EXPOSURE AND VULNERABILITY ASSESSMENT OF BUILDINGS EXTRACTED FROM LIDAR DERIVED DATASETS IN THE FLOOD PLAINS OF STO. TOMAS RIVER BASIN, ZAMBALES, PHILIPPINES

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ABSTRACT: The Philippines is a tropical country that is strongly affected by monsoon and typhoon occurrences annually. Typhoons that cause floods due to torrential rains may cause great risks in man's life and properties. Earth observations, Light Detection and Ranging (LiDAR) and Geographic Information System (GIS) which are important tools in disaster risk management were integrated, considered and utilized in this study. This paper dealt with mapping and assessment of buildings exposure and vulnerability to flooding in Santo Tomas River Basin, Zambales, Philippines through GIS overlay analysis from the outputs of the CLSU PHIL-LiDAR 1 Project, the 3D building GIS database and flood hazard maps. The 3D building GIS database was generated through analysis of various datasets that include 1m resolution LiDAR Digital Elevation Models (DEMs), geo tagged video captured data and high resolution images in Google Earth. The flood hazard maps with different hazard levels were generated with the use of flood models developed using the combined HEC HMS and HEC RAS. Results of this study were series of flood exposure maps and vulnerability maps with statistics at different rainfall scenarios. It was observed that buildings exposed and vulnerable to flood are highest at 100 year return period. With the total of 42,173 building features extracted, the accounted number exposed to hazard at 100 year return period were 24,738 buildings, 12,670 buildings and 4,620 buildings at low, medium and high hazards, respectively. A total of 8,938 buildings, 12,259 buildings and 4,556 buildings were identified that had high vulnerabilities to flood in terms of height at low, medium and high hazards, respectively. These maps can provide valuable informations to the local government units and the communities around Santo Tomas river basin in their flood disaster management and preparedness.

1. INTRODUCTION

1.1. Background of the Study

Flooding is a serious and costly hazard that the Philippines face regularly during monsoon and typhoon occurrences. Flood is defined as extremely high flows or levels of rivers, lakes, ponds, reservoirs and any other water bodies, whereby water inundates outside of the water bodies area (Tambunan, 2007). Flooding also occurs when the sea level raises extremely or above coastal lands due to tidal sea and sea surges. In many regions and countries, floods are the most damaging phenomena that effect to the social and economic aspects of a certain area (Smith et, al., 1998). Due to excessive rainfall in a short period of time caused by natural phenomenon, flooding is a frequent hazard in the flood plains of Santo Tomas River that cause tremendous losses in terms of property and life.

Many flood plains have been occupied by residential areas and industrial parks during the last few decades. In some cases, nearby rivers have been confined in narrow strips by dikes, and cheap and attractive land has been reclaimed. Towns and village areas have been declared as residential areas and, therefore, many potential buyers of property were assured that no flood hazards are to be feared (Kron, 2005). The identification and mapping of flood prone areas are essential for risk reduction. The flood hazard maps display flood hazard information in a given area which can be used in area development and management planning. In the twenty-first century the need to study both exposure and vulnerability as fundamental components of risks has been heightened by the International Strategy for Disaster Reduction, supported by a new focus directed towards the disaster reduction through effective risk management. In the Hyogo Action Framework 2005 to 2015, governments from the whole world were certain to take measures in reducing exposure and vulnerability to natural threats (UNISDR, 2005).

Exposure can be defined as the assets and values located in flood-prone areas (IPCC, 2012). Together, exposure refers to the location of people or economic and social assets in hazard-prone areas subject to potential losses. They are also commonly referred to as "elements at risk". Vulnerability characterizes the circumstances of a community, system or tangible assets that make the subject susceptible to damage and losses from a hazard (UNISDR, 2011b).

As topography is one of the major factors in most types of hazard analysis, the LiDAR data have become a major source of digital terrain information (Raber et al., 2007). LiDAR is a remote sensing technology characterized by precise vertical and horizontal point accuracy (Yunfei, 2008) and is significant for several applications that includes the generation of Digital Terrain Models (DEM) and Digital Surface Models (DSM) and building footprint extraction (Ruijin, 2005). With the existing modern LiDAR technology integrated with some forms of field data within GIS boundary, a better visualization of interactive map overlays and quickly illustrate which areas of a community are in hazard of flooding. Such maps can then be used to coordinate mitigation efforts before an event and recovery after the event (Noah Raford, 1999 as cited in Awal, 2003).

In this study, the mapping and assessment of buildings exposed and vulnerable to flood in the flood plains of Santo Tomas river basin in Zambales was conducted and the generation of the 3D building GIS database that was used for the assessments was also presented. The assessments was done through GIS overlay analysis using the CLSU PHIL-LiDAR 1 Project flood hazard maps outputs and generated 3D building GIS database. This study focuses on identifying the number of buildings exposed to different flood hazard depth at varying rainfall return periods.

The general objective of the study was to generate a 3D Building GIS database and determine the buildings exposure and vulnerability (in terms of height) to flood hazard at varying rainfall return periods in Santo Tomas River basin. Specifically, this study aimed to:

- generate a 3D building GIS database for the Santo Tomas River flood plains.
- map the buildings exposure and vulnerability to flood hazard in Santo Tomas River's basin using GIS
- assess the buildings exposure and vulnerability to flood at different rainfall scenarios with varying intensity and duration.

2. MATERIALS AND METHODS

2.1. The Study Area

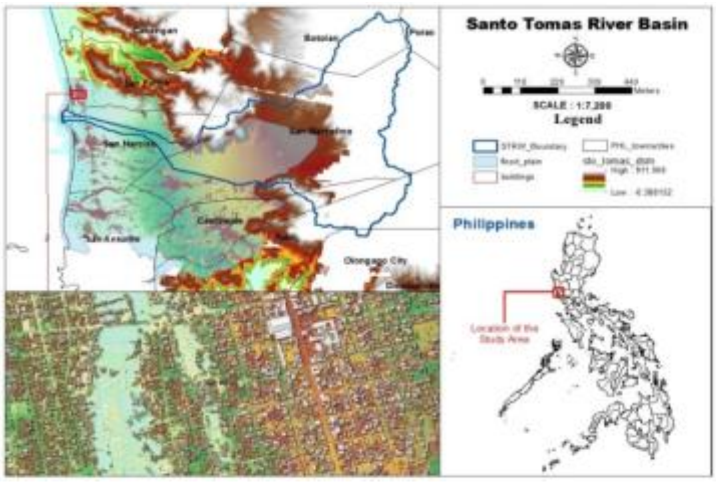


Figure 1. The Santo Tomas River Basin in Zambales, Philippines.

Santo Tomas River is located in the Province of Zambales, Central Luzon, Philippines (Figure 1). Santo Tomas river basin has a total area of 261.22-km^2 with an approximately 313.53-km^2 GIS generated flood plain area. Santo Tomas River is a joined larger river of Marella and Mapanuepe Rivers with the Mapanuepe lake as confluence. The watershed is located in the southern part of the province of Zambales. Bounded on the North by municipalities of Botolan and San Felipe; on the South by municipalities of Subic, Castillejos and San Marcelino: on the West by South China Sea/Philippine Sea: and on the East by Mount Dutdut bordering the province of Pampanga (DENR, 2008). The 6 municipalities in the Province of Zambales were covered by the GIS generated flood plain area of Santo Tomas river basin. These municipalities are the Municipality of San Felipe, San Antonio, San Narciso (at the lowest portion of the river), San Marcelino, Castillejos (at the upper portion of the river) and partly of the municipality of Subic. The 235-km^2 alluvial plain below the junction is populated by some 140,000 inhabitants in five municipalities, each with numerous barangays and sitios (Umbal and Rodolfo, 1992).

2.2. Datasets used

The LiDAR derived Digital Surface Model (DSM) and Digital Terrain Model (DTM) with 1-m resolution acquired and processed by UPD PHIL-LiDAR 1 project were used for the extraction of building footprints in the flood plains of Santo Tomas River basin. These Digital Elevation Models (DEMs) have the Mean Sea Level as vertical datum and were delivered in ESRI GRID format with Universal Transverse Mercator (UTM) Zone 51 North projection and the World Geodetic System (WGS) 1984 as horizontal reference.
For improved accuracy in building footprints extraction, Google Earth images were utilized in rechecking of the existence and shapes of the extracted features from LiDAR DSM where created fishnet of rectangular cells was

overlaid and served as a guide in both building footprint extraction and existence rechecking in Google Earth. Extracted building features were also verified and field validated with the use of video-tagging device or geo tagged video capturing tool wherein informations such as name and type were gathered. The provided table from UPD PHIL-LiDAR 1 project containing a summary of different types of buildings with corresponding codes for the building type attribute.

The flood depth maps generated and by CLSU PHIL-LiDAR1 project were used as input in buildings flood exposure and vulnerability assessment. These flood depth maps represent maximum depth of flooding due to rainfall events with varying intensity and duration (i.e., return period of 5, 25and 100-year). Flood depth maps were transformed into flood hazard maps by categorizing the flood depths in hazard levels as follows: low (< 0.5m depth), medium (0.5 - 1.5 m) and high (> 1.5 m). In order to determine the reliability and accuracy of the generated flood depth maps to the observed flood depths in the area, field validation was conducted. Based from the results of the data from the field, the models had indicated a positive bias with an RMSE value of 0.84 which signify that the generated flood hazard maps can produce a reliable exposure and vulnerability assessment.

2.3. Generation of Building GIS Database

2.3.1. Building Features Extraction

For a more accurate number of buildings in the study area, features were manually digitized where footprints were traced using the polygon feature type from the LiDAR Digital Surface Model using ArcGIS 10.2 software. The existence and shape of the extracted buildings were checked using the corresponding high resolution Google Earth due to the reason that some buildings and their extents were indistinguishable in the DSM.

2.3.2. Building Features Attribution

Table 1. Building types with corresponding codes that were used in the buildings attribution (UP-PHIL-LiDAR).

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

All building features extracted were attributed following the various building types as shown in Table 1. With the use of the integrated Spatial Analyst in GIS, automated buildings height extraction from normalized Digital Surface Model (NDSM) was performed. The normalized DSM represents the height of the object from the terrain which was produced with the difference between Digital Surface Model (DSM) and Digital Terrain Model (DTM). The building height range that was considered are greater than or equal to 2-m. Therefore, digitized buildings with height of less than 2-m were deleted. This assumes that only those features which are having the said height are considered as buildings.

2.4. Generation of Flood Hazard Maps

Through the CLSU PHIL-LiDAR 1 project, Flood depth maps were generated and used as input in building flood exposure and vulnerability assessment in the flood plains of Santo Tomas River basin. The flood depth maps were generated by the use of the developed flood model of the river basin from the combined HEC HMS hydrological model and HEC RAS hydraulic model. The flood depth maps represent maximum depth of flooding due to rainfall events with varying return periods (5-, 25-, and 100-year return periods) where the discharges or flow data inputs were the computed 5, 25 and 100-year return period of rainfall events in the Santo Tomas river watershed. These flood depth maps were transformed into flood hazard maps by categorizing the flood depths into hazard levels as low (<0.50 m depth), medium (0.50 m – 1.50 m depth), and high (>1.5 m depth). Figure 2 displays the Santo Tomas flood hazard maps at 5-year, 25-year and 100-year return period, respectively.

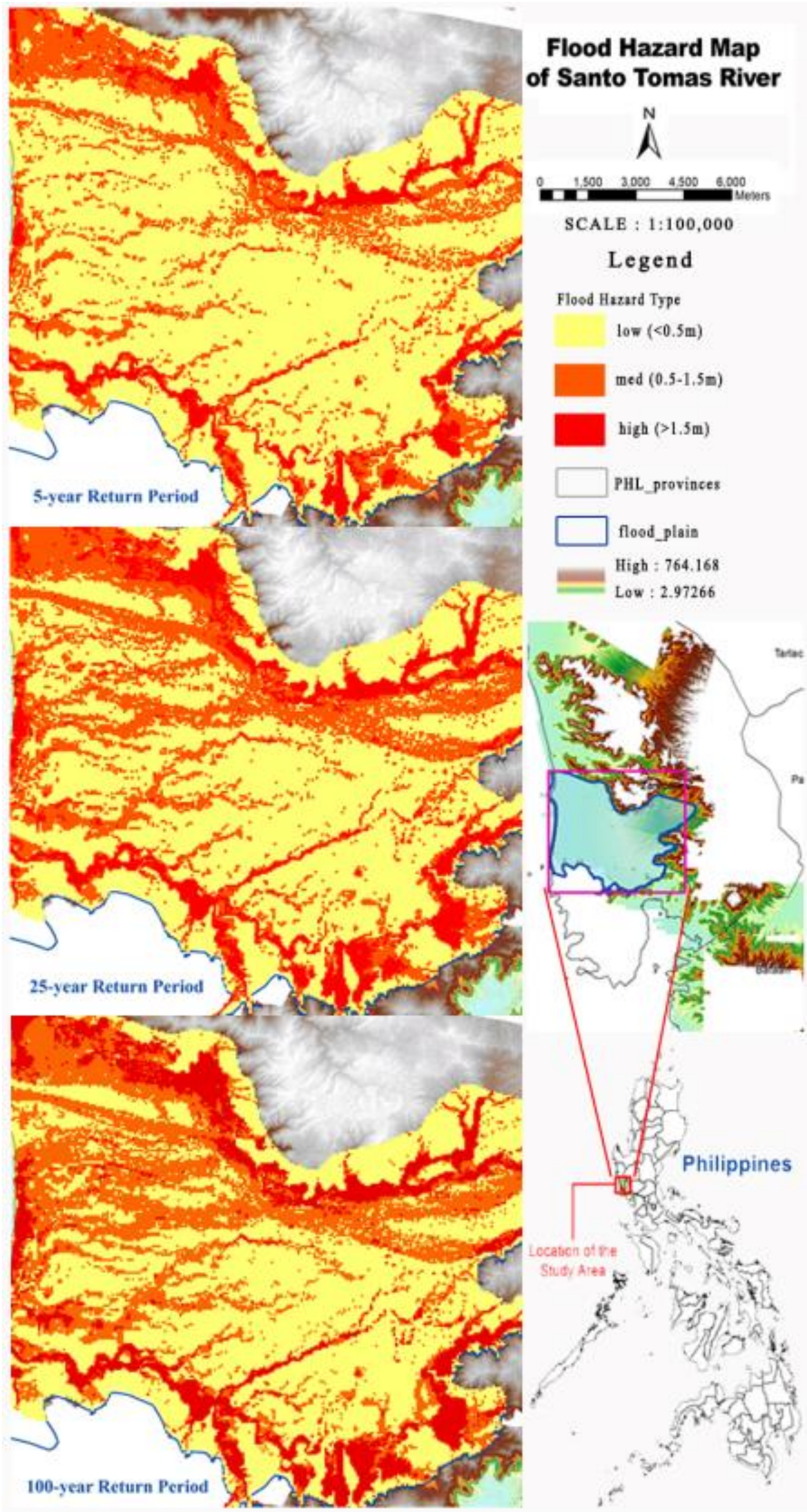


Figure 2. The flood hazard maps of Santo Tomas River at varying rainfall return periods.

2.5. Buildings Exposure and Vulnerability Assessment

GIS overlay analysis of the 3D building GIS database and flood hazard maps for the Santo Tomas river basin was conducted to identify which buildings are exposed to various levels (low, medium, high) of flood hazards. For the determination of buildings vulnerability in the flood plains of the River basin, the degree of buildings exposure to flood was characterized with the comparison of buildings height and simulated flood depths. If the flood depth is less than 0.10 percent of the building's height, then it was coded as "Not vulnerable". If the flood depth is 0.10 to less than 0.30 of the building's height, then the vulnerability was "Low". On the other hand, if the flood depth is equal to 0.30 but less than 0.50, then the vulnerability was medium. If the flood depth is greater than or equal to 0.50 of the building's height, then the vulnerability was high.

3. RESULTS AND DISCUSSION

3.1. GIS Buildings database

The extracted buildings as shown in Figure 3 were saved as GIS shape files. The number of extracted and attributed buildings according to type is presented in Figure 4 where a total of 40, 838 equivalent to more than ninety six percent (96.83%) were identified as residential buildings and the remaining 1,335 equivalent to three percent (3.17%) consisted the other building types.

Figure 3. The extracted building footprints in the flood plains of Santo Tomas River.

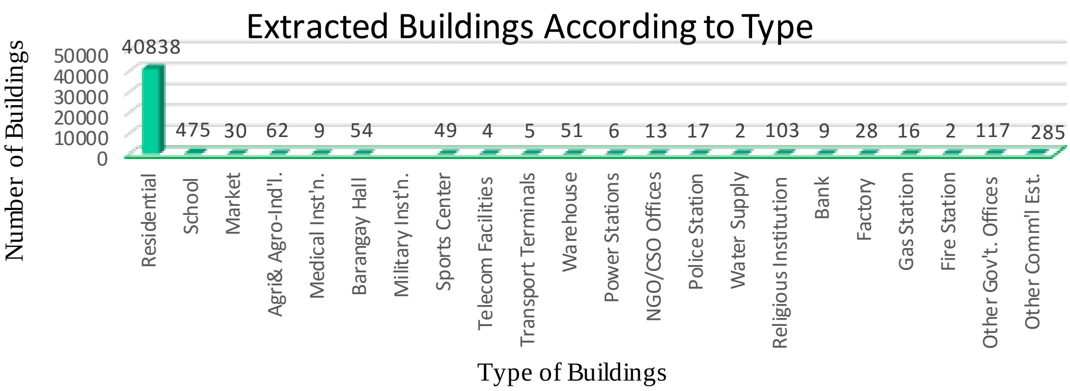


Figure 4. Extracted buildings with attributes in Santo Tomas River flood plain according to type.

3.2. Buildings Exposure to Flood Hazard

As a result of the study, statistics show that the number of buildings affected by flooding increases as the rainfall return period also increases. Majority of the buildings appeared to be flooded in all considered rainfall scenarios. This result might be due to the reason that the riverbed of the Santo Tomas River is higher than the ground level by 6.7 m (maximum) or 1.9 m (average) on the left bank side. On the right bank side, the riverbed is higher than the ground level by 2.4 m (maximum) or 0.5 m (average) as of May 2002 due to the lahar deposits from the Mount Pinatubo 1991 eruption (DPWH, 2003). Figure 5 shows the total number of buildings exposed to flood hazard at different rainfall return periods. For flood-affected buildings, more buildings are exposed to low flood hazard levels than those in medium and high hazard levels. A total of 70.35 percent, 15.54 percent and 2.38 percent of the total buildings exposed at 5-year rainfall return period, 70.04 percent, 20.97 percent and 6.49 percent of the total buildings exposed at 25-year rainfall return period and 58.66 percent, 30.04 percent and 10.95 percent of the total buildings exposed at 100-year rainfall return period were at low, medium and high hazard levels, respectively. Consequently, the total number of buildings at 5-year medium hazard levels increased to 35 percent and 93 percent at 25-year and 100-year hazard levels, respectively, while the number of buildings exposed to 5-year high hazard was increased to 172 percent and 360 percent at 25-year and 100-year hazard levels, respectively. Majority of areas in the flood plain of the river basin where buildings are located are relatively prone to flooding, which also means of high hazard level where many lives and properties are at risk in an instance of flooding. Figure 6 shows the number of buildings according to type that are exposed to flood hazard at different rainfall return periods.

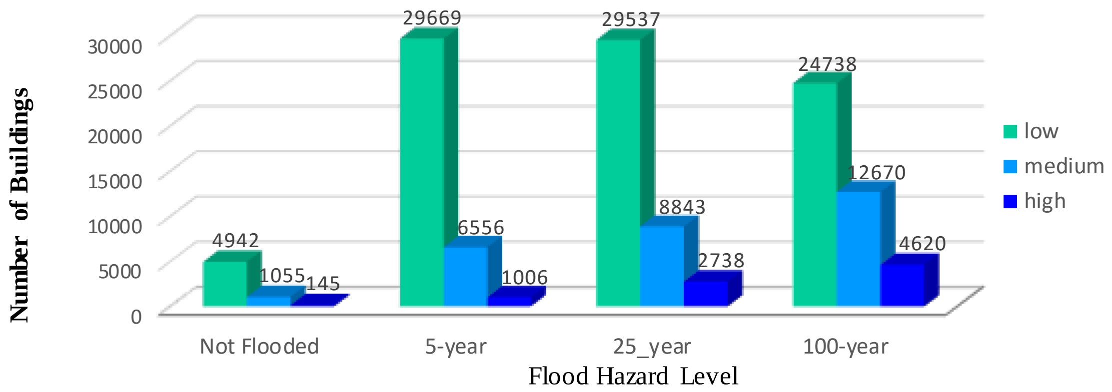
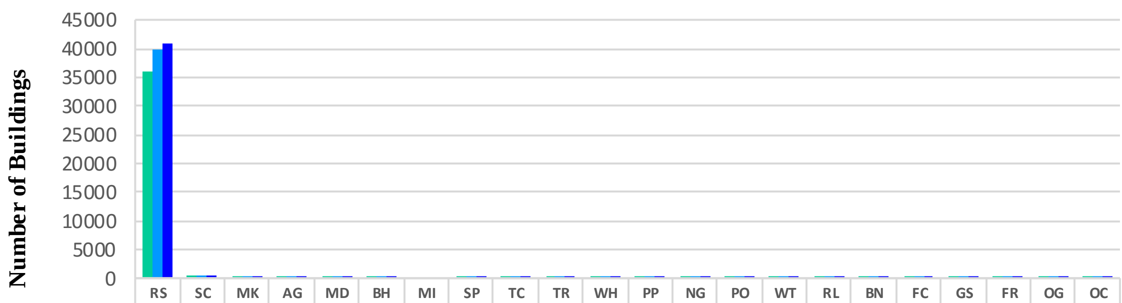


Figure 5. The number of buildings exposed to different hazard levels at varying rainfall return periods.



	RS	SC	MK	AG	MD	BH	MI	SP	TC	TR	WH	PP	NG	PO	WT	RL	BN	FC	GS	FR	OG	OC
5-year	36033	415	24	57	8	49	0	46	4	5	44	5	13	15	2	93	9	26	15	2	101	265
25-year	39803	470	24	62	8	55	0	48	4	4	51	5	13	16	2	100	9	28	16	2	117	281
100-year	40714	470	24	62	8	55	0	47	4	5	51	5	13	16	2	100	9	28	16	2	117	280

Figure 6. The number of buildings exposed to flood hazard according to type at varying return periods.

3.3. Buildings Vulnerability to Flood Hazard

From the building's height and simulated flood depths comparison, statistics show that the number of buildings vulnerable to flooding increases as the rainfall return period also increases where those vulnerable buildings are equivalent to 30 percent, 53 percent and 61 percent of the buildings exposed to flooding at 5-year, 25-year and 100-year return periods, respectively. Figure 7 displays the total number of buildings vulnerable to flood hazard at different rainfall return periods.

Based on the graphs in Figure 7, buildings under medium hazard are highest in number followed by buildings under low hazard. Comparing the results of buildings exposed and buildings vulnerable to flooding, most of the buildings exposed to medium and high hazard are vulnerable to flooding with an equivalent of 98.6 percent and 96.8 percent for medium hazard and 98.9 percent and 98.6 percent for high hazard at 25-year and 100-year return period, respectively, which implies a high rate of risk in times of flooding. However, all result for the building's vulnerability assessment were all based on height and other factors and engineering parameters such as structural components were not considered. Figure 14 shows the number of vulnerable buildings according to type at different rainfall return periods.

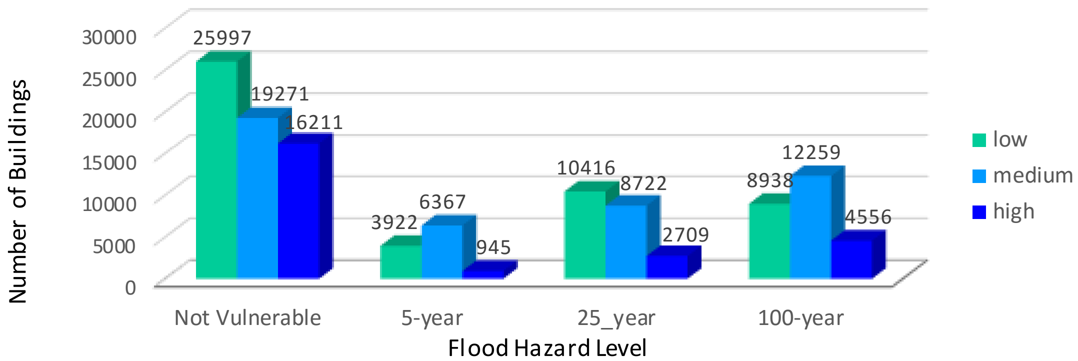
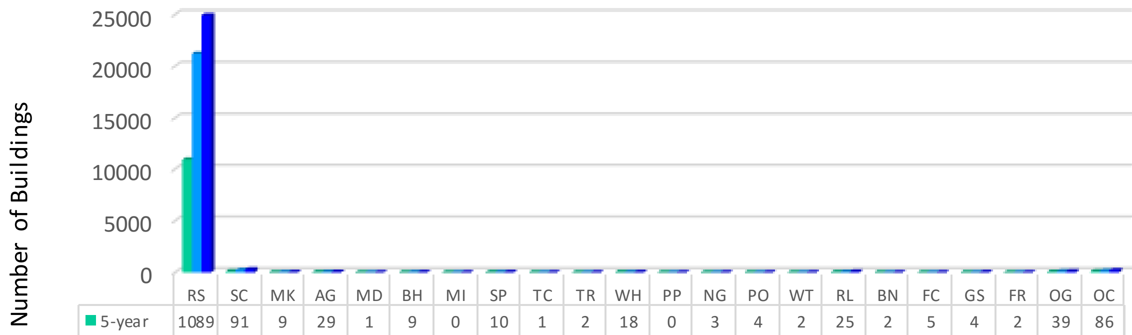


Figure 7. The number of buildings vulnerable to flood in terms of height at different hazard levels.



	RS	SC	MK	AG	MD	BH	MI	SP	TC	TR	WH	PP	NG	PO	WT	RL	BN	FC	GS	FR	OG	OC
5-year	1089	91	9	29	1	9	0	10	1	2	18	0	3	4	2	25	2	5	4	2	39	86
25-year	2118	214	14	41	2	27	0	16	1	2	25	0	5	8	2	48	6	2	9	2	85	151
100-year	2490	282	16	51	5	31	0	26	2	3	33	3	6	9	2	59	7	4	12	2	95	199

Figure 8. The number of buildings vulnerable to flood hazard according to type at varying return periods.

4. CONCLUSIONS AND RECOMMENDATIONS

The 3D building GIS database of Santo Tomas river basin was generated with the integrated modern LiDAR technology and Geographic Information System software. The buildings identified and attributed had a total of 42,173 that consists of 96.83 % residential buildings and 3.17% other building types such as government and private owned buildings. The created building database and flood hazard maps used for the GIS overlay analysis produced a series of building exposure and vulnerability maps corresponding to the 5-year, 25-year and 100-year return period rainfall events.

Although the vulnerability assessment was only based on the building height, it can still be very useful and informative for the community in areas where their building locations were identified to be exposed and vulnerable to flooding. The statistics and maps generated is a valuable information to the residents and local officials of the possible danger when a particular rainfall event of specific return period is expected to occur. Furthermore, the locations of the buildings exposed and vulnerable to flooding identified can be used in undertaking appropriate measures for the possible flood disaster to prevent or reduce loss of life, injury and other environmental consequences.

Due to lack of other necessary data for the analysis during the time that this study was conducted, the analysis were only based on the height of the buildings extracted. It is recommended to expand the analysis where formal engineering decision analysis will be considered.

5. ACKNOWLEDGEMENT

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