ASSESMENT OF SUITABLE EVACUATION SHELTERS TO MITIGATE RISKS CAUSED BY FLOODING THROUGH INTEGRATION OF 3D BUILDING GIS DATABASE FROM LIDAR DATA AND FLOOD HAZARD MAPS

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ABSTRACT: In 2014, severe flooding occurred in the municipality of Jabonga, Agusan del Norte, Mindanao, Philippines when tropical storms “Lingling” (locally named Agaton) and “Jangmi” (locally named Seniang) brought heavy to torrential rains causing damages to both human lives and properties. Identifying buildings within the municipality that are exposed and vulnerable to flooding is important in flood disaster preparedness, risk assessment, and mitigation. In most cases, the availability of a 3D building database where each building is attributed in terms of name, type (e.g., residential, commercial, government, educational, etc.), height, ground elevation, building area, spatial location and structure type makes the required analysis fast, efficient and informative. In this paper, 3D building GIS database from LiDAR data and flood hazard maps were integrated and analyzed to assess buildings suitable for evacuation purposes before and during the flooding. This study’s output consists of series of maps showing which buildings were vulnerable to flooding of various return periods and which ones could be a potential evacuation shelter. Local Government Units and local communities of Jabonga could utilize the outputs of this study to their flood risk reduction and management plans.

1. INTRODUCTION

Mitigation policies such as evacuating people to safer areas are commonly formulated to mitigate the risks caused by flood disasters. Most evacuees depend on evacuation shelters for impermanent protection in which these shelters are practically dual usage where the primary purpose of the facility is for some other public function (Kar and Hodgson, 2008). Most evacuation shelters are always ‘dual-use’, hence, its location in disaster circumstances perhaps are less than ideal and the necessity for identifying suitable shelters is crucial. The availability of resources including transportation and shelters were factors to be considered in evacuation scenarios (Sorensen et al., 2002) because if government fail to provide these resources people may decide to stay in their homes in spite of the hazard they are dealing. However, in cases where shelter-in-place is very dangerous, people resort in moving to self-identified safe zone as soon as possible. During flood events where people are advised to evacuate immediately, some will use vehicles (if possible) and some may hike to the nearest available evacuation shelters. Thus, people were anticipated to evacuate using all the possible ways and with the available traffic network to minimize travel time out of the danger zone. Basically, during flooding scenarios, people tend to find buildings on higher elevations to seek refuge through any available means.

In this paper, we conducted an assessment of suitable evacuation shelters to mitigate risks caused by flooding through integration of 3D building GIS database from LiDAR data and flood hazard maps. This study is an extension of previous research (Santillan et al., 2015) to further innovate and utilize LiDAR outputs in mitigating risk brought by flooding to local communities. Additional information was utilized in this study and various procedures were applied to obtain the objective. In finding potential evacuation shelters, the study considers candidate buildings as those public buildings such as government-owned facilities, schools, sports center and the like (Kar and Hodgson, 2008) since these were the only buildings that are basically open to public use and have large areas, multiple floors and usually, made of concrete materials which could sustain heavy storms and flooding (Table 1).

2. THE STUDY AREA

The Municipality of Jabonga in Mainit-Tubay River Basin located in Agusan del Norte, Mindanao, Philippines was chosen as the study area. The Jabonga Municipality was one of the severely affected areas within the Mainit-Tubay River Basin during the Tropical Storms ‘Agaton’ in January 2014 and ‘Seniang’ in December 2014. Since Jabonga lies adjacent to the Mainit Lake, the municipality experienced severe flooding due to the heavy rains brought by the tropical storms which caused extensive damages in agriculture and various properties as well as the residents. Because Jabonga is a developing municipality, the area is an ideal case for the study of identifying suitable flood evacuation shelters so that the local government and the community could make use of the information resulting from this study for their disaster risk assessments and future mitigation plans. Jabonga municipality covers approximately 270 square kilometers.

Table 1. Facility types considered as candidate evacuation shelters.

Facility	Types
Healthcare	Ambulatory Surgical Center, Clinic, Crisis Stabilization Unit, Family/General Practice, Hospital, Medical Center
Community Center	Community Center
Social Services Center	Child Daycare Service, Government Offices, Health and Welfare Agencies
Cultural Center	Libraries
Civic Center	Auditorium, Conference Center, Convention Center, Civic Center
Religion Center	Center, Church

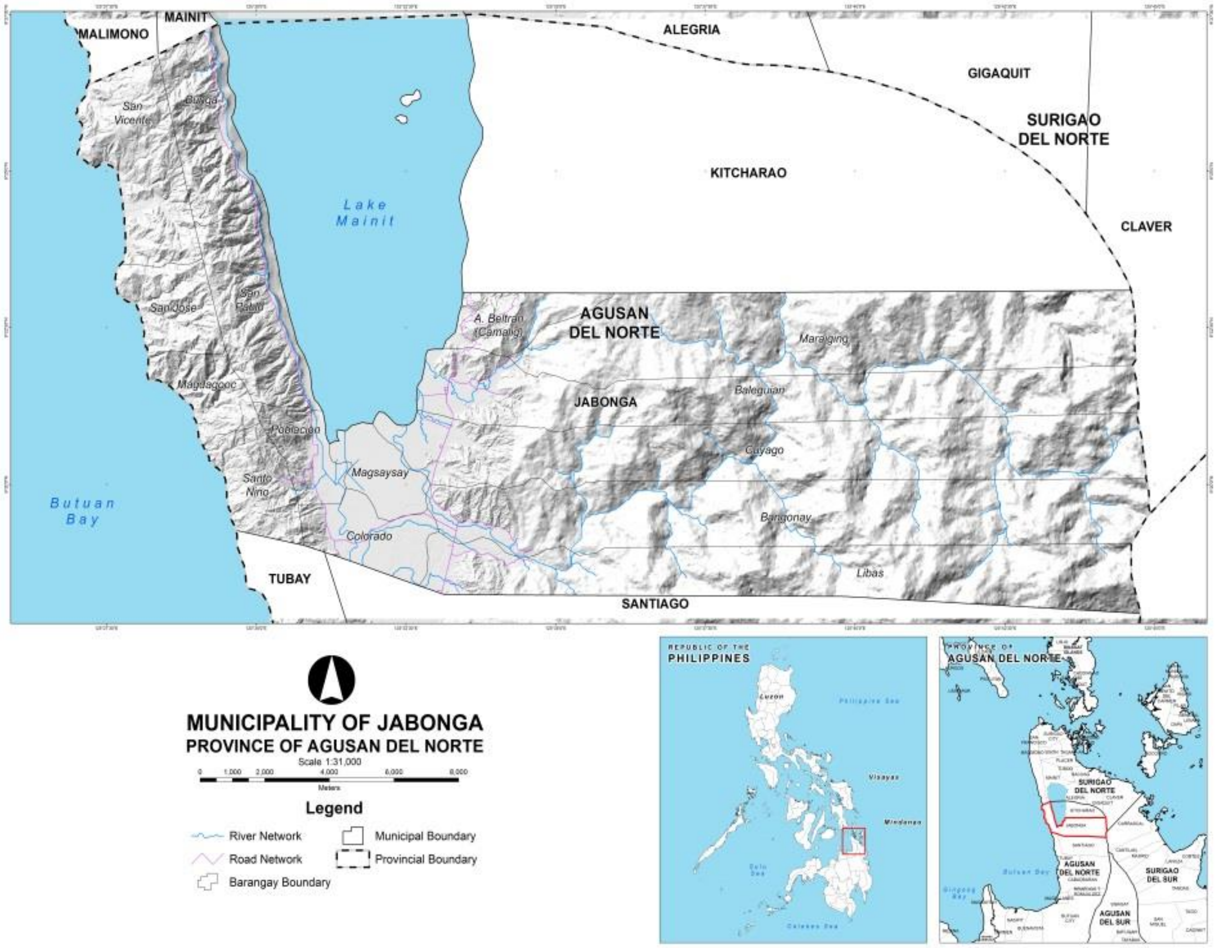

Figure 1. Map of Municipality of Jabonga, Agusan del Norte, Mindanao, Philippines

3. MATERIALS AND METHODS

3.1 Datasets Used

3.1.1 LiDAR-derived Digital Elevation Models: A 1-meter resolution LiDAR-derived Digital Surface Model (DSM) and Digital Terrain Model (DTM) was utilized for extracting the building features within the Municipality of Jabonga (Figure). The LiDAR-derived Digital Elevation Models were acquired and pre-processed by the University of the Philippines-Diliman (UPD) Phil-LiDAR 1 project and processed by the Caraga State University Phil-LiDAR 1 project. The DEMs were in ESRI GRID format with Universal Transverse Mercator (UTM) Zone 51 North projection and World Geodetic System (WGS) 1984 as horizontal reference.

3.1.2 Google Earth High Resolution Images: Extracting the building features using the DSM have some limitations which include the lack of visibility for some buildings covered with dense trees and vegetation. Thus, to supplement this limitation, Google Earth High Resolution Images were utilized in extracting the building features. These images were also used to re-check and verify the buildings extracted from LiDAR DSM.

3.1.3 Free Online Web Maps and Google Maps: Wikimapia (http://wikimapia.org/) and Google Map (https://www.google.com.ph/maps) are free online web maps which were used to acquire information such as the name and type of the buildings extracted within the municipality. However, only government buildings and various commercial establishments' information were available since residential information was private and confidential. Building type codes used in the study were provided by UP-Diliman Phil-LiDAR 1 project for attributing purposes.

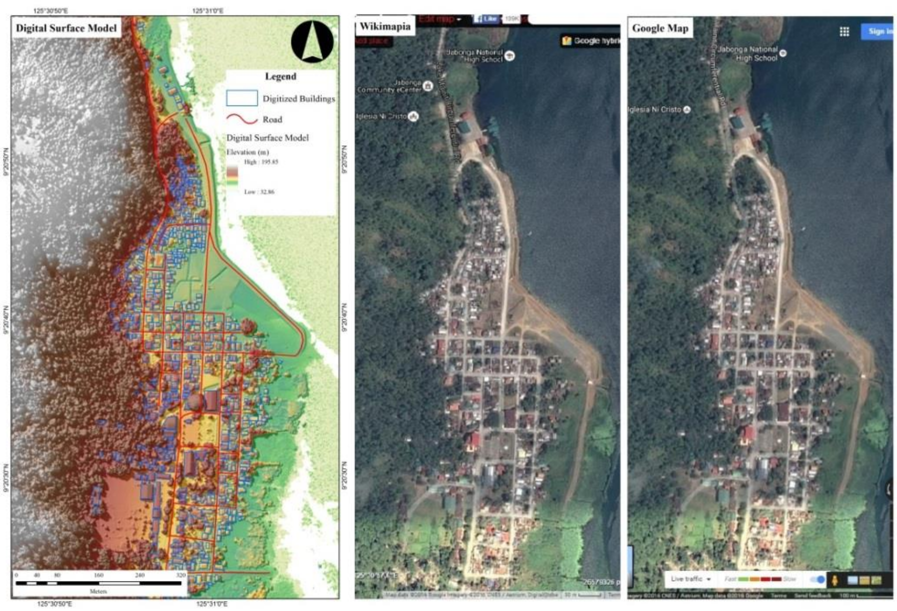

Figure 2. The LiDAR DSM of a portion of Jabonga Municipality (left), Wikimapia screenshot (middle) and Google Map screenshot (right) that were used in building attribution.

3.1.4 Flood Hazard Maps: A calibrated Hydrologic Engineering Center Hydrologic Modeling System (HEC HMS) model was used in simulating the discharge hydrographs for the hypothetical scenarios 2-, 5-, 10-, 25, 50- and 100-year rain return periods (Amora et al., 2015). The discharge hydrographs were used as inputs to Hydrologic Engineering Center River Analysis System (HEC RAS) to compute for the maximum water surface profiles within the domain for the 6 hypothetical scenarios which was converted into flood depth maps. The flood depths was categorized based on its corresponding hazard level: low hazard for depth less than 0.50 meter, medium hazard for depth from 0.50 meter to 1.50 meter, and high hazard for depths greater than 1.50 meter. By identifying which buildings were exposed to low, medium and high hazards and which were not flooded (Figure 3), the researchers assessed the vulnerability of buildings to the different flood hazards.

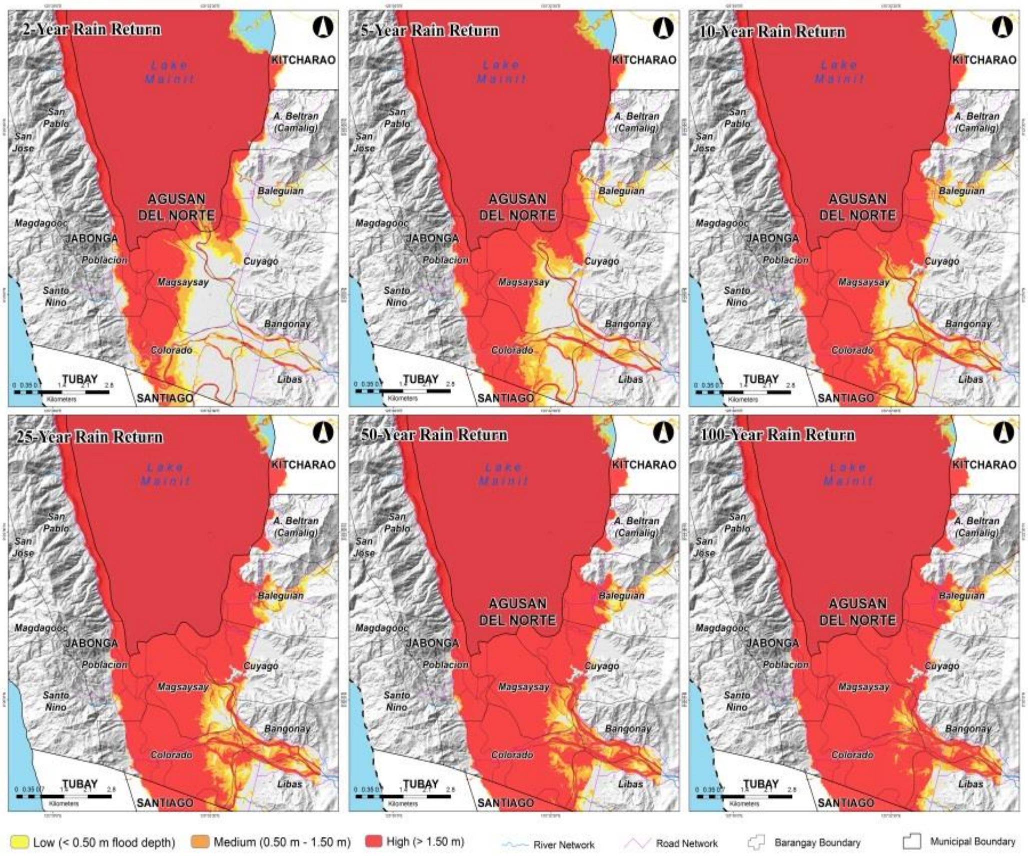

Figure 3. Flood hazard maps of Jabonga for 2-, 5-, 10-, 25-, 50- and 100-year rain return periods.

3.1.5 Building Extraction: The 1-meter resolution LiDAR-derived DSM was utilized to locate and extract building features within the Jabonga municipality through manual digitization using ArcGIS 10.1 software. For some portions in the DSM where the visibility of the buildings were insufficient to be extracted, Google Earth high resolution images were utilized. These images were also utilized in checking the extracted buildings from DSM (Santillan et. al, 2015).

3.1.6 Building Attribution and Height Estimation: Using the Wikimapia (http://wikimapia.org/) and Google Map (https://www.google.com.ph/maps), the extracted buildings were attributed with 'building name', 'building type' and 'building code' (Santillan et. al, 2015). Summary of building codes were shown in table 2. However, as stated in this study, most of the buildings attributed through the free online web maps were commercial establishments and government offices only. Nevertheless, the buildings were supplemented with information from the local government of Jabonga, especially for the residential buildings, through the help of the residents. After using all the possible source of supplementary information, buildings that were not yet attributed with building types were attributed as *unknown type*. Hence, for the main objective of this study which is to assess suitable evacuation shelters, we focus on the buildings with large areas and high height, preferably government buildings, sports center and schools.

3.2.3 Building Vulnerability Assessment: Building vulnerability assessment was practical to identify suitable evacuation shelters. In assessing which buildings have high, medium and low vulnerability, the maximum flood depths of the buildings were extracted and associated to the height of the buildings. In this paper, the vulnerability of buildings for different rainfall events of various rain return periods were assessed and after identifying which buildings were vulnerable to 2-, 5-, 10-, 25-, 50- and 100-year rain return periods, potential evacuation were selected from the buildings not vulnerable from any rain return periods (Santillan et. al, 2015).

Table 2. Summary of building codes for every building type

Building Type	Code
Agricultural & Agro-Industrial	AG
Barangay Hall	BH
Bank	BN
Factory	FC
Fire Station	FR
Gas Station	GS
Medical Institution	MD
Market/Prominent Stores	MK
Military Institution	ML
NGO/CSO Offices	NG
Other Commercial Establishments	OC
Other Government Offices	OG
Police Station	PO
Power Plant/Substation	PP
Religious Institution	RL
Residential	RS
School	SC
Sports Center/Gymnasium/Covered Court	SP
Telecommunication Facilities	TC
Fire Station	TR
Other Government Offices	WH
Other Commercial Establishments	WT

3.1.7 Suitable Evacuation Shelter Assessment: Buildings identified and attributed as government buildings, churches, schools and other public buildings which are not vulnerable to 2-, 5-, 10-, 25-, 50- and 100-year rain return periods only were considered as candidate shelters. Residential buildings which were not vulnerable to 100-year rain return period flood could be a safer preference during a flood event if the residents decide to shelter-in-place. However, residential buildings cannot be considered as an evacuation shelter since its structures, including the floor areas were not designed to sustain numerous evacuees.

Area of the building, proximity to major transportation routes and flood zones were considered significant factors to assess the evacuation shelter candidates (Kar and Hodgson, 2008; Cutter et al., 2000). During flooding scenarios, evacuation shelters must be ideally close to major transportation routes to reduce clearance time from flood hazard zones to the shelters (Kar and Hodgson, 2008; Wisner and Adams, 2002). FEMA and American Red Cross (ARC) indicated that shelters should not be located within a 100 year flood zone (Kar and Hodgson, 2008), hence in this study, suitable evacuation shelters should not be vulnerable to a 100-year rain return period flooding. Closer to major transportation routes are more suitable than the far ones and locations farther to flood hazard zones were more desirable than the closer ones. Each factor was weighted to create a suitability score. The areas of the buildings were classified into 5 equal intervals and were given a weight of 5 for area with the largest area and 1 for the smallest ones. The distances to transportation routes were classified into 5 classes of equal intervals and were given a weight of 5 for buildings closest to transportation routes and 1 to the buildings farthest to the roads. The distances to flood zone areas were classified and weighted in the same manner. A perfect score of 15 means that the buildings were suitable as evacuation shelter considering the three factors. A score of 15 means the building have the largest area, farthest to flood zones and closest to roads.

4. RESULTS AND DISCUSSION

4.1 Building Database

Utilizing all possible information from online web maps and the local government of Jabonga, there were 2,539 buildings extracted, 975 of which is identified and attributed (Figure 4). Out of 975, there were 1 barangay hall (BH), 1 hospital (MD), 1 market (MK), 1 non-government building (NG), 1 commercial establishment (OC), 1 government office (OG), 7 churches (religious institutions), 929 residential buildings (RS), 25 public schools (SC), and 1 sports center (SP). The remaining 1,564 buildings which are attributed as unknown type (UT) were excluded in the evacuation shelter suitability assessment, including 929 residential buildings.

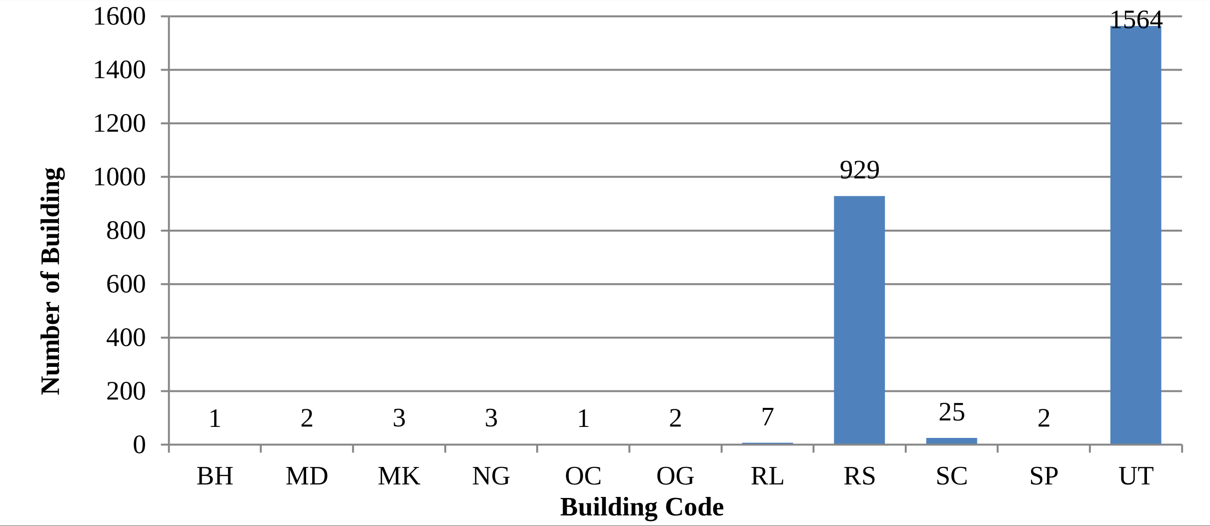

Figure 4. Number of buildings attributed according to building type.

4.2 Flood Hazard Exposure of Building

Figure 5 depicts the number of buildings exposed to different flood hazards for various rain return periods. As shown on the figure, the numbers of not flooded buildings decreases and the buildings on high hazards increases as the rain return period approaches to 100 years.

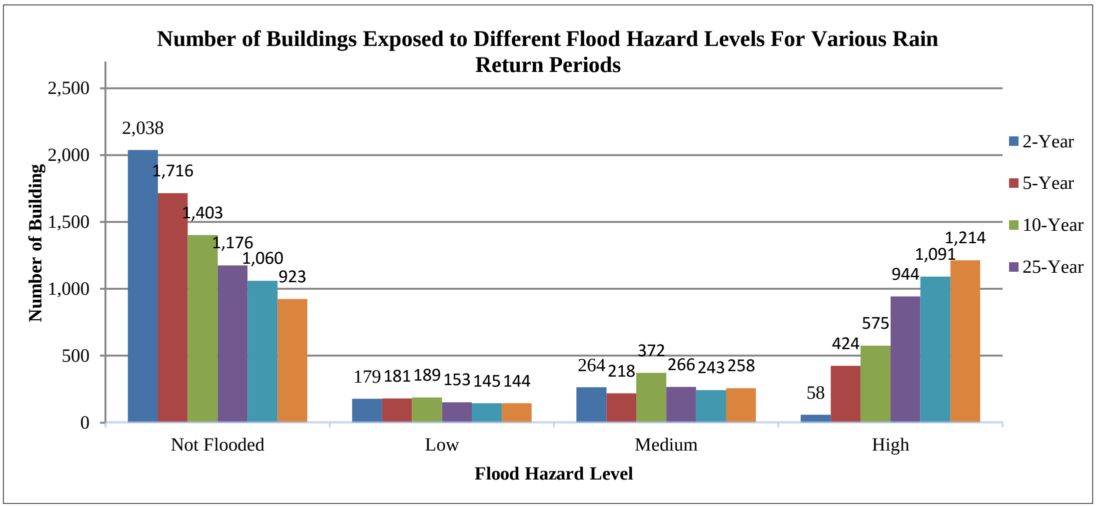

Figure 5. Number of buildings exposed to different flood hazards of 2-, 5-, 10-, 25-, 50- and 100-year rain return periods.

4.3 Vulnerability of Buildings to Flood Hazard

Shown in Figure 6 are the building vulnerability maps that were generated. The statistics of building vulnerabilities are show in Figure 7. It can be observed the numbers of vulnerable buildings increases as the rain return period approaches to 100 years, simultaneously, resulting to a decrease in the number of not vulnerable buildings.

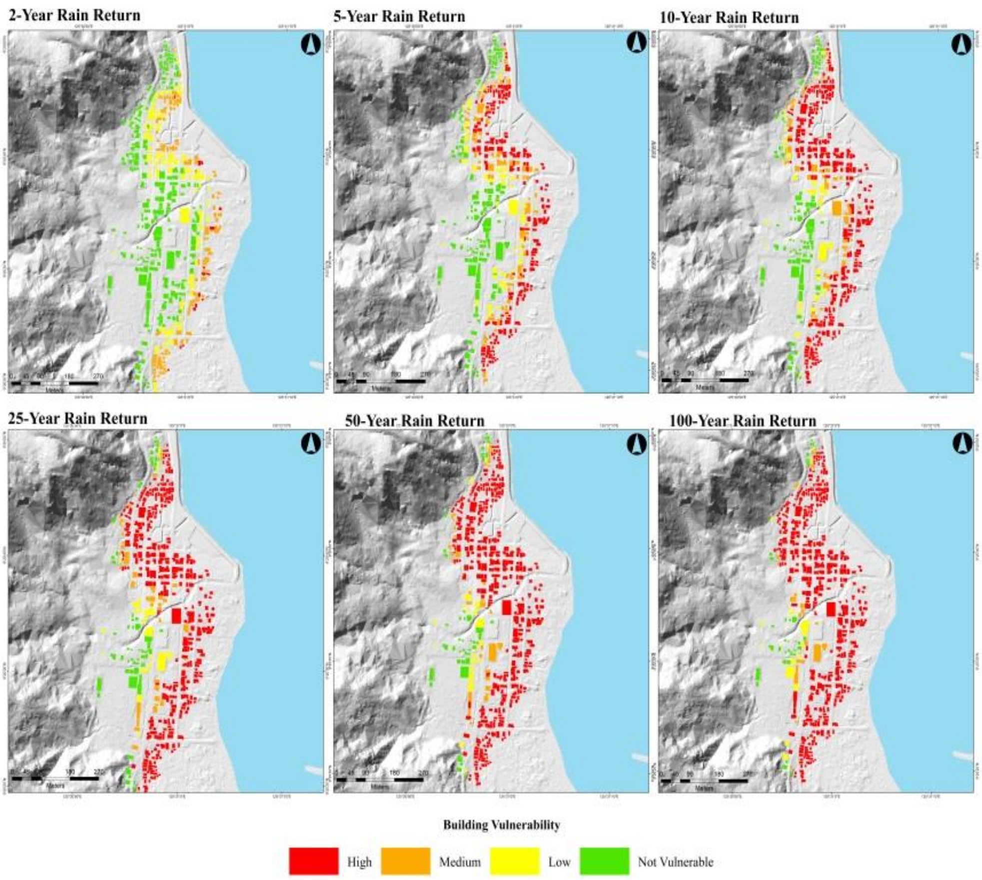

Figure 6. Building vulnerability maps of Jabonga Municipality for 2-, 5-, 10-, 25-, 50- and 100-year return periods based on the different flood hazards for the corresponding rain return periods.

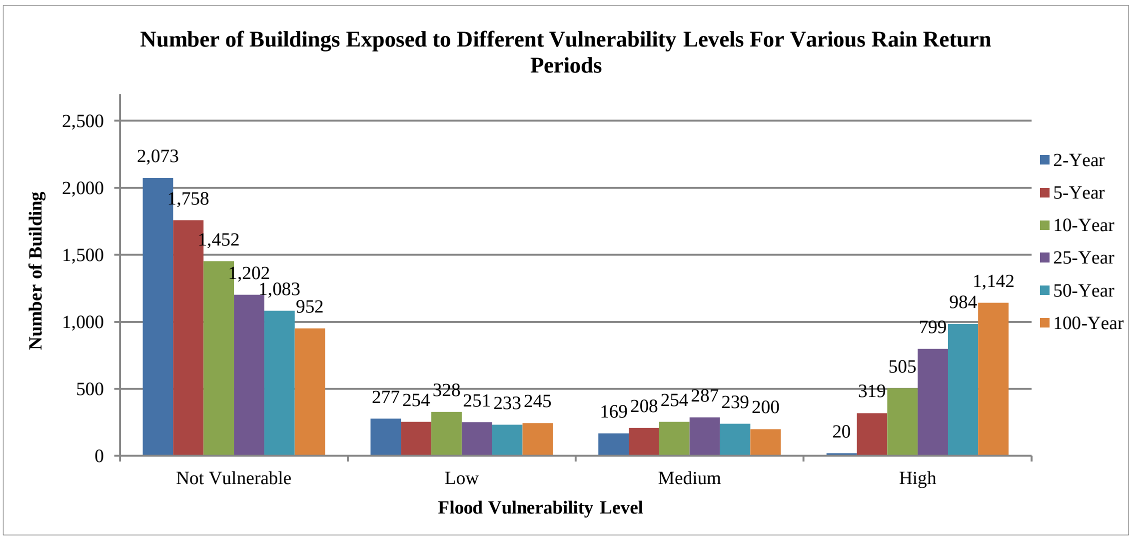

Figure 7. Numbers of buildings under different vulnerability level for 2-, 5-, 10-, 25-, 50- and 100-year rain return periods.

4.4 Candidate Evacuation Shelters

Buildings not vulnerable to a 2-, 5-, 10-, 25- and 50-year rain return period floods were still vulnerable to a 100-year return flood, since shelters should not be located within a 100-year return flood according to FEMA and ARC, this study considered the buildings suitable to evacuation shelters if they were not vulnerable to a 100-year return flood. There were 952 buildings not vulnerable to a 100-year rain return flood (Figure 8, Figure 9), however, out of 952, 731 were attributed as unknown type and 204 were residential buildings. Hence, a total of 17 buildings were identified as government buildings, churches or schools and were not vulnerable to a 100-year return flood. They were assessed for suitable evacuation shelter of this study considering the availability of resources the municipality only have at present.

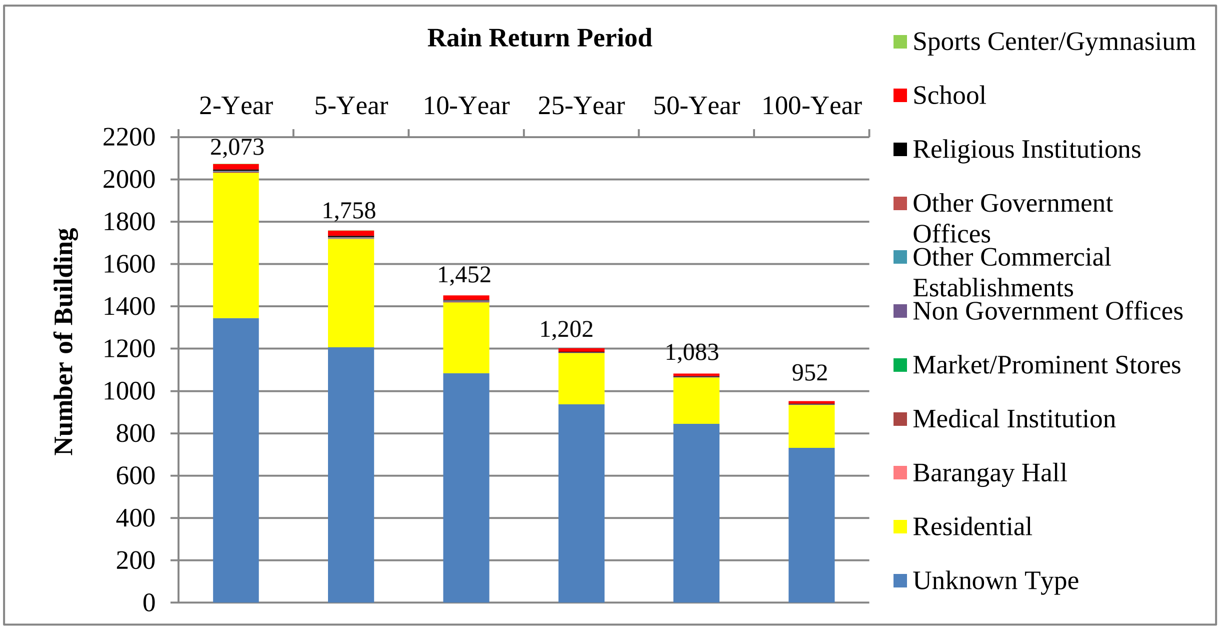

Figure 8. Number of buildings considered as candidates for evacuation shelters for various rain return periods.

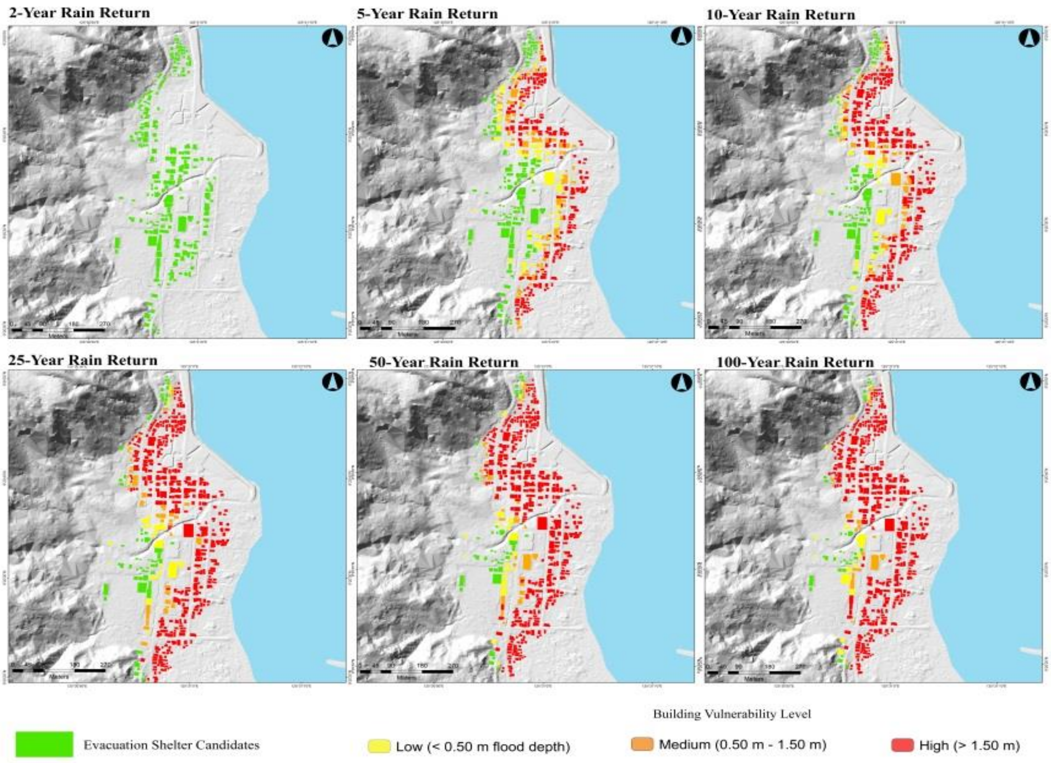

Figure 9. Map of the buildings identified as candidate for evacuation shelters.

4.5 Evacuation Shelter Suitability Assessment

Results of the evacuation shelter suitability assessment (Table 3) showed that the highest score calculated was only 9, hence, considering only the available buildings suitable for evacuation purposes, the buildings with score of 9 were considered as highly suitable. Out of 17 buildings, 1 were less suitable, 8 were moderately suitable and 8 buildings were highly suitable to be an evacuation shelter.

The values of the areas shown in Table 4 are based from the minimum and maximum area of the 17 buildings identified as suitable evacuation shelters. The areas were weighted for the purpose of identifying which buildings were more suitable compare to other buildings. Proximity to roads and flood zones were weighted in the same manner as the area given that, buildings closer to roads were more suitable, and buildings closer to flood zones were less suitable. The building with large area, closer to roads and farther to flood zones will more likely be a highly suitable building for flood evacuation. The building with the lowest score of 5 is a non-government office with an area of 126.80 square meters, 109.81 meters from the road and 6.15 meters from the flood zone area. Most of the high suitable buildings were near from major transportation routes and has larger areas.

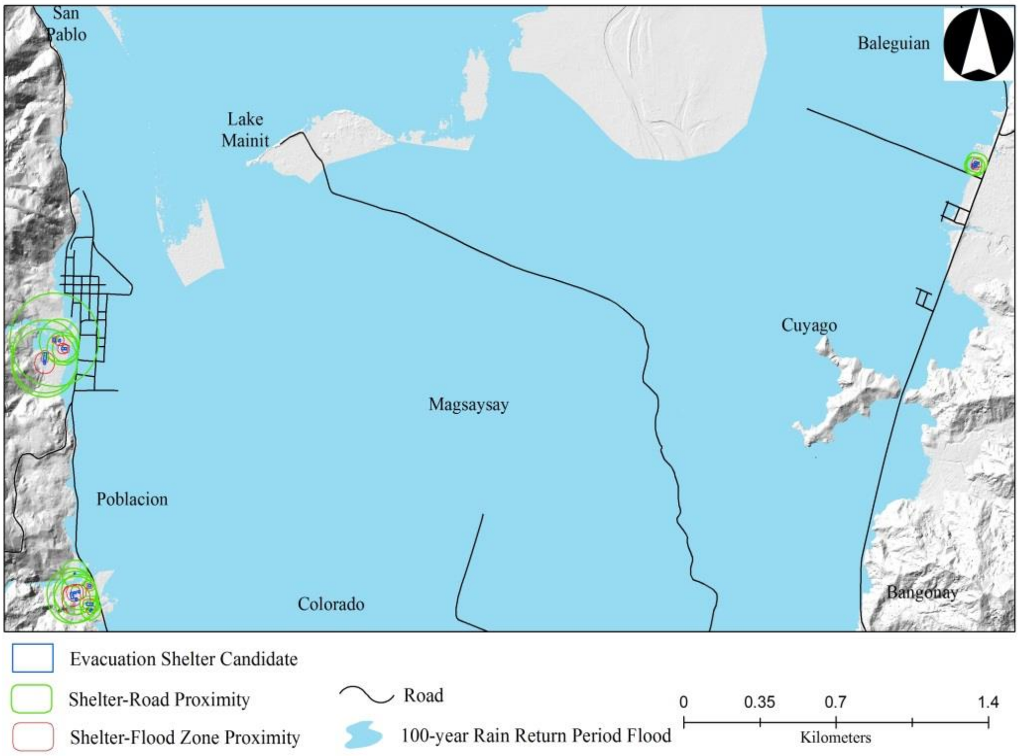

Figure 10. Map showing the 17 candidate evacuation shelters with proximity to transportation roads and flood zone areas.

Table 3. Tabulated summary of the 17 buildings suitable for evacuation shelter with the corresponding weighted sum and suitability level.

No.	Code	Height (meter)	Area (square meter)	Proximity to Transportation Routes (meter)	Proximity to Flood Zones (meter)	Weight			Score	Suitability Level
						Area	Proximity to Transportation Routes	Proximity to Flood Zones		
1	NG	6.59	126.8	109.81	6.15	2	2	1	5	Low
2	NG	5.85	94.87	87.2	15.73	1	3	2	6	Medium
3	SC	3.22	126.05	66.27	17.04	2	4	2	8	High
4	SC	3.26	113.96	53.69	12.24	1	4	1	6	Medium
5	SC	3.99	399.47	143.88	8.45	5	1	1	7	Medium
6	SC	5.62	99.99	144.77	40.55	1	1	4	6	Medium
7	SC	3.59	41.77	55.15	0.45	1	4	1	6	Medium
8	MD	3.35	119.71	17.6	7.51	2	5	1	8	High
9	SC	4.88	338.36	106.79	32.91	4	2	3	9	High
10	SC	3.09	91.14	91.23	32.8	1	3	3	7	Medium
11	SC	3.86	97.45	73.39	28.48	1	3	3	7	Medium
12	SC	3.16	104.44	96.15	60.87	1	2	5	8	High
13	SC	3.54	318.48	29.57	15.73	2	5	2	9	High
14	SC	5.77	98.37	37.42	13.65	1	5	2	8	High
15	RL	2.76	128.06	34.73	9.62	2	5	1	8	High
16	RL	2.49	60.18	35.1	6.46	1	5	1	7	Medium
17	RL	4.9	202.49	37.29	11.58	3	5	1	9	High

Table 4. Area of the candidate buildings classified in 5 equal intervals and their corresponding weights.

Area	Weight
41.77-113.31	1
113.31-184.85	2
184.85-256.39	3
256.39-327.93	4
327.93-399.47	5

Table 5. Distances of the candidate buildings to flooded areas classified into 5 equal intervals and their corresponding weights

Distance to Flood Zone	Weight
0-12.53	1
12.53-24.62	2
24.62-36.70	3
36.70-48.79	4
48.79-60.87	5

Table 6. Distances of the candidate buildings to major transportation routes classified into 5 equal intervals and their corresponding weights.

Distance to Road	Weight
0-43.03	5
43.03-68.47	4
68.47-93.90	3
93.90-119.33	2
119.33-144.77	1

Table 7. Sum of the weights of the candidate buildings from the weight of the area, proximity to flood zones and transportation routes classified into 3 equal intervals and assigned with corresponding suitability level.

Score	Suitability Level	Count
2-5	Low	1
6-7	Medium	8
8-9	High	8

CONCLUSIONS AND FUTURE WORKS

The study identified only 17 buildings suitable to flood evacuation shelters. These buildings were not vulnerable to a 100-year rain return period flood and were classified into low, medium and high suitability level and only 1 building were identified as low suitable building to be a temporary flood evacuation shelter. 8 buildings were moderately suitable and 8 were highly suitable. However, the identified shelters were only for temporary short-term evacuation plan, thus, for a long-term evacuation strategy, the local government of Jabonga should consider building infrastructures for flood evacuation purposes. Residential buildings not vulnerable to flooding could be a safe roof incase the residents decide for a shelter-in-place, however, it could not be considered as evacuation shelter since residential building structures were designed to sustain only limited amount of people. Though buildings have various vulnerabilities, all groups threatened by flood could evacuate during an impending disaster, hence, a strategy could be effective in one case but ineffective in the other. Therefore, disaster preparedness would be possible through a cooperative work between the community and the government.

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