Vulnerability to Hydrometeorological Hazards: A Barangay Level Assessment for the Municipality of Boac, Marinduque

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Abstract

The conduct of vulnerability assessments has helped government units and local communities to manage risks posed by natural disasters. This study focuses on the barangay level vulnerability assessment on the Municipality of Boac, the capital of Marinduque province in the Philippines. The province, being an island, is susceptible to various hydrometeorological hazards. The assessment was made to compute the vulnerability index of each barangay in the municipality. The indicators of exposure, sensitivity, and resilience were identified through various consultations and focus group discussions with the constituents, the local government units, and government agencies assigned on disaster management while the data of each indicator were lifted from the 2015 Community Based Monitoring Systems (CBMS).Using the method of equal weights, the computed indices indicate that about 73.77% of the barangays have moderate vulnerability while the remaining 26.23% were categorized as low vulnerability. Using regression analysis, the indicators that are significant to the barangay's vulnerability were also identified. These indicators include landslide exposure, no. of households with members who are pregnant/lactating, and no. of households with members who have experience or training on emergency response. The study also proved that increasing resiliency is an important factor to decrease the community's vulnerability. This can be done by proper risk assessment, establishing clear evacuation protocols before and during disasters, and educating the vulnerable communities through proper information dissemination.

Keywords
vulnerability, hydrometeorological hazards, barangay level assessment, index method, regression analysis

1. Introduction

The Philippines, a Southeast Asian country with over 300,000 square kilometers of landmass and 7,100 islands have been a hotspot for natural disasters due to its classification as an island nation (UNDRR 2019). Its geographic location plays a part in the imminent occurrence of natural calamities, as it is positioned in the Pacific Ring of Fire where various volcanoes and earthquake generators surround along the ocean belt (World Bank 2014). It was also reported that the country's landmass is susceptible to multiple hazards at a minimum of 60%, while 74% of the population are to be affected (UNDRR, 2019). In addition, the World Risk Report ranked the Philippines as 9th in the highest disaster risk worldwide, while being 2nd in Asia with an overall index of 20.96 and a vulnerability index of 49.55 (Behlert et al., 2020). The effects of climate change also affected the country's increased vulnerability to strong typhoons, the rise of sea level, and storm surges which are projected to affect 40% of those near coastal areas (CFE-DMHA 2018). The country also ranked 4th in the long-term climate risk index from 1999 – 2018, experiencing 317 events with a death toll of over 870 and estimated losses of over US$ 3.12 billion (Eckstein et al., 2019).

The occurrence of such natural calamities considers the evaluation of suitable vulnerability assessment and planning on hazard-prone areas. Vulnerability is defined as "the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards" (UNISDR, 2009). It also goes beyond exposed areas, where the analysis of such does not conclude on the grounds directly affected by hazards, thus claiming the importance of regional approach (Vinet, 2017). The instances of assessing vulnerability can also be linked to a type of hazard in the form of hydrometeorological hazards. This hazard is a result of both meteorological and climate events, including floods, typhoons, and landslides.

The need to do vulnerability assessments due to hydrometeorological hazards can be an advantage as it helps in building preparedness measures. Li et al. (2011) studied the significance of vulnerability assessment, being a process of knowing, measuring, and prioritizing through ranking the vulnerability aspects within a proposed structure.

Frequently, suitable approaches for vulnerability are created for a specific type of hazard. The effectiveness of using indices methods was seen to mitigate better disaster management and risk reduction (Papathoma-Köhle et al., 2019). Van Westen (2016) studied the advantages of using an indicator-based method, finding out that the method allows an all-inclusive risk assessment approach.

This study is focused on vulnerability assessment of hydrometeorological hazards in the capital of Marinduque, the Municipality of Boac. Marinduque Province is positioned in the Southwestern Region, with an approximate distance from Manila, of about 200km, and has a 960 sq. km. of landmass (Salvacion and Magcale-Macandog 2015). Boac is the second most populous municipality with 61 barangays and a population of 54,730 or 23.3% of the whole province (PSA, 2017).

2. Methodology

2.1 Materials and Methods

The data used in this study were taken from the household data of the 2015 Community Based Monitoring Systems (CBMS). CBMS collects information in an organized way at the local level for use of local government units, national government agencies, non-government organizations, civil society, and development partner agencies for planning, program implementation, and monitoring (PEP-CBMS, 2020). The CBMS household data were aggregated to obtain the barangay level data of each indicator of vulnerability. The exposure, sensitivity, and resilience indicators of vulnerability for a barangay were lifted from the study of Robielos et al. (2020) which were identified using the participatory-based method where opinion of experts and key stakeholders were considered. The method of equal weighting was used to identify the corresponding weights of each indicator of vulnerability. This method is widely used in the field of different vulnerability assessments as it helps obtain the index with various indicators (Monterroso et al., 2014; Edmonds et al., 2020). Salazar-Briones et al. (2020) used the similar equation of data normalization and weighing of indicator in their flood vulnerability assessment; citing that the equal weight calculation and the weighting of variables according to the number in each component have evidence of a better correlation between results. Equal weights have also been known to be an easier and straightforward technique in identifying indices (Gan et al., 2017). Table 1 presents the list of indicators and sub-indicators of vulnerability and its corresponding weights.

Table 1. Indicators of Barangay Vulnerability

Exposure (E) 33.34%			
Indicators	**Sub-Indicators**	**Functional Relationship**	**Weights**
Typhoon	E1 – Type of wall material	↑	6.668%
	E2 - Type of roof material	↑	6.668%
	E3 - No. of exposure to typhoon	↑	6.668%

Flood	E4 -Proximity to bodies of water	↑	6.668%
Landslide	E5 - No. of landslide exposure	↑	6.668%
Sensitivity (S) 33.33%			
Indicators	**Sub-Indicators**	**Functional Relationship**	**Weights**
Demographic	S1 - No. of senior citizens	↑	4.7619%
	S2 - No. of persons with disability (PWD)	↑	4.7619%
	S3 - No. of pregnant & lactating mothers	↑	4.7619%
	S4 - No. of infant & children	↑	4.7619%
Livelihood	S5 - Income from employment and/or business	↑	4.7619%
	S6 - Income from agriculture and/or fishery	↑	4.7619%
	S7 - Income from other sources	↑	4.7619%
Resilience (R) 33.33%			
Indicators	**Sub-Indicators**	**Functional Relationship**	**Weights**
Property	R1 - No. of appliances owned	↓	3.0300%
	R2 - No. of vehicles owned	↓	3.0300%
Insurance Coverage	R3 - No. of insurance coverage	↓	3.0300%
Emergency Items	R4 - No. of emergency items	↓	3.0300%
Utilities	R5 - Type of potable water source (PWS)	↓	3.0300%
	R6 - Type of emergency power supply (EPS)	↓	3.0300%
	R7 - No. of communication devices	↓	3.0300%
	R8 - No. of educational facilities available	↓	3.0300%
Organization Membership	R9 - No. of HH members with organization membership	↓	3.0300%
Human Capital	R10 - Highest educational attainment of HH head	↓	3.0300%
	R11 - No. of HH members as emergency responders (ER)	↓	3.0300%

2.2 Computation of the Barangay Vulnerability Index

The barangay data were arranged tabularly to present the indicators of exposure to hazards, sensitivity, and resilience specific for the Municipality of Boac. Then, the functional relationship was identified to determine the relationship of each indicator to vulnerability. An upward (↑) or positive (+) functional relationship indicates that as the value is increasing, the degree of vulnerability is also increasing while a downward (↓) or negative (-) functional relationship indicates that as the value is decreasing, vulnerability is also decreasing. This step is part of the data normalization process, an approach established through the methodology for calculating the Human Development Index (HDI) (Žurovec et al, 2017). Equations 1 and 2 present the equations for data normalization with respect to the functional relationship.

$$\boldsymbol{Xinorm} = \frac{\boldsymbol{Xi - Xmin}}{\boldsymbol{Xmax - Xmin}} \qquad \text{for} \uparrow \text{or } (\textbf{+}) \text{ functional relationship} \qquad (1)$$

$$\boldsymbol{Xinorm} = \frac{\boldsymbol{Xmax - Xi}}{\boldsymbol{Xmax - Xmin}} \qquad \text{for} \downarrow \text{or } (\textbf{-}) \text{ functional relationship} \qquad (2)$$

Where: $Xinorm$ = the normalized value of indicator i of a vulnerability component (E, S, R)
Xi = value of indicator i
X_{max} = maximum value of the indicators of vulnerability component
X_{min} = minimum value of the indicators of vulnerability component

After normalization, the barangay vulnerability index was calculated using Equation 3.

$$HH\ LVI_i = \sum W_i\, Ex_{inorm} + \sum W_i\, Sx_{inorm} + \sum W_i\, Rx_{inorm} \quad (3)$$

Where: W_t = weight of the indicator
Ex_{inorm} = the normalized value of indicator *i* of Exposure (E) component
Sx_{inorm} = the normalized value of the indicator *i* of Sensitivity (S) component
Rx_{inorm} = the normalized value of the indicator *i* of Resilience (R) component

The vulnerability index values range from 0 to 1. Table 2 shows the range of values and its interpretation in terms of vulnerability using five (5) scales.

Table 2. Vulnerability Indicators with Weights

Category	**Index Values**
Very Low Vulnerability	0.0000 to 0.2000
Low Vulnerability	0.2001 to 0.4000
Moderate Vulnerability	0.4001 to 0.6000
High Vulnerability	0.6001 to 0.8000
Very High Vulnerability	0.8001 to 1.0000

2.3 Regression Analysis

Regression analysis was used to examine the most significant indicators contributing to the vulnerability of each barangay. The dependent variable considered in the analysis was the barangay vulnerability index while the independent variables were the raw data of each indicator. Ewaid et al. (2018) described that regression analysis is the best tool for examining the relationship between the multiple variables. Equation 4 exhibits the regression model.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_m + \varepsilon \quad (4)$$

Where: y = independent variable or the LVI
β_0 = y-intercept
β_n = slope coefficient of nth independent variable
ε = error of the residuals

The data were analyzed using Minitab17 software's multiple regression statistical tool.

3. Results and Discussion

3.1 Barangay Vulnerability Index

Table 3 shows the summary of barangay vulnerability indices for the Municipality of Boac.

Table 3. Summary of Barangay Vulnerability Index

Category	**No. of Barangays**	**Percentage**
Very Low Vulnerability	0	0
Low Vulnerability	16	26.23%
Moderate Vulnerability	45	73.77%
High Vulnerability	0	0
Very High Vulnerability	0	0

The overall vulnerability index of the barangays in Boac, Marinduque showed that most of it are classified in the moderate vulnerability scale with 73.77% of the barangays while the remaining 26.23% belong to low vulnerability. The top three barangays with the highest index are Tumagabok with an index of 0.5535, Hinapulan with 0.4814 and Mahinhin, with an index of 0.4721. The barangays with the lowest index values were Isok I (Pob.), Malusak (Pob.), Isok II Pob. (Kalamias) with index values of 0.3070, 0.3072, and 0.3279, respectively.

3.2 Vulnerability Index of Exposure to Hazards

Table 4 shows the summary vulnerability indices with respect to exposure to hazards.

Table 4. Summary of VI of Exposure to Hazards

Category	Scale		Frequency	Percentage
Very Low Exposure	0.0000	0.0666	34	55.74%
Low Exposure	0.0667	0.1333	26	42.62%
Moderate Exposure	0.1334	0.1999	1	1.64%
High Exposure	0.2000	0.2666	0	0
Very High Exposure	0.2667	0.3334	0	0

The summary showed that 55.74% of the barangays has very low exposure, 42.62% under low exposure, and only 1.64% or 1 barangay possess moderate exposure. This lone barangay is Tumagabok, possessing the highest index value of 0.1573. The other top two barangays with high indices are Maligaya with 0.1306 and Tabigue with 0.1296. On the other hand, the barangays with the lowest exposure are Malusak (Pob.), Isok I (Pob.), and Isok II (Pob.) with indices of 0.0153, 0.0154, and 0.0199, respectively.

3.3 Vulnerability Index of Sensitivity

Table 5 presents the summary of the vulnerability indices with respect to sensitivity.

Table 5. Summary of VI of Sensitivity

Category	Scale		Frequency	Percentage
Very Low Sensitivity	0.0000	0.0666	5	8.20%
Low Sensitivity	0.0667	0.1332	53	86.89%
Moderate Sensitivity	0.1333	0.1999	3	4.91%
High Sensitivity	0.2000	0.2665	0	0
Very High Sensitivity	0.2666	0.3333	0	0

Among the barangays, 8.20% are in the very low category, 86.89% under low sensitivity, and only 4.91% in moderate sensitivity. The barangays with moderate sensitivity are Tanza, Cawit, and Mataas na Bayan (Pob.) with indices of 0.1450, 0.1410, and 0.1381 respectively. The barangays with the classification of very low sensitivity and the lowest in the municipality are Isok II (Pob.), Boi, and Balaring with indices ranging from 0.0560 to 0.0660.

3.4 Vulnerability Index of Resilience

The summary of indices with respect to resilience is presented in Table 6. About 26.23% of the barangays in Boac possess very high resilience, 72.13% with low resilience and only a lone barangay or 1.64% under moderate resilience category. The lone barangay of Murallon belong to the moderate resilience category also happens to have the 4th lowest barangay vulnerability index in the municipality. The barangays of Mataas na Bayan (Pob.) with an index of 0.2015 and Isok I (Pob.) with 0.2059 are the next two barangays with low index values. Mahinhin, Tugos, and Tumagabok earned the highest resiliency indices in the range of 0.2814 to 0.2891. Both barangays of Mahinhin and Tumagabok also possess the highest overall barangay vulnerability index in the municipality of Boac despite their high resiliency because Mahinhin has high indices with respect to exposure and sensitivity while Tumagabok has the highest exposure in the whole municipality.

Table 6. Summary of VI of Resilience

Category	Scale		Frequency	Percentage
Very Low Resilience	0.0000	0.0666	0	0
Low Resilience	0.0667	0.1332	0	0
Moderate Resilience	0.1333	0.1999	1	1.64%
High Resilience	0.2000	0.2665	44	72.13%
Very High Resilience	0.2666	0.3333	16	26.23%

3.5 Regression Analysis

In the regression analysis (Table 7), the dependent variable considered was the overall vulnerability index of each barangay while the independent variables were the raw data of each indicator. Equation 5 presents the regression equation as

*Barangay Vulnerability Index = 0.2521 + 0.03644**E1** + 0.01390**E2** + 0.01409**E3** + 0.02189**E4** + 0.3501**E5** + 0.0609**S1** + 0.1782**S2** + 0.7259**S3** + 0.03409**S4** – 0.048**R2** – 0.12**R3** – 0.003579**R4** – 0.002625**R5** – 0.0461**R6** – 0.0001873**R8** + 0.000143**R10** – 0.1708**R11*** (5)

Table 7. Regression Analysis Data

Exposure	P-value	Sensitivity	P-value	Resilience	P-value
E1	0.000	S1	0.003	R2	0.000
E2	0.012	S2	0.000	R3	0.402
E3	0.000	S3	0.000	R4	0.000
E4	0.000	S4	0.000	R5	0.003
E5	0.000			R6	0.056
				R8	0.021
				R10	0.049
				R11	0.000

The sub-indicators that had ($p > 0.05$) are R3 (no. of insurance coverage) and R6 (no. of communication devices) which means that it is not statistically significant. The variables R1 (No. of appliances owned) and R7 (Different types of an emergency power source) were removed from the model for the same reason it had garnered a high p-value which means that it had a high correlation with the other factor thus producing the same linear equation. The sensitivity variables from the livelihood indicator which are S5 (Income from employment and/or business), S6 (Income from agriculture and/or fishery), and S7 (Income from other sources) were also removed from the model because of acquiring 0 coefficient due to similar raw data values.

The variables that significantly contributed to the barangay vulnerability index with a p-value of ≤ 0.05 were all of the exposure indicators which are E1 (Materials used for the assembly of the walls), E2 (Materials used for the assembly of the roof), E3 (No. of the experienced typhoon), E4 (Households covered by the Marinduque flood susceptibility map), and E5 (No. of experienced landslides); sensitivity variables from demographic indicators which are S1 (No. of household residents with age 60 and above), S2 (No. of household residents living with disability), S3 (No. of household mothers that are pregnant and/or lactating), and S4 (No. of household residents below the age of 14); and the resiliency variables are R2 (No. of household vehicles owned), R3 (No. of insurance coverage), R4 (No. of emergency kits available in each household), R5 (Type of potable water source), R6 (Type of emergency power supply (EPS)), R8 (No. of educational facilities available), R10 (Household head's highest attained educational background), and R11 (No. of household residents with emergency response experience or formal training).

Table 8. Model Summary

S	R^2	R^2 (adj.)	R^2 (pred)
0.0086896	96.96%	95.76%	79.46%

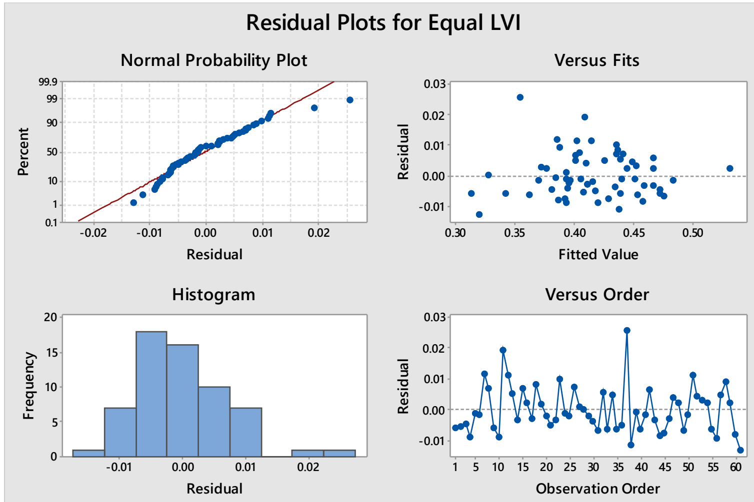

Figure 1. Residual Plots

Table 8 presents the model summary. The model garnered an R^2 (adj.) of 95.76%. The data was also tested using a backward stepwise regression which showed a decrease in R^2 (adj.) of the data, thus proving that the original regression model is a fitted model with standardized residuals of only 4 unusual or large residuals. Based on the results, it can be said that the equal weights model is a fitted model for the data. Figure 1 above shows the normal probability plot of the data. The normal probability plot shows a normal distribution with some outliers. The data of the model proves linearity with some data point exceptions that are from variables with high or unusual residuals and can be disregarded from the data set. A similar study (Prasetyo et al., 2020) using structural equation model also showed the importance of the indicators and its correlation to the vulnerability index of households in Marinduque, giving emphasis to the significance of hazards indicators such as typhoon and landslides, sensitivity indicators such as the vulnerable population, and the various resilience indicators to the overall vulnerability index. This suggests that once a certain indicator is proven and seen to have a substantial significance, it can be a basis for planning of programs and policies that would help decrease its contribution to the overall vulnerability.

4. Conclusion

This study focuses on assessing the vulnerability of barangays in the municipality of Boac, Marinduque with respect to the three (3) dimensions of vulnerability, i.e., exposure to hazards, sensitivity, and resiliency. The assessment was made to help the community minimize the danger and risks brought about by hydrometeorological hazards such typhoon, flood, and landslide. Using the index method of assessment with equal weights, the vulnerability index of each barangay in Boac was computed. The results showed that most barangays possess moderate vulnerability with 45 out of 61 barangays or 73.77% while the remaining 16 or 26.23% fall to low vulnerability category. The barangay of Tumagabok had the highest index value of 0.5535, while the Hinapulan and Mahinhin ranked 2nd and 3rd among the barangays with the highest index. The barangays with the lowest index values were Isok I (Pob.), Malusak (Pob.), Isok II Pob. (Kalamias) with index values of 0.3070, 0.3072, and 0.3279, respectively. For exposure, 55.74% has a category of very low, while 42.62% are under low exposure and 1.64% under moderate exposure. The barangays with the highest exposure index are Tumagabok with 0.1573, Maligaya with 0.1306 and Tabigue with 0.1296. The barangays with moderate sensitivity are Tanza, Cawit, and Mataas na Bayan (Pob.) with indices of 0.1450, 0.1410, and 0.1381 respectively. The percentage of barangays with very low sensitivity are 8.20%, low sensitivity with 86.89%, and 4.91% in moderate sensitivity. Those with very low sensitivity are Isok II (Pob.), Boi, and Balaring with indices ranging from 0.0560 to 0.0660. For resilience, 26.23% has very high resilience, 72.13 with low resilience, and 1.64% under moderate resilience. The barangays of Murallon, Mataas na Bayan (Pob.), and San Miguel (Pob.) have the lowest resilience with 0.1758, 0.2015, and 0.2027, respectively. While, the barangays with the highest resilience are Mahinhin with 0.2891, Tugos with 0.2836, and Tumagabok with 0.2814. The regression model identified that the significant indicators contributing to the barangays' vulnerability index were all of the exposure indicators which are E1 (Materials used for the assembly of the walls), E2 (Materials used for the assembly of the roof), E3 (No. of the experienced typhoon), E4 (Households covered by the Marinduque flood susceptibility map), and E5 (No. of experienced landslides); sensitivity variables from demographic indicators which are S1 (No. of household residents with age 60 and above), S2 (No. of household residents living with disability), S3 (No. of household mothers that are pregnant and/or lactating), and S4 (No. of household residents below the age of 14); and the resiliency variables are R2 (No. of household vehicles owned), R3 (No. of insurance coverage), R4 (No. of emergency kits available in each household), R5 (Type of potable water source), R6 (Type of emergency power supply (EPS)), R8 (No. of educational facilities available), R10 (Household head's highest attained educational background), and R11 (No. of household residents with emergency response experience or formal training. To increase the barangays' resiliency, policies and programs that focus on improving the welfare and providing adequate support and resources during emergency situations may be instituted. This includes optimizing the number of emergency responders for each barangay especially those in the moderate vulnerability category and ensuring that designated evacuation facilities are available for use and compliant to emergency facility standards.

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Biographies

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