	A	B	C	D	E	F	G	normalized principal Eigenvector
(a) Elevation	1	1/6	1/7	1/5	1/4	2/7	1 1/3	3.66 %
(b) Slope	6 2/7	1	5/9	2 1/7	1 5/7	1 5/7	3 4/5	20.80 %
(c) Rainfall	7 4/9	1 7/9	1	2 3/7	4 2/9	3 1/6	5 1/9	32.66 %
(d) Soil Texture	4 7/9	4/9	2/5	1	3 5/8	1 1/6	2 8/9	15.96 %
(e) Land Cover	3 7/8	3/5	1/4	2/7	1	5/9	1 1/3	8.27 %
(f) Fault	3 5/8	3/5	1/3	6/7	1 7/8	1	5	14.02 %
(g) Road	3/4	1/4	1/5	1/3	3/4	1/5	1	4.63 %
TOTAL								**100 %**

Figure 7-8 shows the vertical bar graph of consolidated results of experts’ judgments. It represents the findings in this study. Rainfall received the highest eigenvector because the experts consulted assigned a large value to it. The data obtained demonstrated that both rainfall and slope are more important than the other factors. Furthermore, Dr. Deanna Conners (2019) explained that landslides are especially dangerous in areas with high slopes, such as mountainous areas. The majority of landslides are triggered by a combination of variables that work together to weaken the slope. Water could result in landslides and mudslides through fluctuations in the pressure within the slope, causing slope instability. As a result, the heavy water-laden slope elements will succumb to gravity pulls. Rainfall is regarded to be one of the most prevalent causes of landslides. Landslides are frequently triggered by excessive rain. Meanwhile, elevation was given the lowest relative weight. The result suggests that this variable has the slightest effect on the likelihood of landslides. Nonetheless, this should be considered as significant as the other factors, particularly in AHP, because it employs a pair-wise comparison matrix that treats components as connected to each other rather than separately.

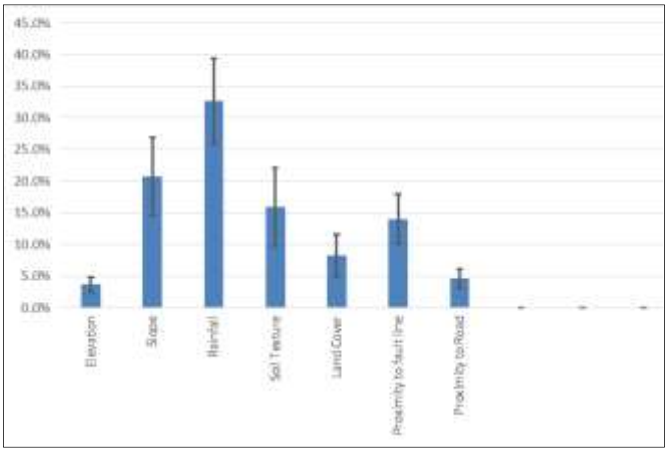

Figure 7-8. Consolidated Results of Experts Judgments and Normalized Eigenvectors.

ArcMap analyzed and processed all the information. Figure 7-9 shows the end result and the final output of this study.

The map has different colors, representing vulnerability ratings. Green symbolizes low vulnerable areas, yellow is moderately vulnerable areas, and orange signifies highly vulnerable areas.

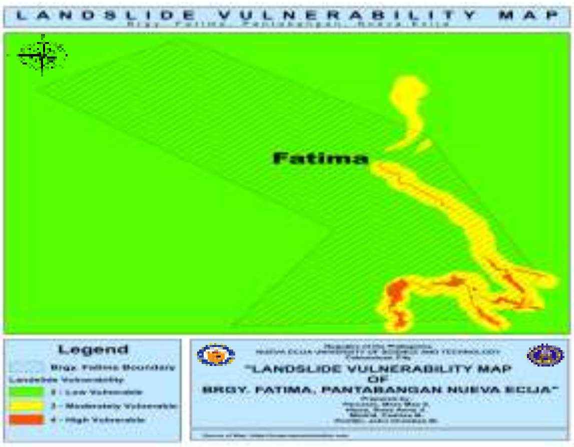

Figure 7-9. Landslide Vulnerability Map of Barangay Fatima,

The final map is comparatively similar to the road map conveying that howbeit it has only 4.63% influence to landslide occurrence, a lot lower than other five factors, the area within road line also has steep slope and high elevation. Since there is steep slope and high elevation in that part of the barangay, it is considered prone to landslide.

Figure 7-9 shows that a large area of the barangay has low landslide vulnerability. This is similar to the findings of Mines and Geosciences Bureau-Region III in 2004. Nevertheless, updating hazard maps such as landslide maps is still essential to monitor the area and the occurrences of natural phenomena that are unforeseeable and inevitable.

VIII. SUMMARY, CONCLUSION, RECOMMENDA -TION

This chapter presented the summary of findings, conclusion and recommendation based on the data presented analysed and interpreted form the previous papers.

A. Summary of findings

According to the calculated relative weights from AHP, rainfall had the greatest influence on the probability of landslides in this research with the value of 32.66% while slope being second with a value of 20.8%. On the contrary, elevation had the lowest calculated eigenvector with the value of 3.66%, indicating minimal impact on landslide incidence. It also demonstrated that the number of criteria used in the pair-wise comparison has impact on the consistency of the results.

Professionals from various areas of interest generated a wide range of assessments, which led to a low consensus percentage. However, the aggregated verdict remained within Saaty's acceptable consistency ratio standard.

B. Conclusion

The goal of this study was to create a landslide vulnerability map for Barangay Fatima in Pantabangan, Nueva Ecija, and to examine the variables that influence the incidence of landslides from most influential to least significant. Based on the findings, rainfall and elevation contributed the most and least to the occurrence of landslides, respectively. This suggests that areas having higher rainfall distribution per year are generally more prone to landslide.

The map shows that a large portion of Barangay Fatima is low landslide vulnerable. Hence, it is similar to the study of MGB-R3 that Barangay Fatima is a low landslide susceptible area. Concurrently, areas that are moderate to highly vulnerable tend to follow the road track. This is because other factors have a uniform class for the entire barangay.

IX. RECOMMENDATION

The accessibility of good data sets for the research locale is one of the prerequisites for producing reliable findings from modelling. As a result, appropriate characterization of the barangay, particularly its biophysical profile, must be done and fully carried out. To get more trustworthy findings, the usage of updated thematic maps in conjunction with updated geographic data sets should be strongly explored.

The application of AHP in assessing landslide risk demonstrated the tool's potential for incorporating expert experience and expertise into the model. Nevertheless, in future research, the number of experts should be raised so that there are more options if some of the judgments appear to be inconsistent.

The future researchers are also encouraged to study a wider area to have a variety of classifications and to generate exact results.

Furthermore, it is strongly advised that monitoring of landslide occurrences in the area be created so that future research can confirm the model's conclusions. Similarly, it is advised that the area's profile in biophysical and socioeconomic elements be updated. Some of the thematic layers appear to be out of date.

Aside from developing a landslide vulnerability map, it is also advised that additional susceptibility maps such as flood, soil erosion, and fire be developed in order to build a barangay multi-hazard map. This is critical in order to reduce the risk and harm that these environmental risks might cause.

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REFERENCES

1. Anderson, J.C. (1983) Philippine Brackishwater Aquaculture Training Project. ICLARM.https://www.fao.org/3/ac061e/AC061E16.htm
2. ArcGIS Pro. (n.d.). Data classification methods. https://pro.arcgis.com/en/pro-app/latest/help/mapping/layer-properties/data-classification-methods.htm
3. Arizapa, J., Combalicer, E, & Tiburan, C. (2015, October). Landslide Susceptibility Mapping of Pagsanjan–Lumban Watershed using GIS and Analytical Hierarchy Process. *Ecosystems & Development Journal* 5(3), 23–32. Retrieved from file:///C:/Users/ASUS/Downloads/216-Article%20Text-624-1-10-20200122.pdf
4. Bhandari, P. (2021, July 7). Correlational Research | When & How to Use. Scribbr. https://www.scribbr.com/methodology/correlational-research/
5. Conners, D. (2019, April 10). "What causes landslides and mudslides?". EarthSky. https://earthsky.org/humanworld/what-causes-landslides/.
6. Cornell University Library. (2023, April). GIS: Geographic Information System: ArcMap.https://guides.library.cornell.edu/gis/arcmap
7. Dolores, J., Galang, M., & Dida, J. (2020, September). Species-site Suitability Assessment of Native Species in Pantabangan-Carranglan Watershed Using Geographic InformationSystem (GIS) and Analytic Hierarchy Process (AHP). *Philippine Journal of Science, 149*(3), 529-537. Retrieved from
8. Donnellan, M., Lucas, R. (2013, October 1). Secondary Data Analysis. Oxford Academic. Oxford University Press. https://academic.oup.com
9. GeoHazard Assessment Map. (2016). https://region3.mgb.gov.ph/mgb_roIII_files/pdf/
10. Goepel, Klaus D. (2013). Implementing the Analytic Hierarchy Process as a Standard Method for Multi-Criteria Decision Making In Corporate Enterprises – A New AHP Excel Template with Multiple Inputs, *Proceedings of the International Symposium on the Analytic Hierarchy Process, Kuala Lumpur 2013.*
    DOI: https://doi.org/10.13033/isahp.y2013.047
11. Glossary of Statistical Terms. (2001, September 25). *Glossary of Environment Statistics, Studies in Methods, Series F, No. 67, United Nations, New York, 1997.* https://stats.oecd.org/glossary/detail.asp
12. Government of Canada. (2015, November 20). https://www.nrcan.gc.ca/maps-tools-and-publications/satellite-imagery-and-air-photos/tutorial-fundamentals-remote-

sensing/educational-resources-applications/land-cover-biomass-mapping/landcover-land-use/9373

13. HazardHunterPH. (n.d.). https://hazardhunter.georisk.gov.ph/map#
14. Jalao, E., Shunk, D., & Wu, T. (2013). A pairwise comparison matrix framework for large-scale decision making. *Arizona State University Bureau of Publications Tempe, AZ United States.*https://dl.acm.org/doi/book/10.5555/2519688.
15. LexisNexis. (n.d.). What is Archival Research? https://internationalsales.lexisnexis.com/glossary/research/archival-research
16. NASA Earth Observatory. (n.d). *Landslide in the Philippines.* https://earthobservatory.nasa.gov/images/16144/landslide-in-the-philippines
17. National Geographic Society. (2022, September 27). *GIS (Geographic Information System)*. National Geographic Resource Library. https://education.nationalgeographic.org/resource/geographic-information-system-gis
18. National Geographic Society. (2022, May 20). *Ring of Fire.* National Geographic Resource Library.https://education.nationalgeographicorg/resource/ring-fire
19. National Geographic Society. (2022, July 15). *Landslide*. https://education.nationalgeographic.org/resource/landslide
20. OECD Glossary of Statistical Terms. (2001, September 25). https://stats.oecd.org/glossary/detail.
21. Pantabangan Municipal Planning & Development Office. (n.d.). Administrative Map.
22. Pantabangan Municipal Planning & Development Office. (n.d.). Climatic Map.
23. Pantabangan Municipal Planning & Development Office. (n.d.). Elevation Map.
24. Pantabangan Municipal Planning & Development Office. (2010). Land Cover Map.
25. Pantabangan Municipal Planning & Development Office. (n.d.). Pantabangan Road Map.
26. Pantabangan Municipal Planning & Development Office. (n.d.). Slope Map.
27. Pantabangan Municipal Planning & Development Office. (n.d.). Soil Map.
28. Passage Technology. (n.d.). https://www.passagetechnology.com/what-is-the-analytic-hierarchy-process.
29. PhilAtlas. (n.d.). https://www.philatlas.com/luzon/r03/nueva-ecija/pantabangan.html
30. PHILVOLCS. (n.d). *Landslide Preparedness.* https://www.phivolcs.dost.gov.ph/index.php/landslide/landslide-prepareness
31. PHILVOLCS. (n.d) *Introduction to Landslide.* https://www.phivolcs.dost.gov.ph/index.php/landslide/introduction-to-landslide
32. PRB. (2006, March 1). *In the News: The Philippines Mudslides*. https://www.prb.org/resources/in-the-news-the-philippines-mudslide/
33. The International Information Center for Geotechnical Engineers. (n.d.). Geoengineer.org. https://www.geoengineer.org/education/slope-stability.
34. University of Tartu. (n.d.). *Digital Image Processing*. https://sisu.ut.ee/imageprocessing/book/1
35. *What is Biophysical Attributes.* (n.d.). IGI Global. https://www.igi-global.com/dictionary/biophysical-attributes.
36. World topographic map. (n.d.). Pantabangan topographic map. https://en-nz.topographic-map.com