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Quantifying Landslide Risk in Bindoy, Negros Oriental: A Barangay-Level Assessment of Hazard, Exposure, and Vulnerability

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Abstract

The study determined the landslide hazard of chosen barangays of Bindoy, Negros Oriental, specifically the barangays of Cabugan, Penahan, Manseje, Poblacion, Bulod, Malaga, and Danawan. A simplified quantitative method was employed to assess the degree of landslide hazard based on three main elements: hazard, exposure, and vulnerability. In assessing the hazard element, the study considered the role of terrain slope and rainfall intensity as contributing elements of landslides. Exposure was determined by counting the residential houses within proximity to slopes and other areas prone to landslides. Meanwhile, the vulnerability element focused on residential conditions, particularly the quality of residential structures and the presence or absence of measures to protect slopes such as retaining walls and vegetation coverage. It was found that the barangays have varying levels of landslide hazards. Specifically, Poblacion showed the lowest degree of hazard with 32%, which is relatively safe due to the presence of mild slopes, fewer residential houses close to slopes and other areas prone to landslides, and better infrastructure conditions. Danawan showed the highest degree of hazard with 51%, primarily due to the presence of steep slopes, greater numbers of residential houses close to slopes, and a lack of measures to protect slopes. In general, barangays with steep slopes, high exposure, and low measures of protection were found to be more vulnerable to landslides.

Keywords: landslide risk assessment, hazard, exposure, vulnerability, Bindoy, Negros Oriental

Introduction

Landslides are one of the most threatening natural hazards occurring in many regions of the Philippines, especially where there is topographic relief, high rainfall intensity, and insufficient protection measures for the slopes. Landslides are generally observed to happen when there is intense rainfall resulting in saturated soil and increased porepressure, leading to instability and subsequent movement of earth material downslope (multi-event assessment of typhoon-triggered landslide susceptibility in the Philippines, 2023; Rainfall-Induced Landslides and Their Implications for Slope Safety, 2020). Many research papers and publications have highlighted this process occurring in the Philippines (Multi-Event Assessment of Typhoon-Triggered Landslide Susceptibility in the Philippines, 2023; Rainfall-Induced Landslides and Their Implications for Slope Safety, 2020). In the case of Negros Oriental, Bindoy is one of the most susceptible to landslide risk because of its topographic nature and increasing residential area close to steep slopes. Danawan and Malaga are among the most susceptible because of their steep topography and residential areas close to potentially unstable slopes. The steeper the land, the more it is subjected to gravitational forces, making it more prone to failure when subjected to heavy rainfall (Spatial landslide risk assessment based on hazard, vulnerability, exposure, and adaptive capacity, 2023). On the other hand, it has been shown that areas of higher household density near slopes have higher vulnerability to exposure because more people and more structures are placed in danger of land displacement (Landslide susceptibility mapping and population exposure analysis, 2025). At the national level, geohazard mapping projects underscore the imperative to respond to landslide hazards in vulnerable communities.

The Department of Environment and Natural Resources-Mines and Geosciences Bureau (DENR-MGB) regularly categorizes barangays based on their vulnerability to rain-induced landslides and flooding, calling on local government units to install early warning systems and evacuation plans in critical zones (DENR-MGB flags hazard-risk zones, warns LGUs to evacuate early, 2025; DENR issues warning on rain-induced landslides and floods, 2025). Such projects underscore the importance of recognizing that landslide hazards are constantly evolving as environmental conditions, land use patterns, and population settlements change. Notwithstanding such efforts, it is apparent that many existing assessments of potential landslide hazards are still limited in scope. The majority of existing hazard maps are only concerned with determining potential landslide sites and do not adequately consider other essential variables such as population vulnerability, housing quality, and measures in place for protecting slopes against landsliding. Consequently, there is still a need for more specific and barangay-level quantitative assessments of potential hazards that can help local government units effectively target their mitigation strategies and resource allocation. Further, existing research studies in this area are characterized by intricate geospatial models that are not easily replicable in smaller municipalities with limited technical capabilities. To address the problem, the current study uses the computational method to determine landslide risks in the selected barangays of Bindoy, Negros Oriental, namely the barangays of Cabugan, Penahan, Manseje, Poblacion, Bulod, Malaga, and Danawan. This study aims to determine landslide risks by considering the integration of the three essential elements, namely hazard (derived from the steepness of the slopes and rainfall), exposure (determined by the number of houses found near landslide-prone sites), and vulnerability (determined by the structural characteristics of houses and the protection of the slopes). Through the integration of the elements into a simple mathematical equation, the study is able to calculate the landslide risks of the selected sites in terms of percentages. This study is important because it offers a localized and data-informed evaluation that could help in informed decision-making on the part of the LGUs, DRRM offices, and barangay officials. Prioritization of landslide-prone barangays to undergo slope stabilization, housing structures, early warning systems, and educational programs could also be made possible with the help of this study. In addition, the study could contribute to the development of knowledge on landslide risk assessment using computation in that it offers a replicable study that could also be applied in other municipalities in the Philippines and in similar hazard-prone areas. Finally, the study could help in improving the preparedness and resilience of barangays in Bindoy, Negros Oriental, to landslides.

Review of Related Literature

The review of Landslide risk assessment has received growing interest in research on disaster risk reduction (DRR) since 2017, especially in areas with mountainous topography and heavy rainfall. It is now recognized that landslide risk is no longer a result of slope failure, but it is a function of a combination of various elements such as risk, exposure, and vulnerability (UNDRR,2017; Fell et al., 2018). Recent international studies have emphasized the importance of multi-criteria landslide risk models. One study carried out in the province of Son La Province created a spatial landslide risk map using a combination of normalized indicators representing landslide hazard, vulnerability, exposure, and adaptive capacity. This study effectively categorized regions as having low, moderate, high, or very high landslide risks. This emphasizes the importance of a combination of landslide hazards and socioeconomic aspects in landslide risk mapping (Spatial landslide risk assessment based on hazard, vulnerability, exposure, and adaptive capacity, 2023). This study also confirmed that regions with high population densities in proximity to sloping terrain have high landslide risks. Rain-induced landslides in Southeast Asia and other tropical countries rank as some of the most frequent and hazardous natural disasters (multi-event assessment of typhoon-triggered landslide susceptibility in the Philippines, 2023). Current literature after 2017 confirms that intense rainfall events, which are exacerbated by climate change, contribute largely to landslide events (IPCC, 2021; UNDRR, 2019). In the Philippines, a multi-event study on typhoon-induced landslide susceptibility showed that landslides in the area are largely affected by terrain factors, soil type, and terrain cover, as well as rainfall intensity (multi-event assessment of typhoon-triggered landslide susceptibility in the Philippines, 2023). The risk assessment approach used in recent landslide research is based on the hazard-exposure-vulnerability model of risk (H–E–V). According to the United Nations Office for Disaster Risk Reduction (UNDRR, 2017), disaster risk is the product of hazard, exposure, and vulnerability. The International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE, 2024) defines hazard as the probability of slope failure, exposure as the presence of people and assets in hazard-prone zones, and vulnerability as the potential level of damage or loss. This approach makes it possible to objectively evaluate landslide risk and is currently used in post-2017 landslide research. In the context of the Philippines, research has highlighted that the vulnerability to landslides is commonly exacerbated by socioeconomic conditions like community settlement on hazardous land, lack of access to early warning systems, and land use on sloping areas (PHIVOLCS, 2018; NDRRMC, 2022). Communities that are close to mountainous and riverine environments are most at risk of landslides due to rainfall. Recent literature also emphasizes the significance of participatory methods for landslide risk assessment. A chapter on site-specific landslide risk assessment in the Philippines explains the importance of community engagement methods like surveys, focus group discussions, and participatory mapping in enhancing the assessment of vulnerable communities and local coping mechanisms (Assessing and contextualizing site-specific landslide risk in the Philippines, 2025). These methods can be combined with quantitative models to assess risk by using local knowledge. Exposure assessment, particularly population and household distribution, is still an important part of landslide risk assessment. Exposure is defined as the presence of population and properties at risk in landslide-prone areas (UNDRR, 2017). Research reveals that communities with higher household density in landslide-prone slopes have a higher potential risk of damage from landslide hazards (Tacconi et al., 2019). The distribution of households in Bindoy, Negros Oriental, varies from one barangay to another. Using data from (PhilAtlas (2020), it was found that Cabugan has 398 households, Poblacion has 747 households, Bulod has 446 households, Malaga has 424 households, and Danawan has 227 households. The exposure of some of the barangays, such as Poblacion and Bulod, is higher due to higher household density, potentially at risk of landslide hazards. In cases where data for individual households are not available for each barangay, population-based estimations are employed (Philippine Statistics Authority, 2021). Household population and housing characteristics. population of 754 and Bindoy's average of 4.1 persons per household, for example, 184 households can be approximated (PhilAtlas, 2020; PSA, 2021). This can also be derived for Manseje's population of 1,000, estimating 244 households. These estimation procedures can be deemed reasonable for exploratory analysis of exposure (Fell et al., 2018; (10) UNDRR, 2019). Indeed, in general post 2017 literature, there is a consistent reinforcement of the fact that landslide risk evaluation has to be done by considering both hazard and vulnerability along with exposure in a manner that takes into account quantitative as well as qualitative inputs (PHIVOLCS, 2018; (Spatial landslide risk assessment based on hazard, vulnerability, exposure, and adaptive capacity, 2023). In a landslide risk area like Bindoy in Negros Oriental, a combination of scientific inputs and local knowledge can form a well-rounded basis for disaster risk reduction as well as landslide risk management (PHIVOLCS, 2018).

Conceptual Framework

The conceptual framework for this study was conceptualized in the notion that landslide risk is measured by various parameters that affect the risk level in identified barangays in Bindoy, Negros Oriental. This study hypothesized that landslide risk does not only depend on one factor but on the interaction and combination of various natural, settlement, and structural vulnerabilities. Through the application of a quantitative approach in the computational method, the study aims to transform various information into numbers that can be compared and ranked in a quantitative manner. The conceptual framework for this study was conceptualized in the notion that the final landslide risk percentage depends on the interaction and combination of various parameters in a mathematical formula. The independent variables of this study are hazard (H), exposure (E), and vulnerability (V), which correspond to different aspects of landslide risk. Hazard refers to natural physical processes that can cause landslides, specifically the steepness of slopes and rainfall. These two variables are measured, and their average value is calculated to produce a hazard index showing the susceptibility of each barangay to landslide risk. Exposure (E) refers to how houses and communities are susceptible to landslide hazards due to their proximity to landslide-susceptible slopes, measured by how many houses are close to slopes against the total number of houses. Vulnerability (V) refers to susceptibility to landslide hazards of houses and their residents, measured by house structures and the existence of protection structures for slopes. These variables are expected to affect landslide risk because they correspond to both the cause and effect of landslide hazards. Dependent variable: Final landslide risk percentage. This variable is the most significant outcome of this research. This variable depends on all other variables as it is assumed to be influenced by all independent variables by means of an equal-weighted computation formula. According to this assumption, if there are high levels of hazards, exposure, and vulnerability, then there will be a high-risk percentage as well. On the contrary, if there are low levels of hazards, exposure, and vulnerability, then there will be a low-risk score as well. Mediating variables are not used in this research; however, computation in mathematical terms helps to create a standardized relationship between variables. The purpose of this conceptual framework in this research context is to help this research systematically identify how all variables are contributing to landslide risks in evidence-based planning for disaster management in the selected barangays.

Results

This study used a quantitative descriptive computational approach to assess landslide risk in selected barangays of Bindoy, Negros Oriental. The method focused on measuring and comparing landslide risk using numerical data and mathematical formulas. The assessment was based on the disaster risk framework, where landslide risk is determined by hazard (H), exposure (E), and vulnerability (V). Each component was computed separately using normalized scores to ensure fair comparison among barangays.

Hazard was assessed using slope steepness and rainfall exposure. Exposure measured the proportion of houses located near slopes, while vulnerability considered housing condition and slope protection. These values were combined using simple mathematical formulas to produce a final landslide risk percentage.

Overall, this methodology provides a clear and objective way to identify barangays with higher landslide risk and supports planning for disaster preparedness and mitigation in Bindoy, Negros Oriental.

Table 1: Hazzard Assessment Scores

Barangay	Slope Score	Rainfall Score	Hazard
Cabugan	0.4	0.6	0.5
Penahan	0.7	0.6	0.66
Manseje	0.7	0.7	0.68
Poblacion	0.5	0.6	0.55
Bulod	0.7	0.6	0.65
Malaga	0.7	0.7	0.70
Danawan	0.8	0.7	0.75

Table 1 presents the hazard assessment scores for the selected barangays in Bindoy, Negros Oriental. The hazard score for each barangay was determined using two key physical factors that influence landslide occurrence: slope steepness and rainfall intensity. These factors are widely recognized in landslide studies as major contributors to slope instability. First, each barangay was assigned a slope score based on the steepness of its terrain. Barangays with gentler slopes were given lower scores, while those with steeper slopes received higher scores, reflecting a greater likelihood of landslides. Second, a rainfall score was assigned based on the level of rainfall exposure in each barangay. Areas experiencing heavier or more frequent rainfall were given higher scores because rainfall increases soil saturation and reduces slope stability.

Hazard Score = (Slope Score + Rainfall Score) ÷ 2

For example, we will solve for the hazard score of Cabugan. We will take its slope score which is 0.4 and add it to its rainfall score 0.6 and divide it by 2 to get the hazard score of 0.5

Hazard Score = $(0.4 + 0.6) \div 2 = 0.5$

Based on the table, Cabugan has a slope score of 0.4 and a rainfall score of 0.6. Averaging these values results in a hazard score of 0.5. Similarly, Danawan, which has steeper slopes (0.8) and high rainfall exposure (0.7), obtained the highest hazard score of 0.75, indicating a higher susceptibility to landslides.

Overall, the table shows that barangays with steeper terrain and higher rainfall exposure tend to have higher hazard scores. This hazard assessment serves as an important component of the overall landslide risk analysis is and provides a basis for identifying barangays that require closer monitoring and preventive measures.

Table 2: Exposure Assessment Scores

Barangay	Houses Near Slopes	Average Total Houses	Exposure(E)
Cabugan	84	398	0.21
Penahan	56	155	0.36
Manseje	60	200	0.3
Poblacion	90	747	0.12
Bulod	66	446	0.15
Malaga	70	424	0.17
Danawan	80	227	0.35

Table 2 shows the exposure assessment scores of the selected barangays in Bindoy, Negros Oriental. Exposure refers to the extent to which people and properties are located in areas that may be affected by landslides. In this study, exposure was measured using the number of houses situated near slopes relative to the total number of houses in each barangay.

First, the number of houses near slopes was identified for each barangay. These houses were considered exposed because their proximity to slopes increases the likelihood of damage in the event of a landslide. Next, the average total number of houses in each barangay was obtained from available census data and population estimates.
To compute the exposure score, the following simple ratio was used:

Exposure (E) = Number of Houses Near Slopes ÷ Average Total Houses
This formula produces a value between 0 and 1, where higher values indicate greater exposure to landslide hazards. An example of this is if we solve for the exposure of Barangay Cabugan. We have the number of houses near a slope, which is 84, and the average total number of houses, which is 398. Giving us the final exposure of 0.21
Exposure (E) = 84 ÷ 398 = 0.21

For example, Cabugan has 84 houses located near slopes out of an estimated 398 total houses. Dividing 84 by 398 results in an exposure score of 0.21. In contrast, Penahan has 56 houses near slopes out of only 155 total houses, yielding a higher exposure score of 0.36, indicating that a larger proportion of its population is exposed to landslide risk. Poblacion recorded the lowest exposure score (0.12) because, despite having many houses near slopes, it also has a much larger total number of houses.

Overall, the table highlights that barangays with fewer total houses, but many located near slopes tend to have higher exposure scores. These exposure values contribute directly to the final landslide risk calculation by indicating how many households may be affected if a landslide occurs.

Table 3: Vulnerability Assessment Score

Barangay	Structural Score	Protection Score	Vulnerability
Cabugan	0.3	0.26	0.28
Penahan	0.36	0.32	0.34
Manseje	0.36	0.34	0.35
Poblacion	0.3	0.3	0.3

Bulod	0.4	0.36	0.38
Malaga	0.42	0.38	0.4
Danawan	0.48	0.42	0.45

Table 3 presents the vulnerability assessment scores of selected barangays in Bindoy, Negros Oriental, based on two components: structural condition and slope protection. The overall vulnerability score for each barangay was computed by combining these two factors. So, in order to solve for the overall vulnerability of a barangay, we need to add its structural score and protection score, then divide it by 2 to get its overall vulnerability.
Vulnerability = (structural score + protection score) ÷ 2
Vulnerability = (0.3 + 0.26) ÷ 2

Results show that Danawan has the highest vulnerability score (0.45), indicating weaker housing structures and limited slope protection. Malaga (0.40) and Bulod (0.38) also exhibit relatively high vulnerability, suggesting greater susceptibility to landslide impacts. In contrast, Cabugan (0.28) and Poblacion (0.30) recorded lower vulnerability scores, reflecting better housing conditions and more adequate protection measures.

Overall, the table indicates that barangays with higher structural and protection scores tend to have greater vulnerability, emphasizing the need to strengthen housing quality and slope protection, particularly in highly vulnerable areas.

Table 4: Final Landslide Risk

Barangay	**H**	**E**	**V**
Cabugan	0.5	0.21	0.28
Penahan	0.66	0.36	0.34
Manseje	0.68	0.3	0.35
Poblacion	0.55	0.12	0.3
Bulod	0.65	0.15	0.38
Malaga	0.7	0.17	0.40
Danawan	0.75	0.35	0.45

Explanation of Table 4
Table 4 presents the final landslide risk assessment of selected barangays in Bindoy, Negros Oriental using three components: hazard (H), exposure (E), and vulnerability (V). These components were combined to determine the overall level of landslide risk for each barangay. In order to get the final risk percentage, we need to add H, E, and V then divide everything by 3, and multiply by 100 to get the percentage.
Risk = {[hazard (H) + exposure (E) + vulnerability (V)] ÷ 3 } x 4
Risk = {[0.5 + 0.21 + 0.28] ÷ 3 } x 4

The results show that Danawan has the highest landslide risk due to its high hazard value (0.75), relatively high exposure (0.35), and the highest vulnerability score (0.45). Malaga and Manseje also exhibit elevated risk levels, mainly influenced by steep slopes and higher vulnerability. In contrast, Poblacion recorded lower exposure (0.12) and moderate hazard and vulnerability values, indicating the lowest overall landslide risk among the barangays.
Overall, the table indicates that barangays with higher hazard and vulnerability values tend to have greater landslide risk, particularly when combined with higher exposure. These results highlight the importance of focusing risk reduction and mitigation efforts on barangays with high hazard, exposure, and vulnerability scores.

Table 5: Barangay Ranked by Landslide Risk Percentage

Rank	Barangay	Final Risk (%)	Risk Level
1	Danawan	51%	High
2	Pinahan	45%	Moderate high
3	Manseje	44%	Moderate high
4	Bulod	42%	Moderate high
5	Malaga	42%	Moderate high
6	Cabugan	33%	Moderate
7	Poblacion	32%	Moderate

Table 5 shows the ranking of barangays in Bindoy, Negros Oriental, based on their final landslide risk percentages. The ranking highlights differences in risk levels among the barangays, allowing for easier comparison and prioritization.

Danawan ranked first with the highest landslide risk at 51%, indicating a greater need for immediate mitigation and preparedness measures. This was followed by Penahan (45%) and Manseje (44%), which also showed relatively high-risk levels. Bulod and Malaga both recorded a risk level of 42%, placing them in the middle of the ranking. In contrast, Cabugan (33%) and Poblacion (32%) ranked lowest, suggesting comparatively lower landslide risk.
Although all barangays were classified under a moderate risk level, the ranking emphasizes which areas should be prioritized for risk reduction efforts. Barangays with higher risk percentages may require enhanced slope protection, improved land-use planning, and stronger disaster preparedness programs to reduce potential landslide impacts.

Interpretation:

- Highest Risk: Danawan – very steep slopes, high exposure, and weak protection.
- Moderate–High Risk: Penahan, Manseje – steep slopes and moderate exposure.
- Moderate Risk: Bulod, Poblacion, Cabugan, and Malaga – lower slope steepness and better protection.

Discussion

The data from this research indicate the variation of landslide risk in the different barangays of Bindoy, Negros Oriental. The lowest risk was in Poblacion (32%), which is believed to be the result of the relatively gentle slopes in the area, the small number of residences directly on the unstable slopes, and the relatively adequate protection measures in place, including drainage systems and community awareness (Spatial landslide risk assessment based on hazard, vulnerability, exposure, and adaptive capacity, 2023). However, the highest risk was in Danawan (51%), believed to be the result of the relatively steeper terrain in the area, the high number of residences on the unstable slopes, and the lack of protection of the slopes against potential landslides, all of which are supported by the existing knowledge that the main factors in landslide hazard are the gradient of the terrain and the amount of rainfall in the area (Multi-event assessment of typhoon-triggered landslide susceptibility in the Philippines, 2023). The steeper the terrain, the higher the shear stress on the terrain, making it more unstable, as supported by the existing literature on landslide research, where the number of landslide occurrences is directly proportional to the steepness of the terrain (Spatial landslide risk assessment based on hazard, vulnerability, exposure, and adaptive capacity, 2023). Hazard in this study was measured in terms of slope steepness and rainfall exposure. Rainfall, particularly when it is prolonged and intense, results in soil saturation, hence higher pore-water pressures and loss of cohesion of soil particles, which in turn causes slope failure (Characteristics and influencing factors of rainfall-induced landslide and debris flow hazards, 2019). This strengthens the notion that hazard mapping should not be considered in isolation from climatic factors, as rainfall is a key triggering factor of landslides. Exposure variables used in this research were determined through the number of households located close to possible landslide areas. Indeed, overall research on exposure to landslides has proved that exposure is a significant consideration since communities living close to hazardous slopes are more susceptible to potential dangers (Landslide susceptibility and building exposure assessment using machine learning models and geospatial analysis techniques, 2024). The exposure scores were high for barangays where many houses were located close to steep slopes, such as Danawan. Another factor that played an important part in determining the level of risk in every barangay was vulnerability. Vulnerability refers to susceptibility to landslide hazards. Factors such as housing quality, age composition of the population, and slope protection structure have been known to affect landslides (Spatial landslide risk assessment based on hazard, vulnerability, exposure, and adaptive capacity, 2023). Those barangays with lower housing quality and less slope stabilization structure were found to have higher vulnerability levels and thus higher levels of overall risks. The patterns support the landslide risk concept, which is widely used in the study of disaster risk, and is expressed as risk = f (hazard, exposure, and vulnerability), whereby the highest hazard and exposure combined with the highest vulnerability result in the highest risk (International Society for Soil Mechanics and Geotechnical Engineering, 2024). This combined concept has been used worldwide in different situations to focus attention on disaster risk management. Additionally, research carried out in other hazard situations has found that it is necessary to understand the level of exposure and vulnerability to achieve successful risk management, as moderate hazards can pose considerable risks if the level of exposure is considerable or the level of vulnerability is extreme (Climate change vulnerability and disaster risk assessment in Zambales, 2021). In general, it can be noted from the results that landslide risk in Bindoy is not homogeneously distributed but is affected by both biophysical variables (land slope and rainfall) and socio-demographic variables (housing structure), such that specific preparedness measures have to be taken for particular communities with high-risk scores, such as Danawan.

Conclusion

From the above analysis, it is clear that the risk level for landslides in Bindoy, Negros Oriental, is not the same for all barangays but is highest in Danawan barangay and lowest in Poblacion barangay. These findings support earlier research on landslides that landslide risk is not solely dependent on the level of hazard but is a product of the combined influence of the level of hazard, exposure, and vulnerability. These results are very useful in planning disaster risk reduction in the locality since they give a clear and understandable representation of landslide risk in percentage form. These outcomes can be used by the local government units and disaster risk reduction offices to identify and give priority to areas that are highly prone to landslides, such as Danawan, Penahan, and Malaga, and provide them with immediate attention and mitigation measures such as slope stabilization projects, enhanced drainage systems, more stringent land use zoning regulations around areas with very steep slopes, relocation programs for communities that are highly susceptible to landslides, and early warning systems for landslides. At a community level, residents can protect themselves by engaging in disaster preparedness training programs, ensuring that drainage channels remain clear, avoiding building in areas of unstable slopes, and reporting any indication of slope movement, such as cracks and soil creep. Community-based monitoring programs can help communities cope with landslides. In conclusion, this research emphasizes the value of data-informed and barangay-level risk assessment in terms of both physical and social aspects. In this research, a computation model has been developed as a useful and easily replicable process to assist in proactive disaster risk management and coordination between government and non-government sectors to create safer barangays in Bindoy, Negros Oriental.

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