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Riverine Flood Vulnerability Assessment Using Composite Index Approach: Case of Rice Farm Areas in Butuan City, Caraga Region, Philippines

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Abstract
Assessing the vulnerability of an area can serve as a useful planning tool in increasing the resilience to particular climate-related hazards. This study sought to evaluate the geospatial landscape status on vulnerability to riverine flood in Butuan City, Caraga Region, Philippines by integrating the actual information gathered from interviews, surveys, and GIS analysis. The analysis includes physical, agro-ecological, and socio-economic indicators clustered under the components such as exposure, sensitivity, and adaptive capacity. Key Informant Interview (KII) was conducted to assign the weights of each indicator and was determined using the Analytical Hierarchy Process (AHP). Results revealed that five (5) barangays, among 44 barangays, topped as the most vulnerable to flood attributed to exposure to riverine flooding. These barangays are attributed little ability to adjust or survive to certain hazard disturbances. Also, the adaptive capacity has contributed significantly to the entire vulnerability status of an area since its effect was influenced by the availability of the coping mechanisms of the farmers to adjust such disturbances.
Keywords: Analytical Hierarchy Process; Flood Vulnerability, GIS

Introduction

In the context of climate change, the impact of flooding on social-ecological systems is of global significance (Doch et al., 2015). Globally, it said that flood caused human casualties and injuries, considerable infrastructure damages and losses of agricultural production (Center for Research on the Epidemiology of Disaster, 2011). Floods are considered into two categories, namely, flash floods and general or river floods. This phenomenon negatively impacted the agriculture sector of the Philippines. Relatively, rice farming is among the most exposed to climate-related hazard such as flood because it is often practiced in open areas (Israel, 2012). Impacts of climate change on food production systems depend primarily on the adaptation measures undertaken by local communities (ICCG, 2016). These adaptation strategies will also apply to the complex issues on water use and food production as affected by climate change. The lack of adaptive capacities of the farmers to cope with such climatic variability increases its level towards drought vulnerability. Vulnerability to climate change is defined as: "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2007).

In the Philippines, due to its geographical and environmental setting, it has become extremely vulnerable to the impacts of natural disasters including the incidents of the effects of climate change (Senate Economic Planning Office (SEPO), 2013). SEPO (2013) quoted that “The Philippines is one of the most hazard-prone countries in the world.” At the regional scale, it has reported during 2011-2015, the north-eastern Mindanao region (Caraga) was hit by typhoons that caused tremendous agricultural damage. Typhoons Sendong, Agaton, Pablo, and Senyang have been the most publicized ones that brought disasters to the region. In 2012, Typhoon Pablo caused an estimated PHP 3.6 B damaged in agriculture in Regions 4b, 6, 7, 10, 11 12 and Caraga (NDRRMC, 2012). In Caraga, where Butuan City as the being well-known as one of the flood-prone areas in the region where all the waters of Agusan River basin empty into Butuan Bay. A study has shown that main areas in the low-lying barangays (the small political unit of the country) of the area have identified with a high degree of exposure to flood hazard which is mostly, residential, agricultural and commercial areas (Monteverde et al., 2006).

With these remarkable extreme events that significantly impacted the agricultural sector and underscored the growing vulnerabilities of the agriculture-dependent economy and livelihood of its farming communities. Hence, in this paper, we assessed the flood vulnerability status in a geospatial landscape at the municipal level by integrating the actual information gathered from surveys, GIS datasets, and employed some geospatial techniques. The result of the study is a useful planning tool in increasing the agricultural sector's adaptation measures to climate change.

Study Area Profile

Butuan City (Figure 1), a highly urbanized city of the Philippines, it is in the north-eastern part of the Agusan Valley, Mindanao. The city with a land area of 81, 662 hectares (Philippines Atlas, 2007), and boasted a population of 337, 603 (Philippines Statistic Authority (PSA), 2015). It is geographically located in Caraga Region with typical climate Type II zone where there is "no dry season with a very pronounced maximum rain period from December to February. Minimum monthly rainfall occurs during the period from March to May" according to PAGASA. The city sits below sea level and is exposed to flooding. All waters from Davao, Compostela Valley, and Agusan del Sur – the major regions in Mindanao empty into Butuan Bay (UNISDR, 2013). This situation causing several barangays along the West and East Bank, particularly the alluvial floodplain of Agusan River in Butuan City is highly exposed to flood due to its geographical location and its proximity to Butuan Bay (Monteverde et al., 2006). The selection of Butuan City, Caraga Region, Philippines as the study site is very timely and important. Aside from its accessibility and as a being "center city" in Caraga Region, people in this area still lured since ancient times because of its fertile alluvial soil, access to coastal resources and as a locus for urbanization in the region.

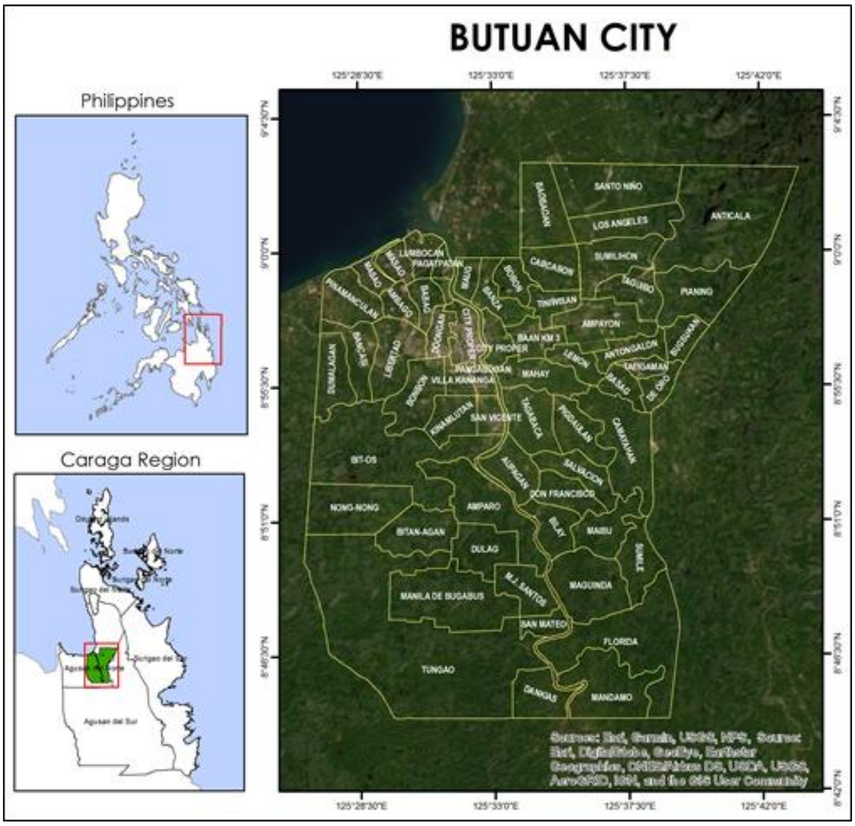

Figure 1 The Study Area: Butuan City, Caraga Region, Philippines.

**Source: Philippines political boundaries (provincial) were acquired from National Statistics Office (NSO) thru the National Mapping and Resource Information Authority while barangay boundaries (yellow lines) were acquired from the Local Government Unit of Butuan City. RGB image were extracted from ESRI.*

There were 44 barangays identified as rice farm areas in Butuan City as shown in Table 1.

Table 1: List of Rice Farm Barangays in Butuan City

Name of Barangay	Name of Barangay	Name of Barangay	Name of Barangay
Ambago	Bitan-agan	Kinamlutan	Pinamanculan
Amparo	Bit-os	Lemon	Salvacion
Ampayon	Bobon	Libertad	San Mateo
Antongalon	Bonbon	Los Angeles	San Vicente
Aupagan	Cabcabon	M.J. Santos	Santo Niño
Baan Km3	Camayahan	Maguinda	Sumilihon
Bancasi	City Proper	Mahay	Tagabaca
Banza	Doongan	Mandamo	Taguibo
Baobaoan	Dulag	Maug	Taligaman
Basag	Dumalagan	Nong-nong	Tiniwisan
Bilay	Florida	Pigdaulan	Villa Kanaga

Source: Butuan City Agriculture Office (BCAO)

Methodology

Composite index method was used to asses and evaluate the impact and level of vulnerability to riverine flood in rice farm areas. Using this method, the calculation of composite indices from indicators is a collective way of evaluating, quantifying, and communicating the vulnerability to hazards through map visualization (Wiréhn, Danielsson, & Neset, 2015). The same studies used this method include Doch et al. (2015) and Jose et al. (2017) to measure the vulnerability, particularly in the agricultural production flooding.

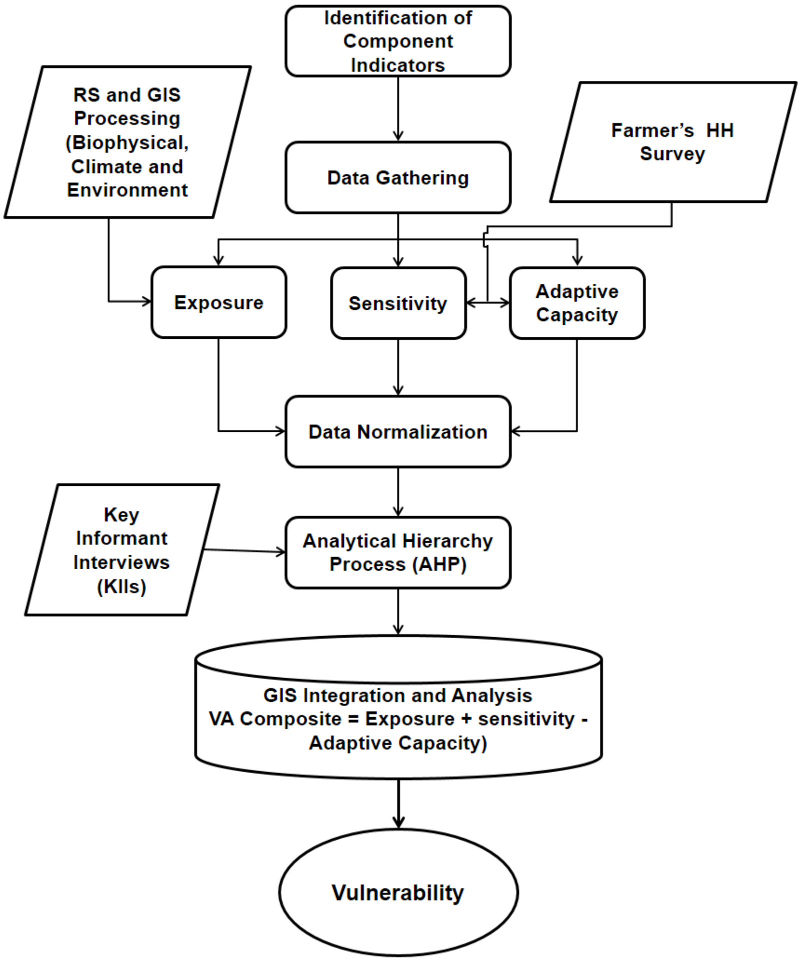

Figure 2 Vulnerability Assessment Process Workflow

Vulnerability assessment commenced once each of the component indicators (exposure, sensitivity and adaptive capacity were identified (Figure 2). Exposure component involved GIS processing of the different spatial datasets. For sensitivity and adaptive capacity indicators, the data for household survey were utilized prior to the conduct of data normalization. Key informant interviews (KIIs) was also conducted to determine the weight each of the indicator. The accumulated normalized and weighted indicators were integrated using the concept of vulnerability.

Identification of Indicators and Data Collection

Identification of the components indicators was made through focus group discussions (FGD) represented by the concerned agencies and local stakeholders. Local consultation for these indicators was also conducted to verify that these indicators are applicable in the area. Each indicator was clustered into components such as exposure, sensitivity, and adaptive capacity. Exposure component indicators were bio-physical and bio-climatic to which the rice production areas in Butuan City were exposed to significant climatic variations. On the other hand, sensitivity and adaptive capacity component indicators were socio-economic, cultural, and political aspects. The adaptive capacity indicators were the mitigating factors to which the rice productions areas were adjusted by taking some opportunities in coping the consequences.

Data collection was initiated based on the finalized indicators considered in this study. The flood hazard map of Butuan City was obtained from the Disaster Risk Reduction and Exposure Assessment for Mitigation (DREAM) Program of the University of the Philippines (UP Diliman) and Department of Science and Technology (DOST). Flood models were generated using the LiDAR data, Synthetic Aperture Radar (SAR) DEM and other datasets such as river water level and discharge, soil shapefile, land cover, meteorological data from PAGASA and DOST-Advanced Science and Technology Institute (DOST-ASTI), and the software FLO-2DS Pro (DREAM, 2016; Jose et al., 2017). Rice production areas were delineated from the generated agricultural land cover maps and Digital Terrain Model (DTM) from DOST Phil-LiDAR 2 project. The list of rice farmers and irrigated areas were acquired from the Local Government Unit of Butuan City. Soil series data was obtained from the Bureau of Soils and Water Management (BSWM) while climatic data such as rainfall and temperature were obtained from PAGASA of Butuan City. Lastly, datasets for Sensitivity and Adaptive Capacity were obtained through a farmer's household interview.

Data Normalization

The normalization method applied was linear normalization where maximum and minimum values of the data were used. It is done by getting the difference between the largest and the smallest possible value and dividing them by the difference of the largest possible and smallest possible values (range of each indicator). Linear normalization was done using the formula:

$$Z_{ij} = (X_{ij} - X_i^{min}) / (X_i^{max} - X_i^{min}) \quad (1)$$

Where:

Z_{ij} = is the normalized value of indicator i of the barangay j
X_{ij} = original value of indicator i of the barangay j
X_i^{min} = minimum value among all barangays
X_i^{max} = maximum value among all barangays

Analytical Hierarchy Process

Analytic Hierarchy Process (AHP), which is also called Saaty Method, is a complex decision-making tool introduced by Thomas Saaty. AHP is a theory of measurement primarily performed through pairwise comparisons and relies on the judgments of experts to derive priority scales. AHP was used in the assessment to determine the weights of each component indicator (Saaty, 2008). The ratings were obtained from the experts corresponding to the hierarchic structure in the pairwise comparison of alternatives on a qualitative scale. Experts have assigned the corresponding weighted scales depends on their perceived importance of each indicator compared to the other indicator. The ratings were used to fill the Saaty matrix and solve the values needed to check the overall experts' rating consistency. The ratings perceived by the experts was evaluated using the consistency ratio (CR).

Table 2: Vulnerability Component Indicators and corresponding weights obtained by AHP

Vulnerability Component	Indicator	Description	Weight
Exposure	Hazard Level	Hazard level in the barangay	0.326
	Hazard Area	The area in percent covered by the hazard over the area of the entire barangay	0.285
	Land Use	Rice production areas to total areas of the barangays	0.169
	Flow Depth	Flow depth in the barangays	0.160
	Percent Irrigation Area	The total percentage rice farms areas were irrigated (NIA, SSIPs, etc) to total rice areas	0.060
Sensitivity	Tenurial Status	Ownership of the agricultural land (i.e. owned, tenant, leased, etc	0.204
	Human Sensitivity	Ratio of number of HH - members that are elderly (65y/o<), children (>5y/o), PWD (person with disability), pregnant, with chronic illness to the total number of HH members	0.180
	% Income from Agriculture	HH Percentage Income from Agriculture to Total Income	0.116
	% Debt/Loan	Percentage HH Debt / Loan to total Income	0.083
	Membership in Farmer’s Organization	Farmer’s HH involved to any agri-related organizations	0.081
	Access to Post Harvest and Facilities	Farmer’s HH access to Post Harvest and Facilities	0.079
	Dependence Ratio	Ratio of the number of unemployed HH members to the total number of HH members	0.073
	Population Density	Ratio of the number of people per km2	0.068
	Access to Roads and Bridges	Access to various transportation media	0.063
	Level of Education	Household (HH) member with the highest educational attainment	0.053
Adaptive Capacity	Insurance	Insurance of agricultural land and/or crops	0.205
	Percent Savings	Percent assets/savings over total income	0.102
	Access to Rehabilitation Aid	HH access to rehabilitation and aid	0.094
	Access to Financial Aid	HH access to financial aid from government and/or non-government organizations	0.093
	Crop Selection	Whether crop selection is determined by season/potential hazards	0.085
	Access to Credit/Loan	HH access to loans or credits	0.075
	Access to Alternative Water Sources	Access to alternative water sources both Domestic and Agriculture	0.064
	Access to Water Treatment	Access to domestic water treatment	0.061
	% Income from Non-Agriculture	Percent of income from non-agriculture activities over total income	0.053
	Level of Farm Mechanization	Level of agricultural mechanization (e.g. use of machineries)	0.052
	Farming Experience	Length of farming experience of the HH	0.048
	Access to Training Courses	HH access to training courses focused particularly on climate variability and farming	0.037
	Means of Transportation	Means of transportation of the HH (motorized and non-motorized)	0.031

The acceptable computed CR should be less than or equal to 10% or 0.1, otherwise, rating/s should be either repeated or disregarded (Saaty, 1980). But it was acknowledged in the study Alonso and Lamata (2006) argued that tolerance can be raised to 20% which corresponds to an acceptable CR of less 0.2. Another study conducted by Jose et al. (2017) employed this acceptable threshold CR ratio. Hence, in this paper, we employed acceptable threshold ratio of 0.2.

The selection of experts was important to ensure the credibility of the result significantly influenced on it. The criteria selection of field experts was based on its familiarity of the area and the knowledge on the impact of flooding on agriculture. Five local experts were consulted to rate the level of importance of each indicator were from Academe, City Agricultural Office (CAO), City Disaster Risk Reduction Management Office (CDRRMO), Philippine Rice Research Institute (PhiRice – Agusan), and national agency. Table 2 shows the final weights of each indicator obtained by AHP and is used as suitability weights to identify the component index level towards vulnerability to riverine flood.

Component indicators with the highest rating means the most important than the other indicators. In contrast, the lowest rating means the least important compared to the other indicators towards riverine flood vulnerability. The hazard level indicator in the exposure component ranked highest (0.326) while the total percentage of rice farms areas were irrigated indicator was the lowest (0.060). The rice farms' exposure to the hazard level to a flood event is the most influenced. On the other hand, tenurial land status ranked the most significant indicator in the sensitivity component, with an average weighted rating of 0.204. Land ownership affects farmers' susceptibility, especially farmers having a tenant status where farmers must pay the rentals without failure production. While level of education of the farmer's household indicator was the lowest with an average weighted rating of 0.053. Even farmers have not attained a high education, training conducted by the respective government agency, LGUs, and NGOs has alternatively empowered the farmers.

In the adaptive capacity component, the experts emphasized that the crop covered by insurance ranked the highest among the indicators with an average weighted rating of 0.205. This study suggested that rice farmers should have crop insurance to reduce the impact to flood vulnerability. The experts believed that the agricultural products covered by insurance, farmers' household assets/saving, and access to rehabilitation aid are the best coping strategies to reduce flood vulnerability. However, the means of transportation perceived the lowest with the average weighted rating of 0.031

Vulnerability Index

Factors that influenced vulnerability are numerous. According to Doch et al. (2015) and acknowledged by Jose et al. (2017) that the scale significantly affects its vulnerability result because its scale depends on it. Hence, in this paper, the analysis was set to the barangay level. We used the political boundary from the local government unit of Butuan City and the calculations were made per barangay identified with rice production areas. The overall vulnerability was computed using the formula (Jose et al., 2017):

$$\text{Vulnerability } V = [(\text{Exposure } E + \text{Sensitivity } S) - \text{Adaptive Capacity } AC] \quad (2)$$

Results and discussion

Flood vulnerability model was constructed using the GIS platform to pre-process the spatial and aspatial datasets of the clustered components to arrive the composite indexed level. The composite indices were calculated individually by integrating the normalized datasets. Figure 3 shows the indexed level map of the three main drivers towards flood vulnerability. It can be observed that the potential impact (exposure and sensitivity) of the barangays shows the variations on how these areas and the farmers exposed and adversely affected by the flood hazard events.

The exposure component shows that three barangays (San Vicente, City Proper, and Doongan)) located close to the Agusan River have very high exposure with values greater than or equal to 0.8. Other barangays identified as high exposure to flood were validated through damaged assessment report from the local government unit of Butuan City from the year 2012-2018, where most of the rice production areas in these barangays were highly affected by flooding. Whereas barangays with higher elevation especially in the southern part of the city have low exposure indexed values. It can be noted that most of the barangays of the city are identified as moderate to highly sensitive based on the ten (10) indicators considered.

The adaptive capacity levels of the farmer's households in the barangays show from very low to moderate index level. This means that most farmers are having low to moderately coping mechanisms and strategies to counteract the effect of flood. Based on the calculated result, Taguibo, Pinamanculan, and Dumalagan with an adaptive capacity index of 0.24, 0.47 and 0.13 respectively, ranked as the most adaptive among barangays in Butuan City. The low-level adaptive capacity barangays were affected by the calculation of how the farmer's household responded in the interview. Farmers responded in the interview were occasionally implemented the available coping strategies and the support or any related program aides (monetary and non-monetary) from the local governments were not reached to them.

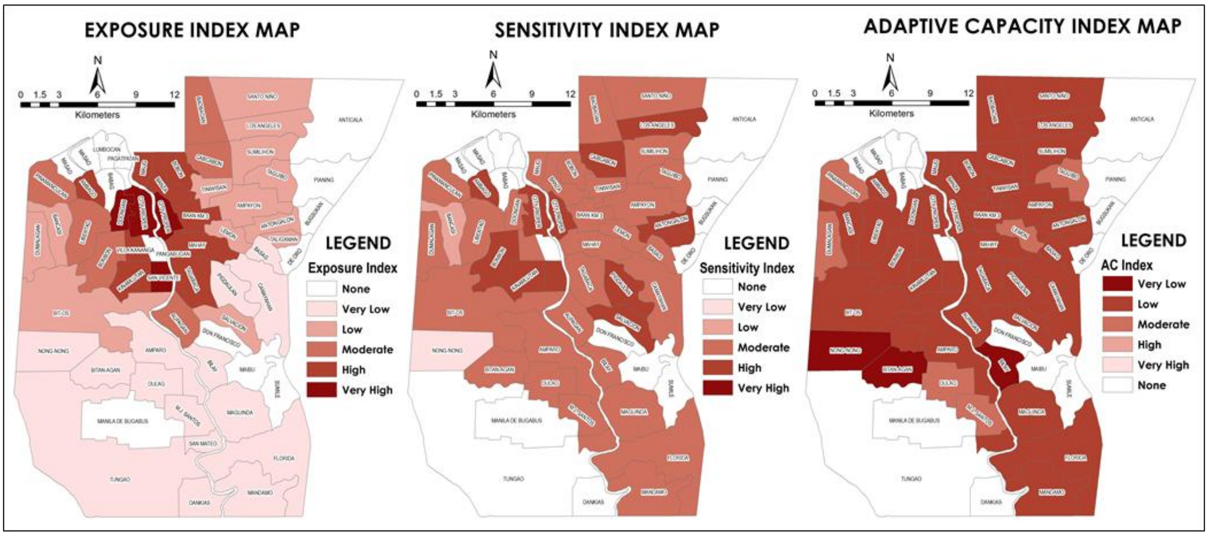

Figure 3 Component Index Map (exposure, sensitivity and adaptive capacity) towards riverine flood in Butuan City

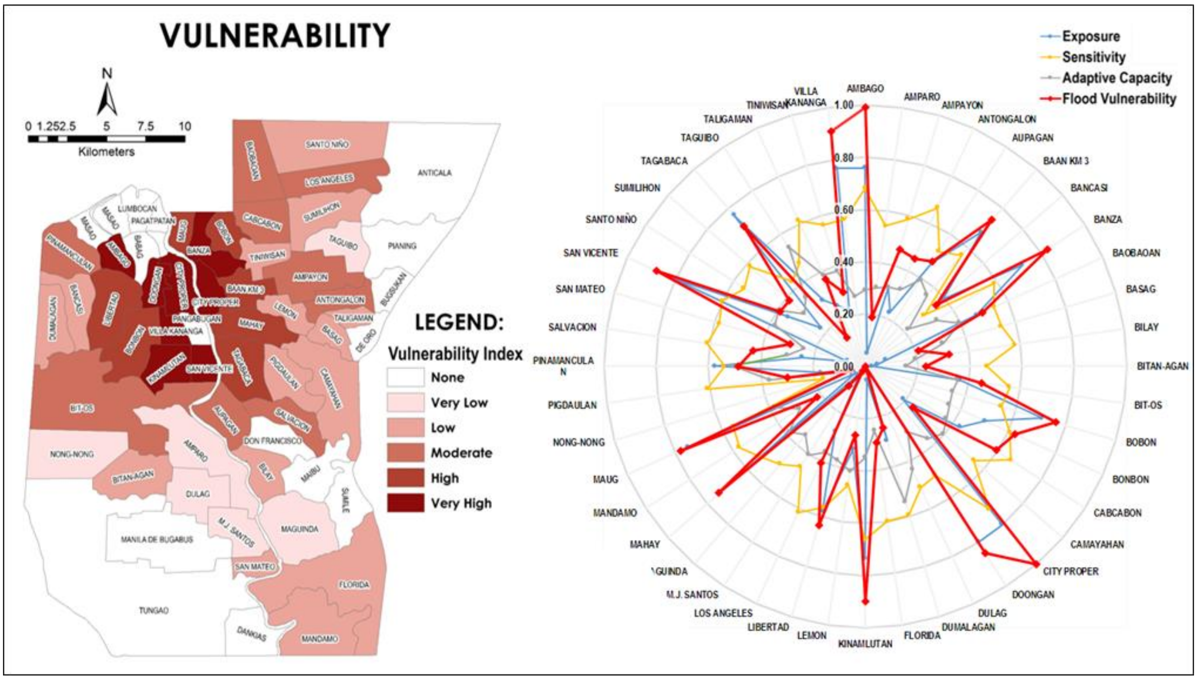

Figure 4 Riverine flood vulnerability in Butuan City, Caraga Region, Philippines

The radar graph (Figure 4) shows the vulnerability index values represented by red lines and other contributing factor values such as exposure (blue lines), sensitivity (orange lines), and adaptive capacity (grey lines). The exposure and sensitivity represent the potential impact, i.e., the combined effects of exposure and sensitivity, which may be caused by the hazard (Jose et al, 2017). Among the vulnerable barangays, City Proper ranked most (very high) vulnerable with a rating of 1.0 followed by the four next in ranked Ambago (0.99), Villa Kananga (0.91) and Kinamlutan (0.90) and San Vicente (0.87). Also, Seven barangays were also accounted as highly vulnerable with a rating greater 0.62 but less than 0.77. It can be observed that most of these barangays are located near the Agusan River and other river tributaries. Since the majority of the rice crop of these areas were exposed to riverine flood. The overflowing of flood waters from its rivers banks was one of the main drivers of inundation to the subject area.

The radar graph also shows the interaction between the adaptive capacity and potential impact (exposure and sensitivity) that affects the level of vulnerability per barangay. High results in adaptive capacity show the positive counteract effect on vulnerability. As observed in Taguibo, Pinamanculan, and Dumalagan with vulnerability ratings of 0.24, 0.47 and 0.13 respectively, tagged as top 3 high adaptive communities. These barangays have the least vulnerability due to high indexed in adaptive capacity, but moderate potential impact indexed (exposure and sensitivity) gained. When the exposure ratings examined alone, San Vicente, City Proper, and Doongan are the top four most vulnerable (exposed) barangays were observed. Finally, it can be observed that the rest barangays that fall under moderate to very low vulnerability classes are located away from the riverbanks and with high elevated areas where flooding occurrences was not prevalent. The result was validated based on the historical accounts and damage reports from the local government unit of Butuan City thru the city agriculture office.

Conclusion

The vulnerability of rice production towards flood was influenced by a number of factors. The localized indicators are very much important to consider in assessing the total vulnerability of an area. Limited coping mechanisms of the farmers in barangays could influence the degree level of vulnerability. The vulnerability map generated through this study has been made available for the local government unit of Butuan City as the basis for planning priorities and interventions. The maps on sensitivity, exposure, and adaptive capacity will be useful inputs in investment planning for agriculture, particularly in rice production for the adaptation to climate change. These maps will guide farmers and the LGU technologists to improve the coping mechanisms or strategies of the farming communities to respond to climate-related hazards and evacuation. Also, the assessment was made to inform and guide the decision makers in the area that are most need interventions.

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