Assessment of Multi-Hazard Risk Using Geomatics Approach: A Case in Agusan del Norte Province, Philippines

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Abstract: *This study introduces a geomatics-based approach for multi-hazard assessment in Agusan del Norte, Philippines, aiming to enhance disaster preparedness and land use planning. By integrating GIS, remote sensing, and the Analytic Hierarchy Process (AHP), a spatial hazard model was developed. The methodology analyzed seven key factors: earthquake-induced landslide, proximity to faultlines, flood, rain-induced landslide, sea-level rise, storm surge, and liquefaction, weighted using AHP based on expert input. This generated weighted overlay maps delineating none, low, moderate, and high hazard zones. The AHP-based approach proved superior in identifying high-risk areas, particularly in coastal, riverine, and mountainous zones. Findings show approximately 1,822.61 sq. km as low hazard, 618.35 sq. km as moderate, and 225.89 sq. km as high hazard. This geomatics-driven method is a vital tool for local government units and disaster management agencies, supporting the visualization and prioritization of hazard-prone areas for improved climate resilience and disaster risk governance.*

Keywords: Multi-Hazard Mapping, Geomatics, Analytic Hierarchy Process (AHP), Disaster Risk Reduction

1. INTRODUCTION

Agusan del Norte, situated in the Caraga region in the eastern Philippines, is highly susceptible to a variety of natural hazards, including floods, earthquakes, cyclones, and landslides [1]. The province experiences a tropical climate with heavy rainfall, which often results in flooding, especially in low-lying areas. Flooding can lead to infrastructure damage, crop losses, destruction of properties, and displacement of people [2].

The study site is also located near the proximity of the Pacific Ring of Fire, a seismically active zone, which means that there is a high risk of earthquakes in the region. Earthquakes can cause structural damage to buildings and infrastructure and can also trigger landslides and tsunamis [3]. With its mountainous and steep slopes, the region is particularly prone to landslides, especially during heavy rains. Landslides can block roads and cause significant damage to infrastructure and homes [4].

Additionally, it is also located in the path of tropical cyclones, which are also known as typhoons. Typhoons can bring strong winds, heavy rains, and storm surges, resulting in widespread damage to infrastructure and agricultural lands. Typhoons can also exacerbate the risks of flooding and landslides [5].

These natural hazards possess the potential to exert a substantial influence on the process of development planning and the implementation of risk mitigation strategies within the area. The presence of flood hazards poses challenges in the strategic planning of new infrastructure development within regions characterized by low-lying topography. The presence of seismic activity poses challenges in constructing buildings that are both secure and capable of withstanding potential earthquakes. The presence of landslide hazards poses challenges to the development of land in hilly regions. To address the potential risks associated with these hazards, it is crucial to implement appropriate planning and risk mitigation strategies.

A geomatics-based approach to multi-hazard mapping and analysis can be used to help address this challenge. Geomatics is a broad term that encompasses the use of geographic information systems (GIS), remote sensing, and other technologies to collect, analyze, and visualize spatial data. By using geomatics, it is possible to develop a comprehensive understanding of the hazards affecting the province. This information can then be used to develop more resilient urban and rural development plans that account for disaster risks.

Beyond planning, geomatics also plays an important role in disaster risk reduction. For example, GIS can be used to identify areas that are at high risk of flooding and landslides. This information can then be used to build levees or other infrastructure to protect these areas. Remote sensing real-time monitoring of natural hazards, facilitating early warning systems to safeguard residents. The integration of geomatics into multi-hazard modeling is a promising approach for improving urban and rural development planning and risk mitigation in Agusan del Norte. By using geomatics, it is possible to develop more resilient and sustainable communities that are better prepared for the challenges of natural disasters.

2. METHODOLOGY

2.1 Methodological Flow

The methodological framework for this study follows a structured process for developing multi-hazard maps using a geomatics-based approach, as shown in Figure 1. The flowchart illustrates the sequential steps involved, from data acquisition to analysis, ensuring a more detailed analysis of hazards in Agusan del Norte.

The process began with the collection of relevant secondary geospatial datasets. These datasets serve as the foundation for hazard mapping and analysis. Using GIS, the collected datasets were processed to generate spatial data layer maps. The spatial data layers were then converted into raster format to ensure uniformity in analysis. Each layer was reclassified based on hazard susceptibility, assigning values that represent varying levels of risk (e.g., low, moderate, high). A multi-criteria decision-making approach, the Analytical Hierarchy Process (AHP), was employed to determine the relative importance of each hazard factor. The AHP method is a robust and flexible multi-criteria decision-making tool for dealing with complex decision problems [6]. This method divides a complex or complicated system into a hierarchical system of elements, which usually includes purposes, evaluation criteria, and alternatives. AHP is a simple and powerful method for making decisions. It is commonly used for project prioritization and selection. AHP captures all our strategic goals as a set of weighted criteria that we have and then use to score projects. This involves expert judgment and pairwise comparisons to derive weights for each criterion. The weights obtained from the AHP analysis were assigned to the respective hazard layers, ensuring that the influence of each factor is appropriately accounted for in the final hazard assessment. The reclassified raster layers were integrated using a weighted overlay analysis. This process generated composite hazard maps by combining multiple hazard layers based on their relative importance. Two sets of maps were generated: one based on equal influence, where all hazard factors are given the same weight, and another using AHP-derived weights, where hazard factors are weighted based on their relative importance. Finally, the generated multi-hazard maps underwent statistical evaluation to quantify hazard exposure, affected areas, and risk distribution. This analysis provides insights into the extent and severity of hazards in Agusan del Norte, supporting data-driven decision-making for disaster risk reduction and land use planning.

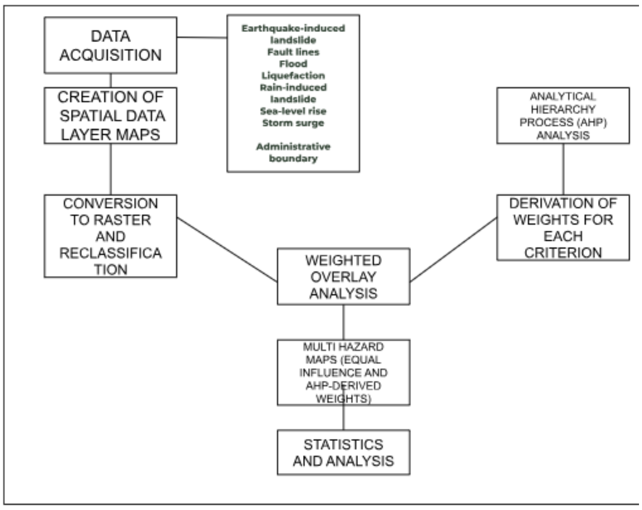

Fig. 1. The methodological flow of the study.

2.2 Study Area

Agusan del Norte is a province located in the northeastern part of Mindanao, Philippines, and is part of the Caraga region (Region XIII) [7]. It shares borders with the provinces of Agusan del Sur to the south, Misamis Oriental to the west, Surigao del Norte to the north, and Surigao del Sur to the east. The province is bounded by Butuan Bay to the northwest, providing access to coastal resources and maritime activities. Butuan City, a highly urbanized city, serves as the regional center of Caraga and a major hub for economic, educational, and administrative functions [8].

The province covers a land area of approximately 2,730.24 square kilometers, consisting of 10 municipalities and one component city (Cabadbaran City). The terrain of Agusan del Norte is characterized by a mix of low-lying floodplains, rolling hills, and mountainous regions, making it susceptible to various natural hazards such as flooding, landslides, earthquakes, and typhoons. The presence of the Agusan River Basin, one of the largest river systems in Mindanao, further contributes to the province's exposure to hydrological hazards.

According to the 2020 Census, Agusan del Norte had a total population of 387,503 people, contributing to the 2,804,788 individuals in the Caraga region. This accounts for approximately 10.68% of Mindanao's total population and 2.57% of the entire Philippine population. The population density of Agusan del Norte is estimated at around 142 people per square kilometer, with urbanized areas such as Butuan City having higher concentrations of inhabitants.

The province experiences a tropical rainforest climate, with significant rainfall throughout the year, particularly during the monsoon season. It is also within the Pacific Ring of Fire, making it vulnerable to seismic activities and associated hazards such as ground shaking, tsunamis, and landslides. The combination of these environmental factors highlights the importance of implementing a geomatics-based multi-hazard mapping approach to support disaster risk reduction, urban planning, and sustainable development in Agusan del Norte.

Figure 2 illustrates the geographical location of Agusan del Norte, showing its boundaries, neighboring provinces, and its position within the Caraga region. The map serves as a reference for spatial analysis and hazard assessment conducted in this study.

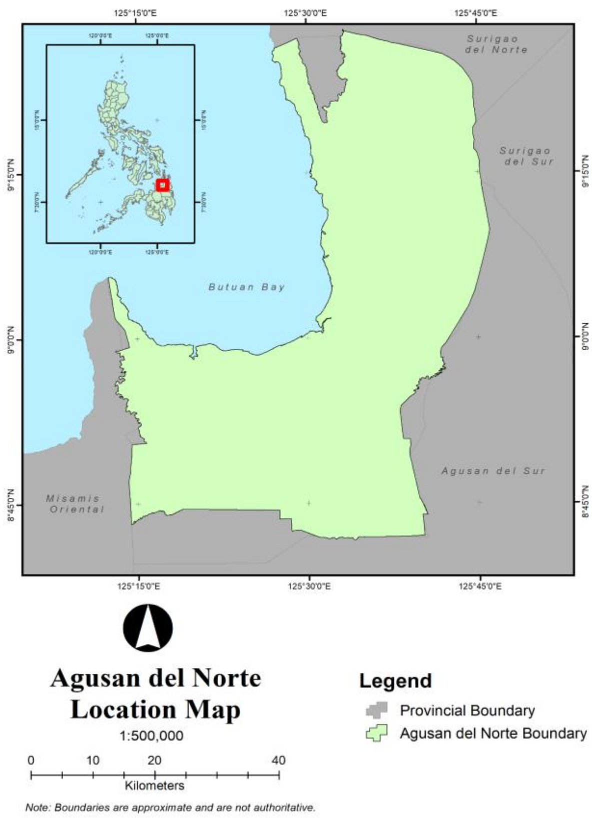

Fig. 2. Province of Agusan del Norte as the Area of Interest of the Study

2.2 Datasets Used

Table 1 shows the type and source of data used in this study. The data for the earthquake-induced landslide, fault lines, flood, liquefaction, rain-induced landslide, sea-level rise, and storm surge hazards were obtained from the Provincial Disaster Risk Reduction Management Office (PDRRMO) - Agusan del Norte. All these data were in the form of vector shapefiles. The administrative boundary data was provided by the Caraga Center for Geo-informatics (CCGeo).

Table 1. Summary list of geospatial datasets acquired and the corresponding descriptions

Data in Hazards	Data Type	Source
Earthquake-induced landslide	Vector data (multi-polygon shapefile)	PDRRMO) - Agusan del Norte
Distance to Fault lines	Vector data (linestring shapefile)	PDRRMO) - Agusan del Norte
Flood	Vector data (multi-polygon shapefile)	PDRRMO) - Agusan del Norte
Soil Liquefaction	Vector data (multi-polygon shapefile)	PDRRMO) - Agusan del Norte
Rain-induced landslide	Vector data (multi-polygon shapefile)	PDRRMO) - Agusan del Norte
Sea-level rise	Vector data (multi-polygon shapefile)	PDRRMO) - Agusan del Norte
Storm surge	Vector data (multi-polygon shapefile)	PDRRMO) - Agusan del Norte
Administrative boundary	Vector data (multi-polygon shapefile)	Caraga Center for Geo-informatics (CCGeo)

2.3 Creation of Spatial Data Layers

The raw maps acquired were processed into separate spatial data layer maps. Since the original maps were in an incompatible format, conversion was required to ensure their usability. These individual spatial data layers were created to facilitate multi-hazard assessment. Subsequently, the spatial data layers were transformed into raster format, which served as input for the Weighted Overlay Analysis.

2.4 Analytical Hierarchy Process (AHP)

For the parameters to undergo pairwise comparison, an AHP form was created and sent to the chosen experts. These experts were selected based on their work and knowledge. Since they are the front line of the emergency response unit during crises, experts from the disaster-related units were selected. Since the research is about earthquakes and seismic activity, experts in geology were chosen. This level of specialization is appropriate for their work.

Following the evaluation, the scores are used to determine the weight assigned to each criterion based on the evaluators' decisions. To evaluate the weight, the nth root is calculated first, as shown below.

$$\text{Nth root}=(X1 * X2*X3...*Xn)1/n \quad \text{(eq.1)}$$

Where:
X = Rating of expert in pairwise comparison
n = Number of Indicator
The Eigenvector, also called the Priority Vector, is used to describe the weight. Equation 2 is used to measure this. The results of this will reflect the weight assigned by the evaluators to each criterion.

$$\text{Eigenvector}=\text{Nth root}(\text{Nth root}) \quad \text{(eq. 2)}$$

The resulting raw weight is not yet final; consistency still needs to be applied. The term "consistency" refers to the Consistency of Ratio. This metric indicates the accuracy of the experts' judgment in making their decisions. This is determined by using the value of the consistency index and the value of the random index. Equation 3 is provided to calculate the Consistency Index or CI.

$$CI = (-n)(n-1) \quad \text{(eq.3)}$$

Where:
CI = Consistency Index
λ = Lambda max; derived from the summation of products between each criteria eigenvector and the sum of each respective column on the matrix
n = Number of Indicator
The Consistency Ratio is then calculated using the Equation 4:

$$CR = CI * RI \quad \text{(eq.4)}$$

Where:
CR = Consistency Ratio
CI = Consistency Index
RI = Random Index

In Pairwise Comparison, the Random Consistency Index (RI), presented in Table 4, is used to calculate the Consistency Ratio. According to Saaty's cut-off consistency indexes is Acceptable (10%), and Tolerable (20%). The required ratio was based on Consistency Prediction for incomplete AHP Matrices, which was published by William C. Wedley, indicating that the decision maker's assessment is reasonably consistent [6]. However, if the ratio exceeds, the assessment should be redone, as this indicates that the evaluation was conducted inconsistently. The table below shows the random cut-off of consistency indexes based on the size of the matrix.

2.5 Raster Conversion and Reclassification

Raster-formatted maps were utilized for the Weighted Overlay Analysis. Initially, all maps were in vector

format, necessitating their conversion to raster. To achieve this, the researcher employed the Feature to Raster tool from the Conversion toolbox in GIS. Each map was converted using a uniform output cell size, ensuring consistency in spatial resolution [6].
Once converted, the raster maps underwent reclassification to facilitate the assignment of new or alternative values. Reclassification involves adjusting cell values based on predefined intervals, groups, or categories. In this study, three hazard levels were applied: no hazard (0), low hazard (1), moderate hazard (2), and high hazard (3)

Table 2. Random and cut-off consistency indexes based on Consistency Prediction for incomplete AHP Matrices [9]

Size of Matrix	4	5	6	**7**
Saaty's Cut-off Consistency Indexes				
Consistency Index (Random)	0.90	1.12	1.24	***1.32***
Acceptable (10%)	0.090	0.112	0.124	***0.152***
Tolerable (20%)	0.180	0.224	0.248	***0.264***

3. RESULTS AND DISCUSSION
3.1 Reclassified Maps
The researcher converted the maps into raster format to serve as inputs for the Weighted Overlay analysis. The reclassified maps play a crucial role in developing the multi-hazard maps. The subsequent pages present the figures for the reclassified maps of earthquake hazards, floods, rain-induced landslides, and climate change-induced hazards.
Figures 3 - 7 show a difference with respect to the original map layer, where high and very high risk areas are now combined, thus resulting in none, low, moderate, and high risk categorization.

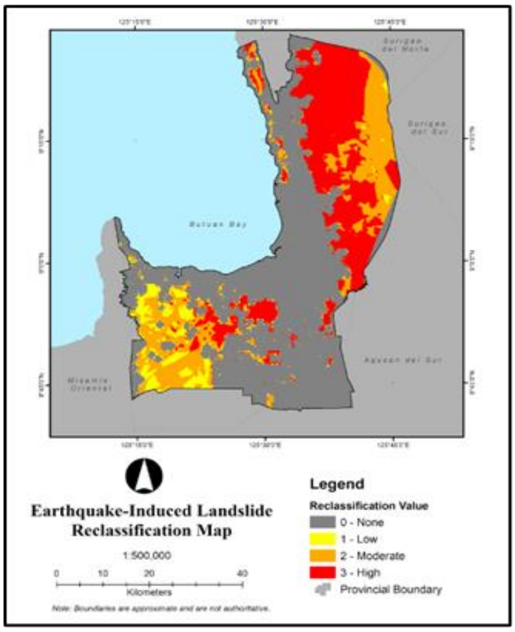

Fig. 3. Reclassified earthquake-induced landslide map of Agusan del Norte

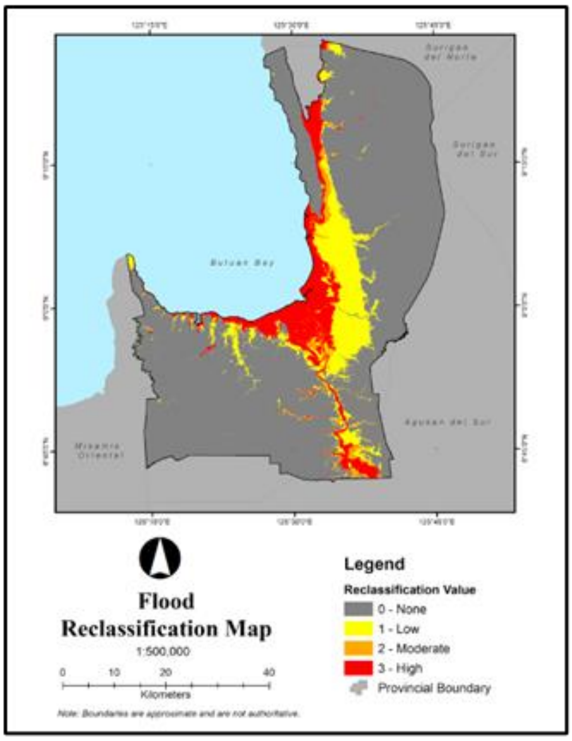

Fig.4. Reclassified flood map of Agusan del Norte

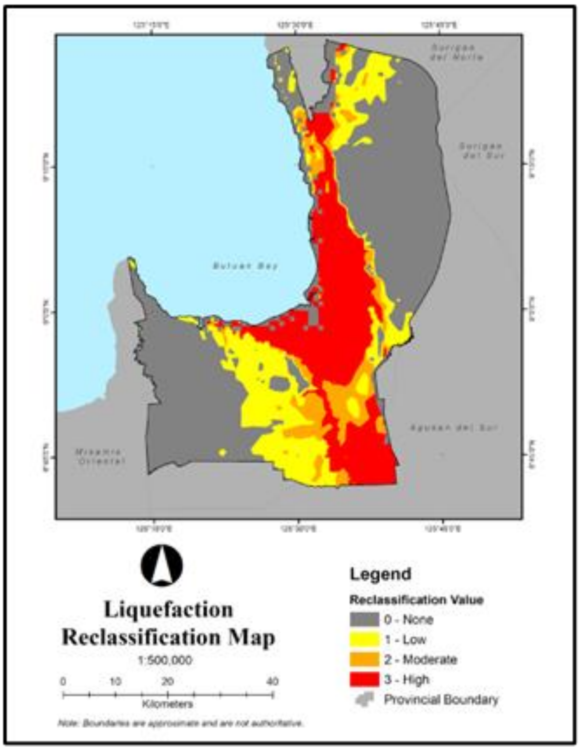

Fig.5. Reclassified liquefaction map of Agusan del Norte

To assess Faultline-related hazards within the study area, a Euclidean distance analysis was performed using the Faultline shapefile as input. This process generated a continuous raster surface wherein each pixel represented the straight-line distance to the nearest active fault segment. The resulting raster contained distance values in meters, with lower values indicating areas in close proximity to fault lines and higher values representing areas farther away. To convert the continuous distance values into discrete hazard categories, the Natural Breaks

(Jenks) classification method was applied. This statistical approach determines optimal class breaks by minimizing variance within classes while maximizing variance between them, making it suitable for skewed datasets such as distance rasters. The classified output was divided into four categories: no hazard, low hazard, moderate hazard, and high hazard. In this context, areas closest to the fault line were categorized as high hazard due to the higher likelihood of ground rupture and intense seismic shaking, which is around 0 meters to 3559 meters. Areas moderately distant were classified under moderate, that is, around 3559 meters to 7990 meters, and low hazard levels resulted in 7,991 meters to 12,798 meters, while the farthest zones, often beyond 12,798 meters, were classified as no hazard or very low hazard, reflecting a reduced risk of direct fault-related impacts as shown in Figure 8.

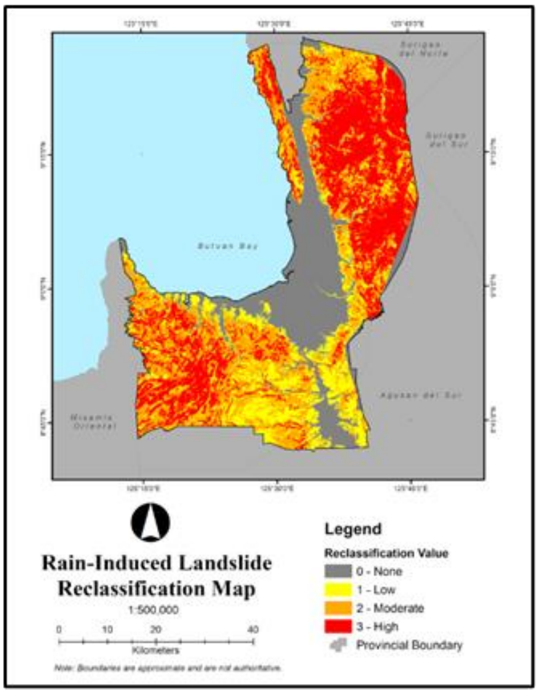

Fig.6. Reclassified rain-induced landslide map of Agusan del Norte

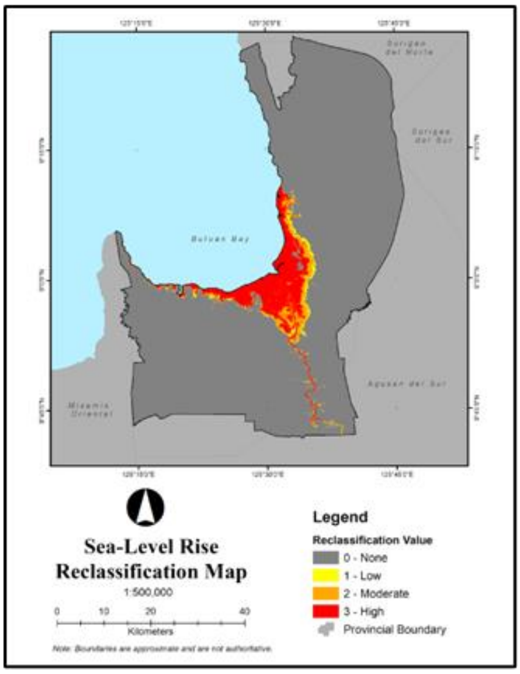

Fig.7. Reclassified sea-level rise map of Agusan del Norte

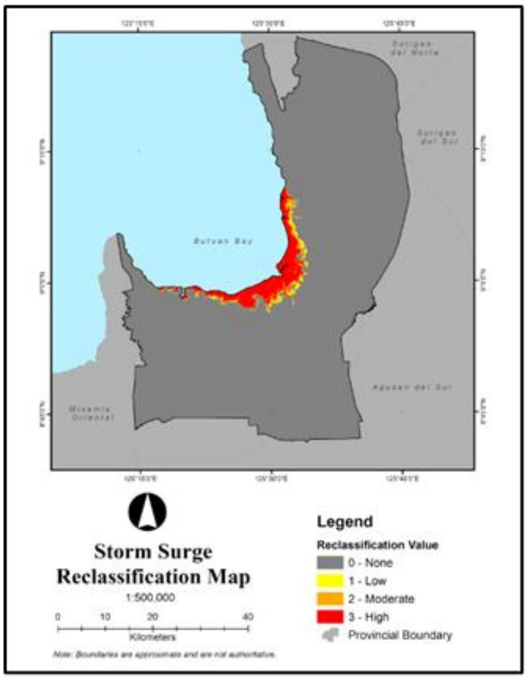

Fig. 7. Reclassified storm surge map of Agusan del Norte

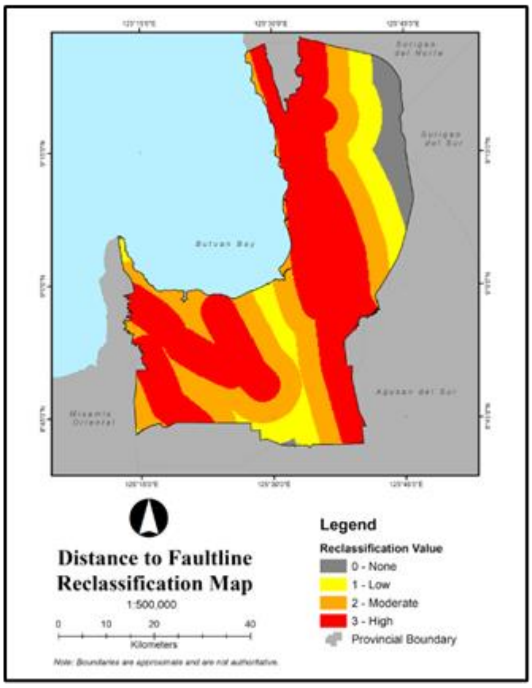

Figure 8. Reclassified active fault map (in terms of proximity) of Agusan del Norte

3.2 Assigned Weights from AHP

Since the study identified specific parameters for generating a multi-hazard map, six experts assigned weights using the AHP Pairwise Comparison method. These weights were utilized to prioritize each criterion. The experts' individual assessments were then aggregated to derive the final weights for each parameter. Table 3 presents the criteria weights for all scenarios.

Table 3. Final individual weight of each criterion for multi-hazard mapping calculated from AHP

Criterion	Average Weight
Earthquake-Induced Landslide	19.37%
Active Fault (Proximity to Faultlines)	14.46%
Flood	23.40%
Liquefaction	13.33%
Rain-Induced Landslide	13.75%
Sea-Level Rise	6.49%
Storm Surge	9.20%

Additionally, the consistency of each evaluator should be considered and presented in Table 4. The consistency ratio is used to decide whether they are consistent in their judgment. A value of 0.152 and 0.264 for the consistency ratio is sufficient, but values greater than that should be re-evaluated. This is critical because if the consistency ratio value is unacceptably high, it implies that the weights are also unacceptable. Presented in the table are the calculated consistencies of each evaluator for each criterion

Table 4. The consistency ratio of the evaluators. The decision makers' actions were consistent with these principles, which established the validity of the average weights.

Evaluator	Consistency Ratio
Evaluator #1 (CCGeo)	0.09
Evaluator #2 (CCGeo)	0.05
Evaluator #3 (MGB)	0.20
Evaluator #4 (MGB)	0.23
Evaluator #5 (Prime BDM)	0.22
Evaluator #6 (Prime BDM)	0.23

3.3 Multi-Hazard Maps

The generated multi-hazard maps were used to identify which areas of Agusan del Norte are classified as none, low, moderate, or high in terms of susceptibility.

3.3.1. Equal Weights

Figure 9 presents the multi-hazard map of Agusan del Norte, given that the weights are equal for each parameter. This map provides an integrated assessment of various natural hazards affecting Agusan del Norte. It combines multiple hazard layers, including earthquake-induced hazards, flooding, rain-induced landslides, storm surges, and sea-level rise, to present an overall vulnerability assessment of the region.

The hazard levels are categorized into three classes: (1) low hazard (yellow) – areas with minimal exposure to multiple hazards, typically inland or elevated regions with lower susceptibility; (2) moderate hazard (orange) – locations that experience moderate exposure to two or more hazards, requiring caution and preparedness; and (3) high hazard (red) – regions highly susceptible to multiple hazards, particularly low-lying coastal zones, flood-prone riverbanks, and steep mountainous areas prone to landslides. The map highlights that the highest hazard levels are concentrated along coastal and riverine areas, as well as regions with steep topography.

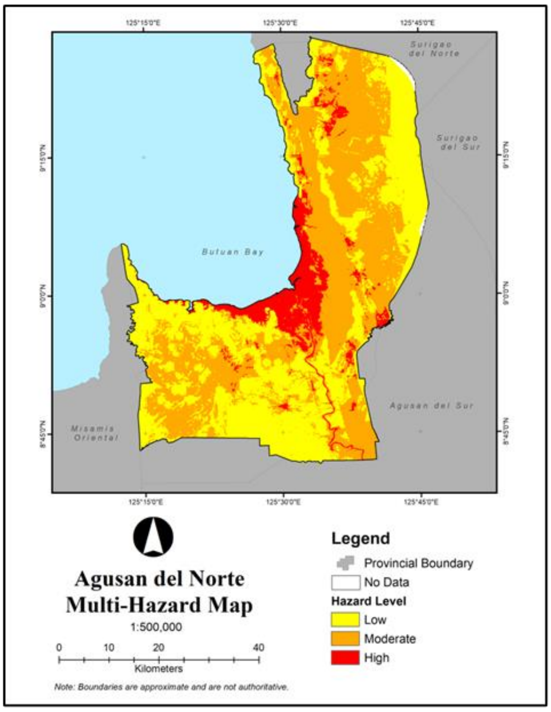

Fig. 9. Multi-hazard map of Agusan del Norte using Equal Weights.

Figure 10 shows the bar graph presenting the spatial extent of flood hazard levels in Agusan del Norte. The data illustrates that areas classified under the Low Hazard Level encompass the largest portion at approximately 1,414.35 sq. km, followed by the Moderate Hazard Level with 1,093.74 sq. km, and the High Hazard Level with 170.14 sq. km. This distribution highlights the relative risk across the province.

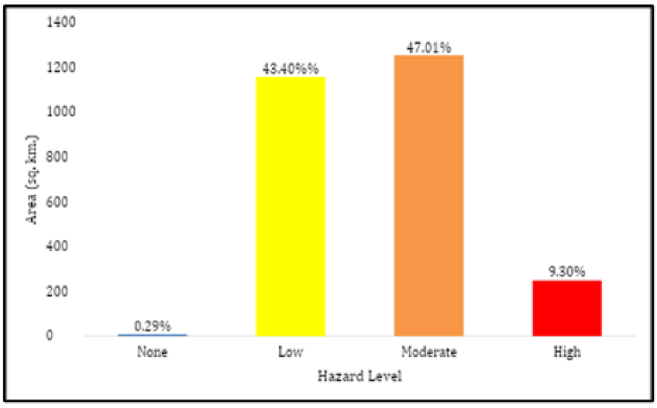

Fig. 10. Bar graph shows the distribution of risk (Equal Weights)

3.3.2. AHP-Derived Weights

The generated multi-hazard map of Agusan del Norte, as shown in Figure 11, derived through the Analytical Hierarchy Process (AHP), illustrates the spatial distribution of hazard susceptibility levels across the province. The map categorizes areas into three hazard levels: low, moderate, and high, based on a weighted overlay of seven contributing factors. These factors were assigned relative importance through the AHP method, incorporating expert judgments to ensure a robust and objective assessment of multi-hazard risks.

The visual output, as shown in Figure 12, clearly demonstrates that low hazard zones dominate the landscape, covering an estimated area of 1,384.82 sq. km, which constitutes approximately 51.7% of the province. These zones are largely situated in the central and western portions of Agusan del Norte, where the terrain is relatively flat and less prone to geomorphological disturbances.

Meanwhile, moderate hazard areas comprise 1,060.43 sq. km or 39.6% and are primarily located along transition zones between lowland and upland regions. These areas are likely influenced by a combination of moderate slope, proximity to water bodies, or land use patterns that moderately elevate hazard exposure.

The high hazard zones, although limited to an extent of 232.98 sq. km or 8.7%, are concentrated along riverbanks, coastal zones, and steep slopes. These areas are particularly vulnerable to flooding, erosion, and landslides—hazards that are common in geologically active or hydrologically dynamic environments. The concentration of high-risk zones in these areas underscores the importance of implementing strict land use regulations and early warning systems to minimize exposure and damage.

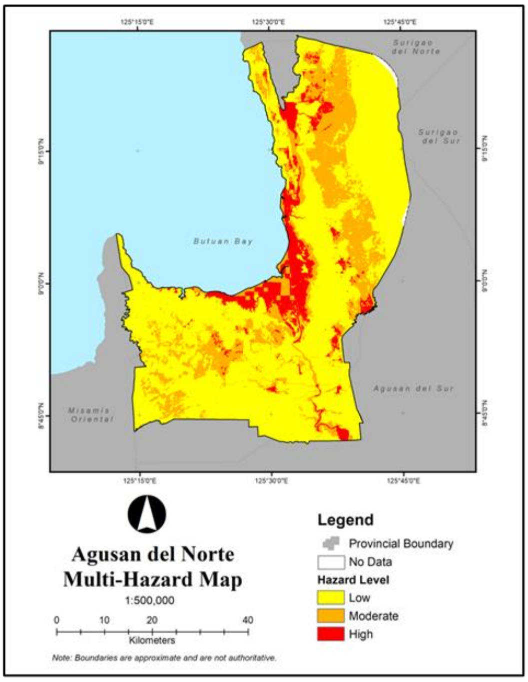

Fig. 11. Multi-hazard map of Agusan del Norte using AHP-derived Weights.

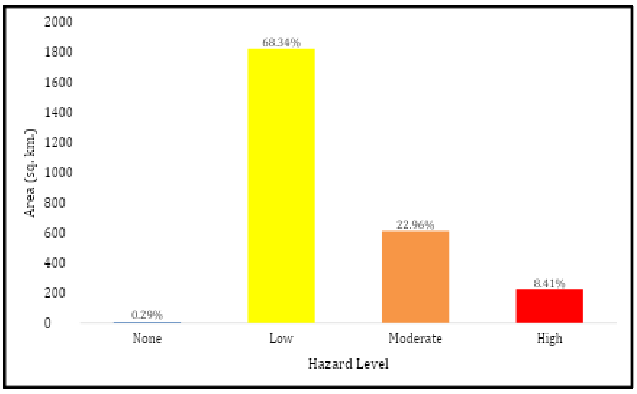

Fig. 12. Bar graph shows the distribution of risk (AHP-derived Weights)

3.4 Analysis

To assess the influence of weighting methodology on hazard susceptibility mapping, two multi-hazard maps were generated for Agusan del Norte, where one using equal weights and the other utilizing AHP-derived weights. These maps highlight differences in hazard level classifications when all factors are treated uniformly versus when their relative importance is evaluated through expert judgment.

The equal weights map assumes that all contributing factors have the same level of influence in determining hazard susceptibility. As seen in the corresponding bar graph , this approach results in the following area distributions where low hazard zones cover approximately 1157.34 sq. km, moderate hazard zones cover 1253.65 sq. km, and high hazard zones occupy 248.1 sq. km. The distribution considers an equal influence across hazard levels but may overestimate the areas in moderate hazards and the complex interactions among natural and surrounding factors.

In contrast, the AHP-based map incorporates pairwise comparisons and expert-derived weights to assign varying degrees of importance to each hazard-influencing parameter. This approach shows a targeted hazard map that reflects how risks are actually ranked in practice. The bar graph based on AHP weights shows that low hazard areas have increased to 1,822.61 sq. km, which is a 24.95% change compared to Equal weights derived bar graph. Moderate hazard areas have also decreased to 618.35 sq. km, a 24.05% change. Meanwhile, high hazard zones have decreased to 225.89 sq. km, showing a 0.89% decrease. This shift suggests that certain areas, previously classified as low hazard and small portion of high risk under equal weighting, are now recognized as moderate hazard zones due to the stronger influence of critical risk factors where a increase of approximately 665.27 sq.km from low risk areas and 641.49 sq.km decrease from moderate risk areas, and a corresponding decrease of approximately 23.78 sq.km from high risk areas, representing a change from the AHP-based weight-derived map.

This reveals that the AHP-based approach provides a targeted identification of low risk areas, which is vital for disaster preparedness and land use planning. By identifying the distinct influence of each hazard factor, the use of Analytical hierarchy process (AHP) enhances the spatial accuracy of hazard maps and promotes more effective risk mitigation strategies. On the other hand, the equal weights method may still be useful for preliminary assessments but may overlook significant danger zones due to its generalized assumptions.

4. CONCLUSIONS AND RECOMMENDATIONS

This study successfully demonstrated the application of a geomatics-based approach to develop a multi-hazard exposure and analysis framework for Agusan del Norte, a province highly susceptible to natural hazards such as floods, landslides, earthquakes, and typhoons. Through the integration of geographic information systems (GIS), remote sensing, and multi-criteria decision analysis, particularly the Analytic Hierarchy Process (AHP), a comprehensive spatial hazard model was developed to support risk assessment and disaster preparedness.

The resulting multi-hazard maps effectively identified areas of varying susceptibility, with hazard levels ranging from low to high. Notably, the AHP-weighted approach provided more refined and targeted identification of high-risk zones compared to the equal-weight method. This highlighted the importance of expert-informed criteria weighting in hazard assessment.

Furthermore, the study revealed that a portion of Agusan del Norte’s population and infrastructure is exposed to overlapping hazards, especially in low-lying and coastal areas. Municipalities and cities such as Butuan City, Cabadbaran City, Magallanes, Buenavista, Kitcharao, Jabonga, and Las Nieves were observed to be among the most hazard-prone. These findings stress the need for more informed land use and development planning that explicitly considers hazard exposure and risk levels.

Overall, this research confirms the potential of geomatics as a vital tool for improving multi-hazard analysis, enhancing early warning systems, and supporting disaster risk reduction (DRR) strategies. The outputs generated such as hazard classification maps and AHP-based susceptibility models are valuable resources for local government units, planners, and stakeholders involved in climate adaptation, emergency response, and sustainable development.

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