Assessment of physical vulnerability to flood in Saint Lucia. Case studies: Castries old Central Business District and Dennery Village

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April, 2015

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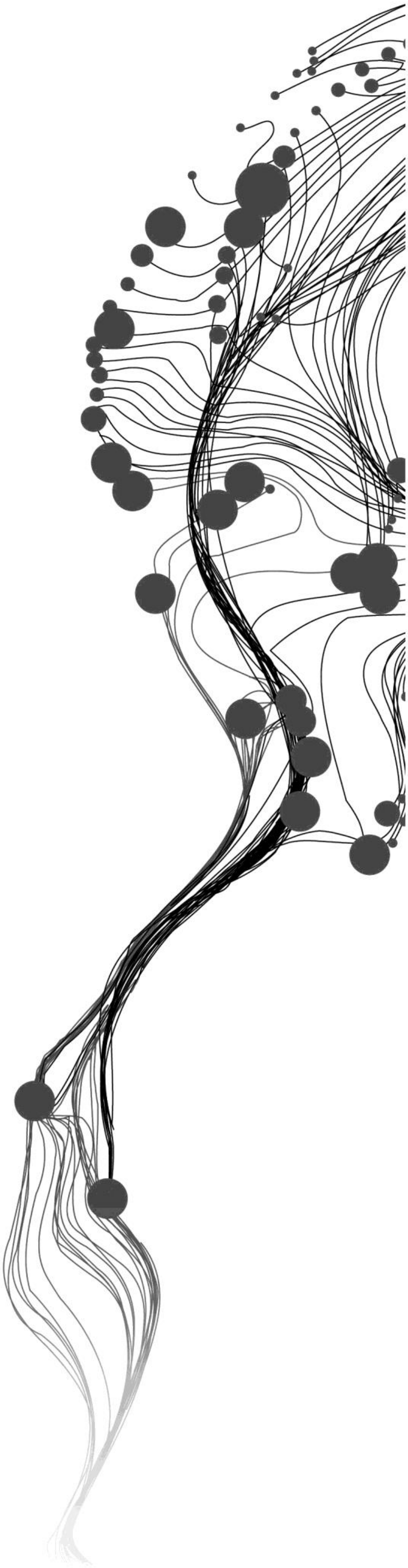

Assessment of physical vulnerability to flood in Saint Lucia. Case studies: Castries old Central Business District and Dennery Village

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Enschede, The Netherlands, April, 2015

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Hazards and Disaster Risk Management

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ABSTRACT

Castries old Central Business District (CBD) and Dennery Village, in Saint Lucia are confronted by the occurrence of floods. Both study areas have experienced a substantial amount of loss from the impact of floods. This research is focused on assessing the exposure and vulnerability of the elements at risk to floods in the study areas.

The method of data collection for the assessments was through the use of a participatory approach (voluntary mapping) by the local people. This proved to be effective in achieving the objectives of the research. Data on building characteristics for 536 buildings and 339 buildings were collected through the participation of the volunteers at Castries old CBD and Dennery Village, respectively. Furthermore, additional building and population characteristics were collected at 94 households during the household interview at Dennery Village.

Exposure analysis was carried out to assess the exposure of buildings and population during the December 2013 flood event, at Dennery Village. The result indicated that the buildings and population had a low exposure during the event. However, this result can be improved through the use of an improved flood map.

Physical vulnerability assessment of buildings was conducted using two methods, namely, depth-damage and Spatial Multi-Criteria Evaluation (SMCE). The depth-damage method was used to assess the vulnerability of building structures of the households that were affected by the December 2013 flood event at Dennery Village. Eight common structural types were found in the study area during the building inventory. However, out of these eight types, the interviewed households had four structural types. The relationship between flood depth and damage for the four structural types was plotted into a vulnerability curve. From the assessment it was observed that the most vulnerable structural type of building from the interviewed households is the structural type made of wood wall, wood floor, and galvanized iron sheet roof. While the least vulnerable is the structural type made of concrete wall, ceramic tiles floor, and painted steel sheet roof. The SMCE method was used to assess the physical vulnerability of the entire buildings in Castries old CBD and Dennery Village. The weights assigned to the selected 'factors' and 'classes' were derived during an expert session with stakeholders (experts) from the island. From the assessment, 14% and 32% of the buildings in Castries old CBD and Dennery Village, respectively, were found to be highly vulnerable to floods. A comparison of the physical vulnerability maps of buildings produced from the two methods was conducted at the Dennery Village study area. The outcome of the assessment showed that the vulnerability values of the buildings from both maps are not comparable.

Keywords:
Saint Lucia; Flood; Exposure; Physical Vulnerability Assessment; Voluntary Mapping.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Background

The world is faced with an increase in disasters due to natural hazards, which often leads to great loss in the society. Hundreds of millions of people are killed and every year millions are injured, affected or displaced. According to International Council for Science (2008) most disaster losses originate from climate related hazards like hurricanes, floods, landslides, heat waves and drought; and current evidence has shown that global climate change will continue to increase the frequency and severity of these hazards.

The risks associated with natural hazards are constantly increasing due to urbanization, rapid population expansion, and widespread poverty in hazard-prone areas (International Council for Science, 2008). For example, most of the largest cities in the world are located in either coastal or seismically active regions, which are dangerous. Also, certain activities of the people increase the risks, like changes in land use which can increase landslides and flooding; destruction of mangroves that can reduce the impact of storms in coastal areas; and slash and burn type of agriculture that contributes to greenhouse gases which increases global warming.

Saint Lucia is confronted with the occurrence of natural hazards including floods. Its location in the Atlantic Hurricane belt makes it highly exposed to tropical storms and hurricanes that often results to floods (Global Facility for Disaster Reduction and Recovery, 2010). Notable storms include Hurricane Allen (1980), Tropical storm (later Hurricane) Debby (1994), Tomas (2010), and tropical storm (Christmas Eve 2013).

The damage and losses as a result of flooding is much and impedes on the growth and development of the country. Disaster statistics of PreventionWeb (Disaster Statistics - Saint Lucia - Americas - Countries & Regions - PreventionWeb.net, n.d.), shows that a considerable amount of damage, deaths, and affected people from 1980-2010 results from storm events. Recent example was the passage of a tropical weather trough in December 2013 which resulted to combined damage and losses of US$ 99.8 million, which is an equivalent of 8.3 percent of the island's GDP (Fisseha, 2014). The event led to widespread flooding in Central Castries and Dennery village, several people had to be evacuated from flood-inundated houses because the water depth was up to five feet (1.5 meters); and some bridges where damaged or overrun by flood (Freak Storm Devastates Saint Lucia, Dominica and St Vincent on Christmas Eve | Caribbean Book Blog on WordPress.com, 2013). Another example was Hurricane Tomas in 2010 with a total impact estimated at US$ 336 million, affected major sectors of the economy and diminished growth to roughly 34 percent of the island's GDP (Fisseha, 2014).

Saint Lucia is highly vulnerable to floods due to activities by the people such as, the use of substandard materials for construction; lack of uniform enforcement of building codes; lack of legal title (land ownership/tenure) which has led to unsustainable land use and poor conservation practices (Global Facility for Disaster Reduction and Recovery, 2010). In addition, most of the island's economic and critical infrastructures such as seaports, airport, fuel storage, water production for the north of the island, and roads are concentrated along the coast or on low-lying reclaimed coastal areas of Castries (Miller et al., 2012). Furthermore, the location of most towns, including Castries old Central Business District (CBD) and Dennery Village, in relatively flat stream valleys adjacent to the coast makes them highly susceptible to storm surge and floods. The conversion of upper watersheds to agricultural land use has resulted to an increase in rainfall runoff which has consequently increased the potential for coastal flood.

The impact of floods on the built environment and population can be reduced by a proper physical vulnerability assessment. On the other hand, identification and estimation of the exposed buildings and population will aid in defining areas of priority for effective planning and mitigation strategies. Thus, vulnerability assessment (including physical) is an essential step to reduce the negative consequences of natural hazards on the vulnerable society or exposed elements at risk (Fuchs et al., 2012).

1.2. Problem Statement

As discussed above, major towns of Saint Lucia including Castries old CBD in Central Castries and Dennery Village are being affected by the impact of floods. Several factors have made it difficult to conduct a proper physical vulnerability assessment in the island, including both study areas. They include lack of adequate and sufficiently detailed geospatial data, and non-incorporation of local knowledge (Opadeyi et al., 2003). In terms of lack of data, the building footprint of both study areas does not have the necessary attributes required for physical vulnerability assessment. Consequently, conducting a proper risk assessment in both study areas and the entire island is difficult or even impossible.

There has not been any precise physical vulnerability assessment in both study areas due to some of the reasons outlined in the preceding paragraph. Therefore, this research is aimed at identifying and collecting the required data that can be used for conducting a physical vulnerability assessment of buildings and population to floods in both study areas. Additionally, the research intends to incorporate the knowledge and participation of the local people as the main method for data collection.

1.3. Research Objectives

The main objective of this research is to identify and collect relevant characteristics for assessing the physical vulnerability of buildings to floods; and to carry out an exposure analysis.

To achieve the main objective the following sub-objectives are defined:

1. To assess the feasibility of collecting the required characteristics of elements at risk with voluntary mapping during field survey.
2. To carry out an exposure analysis of buildings and population in Dennery Village study area.
3. To conduct vulnerability assessment of buildings using two different methods, namely depth-damage and Spatial Multi Criteria Evaluation (SMCE).

1.4. Research Questions

1. Is the use of voluntary mapping for collecting the characteristics effective?
2. How is the exposure of buildings and population in Dennery Village to the December 2013 flood event?
3. Which structural type of buildings are the most vulnerable in Dennery Village?
4. What percentage of building structures is highly vulnerable in Castries old CBD and Dennery Village?
5. Are the results derived from physical vulnerability assessment of buildings using both methods comparable?

1.5. Project framework or cooperation with other groups

This research is part of the World Bank project-Caribbean Handbook for Risk Information Management (CHARIM) funded by the African, Caribbean and Pacific Group of States-European Union (ACP-EU). The project started in February, 2014 and will end in 2015. The main aim of the project is to build the capacity of government organizations in the Caribbean region including Saint Lucia; to develop flood and landslide hazard and risk information that will be applied in disaster risk reduction use cases with a focus on planning and infrastructure through the development of a handbook, hazards maps, use cases, and data management strategy. One of the objectives is to develop a number of use cases of the application of hazard and risk information to inform projects and program of planning and infrastructure sectors. In the framework of the project, this research was carried out to assess the exposure and physical vulnerability of the elements at risk to flood hazard. The outcome of this research can be used as a valuable input by planners for effective spatial land use planning and risk zoning in Castries old CBD and Dennery Village.

1.6. Structure of Thesis

Chapter 1: Introduction. This chapter gives a short introduction about the research, the background, problem statement, objectives and research questions to be achieved, and the project framework within which this research is conducted.

Chapter 2: Literature review: This chapter provides a review of literature pertaining to definitions, concepts, and methods that are relevant to this research.

Chapter 3: Study area: This chapter gives a description of the two case study areas which includes its location, topography, climate and rainfall, demography, urban settlement and land use, and economic activity. Physical vulnerability of buildings to floods using the indicator based method (SMCE) is conducted for both study areas. While the comparison of depth-damage and indicator based method is performed at one study area.

Chapter 4: Research methodology. This chapter provides a detailed description of the research methodology at the various stages, starting from pre-fieldwork to post-fieldwork. It also explains the methods adopted in data collection, and analysis.

Chapter 5: Analysis of elements at risk. This chapter presents the analysis of the characteristics of elements at risk for the case study areas.

Chapter 6: Exposure analysis to flood. This chapter describes the flood hazard including flood depth and flood level based on data derived from the local people's knowledge and participation, at one study area. It also, includes the exposure analysis of buildings and population to flood, and the results obtained from the analysis.

Chapter 7: Analysis of physical vulnerability to flood. This chapter explains the physical vulnerability assessment for buildings at both case study areas, and the outcome of the results.

Chapter 8: Conclusion and recommendation. The final chapter states the conclusion of the results obtained for each research question, and recommendation for future research.

2. LITERATURE REVIEW

2.1. Hazard

There are several definitions of hazard. Varnes (1984) defined natural hazard as the probability of occurrence of a potentially damaging phenomenon within a given area and a specified period of time. This implies that hazards can be potentially dangerous especially if they occur in populated areas and may lead to great impact in such areas depending on the hazard intensity and how vulnerable the elements at risk are. UN-ISDR (2004) mentioned that every hazard is characterised by its location, intensity, frequency and probability. Their definition of hazard is a "potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation". Crozier (1993) as cited by Hufschmidt (2011) defined natural hazard "as a condition that expresses the probability of a damaging event occurring with a specified magnitude within a defined time period and area, i.e. the magnitude-frequency relation of processes such as earthquakes, floods or landslides". According to Hufschmidt (2011) such a conceptualization of hazard is widely accepted and applied in present day risk researches.

2.1.1. Flood hazard

Among all natural disasters, flood is the most frequent in occurrence (Jha et al., 2012); and are among the most destructive and widespread hazards in the world (Alkema et al., 2011). It may occur as a result of ground infiltration; failure of dams, pumping systems and reservoirs; from glacial melt, snowmelt or rainfall which can develop into flash or riverine floods; and can originate from the sea in the forms of coastal degradation and storm surge (Jha et al., 2012). Other causes of flooding includes population growth; urbanization; land use such as deforestation, intensive agriculture, and unplanned flood control measures; cyclones; and climate change (ADPC, 2005).

There are several types of floods. Jha et al. (2012) categorized floods into the following classes, namely, urban flooding, flash flood, river or fluvial floods, semi-permanent flooding, coastal floods, groundwater floods, pluvial or overland floods. Additionally, the characteristics of floods are important in understanding the physical hazard posed by that flood type. These includes water depth and its spatial variability; spatial extent of inundation, particularly at areas that are not normally covered by water; water velocity and its spatial variability; duration of flooding; suddenness of onset of flooding; and the capacity for erosion and sedimentation (WMO, 1999).

In Saint Lucia the flood type is usually classified as flash flood. Most of the floods originates from tropical storms; and affects the flat low-lying areas of the island. This flood type is characterized by high water velocity, short duration, and most times it leads to erosion and sedimentation in the environment.

2.2. Exposure

Messner et al. (2007) defines exposure as the quantification of the receptors (e.g. population) that may be influenced by a hazard (flood), for example, number of people and their demographics, number and type of properties, etc. Exposure is one of the components of risk; and (Jha et al., 2012) stated that to fully evaluate risk, it is important to consider the degree of exposure, the nature of exposed receptors (vulnerability) and their potential to sustain or resist damage. Hence, it can be concluded that exposure is a function of the interaction of hazards, including flood, with the elements at risk. The term elements at risk is defined as "objects which possess the potential to be adversely affected, e.g. people, properties, infrastructure and economic activities including public services" (Hufschmidt et al., 2005).

In most assessments, exposure is usually carried out through the combination (spatial overlay) of a hazard (flood) map with the elements at risk map in a specified location (s), and at a given period of time. After that, the number of exposed elements at risk is calculated. An example is a study conducted by (Peduzzi et al., 2009), where the exposure of people to four different natural hazards, including floods was extracted by an overlay of the hazards with the population distribution using the Disaster Risk Index (DRI) model.

2.3. Vulnerability

Vulnerability is a broad concept with several meanings depending on the perspective of the various disciplines. According to Birkmann (2006), the current literature contains more than 25 different definitions, concepts and methods to systematise vulnerability. He also, states that despite the lack of a universal definition of vulnerability, various disciplines have developed their own definitions and pre-analytic visions of what vulnerability means.

Currently, the two main perspectives on the concept of vulnerability are, one from natural and engineering science, and the other from social science (Hufschmidt et al., 2005; Sterlacchini et al., 2014). Natural scientists relate vulnerability to the susceptibility of people, infrastructure and buildings to a hazard; engineers describe vulnerability on a structural perspective, for example building structures, bridge designs, etc.; while social scientists focuses on the vulnerability of people (Hufschmidt et al., 2005).

UNDRO (1979) defines vulnerability as the degree of loss to a given element at risk or a set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage).

UN-ISDR (2004) defines vulnerability as "the conditions determined by physical, social, economic, and environmental factors or processes, which increases the susceptibility of a community to the impact of hazard". This definition encompasses various conditions that have impact on the susceptibility of a community (Birkmann, 2006). The physical aspect of vulnerability refers mainly to considerations and susceptibilities of the built environment and location; and may be determined by population density levels, the site, design and materials used for critical infrastructure and housing, and remoteness of a settlement. Social vulnerability refers to the level of well-being of individuals, communities and society; it includes aspects related to levels of literacy and education, the existence of peace and security, access to basic human rights, systems of good governance, social equity, positive traditional values, customs and ideological beliefs and overall collective organizational systems. Economic vulnerability relates to economic status of individuals, communities and nations; the poor and elderly group in most regions are more vulnerable than economically better off segments of society. Also, inadequate access to economic infrastructure such as water, transportation, sewage and health care facilities, increase people's exposure to risk. Finally, environmental vulnerability refers mainly to the state of resource degradation and the extent of natural resource depletion. Factors like inappropriate forms of waste management especially in densely populated urban areas; reduced access to clean air, safe water and sanitation; diminished biodiversity, soil degradation or growing water scarcity, and pollution influence environmental vulnerability.

According to van Westen & Kingma (2011), physical vulnerability "refers to the potential for physical impact on the built environment and population". The authors stated that it can be relatively quantified because it is directly dependant on the physical impact of a hazard event; and it relates to the magnitude and intensity of the hazard, and the characteristics of the elements at risk.

In this research, the focus of vulnerability is on the physical environment, and in particular, on the impact of flood to the built environment. Although the main focus is on buildings, population is also, considered because they reside in buildings and might be injured or killed during an impact of hazard (flood) to buildings.

2.4. Physical vulnerability assessment

Physical vulnerability assessment to floods deals with ascertaining the level of damage or loss to a set of elements at risk in a specified location. These losses (damage) can be either direct or indirect. Direct damage refers to damage that occurs due to physical contact of floodwater with human beings, properties or any object. Conversely, damage which is induced by the direct impact such as disruption of traffic, trade and public services, but occurs in space or time outside the flood event is referred to as indirect damage (Büchele et al., 2006). However, the most frequently evaluated losses are structural damage or collapse to buildings; non-structural damage and damage to contents; fatalities; and injuries (van Westen & Kingma, 2011).

There are two major approaches of flood vulnerability assessment (Ciurean et al., 2013). One approach focuses on economic damage in terms of quantifying the expected or actual damages to a structure expressed in monetary terms or through an evaluation of the percentage of the expected loss; while the second approach deals with the physical vulnerability of individual structures and on estimating the likelihood of physical damages or collapse of a single element, for example, building. Furthermore, the authors mentioned that within the second approach two main methods namely, empirical and analytical method can be identified. Empirical methods are based on the analysis of observed consequences through field mapping, questionnaires, and interviews. In other words collection of actual flood damage data after an event. The main advantage of empirical methods is the use of real data; but it depends also on respondents' risk perception and data availability. In contrast, analytical method involves the direct control and quantification of different flood parameters such as duration, impact pressure, velocity, etc., on the structure. However this method is resource demanding (time and money) but permits a better understanding of the relation between flood intensity and degree of damage to an exposed structure with definite characteristics.

Based on the above explanations, the scope of this research is limited to direct physical flood damage to buildings using data collected from field mapping, questionnaires and interviews (empirical method).

2.4.1. Physical vulnerability assessment methods

Three main methods are commonly used in the empirical approach of physical vulnerability assessments and each method requires different parameters for expressing it. The methods are stage-damage functions (vulnerability curves), vulnerability indicators, and damage matrices. However, the first two methods are commonly used for vulnerability assessment to floods.

A. Stage-damage method

Direct flood damage in physical vulnerability assessment is often conducted using the stage-damage method. In stage-damage method, direct damage is based on stage height (water depth) with either the percentage damage or loss to building structure and /or to building contents (Middelmann-Fernandes, 2010). This method requires extensive information on damaged buildings. Also, damage is restricted to one characteristic of a building without taking into consideration other factors such as building age, height from the ground, etc., that influences the vulnerability of the building (Kappes et al., 2012). However, it shows the explicit relationship between hazard, vulnerability and damage (Menoni et al., 2006). According to Smith (1994), stage-damage functions (curves) are the essential building blocks upon which flood damage assessments are based, and are internationally accepted as the standard approach to assess urban flood damage.

Stage-damage functions are produced in two ways, namely empirical curves and synthetic function (Middelmann-Fernandes, 2010). The former is based on actual damages from a historical flood event in a particular location and includes the influence of many physical factors (parameters) on buildings such as, water depth, velocity, contamination, sediment, debris load, duration of inundation and warning time. The latter are hypothetical curves developed independently from historical flood data for a specific area, and are based on one or two parameters such as, water depth, duration and/or warning time.

Several physical vulnerability assessments have been conducted using the stage-damage function, and in such assessments, one or more parameters have been considered. Kreibich et al. (2009) considered water depth and flow velocity as the flood parameter. Prettenthaler et al. (2010) considered water depth, contamination by oil and static damage. Middelmann-Fernandes (2010) in a damage assessment of residential structures to floods in Perth, Australia considered water depth and velocity. In the study a comparison of damage was made using water depth and damage; and velocity, water depth and damage parameters. In HOWAS database, the water depth parameter was considered for assessing the damage to buildings that occurred in nine flood events in Germany (Messner et al., 2007).

In order to develop stage-damage functions for a building (s), several steps are taken. In a study by (Schwarz & Maiwald, 2008), the steps taken includes, harmonization of damage descriptions and assignment of repeatedly observed effects; definition of damage grades; correlation of flood impact parameters and building damage; aggregation of building types into their vulnerability classes; and correlation between damage grade and inundation level. The damages are usually expressed on a scale of 0 to 1 at the y-axis with 1 meaning total destruction. While the x-axis shows the intensity of the hazard (flood).

In line with the above discussion, water depth is considered as the parameter for assessing the damage to buildings by flood, in this research.

B. Vulnerability indicators

In vulnerability indicator method, damage assessment is conducted by taken into consideration all the factors that influence the physical vulnerability of a building. According to Villagran De Leon (2006), the three vital aspects in the context of indicators are the characteristics or inherent properties of such indicators, the methodologies regarding data management and processing inherent to each one, and the availability of data to obtain them. Additionally, the design of the indicators is usually based on their expected use.

Several researchers (e.g. Papathoma-Köhle et al., 2007; Alkema et al., 2012; Kappes et al., 2012; Thouret et al., 2014) have conducted physical vulnerability assessments through the application of different indicator-based methods. Among them are SMCE and the Papathoma Tsunami Vulnerability Assessment (PTVA). SMCE method was used by Alkema et al. (2012), for the assessment of multi-hazard vulnerability (including physical) at Nocera Inferiore, in Southern Italy. The main steps that was used for the assessment includes, a structuring of the decision problem; standardization of the parameter maps (i.e.

transformation of the parameter values into scores of 0-1); prioritization (i.e. assigning of weights to the criteria); and aggregation of the maps (i.e. the combination of the maps in a decision model).

Additionally, the selection of factors (indicators) for physical vulnerability assessments varies, and it is usually influenced by the aim (goal) of the assessment and the type of hazard. In the study by (Papathoma-Köhle et al., 2007), the wall material, existence of a surrounding wall around a building, number of floors, existence of large windows towards the slope, and warning signs were the selected factors for assessing the vulnerability of a building to landslides. Alkema et al. (2012) included the material for constructing the building, number of floors, the floor area of the building and other factors in the physical vulnerability assessment for four natural hazards including flood. In the studies by (Thouret et al., 2014; Kappes et al., 2012), the age of a building, level of maintenance, number of floors, and other factors were selected as indictors for assessing the physical vulnerability of buildings to different hazards, including floods. Granger et al. (1999) as cited by Kappes et al. (2012) suggests that floor height is the most important characteristic for physical vulnerability to floods, followed by number of stories, building age, wall material, and the existence of large unprotected windows as well as plan regularity.

In this research, physical vulnerability assessment of buildings to flood will be conducted using the SMCE indicator-based method. SMCE was considered because it enhances participatory approach, and includes the use of the people's perceptions and priorities in the assessment. The selected factors that will be used in the physical vulnerability assessment are building age, wall material, maintenance, height above the ground, and number of floors.

2.5. Elements at risk

Identification and mapping of elements at risk is an important task in physical vulnerability assessments. In order to map the elements at risk an understanding of its characteristics is essential. Various elements at risk, for example buildings and population have different characteristics that are necessary for flood physical vulnerability assessments. In terms of buildings, characteristics such as wall material, occupancy type, building height from the ground, number of floors, etc. are necessary. While the number of people in a building, the age distribution, number per building during the day or night, and other characteristics depending on the purpose of the study are necessary for population vulnerability. Additionally the characteristics differ for different hazards. For example, the characteristic of a building's shape is important for earthquake while it is not so important for floods.

However, one of the limitations is the lack of required data regarding the characteristics of elements at risk; or if such data exists, it may either be inadequate or may not be suitable for the level (scale) or purpose of the assessment. For example, Papathoma-Köhle et al. (2007) noted in an assessment of physical vulnerability of elements at risk that the main limitation was data availability and costs. They suggested that data for characteristics of elements at risk can be collected through air-photographs and remote sensing, local authorities, questionnaires and field surveys. Also, Kappes et al. (2012) indicated during an assessment of the physical vulnerability of multi-hazards (including flood) that the major drawback of the method was lack of data. They suggested that complementary data through the use of Google Street view (if available) or completion of questionnaires by people that reside in the hazardous areas, will considerably improve the vulnerability assessment.

2.5.1. Land use classification schemes

Land use is one of the most important spatial characteristics of a defined location for elements at risk inventory (van Westen et al., 2011). It determines to a large extent the type of buildings that can be expected in a defined location, the economic activities that are carried out, the density of the population at different periods of the day, etc. Land use types can be determined through the interpretation of satellite imagery (preferably high resolution image), field survey, Google Street view, aerial photographs, etc.

There are several land use classification schemes. Examples are, the classification of the urban or built-up land by Anderson et al. (1976) into seven classes, namely, 1) residential; 2) commercial and services; 3) industrial; 4) transportation, communications, and utilities; 5) industrial and commercial complexes; 6) mixed urban or built-up land; and 7) other urban or built-up land. Another type of classification of the urban and developed land into eleven classes is by the North Carolina Center for Geographic Information and Analysis (CGIA, 1994). In the HAZUS-MH methodology building occupancy (which also refers to land use) was classified into seven main classes, namely, 1) residential; 2) commercial; 3) industrial; 4) agriculture; 5) religious/non-profit; 6) government; and 7) education (FEMA, n.d.).

In line with the preceding paragraphs, elements at risk inventory for this research is conducted through field survey; and the land use classification is adapted from a combination of the above classification schemes, with main focus on buildings.

2.6. Participatory approaches

According to the UN-ISDR Hyogo Framework for Action (2005-2015), community involvement is vital for disaster risk reduction (UN-ISDR, 2005). An integration of the knowledge and participation of the local people can be effective in collecting the required data (or information) for physical vulnerability and risk assessments. Tran et al. (2009) emphasized that importance of community knowledge of the physical and social environment is vital for natural disaster management. Especially in the aspect that the local people have a first-hand experience and knowledge of the disasters and are able to talk about the extent, and how they were able to cope during and after the event. Furthermore, the people know a great deal about their surroundings and are able to indicate the areas that are prone to floods, houses that are built on platforms high above the ground and houses that are not, and areas where water currents flow faster during floods.

Some researchers (e.g. Peters-Guarin et al., 2012; Chingombe et al., 2014; Tran et al., 2009) have used local knowledge to retrieve vital information (e.g. on characteristics of elements at risk) that assisted in disaster risk management of an area, and have suggested of its usefulness. Information collected through surveys, interviews, transect walks, focus group discussions, expert knowledge, participatory Geographic Information System (GIS), etc. were then entered, stored, analysed and retrieved using GIS.

Therefore, this research will adopt participatory approach as the main form of data collection. More emphasis is on the use of volunteers during the field survey.

3. STUDY AREA

The two study areas, Castries old Central Business District (CBD) and Dennery Village are located in the Eastern Caribbean island of Saint Lucia (Figure 3-2).

3.1. Geographical Location

Study area 1-Castries old Central Business District (CBD) is situated in the northwest of the island at latitude 14^0 0' 46"N to 14^0 0' 23"N and longitude 60^0 59' 40"W to 60^0 59' 9"W (Figure 3-1), and covers an area of 0.36km^2. It is located in the district of Castries (Figure 3-2) which is the capital and largest city of Saint Lucia. Castries old CBD is classified under the census district of Castries City which is in the political (electoral) constituency of Castries Central (Table 3-1).

Figure 3-1: Location of Castries old CBD

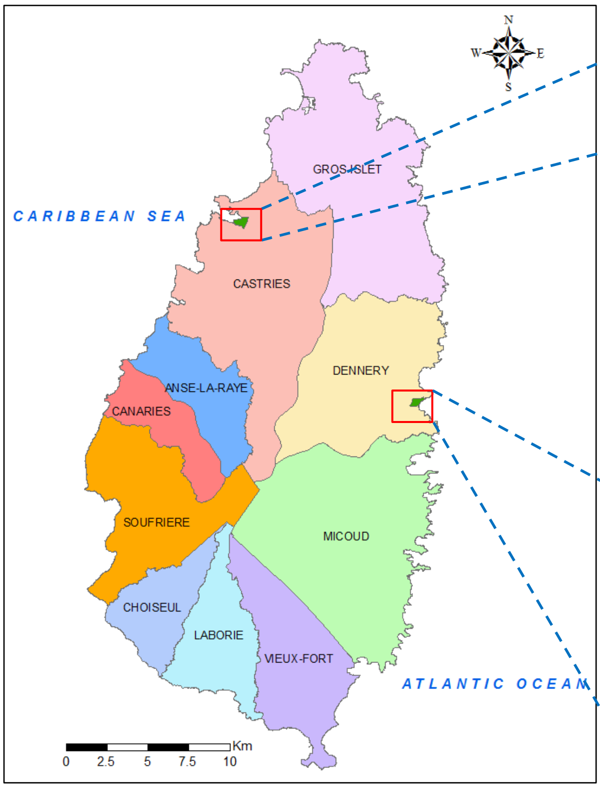


Figure 3-2: Map of Saint Lucia

Figure 3-3: Location of Dennery Village

Study area 2- The precise study area is a part of the entire Dennery Village settlement, specifically the flat valley adjacent to the coast. In this research, the small part of the settlement is referred to as Dennery Village. The study area is located at the east coast of Saint Lucia within latitude 13^0 54' 44"N to 13^0 54' 28"N and longitude 60^0 53' 43"W to 60^0 53' 14"W (Figure 3-3), and covers an area of approximately

0.28km^2. It is located in Dennery district (Figure 3-2) under the political constituency of Dennery South (Table 3-1).

No	Political Constituency	Total Households	Total Population
1	Gros Islet	8 600	22 493
2	Babonneau	4 578	12 723
3	Castries North	4 321	11 825
4	Castries East	4 232	11 939
5	Castries Central	2 813	7 398
6	Castries South	3 424	9 504
7	Anse La Raye_Canaries	2 948	8 291
8	Soufriere	2 875	8 472
9	Choiseul	2 069	6 098
10	Laborie	2 914	8 691
11	Vieux Fort South	3 304	9 140
12	Vieux Fort North	2 351	7 131
13	Micoud South	2 487	7 326
14	Micoud North	2 465	6 982
15	Dennery South	1 770	4 920
16	Dennery North	2 632	7 679
17	Castries South-East	5 108	14 983
Total		**5 8891**	**16 5595**

Table 3-1: Political Constituency and estimated 2010 population
Source: Central Statistics Office (2011)

3.2. Topography

The topography of Saint Lucia is mountainous, and it is dominated by a central mountain ridge that extends along the north-south axis of the island. The highest elevation is at Mt. Gimie (950 m) where the slopes are extremely steep. Other high peaks at the south-western coast of the island include the twin peaks of Gros Piton (797 m) and Petit Piton (750 m). The main drainage networks emanates from these mountains towards the Atlantic Ocean to the east and the Caribbean Sea to the west.

Castries old CBD is located in a flood plain with a maximum elevation of 10m above sea level. The slope varies from 0-25% and about 64% of the study area falls within the slope range of 0-2 %. The principal drainage system consists of Castries River at the southern part of the study area.

Dennery Village is located at the flood plain of Dennery River, and it is surrounded by urbanized hills. The slope varies from 0-55% and the highest elevation is approximately 31m above sea level. The main drainage network consists of Dennery River at the south, and a central drain network that is connected to the Dennery River.

3.3. Climate and rainfall

Saint Lucia has a tropical, humid climate moderated by north-east trade winds, all year round. Mean annual temperatures at sea level, range from 26° C to 32° C and drops to an average of 13° C at the mountain peaks. Relative humidity ranges in the high of 70% year round. Two distinct rainfall patterns are, dry season from December to May and wet season from June to November. During the wet season the island is invariably affected by hurricanes and other tropical storms; and the season is sometimes referred to as the hurricane season. Average annual rainfall ranges from 1300 mm at the coastal areas to 3810 mm in the rainforest interior area. This is mostly due to orographic effect of the general topography of the island with a lower coastal areas and high central mountain range (World Bank, 2013).

3.4. Demography

Castries is the most populous district in Saint Lucia with a total estimated 2014 population of 65, 950 persons (Francis, 2014). The district's population density is 830/km^2. From the 2010 census, the population of Castries City fell from 7.9% in 2001 of the district's total population to 2.5% in 2010. This was due to the movement of people from Castries City to Castries Rural and Gros-Islet. However, the estimated household population of Castries City is 4, 173; and out of this sum 2, 044 are males while 2, 129 are females.

The estimated total population of Dennery district from the 2010 census is 12, 599 persons. The population density is 181/km^2. According to the 2010 census, Dennery is among the districts in Saint Lucia that has experienced a decline of -1.5% in population size (Central Statistics Office, 2011). However, the estimated household population in Dennery south constituency is 4, 920; and out of this sum 2, 433 are males while 2, 487 are females.

Furthermore, there has been a decrease in the average household size of the island from 1991 to 2010. The average household size decreased from 4.0 persons per household in 1991 to 3.3 and 2.8 persons per household in 2001 and 2010, respectively. However, the average household size of the island has been steady with a 2014 estimate of 2.8 persons per household (Francis, 2014).

3.5. Urban Settlement Pattern and Land use

In Saint Lucia, most of the settlement patterns are located along the flat coastal areas. With an increase in population, the settlement pattern has expanded from the low lying urban areas to the surrounding hills where most of the settlements are unplanned.

In terms of land use, 100% of the land use in Castries old CBD is urban settlement. The total number of buildings and business places from the 2010 census, in Castries district is 23, 966 and 3, 360, respectively. While in Castries City the total number of buildings and business places is 1, 826 and 1, 132, respectively.

In Dennery Village, there are five land use types, namely, Rock and Exposed Soil; Scrub Forest; Urban Settlement; Grasslands and Open Wood; and Mangrove. However, urban settlement makes up 69.5 % of the land use types. From the 2010 census the total number of buildings and business places in Dennery district is 5, 254 and 463, respectively.

3.6. Economic Activity

The main economic activity in the island is tourism. About 62% of the national Gross Domestic Product (GDP) is derived from the services sector of which tourism is the main contributor (Global Facility for Disaster Reduction and Recovery, 2010). Other activities include agriculture, fishing, and small manufacture.

4. RESEARCH METHODOLOGY

This chapter explains the methodology used in this research. The research was conducted because of the need for assessing the exposure and physical vulnerability of elements at risk in flood affected areas of Saint Lucia. Participation and knowledge of the local people was used as the main method for achieving the objectives of this research. The research methodology was conducted in three stages, namely, pre-fieldwork, fieldwork, and post-fieldwork (see Figure 4-1).

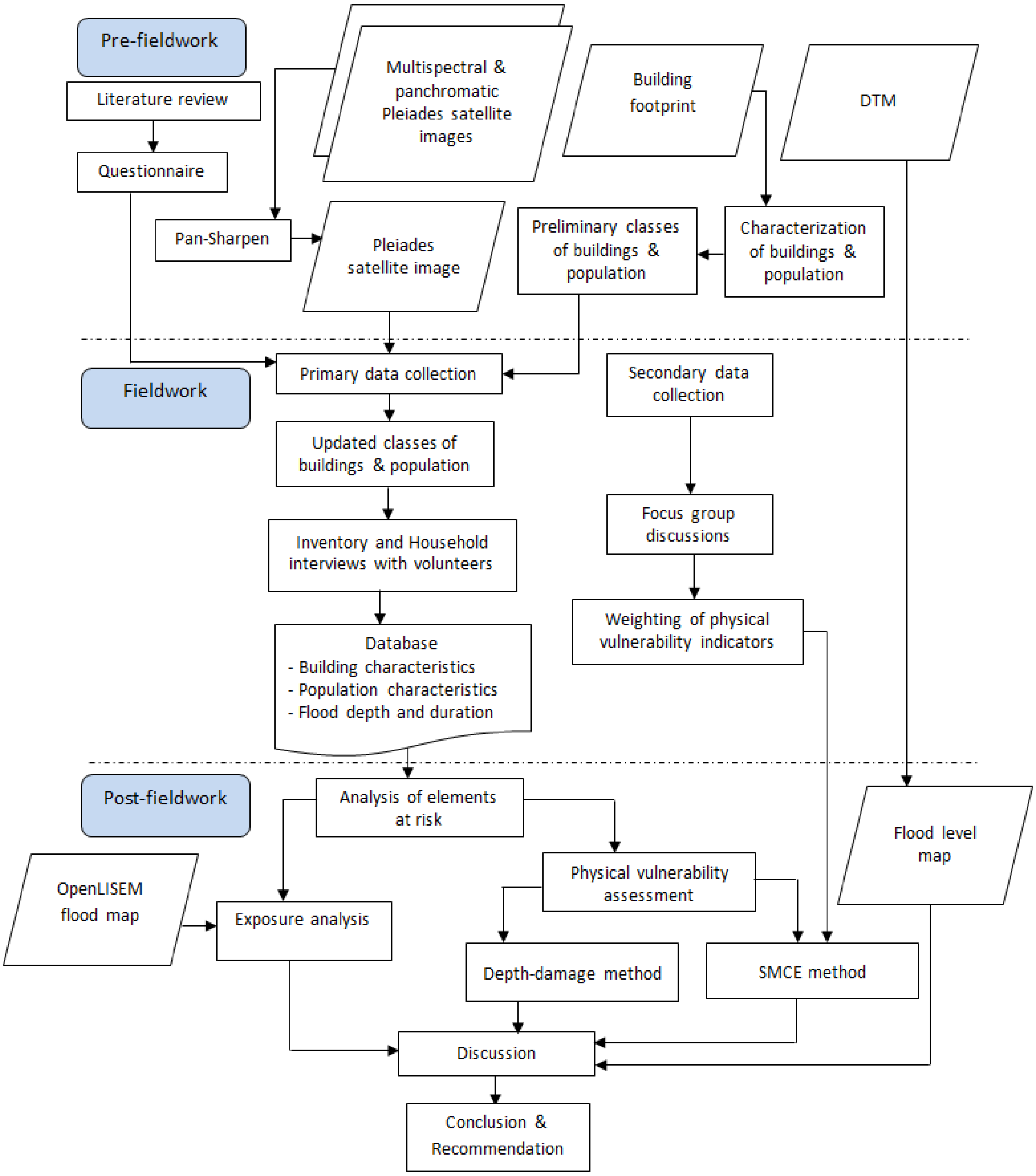


Figure 4-1 Flowchart showing research methodology

4.1. Pre-fieldwork

Before the fieldwork, literature review was carried out with journals articles, books, reports and previous studies related to information about data needs and methods that will be used during the fieldwork and in data analysis. The pre-fieldwork steps are described below.

4.1.1. Data Requirement and Availability

Most of the data that was needed to achieve the overall objective and sub-objectives of this research were not available (see Table 4-1). This prompted the need to collect the required data from fieldwork.

No	Data Analysis	Data Requirement	Data Sources
1	Delineation of study area	Satellite Image	2014 Pleiades images (0.5m panchromatic, and 2m multispectral) from provided base data
		Digital building footprint; road map	Available from provided base data
		Land use	Scanned paper map 1:50000 scale from the Canadian Agricultural Research and Development Institute (CIDA) project
2	Generating an Elements at risk database	Building attributes inventory	Fieldwork and Household interviews
3	Analysis of Elements at risk	Building Attributes Inventory	Fieldwork and Household interviews
4	Exposure analysis	Flood depths of study area Digital Terrain Model (DTM)	Field work; 10m open Limburg Soil Erosion Model (openLISEM) flood map from Prof. Jetten; 10m DTM (from provided base data)
5	Flood physical vulnerability assessment	Depth Structural damage to buildings (Depth-damage method)	Fieldwork (through household interviews)
		Characteristics of buildings (SMCE method)	Fieldwork, and Expert session

Table 4-1: Data requirement and availability

Prior to fieldwork, Castries City was chosen as the main study area due to its unique role (key economic activities and location of critical infrastructures) in Saint Lucia, and its susceptibility to floods. However, the choice of including Dennery Village as another study area was necessitated due to information obtained during meetings with stakeholders such as the Physical Planning Department in Ministry of Planning Development Housing and Urban Renewal (MPDHUR), and National Emergency Management Organization (NEMO), during the field work. From the meeting it was made known that structural damage due to floods in other parts of the island such as Dennery were more severe than in Castries City; and the NEMO has initiated a project on providing an early warning system for Dennery community and will need information on building characteristics and vulnerability assessment.

4.1.2. Base maps preparation

The base map for Castries old CBD study area was prepared before fieldwork, while the base map for Dennery Village was prepared during fieldwork. The base maps were derived through the combination of two 2014 Pleiades Satellite images (0.5m panchromatic and 2m multispectral) in ArcGIS. The result was a pan-sharpened image (0.5m) of Castries old CDB and Dennery Village. The map projection used in this research is UTM (Universal Transverse Mercator) Zone 20 Northern Hemisphere, and Geographic Coordinate System (GCS) WGS (World Geographical System) 1984.

The pan-sharpened Pleiades satellite image and building footprint map of the study areas were imported and stored digitally using ILWIS 3.4 and 3.8. Segment maps of the building footprints were created to enable editing of buildings during field survey. A Point map that was linked to each building ID was created. Hard copies were produced as base maps for field survey.

4.1.3. Characterization of buildings and population

After an extensive study on literature, relevant characteristics for assessing the exposure and vulnerability of buildings and population were developed. This was necessitated because the provided building footprint maps had attributes such as elevation, area, and building height, which were not sufficient for the assessment. However, building attributes developed were occupancy type, building function, wall material, floor material, roof material, number of floors, height above the ground (i.e. height of first floor of building from the road), maintenance, and built-up or on columns. Population characteristics developed includes, selected temporal scenarios (day/night time); age distribution; and number of people per household.

A classification scheme for the occupancy types was adopted and modified from literature. Preliminary classes for other building attributes were developed and codes were assigned to the various classes (an example is shown in Table 4-2). These attributes were used to update the attributes in the building footprint map (elements at risk database), digitally using ILWIS-GIS. Also, they were entered in Building Survey Form (see Appendix 1) that was used for data collection during fieldwork.

CODE	DESCRIPTION
OCCUPANCY TYPE	
Residential	
RES_1	Single dwelling
RES_2	Multiple dwelling
Commercial	
COM_1	Retail trade (e.g. supermarkets, shops)
WALL MATERIAL	
CBM	Concrete block
PB	Wood

Table 4-2: Example of building attribute classes

4.1.4. Questionnaires

The questionnaire was developed to collect detailed information on flood depth-damage to building structure, and other characteristics that influence vulnerability of buildings (see Appendix 2), from the local people's knowledge. It was used during household interviews at Dennery Village, and the information obtained was used to generate a database that aided in the analysis of physical vulnerability. The questionnaire was divided into four main sections, namely, general information; elements at risk; floods; and damage and losses.

4.1.5. Pre-contact to local authorities

Before the fieldwork, contact was made with the contact person (for the World Bank project) in the island, and a meeting was scheduled with representatives of various organizations at Physical Planning Department of MPDHUR.

4.2. Fieldwork

As stated above, fieldwork was needed to obtain the relevant data that will be used for achieving the objectives of this research. Collection of data for this research was carried out in two forms, namely, primary and secondary data collection. Primary data was collected through building inventory (at both study areas) and household interviews (at Dennery Village), during field survey. Secondary data was collected from the various ministries and organizations visited during the Focus Group Discussion. Additional secondary used in this research is a flood model (openLISEM) map that was obtained after field work. Fieldwork was conducted from September 22 to October 17, 2014. Equipment used includes measuring tape, small computer, Digital Voice tape recorder, Digital camera, and base maps of both study areas. It was accomplished through the participation and knowledge of the local people.

4.2.1. Focus Group Discussions at various Ministries

Before field survey, Focus Group Discussions was held at various institutions (see Appendix 3) with key actors of hazards and disaster risk management in the island. It was aimed at acquiring detailed knowledge, based on their experiences on flood hazard in both study areas and its causes; activities by the people that increase their vulnerability; and mitigation efforts (projects). Also, to know if there is an existing database that contains building characteristics and any general land use classification scheme in the island. It was made known that there was neither any building characteristics database nor a general classification scheme. Furthermore, the stakeholders provided an effective way to collect data for hazard and vulnerability assessments through target groups like the District Disaster Committees; and created the possibility of conducting building inventory in Castries old CBD through the assistance of some staff members from the Physical Planning department of MPDHUR.

4.2.2. Preliminary field survey

A visit round Castries old CBD (study area 1) was carried out with Dr Naveed Anwar, a structural engineer from the Asian Institute of Technology (AIT), Thailand. It was aimed at developing a correct classification of structural types of buildings for the elements at risk database. After the field observation, building attributes and classes that will be collected were modified and updated in the database.

Before the actual field survey with volunteers, a pilot test was carried out in Castries old CBD using a small computer, provided, to directly enter attribute information regarding each building, in ILWIS-GIS. It was not used throughout the field survey period due to technical issues such as: very slow to open ILWIS and to load the maps; even when you click on the points that represented buildings on the point map, it takes too long for the attribute table to open; the battery life was about 2 hours 30 minutes and no extra battery; ILWIS was oftentimes displaying the message ‘Close program’. Apart from the issues mentioned, it would have been a very good data entry approach whereby building information is entered directly to the database; which is less time consuming. Additionally, it minimizes the loss of data and errors which oftentimes results from transferring data from paper to a database (GIS).

4.2.3. Data collection (Study area 1)

Building Inventory- Castries old CBD

Three members of staff, a physical planning officer that was currently working on building mapping in Central Business Districts of Castries, a physical planning technician, and a GIS technician from the Physical Planning Department of MPDHUR and the researcher conducted the field survey. A short training aimed at instructing the volunteers (staff members) on procedure of data collection and documentation was carried out. Most of them already have experience in spatial data collection (mapping), entry, and analysis. Satellite image of the study area, building survey forms, measuring tapes and writing materials, were used during the field survey. Additionally, the 2008 aerial photographs for Castries old CBD (12.5cm resolution) and Dennery village (25cm resolution) that was provided by GIS section of Physical Planning department-MPDHUR were used to supplement the recent, 2014 satellite image in the field.

Building mapping was conducted at a detailed level of collecting attributes for individual buildings. Attribute data, namely, occupancy type, building function, wall material, floor material, roof material, number of floors, height above the ground, maintenance, and built-up or on columns, for 536 buildings were collected. Additionally, pictures of different buildings and features were taken. Attribute data of buildings was documented in building survey forms with unique ID's that corresponded with each building's ID on the paper maps (see Figure 4-2). A Global Positioning System (GPS) was not used because the X-Y coordinates of each building could be retrieved from the digital map of the study area. Hence, considering the number of attributes that needs to be collected for a large number of buildings, it will be faster collecting them without a GPS. At the end of each field survey (i.e. each day) the data that was collected was cross checked and transferred from the building survey form to the database created in the Integrated Land and Water Information System (ILWIS) GIS by the researcher. During the field survey, it was observed that some of the buildings that were initially grouped together (digitized) as a single building in the building footprints were separate buildings. Such buildings were edited and digitized as separate buildings.

Figure 4-2: Building inventory during fieldwork

Survey with District Disaster Committee member

A field survey was also, conducted together with Mr Junior Mathurin (vice president of Castries District Disaster Committee) around Castries old CBD. Its aim was to gain more knowledge about high, moderate and low flood areas in the study area. Visits were made to those locations and structural mitigation measures like the use of sandbags at buildings were observed.

Assigning of scores (weights) to selected building characteristics was performed with Mr Junior Mathurin based on his experience during disasters. The scores were assigned based on the number of building characteristics classes in each factor; on a scale of 1 to the maximum number of classes (Table 4-3). The class with the highest number of score is the most vulnerable, while the least vulnerable class of building characteristics was given a score of 1. For example, the factor 'number of floors' has 4 classes, and the score for the classes if from 1-4. This means that one storey buildings are the most vulnerable to floods while buildings with more than three storeys are the least vulnerable.

Factors	Building characteristics classes	Score
Wall Material	Concrete Block	1
	Wood and Concrete Block	2
	Wood	3
Height above the ground (in meters)	<0-0.0	5
	0.1-0.5	4
	0.6-1.0	3
	1.1-1.5	2
	>1.6	1
Number of floors	1	4
	2	3
	3	2
	>3	1
Maintenance	Good	1
	Moderate	2
	Poor	3

Table 4-3: Scores assigned to the classes by Mr Junior Mathurin

These scores (weights) will be referred to during the assessment of physical vulnerability using the indicator method (SMCE) in section 7.2.

4.2.4. Data Collection (Study area 2)

Building Inventory-Dennery Village

Data collection in Dennery village was carried out in collaboration with a team of five members from the community. Some of them are Red Cross volunteers and have experience in mapping, and assisting during disasters in the community. Before the field survey, a short training aimed at instructing the team on procedure of collecting and documenting required data was conducted. The researcher worked closely together with the volunteers to further guide and respond to any questions raised regarding data collection. Attribute data (as stated in section 4.2.3) for 339 buildings was collected.

Household Interviews

Household interviews aimed at gaining more knowledge about flood events, damage information of various structural types, flood depth-duration relations/data, population scenario distribution, was conducted at 94 households using questionnaires. The interviews were conducted simultaneously with inventory on building characteristics. Due to the very short time frame of data collection in Dennery Village, the volunteers assisted in pointing out the buildings that were and were not affected by the December 2013 flood. Building sample points were selected based on the information provided by the volunteers. Height of flood in affected buildings was measured inside the house, from the mark shown by the respondent on the wall to the ground of the first floor. Additionally, some households were affected by previous flood events in October 2013, and October 2010 (Hurricane Tomas), and during the interviews data on those events were collected.

Most respondents were unable to provide the amount of money spent on repairing damages to building structure due to flood. Some of the excuses given are, their husband that carried out the repair is not present as at the time of the interview; they cannot remember the exact cost of repairs; and some did not want to disclose the amount.

It was difficult to obtain damage data on building contents which was expressed as, the percentage of the cost of building and entire contents in it divided by the total amount of damaged building content (due to flood). Most respondents stated that they do not know the value of the building in for example, 2013 because it was built more 10 years ago; others stated that they are not the real owners of the houses and are occupying them on rent; and some could not specify the total amount spent in constructing their buildings because money was spent in bits at different times for different aspects of the buildings, e.g. roofing, doors and windows, placing of tiles, etc. Most respondents mentioned that items such as television, clothes, furniture, fridge, microwave, mattress, etc., were damaged.

Flood map from volunteers

The volunteers drew a sketch map (see figure 4-3) showing locations that had high, moderate, low, and no-flood water during the December 2013 flood. It gave the researcher a better knowledge of the flood event and extent.

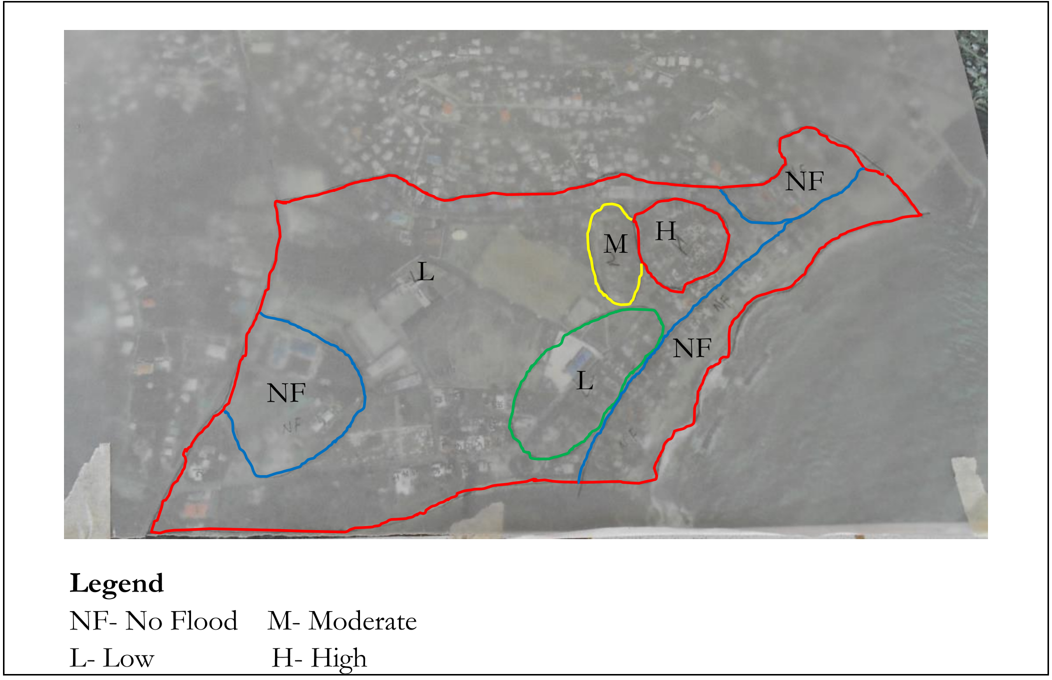


Figure 4-3: Sketch map from volunteers showing December 2013 flood extent

4.3. Database generation and Data Analysis

After the fieldwork, all the data derived during the building inventory at Dennery Village was transferred to the database in ILWIS through the following steps: each building in the footprint (GIS) was located on the base maps (hard copy) used during the field survey which had unique ID's that corresponds with the ID's in the building survey forms; the attribute information in the building survey forms were now entered into attributes of the corresponding buildings in the building footprint map. The building inventory data from both study areas were used to generate the elements at risk database. Additionally, information collected during the household interviews with the questionnaires at Dennery Village was entered in the corresponding buildings, using the same procedure explained.

Data collected from fieldwork was processed and analysed using ILWIS 3.4, 3.8, and ArcGIS 10.2.2 software. Spatial analysis of elements at risk and physical vulnerability was processed in ILWIS; spatial analysis of flood depth points derived from household interviews and a provided openLISEM model map was processed in ArcGIS. Correlation analysis was performed using SPSS statistics 22 software. For the exposure analysis, the spatial join of water depths from the model map, and the elements at risk map (buildings and population) was processed in ArcGIS.

The analysis and results from the data collected will be explained in details in the subsequent chapters. They include the elements at risk identified for this study; exposure and vulnerability assessments in chapters 5, 6 and 7, respectively.

4.4. Discussion

The data, methods of data collection during the fieldwork, data preparation and data analysis have been discussed in this chapter. The integration of local knowledge and participation mainly through the volunteers for data collection was very useful and effective.

The strengths as observed by the researcher includes, 1) collection of more data than when one person collects it alone; 2) the correct classes of occupancy types and building functions was documented due to information provided by the local people (volunteers); 3) some information that the local people would not have given to the researcher was collected because the volunteers asked such questions; 4) access to some buildings was possible due to the assistance of the volunteers; 5) security of the researcher was not jeopardized because the volunteers provided information on highly insecure areas, and oftentimes went to collect the data in such places, themselves; 6) ability to collect some of the data at night, when the people are around to answer the questions since they live in the study area; and 7) ability to specify locations of high, medium and low flood areas; and buildings that were and were not severely affected by flood.

In contrast, some of the problems encountered while documenting the information obtained by the volunteers were, 1) mismatching of codes in the Building Survey Form; 2) inconsistencies in data collected e.g. some differences in recorded heights of buildings; and differences in wall, roof, floor, etc. types when compared to that of the researcher.

5. ANALYSIS OF ELEMENTS AT RISK

This chapter explains the various characteristics of buildings collected at the two study areas (Castries Old CBD, and Dennery Village) from the building inventory. Furthermore, additional characteristics of buildings and population are explained based on the household interviews conducted at Dennery Village. The chapter also, describes the relevance of the characteristics for exposure and physical vulnerability assessments of the elements at risk to floods.

5.1. Building description from building inventory

Building characteristics, namely, occupancy type, building function, wall material, floor material, roof material, number of floors, height above the ground, maintenance, built-up or columns for 536 buildings and 339 buildings were collected at Castries Old CBD (Figure 5-1) and Dennery Village (Figure 5-2), respectively. These characteristics will be explained in the following sections.

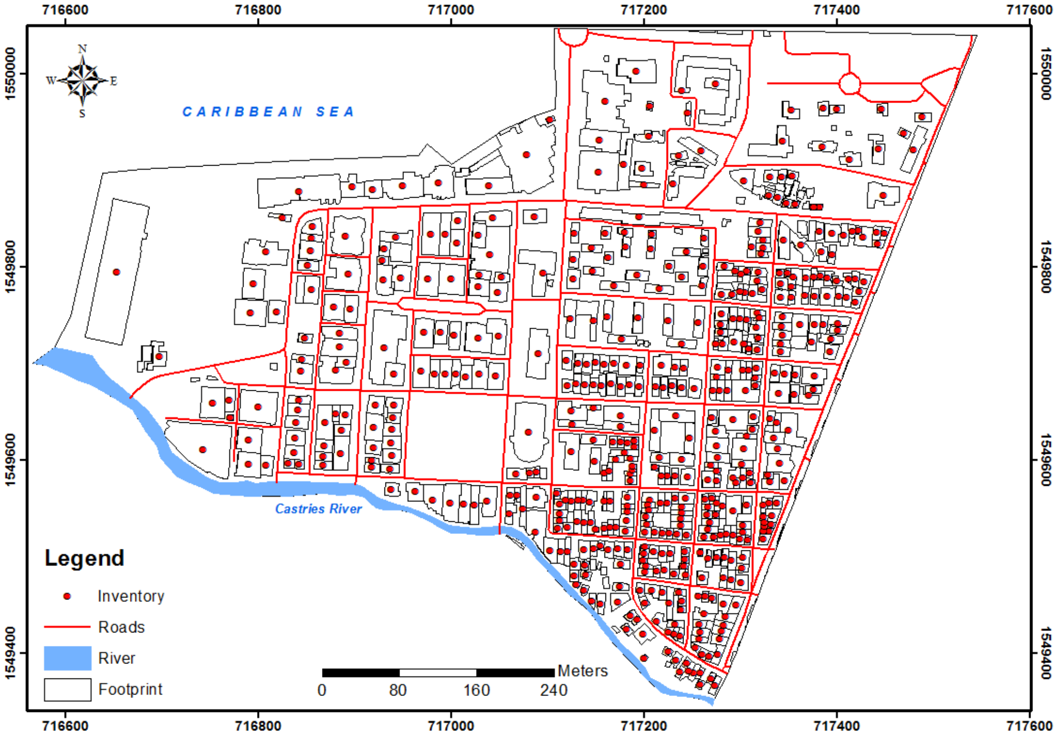


Figure 5-1: Distribution of building inventory in Castries old CBD

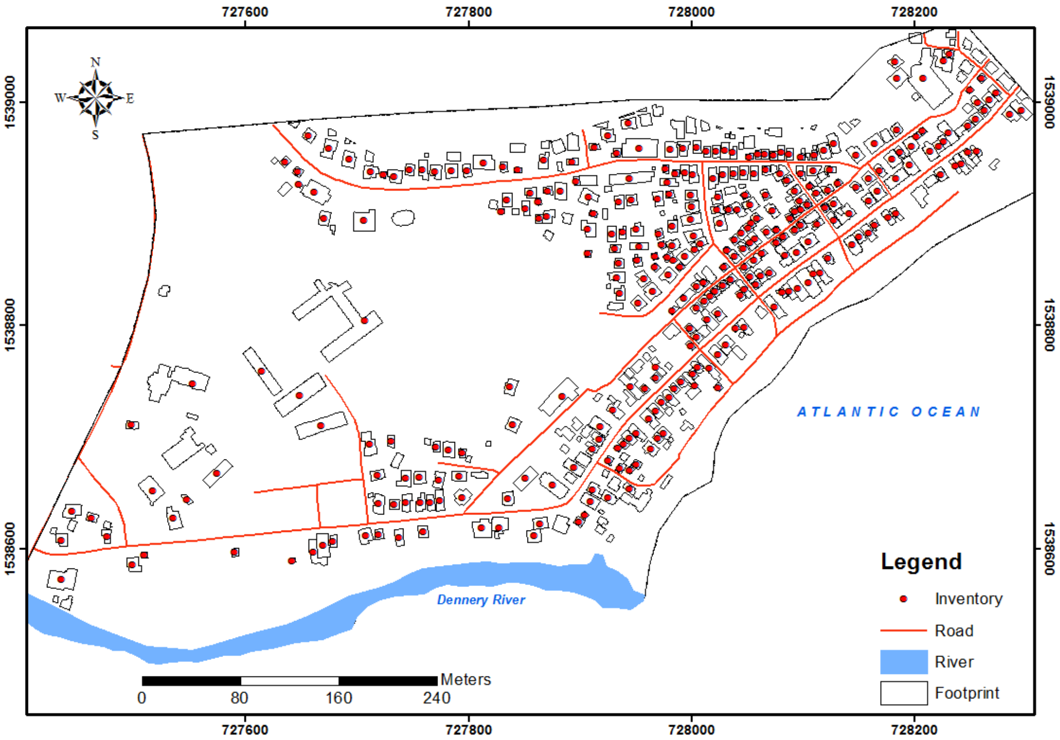


Figure 5-2: Distribution of building inventory in Dennery Village

5.1.1. Occupancy type

An analysis of the various occupancy types shows that the predominant occupancy type in Castries old CBD (Appendix 4a) and Dennery Village (Appendix 4b) is commercial and residential, respectively (see Table 5-1). During the inventory, some buildings had a mixture of more than one occupancy type. Those buildings were categorized as 'mixed use' and the term 'commercial' was used to aggregate the different commercial types into a single class. However, an exception is 'commercial/office' whereby office is also a class of commercial. In this study it was classified as a separate 'mixed use' class in order to separate the professional services-offices and (or) government offices that are in the same building with other commercial types. For example, a building contained the Housing and Urban Renewal department of the MPDHUR (government office) at the second floor and a restaurant at the ground floor.

The occupancy type is important because it can be used as a proxy in determining where the population (number of people) in buildings are high or low at various times of the day and night. In Castries old CBD, the population is high during the day because most of the people are present in their offices, at the shops, factory, etc., and low during the night. In contrast, the population at Dennery Village will be low during the day because most of the people have left the buildings to their work places, or shops, and high during the night when they are back to the buildings. Consequently, if a flood event occurs during the day, Castries old CBD may be more vulnerable in terms of population than Dennery Village, and vice versa.

5.1.2. Building function

This attribute is similar to occupancy type but it gives a more detailed description of the various occupancy classes i.e. the specific function (use) of each building. For example, retail trade store on first floor and residential on second floor (mixed use). A map showing the spatial distribution of the building function could not be presented because it is too detailed to be visualized on a single map document rather it is better visualized in a GIS.

Occupancy type	**Castries old CBD**		**Dennery Village**	
	Number of buildings	**Percentage (%)**	**Number of buildings**	**Percentage (%)**
Residential				
Single dwelling	46	8.6	199	58.7
Multiple dwelling	24	4.5	10	2.9
Squatter	6	1.1	0	0.0
Commercial				
Retail trade (e.g. shops)	154	28.7	19	5.6
Financial institution (e.g. banks, and credit union)	13	2.4	1	0.3
Professional services (e.g. offices such as dentist's office, lawyer's office, insurance agencies, etc.)	52	9.7	1	0.3
Restaurant/bar/tavern	21	3.9	6	1.8
Specialty store (e.g. barbers shop, hairdressers, repair shop, etc.)	18	3.4	9	2.7
Warehouse	7	1.3	0	0.0
Market	7	1.3	0	0.0
Funeral parlour	1	0.2	0	0.0
Bus shelter	2	0.4	0	0.0
Industrial				
Heavy industry (e.g. soft drink factory)	1	0.2	0	0.0
Power/energy related facility	1	0.2	0	0.0
Water related facility	3	0.6	0	0.0
Government				
Government office	7	1.3	1	0.3
Fire/Police station	3	0.6	1	0.3
Courthouse	2	0.4	1	0.3
Post office	1	0.2		
National assembly complex	1	0.2	0	0.0
Town/City hall	1	0.2	0	0.0
Educational				
School (e.g. pre-school, primary and secondary school)	14	2.6	9	2.7
Library	2	0.4	1	0.3
Religious				
Church	8	1.5	5	1.5
Church related residence	3	0.6	3	0.9
Social				
Meeting hall	2	0.4	0	0.0

Club	1	0.2	0	0.0
Recreational				
Outdoor recreation (e.g. building at hockey field, football field, etc.)	0	0.0	2	0.6
Mixed use				
Residential/Commercial	29	5.4	14	4.1
Residential/Office	1	0.2	0	0.0
Residential/Educational	1	0.2	0	0.0
Commercial/Light industry	2	0.4	0	0.0
Commercial/Educational	4	0.7	0	0.0
Commercial/Office	80	14.9	0	0.0
Vacant				
Work in progress	1	0.2	3	0.9
Vacant abandoned	13	2.4	36	10.6
Vacant building	4	0.7	18	5.3
Total	**536**	**100**	**339**	**100**

Table 5-1: Occupancy types from building inventory

5.1.3. Wall material

From the survey, concrete block is the largest wall material type out of the eight types in both study areas (see Table 5-2). The preference of concrete block by most people is due to its resilience in withstanding the impact of fast water currents with debris. Different types of wood wall materials such as plywood, 'tongue and groove' were found during the inventory. However, in this research the variety of wood wall materials are classified as wood. Buildings with wood walls are the second highest, and the people construct their buildings with it because they are more affordable. The uncommon wall material types are galvanized iron sheet, stone, glass and concrete block, brick and stone, and brick. Two wood and concrete block wall types were found during the inventory. The first type consists of buildings constructed with concrete block on the first floor and wood wall on the second floor; while the second type is a mixture of wood and concrete materials on the same floor (mostly 1-floor buildings). The spatial distribution of the wall material types for both study areas are shown in Appendix 5a and 5b; and examples of the wall materials are shown in Figure 5-3.

Wall material	**Castries old CBD**		**Dennery Village**	
	Number of buildings	**Percentage (%)**	**Number of buildings**	**Percentage (%)**
Concrete Block	424	79.1	194	57.2
Wood	100	18.7	126	37.2
Wood and Concrete Block	5	0.9	18	5.3
Glass and Concrete Block	3	0.6	0	0.0
Stone	2	0.4	0	0.0
Brick	1	0.2	0	0.0
Brick and Stone	1	0.2	0	0.0
Galvanized Iron Sheet	0	0.0	1	0.3
Total	**536**	**100**	**339**	**100**

Table 5-2: Wall types from building inventory

Figure 5-3: Types of wall (a) Concrete block (b) Wood (c) Wood and Concrete block (d) Glass and Concrete block (e) Stone (f) Brick (g) Brick and Stone (h) Galvanized Iron sheet

5.1.4. Floor material

There are five types of floor material in both study areas (see Appendix 6a, and 6b). The predominant floor type in Castries old CBD is ceramic tiles with 60% of the buildings (table 5-3); while wood is the predominant type in Dennery Village with 34%. Most people use ceramic tiles floor because they are easier to clean up after flood event. However, some of the people indicated that the tiles were raised after the building was inundated. From the building inventory, some buildings in both study areas have a mixture of two floor types, namely, concrete and wood, ceramic tiles and wood. These floor types were mostly found in wood, and wood and concrete wall buildings.

Floor material	**Castries old CBD**		**Dennery Village**	
	Number of buildings	**Percentage (%)**	**Number of buildings**	**Percentage (%)**
Ceramic Tiles	320	59.7	103	30.4
Concrete	128	23.9	104	30.7
Wood	86	16.0	114	33.6
Concrete and Wood	1	0.2	15	4.4
Ceramic Tiles and Wood	1	0.2	3	0.9
Total	**536**	**100**	**339**	**100**

Table 5-3: Floor types from building inventory

5.1.5. Roof material

Galvanized iron sheet is the predominant roof material type in both study areas (see Table 5-4) with 49% and 77% in Castries old CBD and Dennery Village, respectively. Painted steel sheet and concrete are the second and third highest type, respectively, for both study areas. The analysis also, indicates that asphalt shingles roofs are not common in both study areas (see Appendix 7a and 7b). The low preference by the people is because of its low durability during exposure to high temperatures and water (rainfall). During the inventory, some of this roof type showed signs of decay. Buildings with no roof were found in Dennery Village, among the vacant-abandoned buildings. Examples of the roof types are shown in Figure 5-4).

Roof material	**Castries old CBD**		**Dennery Village**	
	Number of buildings	**Percentage (%)**	**Number of buildings**	**Percentage (%)**
Galvanized Iron Sheet	263	49.1	261	77.0
Painted Steel Sheet	178	33.2	56	16.5
Concrete	94	17.5	13	3.8
Asphalt Shingles	1	0.2	5	1.5
No Roof	0	0.0	4	1.2
Total	**536**	**100**	**339**	**100**

Table 5-4: Roof types from building inventory

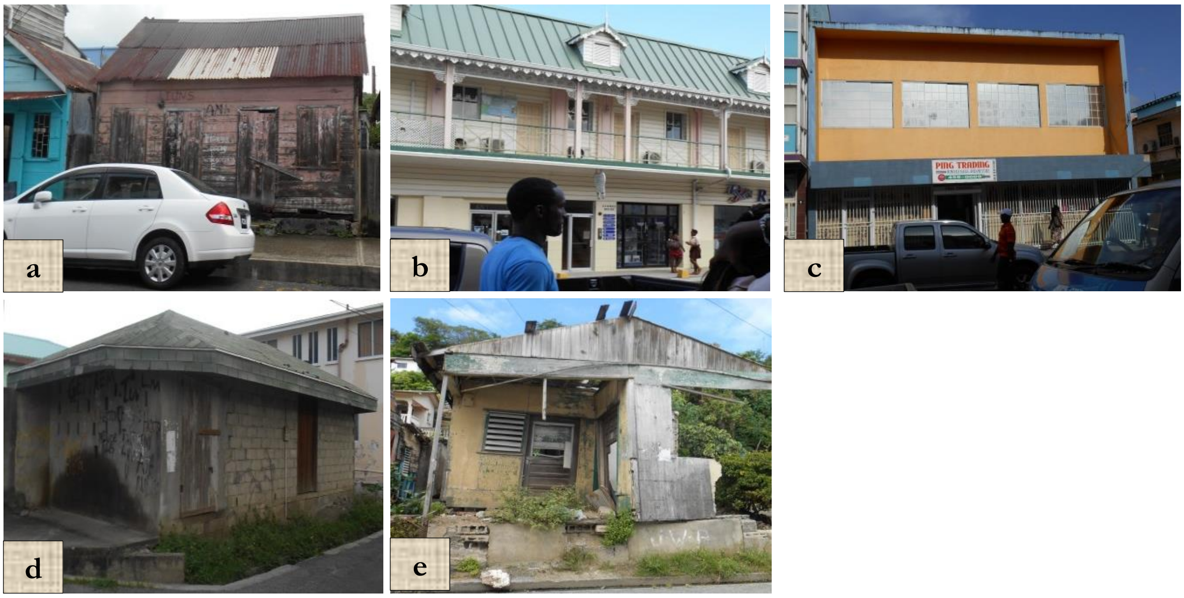


Figure 5-4: Types of roof (a) Galvanized Iron Sheet (b) Painted Steel Sheet (c) Concrete (d) Asphalt Shingles (e) No Roof

5.1.6. Number of floors

The predominant number of floor type is two storeys (50%) in Castries old CBD and one storey (87%) in Dennery Village (see Table 5-5). In Castries old CBD the variety of number of floors is from one to six storeys (Appendix 8a); while in Dennery Village it is from one to three storeys (Appendix 8b). The high population density in Castries old CBD is mostly due to its role as the commercial nerve centre of the island; and has led to the prevalence of buildings with two storeys and above. In order to serve the accommodation needs, the people have resorted to construction of more than one storey buildings.

However, in terms of flood, more than one storey buildings is preferred because the people can move their important belongings to the upper floor; which in turn reduces the amount of damage to building contents.

Number of floor	Castries old CBD		Dennery Village	
	Number of buildings	Percentage (%)	Number of buildings	Percentage (%)
1	171	31.9	294	86.7
2	269	50.2	44	13.0
3	79	14.7	1	0.3
4	15	2.8	0	0.0
5	1	0.2	0	0.0
6	1	0.2	0	0.0
Total	**536**	**100**	**339**	**100**

Table 5-5: Number of floor types from building inventory

5.1.7. Height above the ground

The height of a building above the ground (i.e. height of first floor of building from the road) is important for floods. It may influence the level of inundation of buildings as in most cases most buildings with lower heights above the ground are more inundated than buildings with higher elevations. From the building inventory, 6% and 5% of buildings in Castries old CBD and Dennery Village, respectively, are below 0.1 meters from the road (see Table 5-6). Majority of the buildings in Castries old CBD (see Appendix 9a) and Dennery Village (Appendix 9b) falls within the range of 0.1-0.5 meters above the ground. Examples of the different heights of building above the ground is shown in Figure 5-5.

Height above the ground (in meters)	Castries old CBD		Dennery Village	
	Number of buildings	Percentage (%)	Number of buildings	Percentage (%)
<0-0.0	34	6.3	18	5.3
0.1-0.5	416	77.6	197	58.1
0.6-1.0	79	14.7	100	29.5
1.1-1.5	7	1.3	14	4.1
1.6-2.0	0	0.0	4	1.2
2.1-2.5	0	0.0	1	0.3
2.6-3.0	0	0.0	2	0.6
>3.0	0	0.0	3	0.9
Total	**536**	**100**	**339**	**100**

Table 5-6: Height of building above the ground

Figure 5-5: Building heights above the ground (with reference to the road)

5.1.8. Maintenance

The general criterion that was used for assigning the three types of maintenance (good, moderate, and poor) to the outer parts of the buildings in this research is as follows:

- Good - if parts of the building for example, doors, roof, windows, wall, electrical fittings, does not need any repair or replacement.
- Moderate - if parts of the building needs repair for example painting, fixing of doors, windows, roof, etc., or has minor cracks.
- Poor – if parts of the building needs to be repaired or replaced, has major cracks, holes or decay (for wood structures). Additionally, all dilapidated buildings were included in this type.

The level of maintenance of a building is an important factor in terms of floods. Buildings with poor maintenance tend to have more damage from flood water than buildings with good maintenance. Analysis of the data shows that the predominant maintenance type in both study areas is moderate (see Table 5-7) while poorly maintained buildings are the least. During the inventory it was also, discovered that there were a lot of vacant-abandoned and dilapidated buildings in Dennery Village than in Castries old CBD. This is attributed mostly to the recurring incidence of flooding in Dennery Village. Consequently, most of the people have abandoned their buildings at the flood plain, and have moved to the higher elevated hilly environ which is less affected by floods. However, the amount of vacant abandoned buildings influenced the total number of poorly maintained buildings. A better option would have been to classify dilapidated buildings as 'very poor'. The spatial distribution of the maintenance types for both study areas is shown in Appendix 10a and 10b.

Maintenance	Castries old CBD		Dennery Village	
	Number of buildings	Percentage (%)	Number of buildings	Percentage (%)
Good	211	39.4	101	29.8
Moderate	221	41.2	153	45.1
Poor	104	19.4	85	25.1
Total	**536**	**100**	**339**	**100**

Table 5-7: Maintenance types from building inventory

5.1.9. Built up or Columns (Building style)

During the inventory three types of building styles were found (see Table 5-8). The predominant type is buildings that are built up from the ground, and all the buildings in Castries old CBD belong to this group. Buildings on columns (stilts) were found in Dennery Village, and it was discovered that the people construct their buildings on columns for two main reasons, namely, for social reasons (status), and for flood mitigation. In terms of social reasons they complete the second floor of their buildings while the first floor is still on columns. Built up and columns type is a mixture of columns on one side of the building and built-up on the other side. Examples of the building styles are shown in Figure 5-6.

Building style	Castries old CBD		Dennery Village	
	Number of buildings	Percentage (%)	Number of buildings	Percentage (%)
Built Up	536	100.0	330	97.3
Columns	0	0.0	8	2.4
Built Up and Columns	0	0.0	1	0.3
Total	**536**	**100**	**339**	**100**

Table 5-8: Building style from building inventory

(a) (b) (c)

Figure 5-6: Types of building style (a) built up (b) on column for social reason (c) on column for flood mitigation

5.2. Building description from household interview

Information on building age, ownership, flood insurance, were collected from 94 households (Figure 5-7) during the interview at Dennery Village. Additionally, the common structural type of buildings was derived by combining the wall, floor, and roof materials of buildings (from the inventory); and it will be used in the physical vulnerability assessment using depth-damage method.

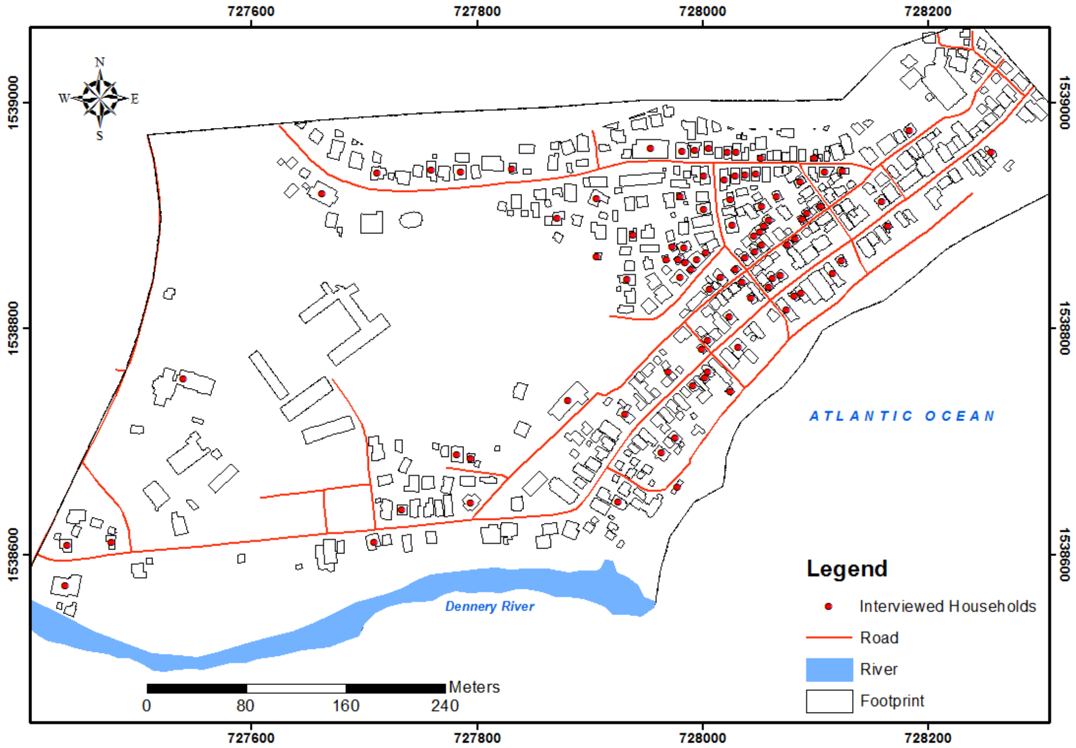


Figure 5-7: Distribution of interviewed household in Dennery Village

5.2.1. Building age

The result from the interviewed households indicates that the largest percentage (52%) of the buildings was constructed more than 20 years ago (see figure 5-8), while about 13% were constructed not more than 10 years ago. Age of a building influences its vulnerability to floods. Without adequate maintenance, the materials used for constructing a building deteriorate with increase in age. Consequently during flood the older buildings tend to have more structural damage from the impact of water currents mixed with debris, than the newer buildings. The spatial distribution of the age of buildings from the interviewed households is shown in Appendix 11.

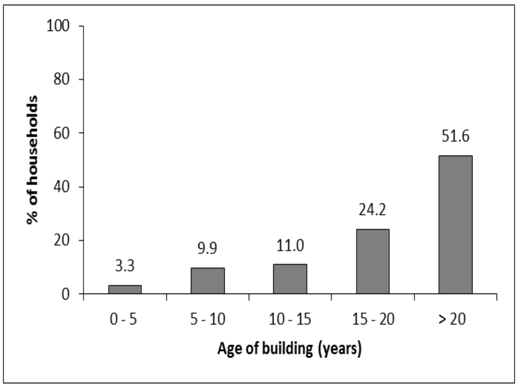


Figure 5-8: Age of household buildings

5.2.2. Building Size

The building size of majority of the households that were interviewed is between 51-100m^2 (Figure 5-9). In contrast, buildings with sizes of more than 200m^2 are the least. From the data, it was observed that the size of most of the single residential family buildings were not more than 100m^2. Information on the size of buildings is relevant because it can be used to estimate the amount of people that are in the building.

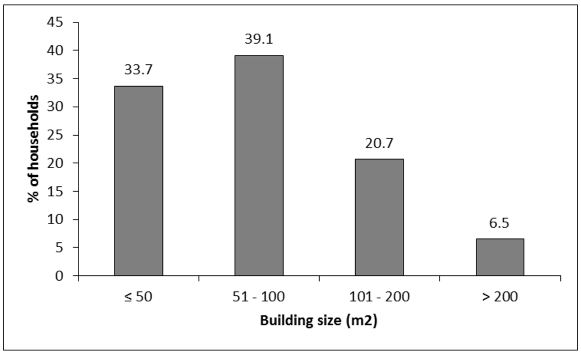


Figure 5-9: Size of household building

5.2.3. Building Ownership

Based on the responses given by the respondents during the household interviews, 80% of the buildings are owned by the people, while 20% are on rent (see Figure 5-10). Ownership status may have an influence on the way people react or respond towards mitigation measures that needs to be implemented in safeguarding their buildings against flood.

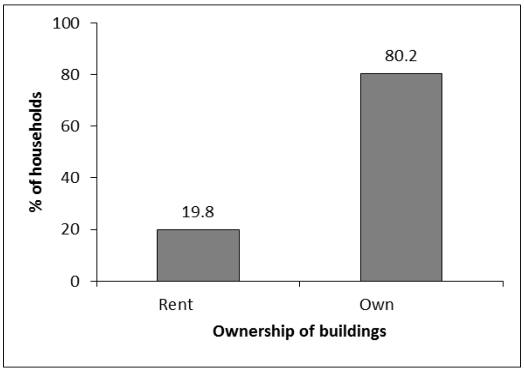


Figure 5-10: Ownership of household buildings

5.2.4. Flood insurance

The result from the household interviews shows that over 90% of the people do not have flood insurance (see Figure 5-11). According to the respondents that have, they insured their buildings to flood at the newly developed credit union. An analysis of building age and ownership status of the households that have flood insurance was performed. The result showed that the building age of those households were from 10 years and above, and were all owned by the people.

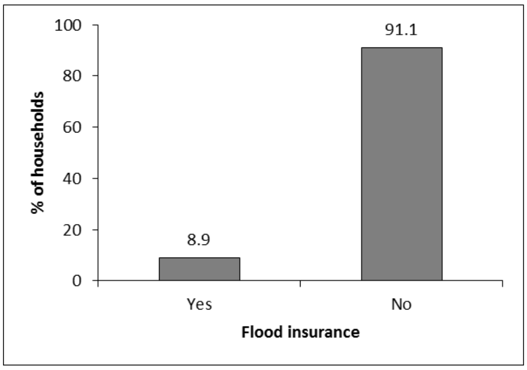


Figure 5-11: Flood insurance by respondents

5.2.5. Combination of wall-floor-roof material

Structural vulnerability of buildings to floods is influenced by the type of material that was used in constructing the building. In this research, vulnerability assessment of buildings using curves will be conducted by analysing the damage to the wall, floor and roof material.

In order to derive a meaningful classification of the various structural types in Dennery Village, a cross-tabulation of the wall, floor, and roof material for 94 households that were interviewed was performed using pivot table function in Microsoft Excel. The result indicated that there are four common structural types (see Appendix 12). The same analysis was performed for the entire 339 buildings (from the inventory) in the study area, and the result indicated that there are eight common structural types of buildings (Appendix 13). As stated earlier in methodology, the building inventory was conducted simultaneously with the household interviews due to time constraint. This made it difficult to conduct the interviews based on selection of sample locations (buildings) after an analysis of the common structural types of the 339 buildings in the study area. Hence, depth-damage information for four additional, structural types of buildings was not collected. The eight common structural types from the entire buildings are shown in Table 5-9.

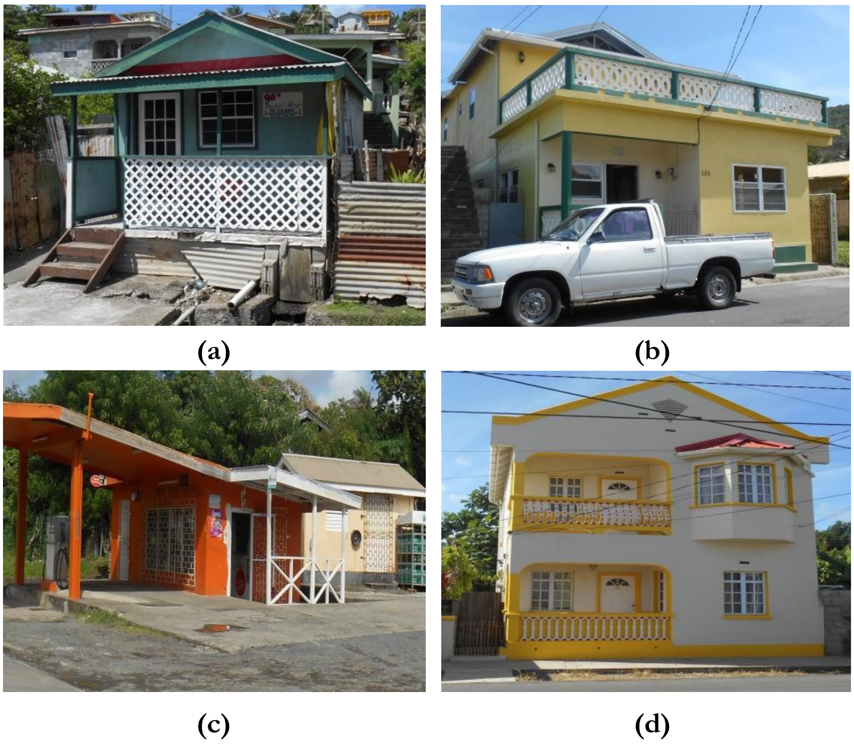
Structural type	Wall	Floor	Roof
Structural type 1	Wood	Wood	Galvanized Iron Sheet
Structural type 2	Concrete Block	Ceramic Tiles	Galvanized Iron Sheet
Structural type 3	Concrete Block	Concrete	Galvanized Iron Sheet
Structural type 4	Concrete Block	Ceramic Tiles	Painted Steel Sheet
Structural type 5	Concrete Block	Concrete	Concrete
Structural type 6	Concrete Block	Concrete	Painted Steel Sheet
Structural type 7	Wood	Concrete	Galvanized Iron Sheet
Structural type 8	Wood and Concrete Block	Concrete and Wood	Galvanized Iron Sheet

Table 5-9: Eight common structural types from building inventory

From the household interviews, the four common structural types are:

- Structural type 1 - wood wall, wood floor, and galvanized iron sheet roof;
- Structural type 2 - concrete block wall, ceramic tiles floor, and galvanized iron sheet roof;
- Structural type 3 - concrete block wall, concrete floor, and galvanized iron sheet roof; and
- Structural type 4 - concrete block wall, ceramic tiles floor, and painted steel sheet roof.

The structural type that contains the highest number of buildings from the interviewed household in Dennery Village is structural type 1 while the least is structural type 4. Examples of the structural types of buildings are shown in Figure 5-12. These structural types will be used for further analysis in Chapter 7.



(a) **(b)**

(c) **(d)**

Figure 5-12: Common structural types of buildings from interviewed household (a) Structural type 1 (b) Structural type 2 (c) Structural type 3 (d) Structural type 4

5.3. Population characteristics

Population density and distribution in time and space are relevant components for exposure and vulnerability assessment. Information regarding characteristics of the people such as household size, age distribution, and population distribution for day time and night time scenarios were obtained from respondents, during the household interviews. The results obtained are presented and explained in the following sub-sections below.

5.3.1. Household size

The data derived from the household interview shows that the highest household size consists of 9 and 10 persons per household (see Figure 5-13). Also, the data indicates that small household sizes (from 1 to 4) are predominant with 74% of the total number of respondents. In terms of flooding, the higher the number of persons per household the more vulnerable they are.

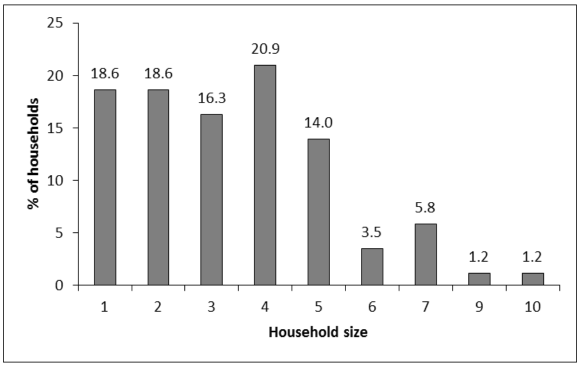


Figure 5-13: Household size

5.3.2. Age distribution

The result shows that the highest percentage of the population from the interviewed households is between the ages of 25-39 (Figure 5-14). Also, the percentage of population between the ages of 0-4 and from 65 years and above is about 10% of the total population. In terms of disaster (floods), the more vulnerable population are the very young and very old people (UN-ISDR 2004), because oftentimes they need special assistance and help.

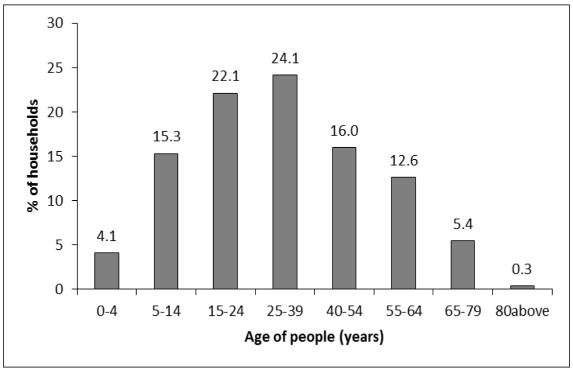


Figure 5-14: Age distribution of interviewed households

5.3.3. Population distribution pattern

The population distribution pattern of the interviewed households shows that the numbers of people in the houses are more from 6pm to 6am (night time scenario) than during the day (Figure 5-15). This is because most of the people leave their houses for work, school, and other activities during the day; and they come back to their family during the night. As can be seen from the graph (Figure 5-15), between 9-3pm is when the number of people are lowest in their houses. Information on the number of people present at various times of the day and night can be useful in estimating the population per building during each period of the day and night. Also, it can be used by emergency responders to locate the more vulnerable houses (in terms of number of population) depending on the time of the day or night during a flood event, and rescue the exposed population.

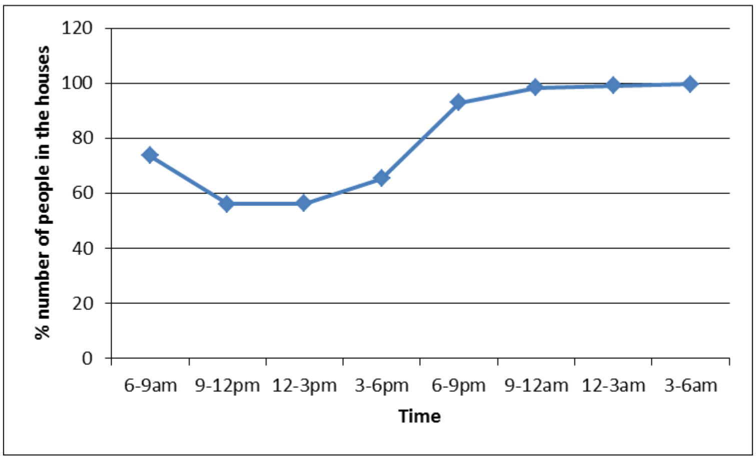


Figure 5-15: Household population distribution pattern

5.4. Conclusion

In this chapter, the elements at risk and some characteristics that influences their vulnerability to flood hazard has been discussed. The various characteristics of the buildings and population explained will be used for the exposure and vulnerability assessment in the subsequent chapters.

6. EXPOSURE ANALYSIS TO FLOOD

This chapter describes the flood events; and the people's perception on the causes of floods for Dennery Village study area, only. Flood depth data was obtained from the respondents during the household interviews at Dennery Village. It also describes the comparison of the December 2013 field measured flood depths, and the flood depth from openLISEM model. Furthermore, it examines the exposure analysis of buildings and population that was conducted using the flood model map. The subsequent analysis in this chapter could not be conducted for Castries old CBD study area because conducting household interviews (during the fieldwork) to obtain the data could not be achieved, due to time constraint.

6.1. Flood events in Dennery Village

Dennery Village has been affected by several flood events including the December 2013 flood. The cause of this flood was due to the passage of a tropical trough through the island on December 24 (Christmas Eve). According to the World Bank (2014) report, an extremely intense rainfall developed rapidly without warning when a tropical trough forecast was made for the region; and a peak rainfall occurred between 5:00 p.m. and 9:00 p.m. The intensity and volume of rainfall over a few hours made the December 24-25 trough significant. An analysis of the return period of the event indicated that it may be in excess of a 1-in-100 year event. The impact of this event on the people was increased significantly due to several reasons such as, a reduction of the soil's capacity to absorb additional rainfall due to the persistent rainfall that occurred in the previous week up to December 24. Also, the event occurred in the late afternoon/early evening when most of the people were in transit from work and (or) from holiday shopping with the result that most of the people were stranded and unable to return to their homes.

According to the respondents the flood water came from the Dennery River; and from the Ravine Trou à l'eau (see Figure 6-1) which is located outside the study area. The ravine is precisely at the northern, hilly environs of the study area.

Several factors that lead to flooding in the study area were obtained during household interviews and general discussion with the people. The factors include excessive rainfall; hurricane; high water level from the sea; garbage; uncontrolled city development; and river outbreak.

In this research the main focus on flood events in the study area is the December 2013 flood. However, during the interviews information on previous flood events was gathered by asking the respondents about the highest flood depth that has occurred in their houses. Data on flood depths was obtained at the households that were flooded.

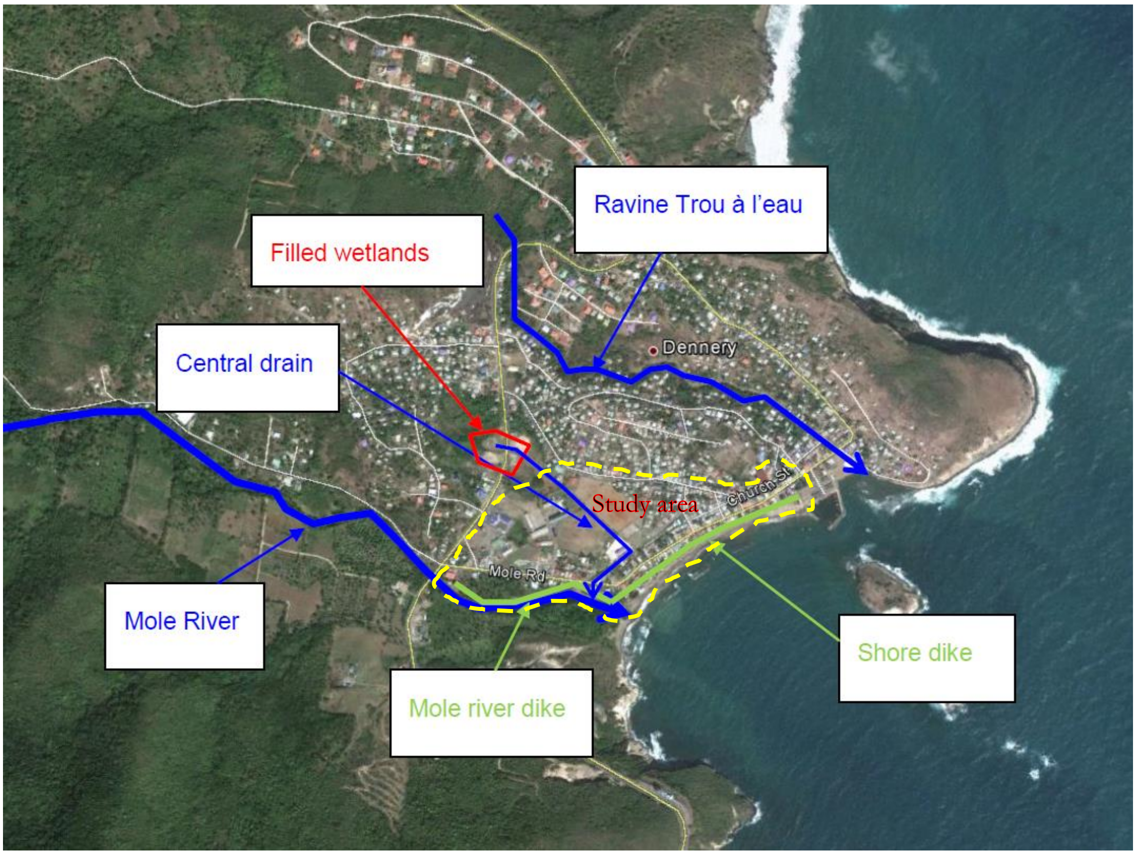


Figure 6-1: Characteristics of the study area

Source: Adapted from Marmagne & Fabregue (2013)

6.2. Flood depth analysis

The flood depth analysis was performed for two scenarios, namely, December 2013 flood event, and highest flood depth that has occurred at the interviewed households. Information on causes of flood for the two scenarios from the people's perception, flood duration, and some practices that lead to exposure of the people are explained.

6.2.1. December 2013 flood depth from fieldwork

The flood depth data was obtained during interviews from 47 households that were affected during the December 2013 flood event. The flood depth point for each house was obtained by measurements taken inside the house, from heights indicated by the respondents on the wall to the ground of first floor. The height of the first floor to the ground (foundation) was then, added to obtain the actual flood depth point for each house (see Figure 6-3). It is important to note that the field measured flood depth points could not be interpolated into a raster flood depth map because the spatial distribution of the collected samples (interviewed households) were clustered, mostly, at the high flood location of the study area. Hence, extrapolating the clustered points for the entire study area could lead to wrong estimates of flood depths. However, the flood depth points will be used as input for the physical vulnerability assessment of buildings, using the depth-damage method in chapter 7.

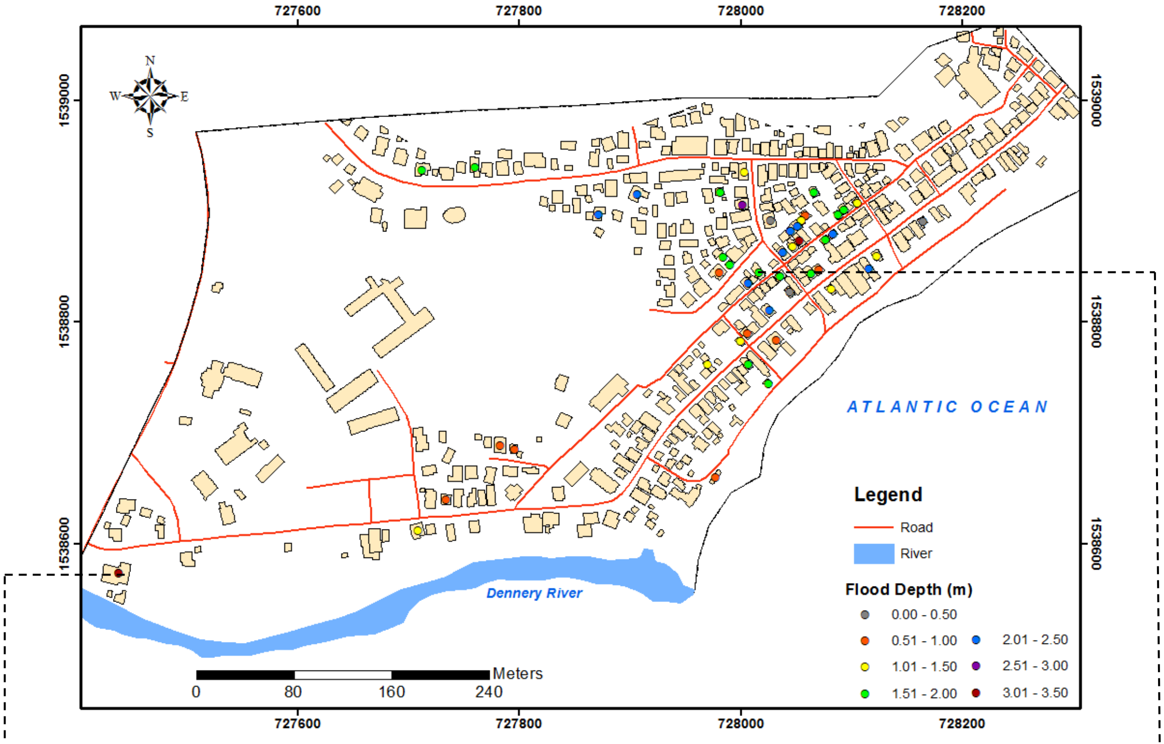
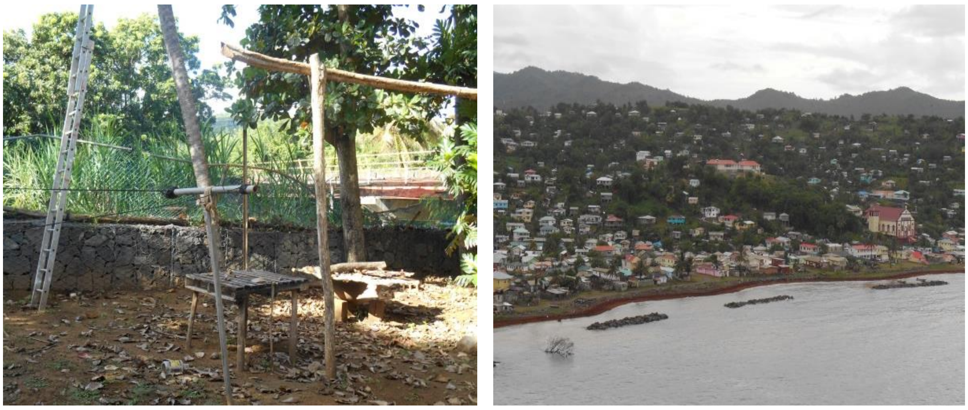


Figure 6-2: Distribution of December 2013 flood depth points from the household interviews

From the household interview, 98% of the respondents indicated that the cause of December 2013 flood event was rainfall, while 2% pointed out that it was due to garbage that clogs the drainage system. The maximum flood duration of the event from interviewed households was 7 hours while the least was 1 hour. According to the respondents, the flood water entered their houses through the doors, windows and roof but, majority (61%) was through the doors. Additionally, majority (71%) of the inundated houses have the 'glass panel' window type. On the other hand, the majority (52%) of the inundated houses had the 'wooden' door type, which is followed by 'glass panel' door type with 46%. From the researchers discussion with the people most of them stated that they prefer the 'glass panel' door type because it does not have much opening from the floor where water can enter the house, when compared to the wooden doors. But, because it is more expensive than the wooden doors, people that cannot afford it still use the wooden door. Sufficient data on the height of windows could not be obtained due to time constraint during the entire survey and the time spent on each interview. Otherwise, it would have been used to assess the window height (either high or low) of those houses that water came in through the window.

Oftentimes, houses with lower window heights are more prone to flood water than houses which the windows are placed at a higher elevation from the ground.

Also, an analysis of the data from the interview showed that 70% of the inundated houses have flood proofing while the remaining did not have. This is an indication that most of the people are aware of the hazard (flood) and implement structural mitigation measures to protect themselves against it. The type of flood proofing found in the study area are, raised houses (i.e. houses with foundations that are raised well above the ground), stilts, dyke and stilts, and shutters for the door. Furthermore, among the entire flood proofing types the most common type is raised houses. It was also observed that there are structural mitigation works from previous projects such as the dyke at the Dennery River, along Mole road, and an embankment at the sea (shore dyke) to protect the people against flood (Figure 6-4). The location of these structural mitigation works in the study area is shown in Figure 6-1.



(a) **(b)**

Figure 6-3: Structural mitigation work (a) Dennery (Mole) River dyke (b) Embankment at the sea

6.2.2. Maximum flood depth

The maximum flood depth data was obtained during the household interviews from 59 households. Some of the respondents stated that the maximum flood depth occurred during previous flood events in October (2013 and 2010-Hurricane Tomas), and others mentioned December 2013. The flood depth point for each house was measured as explained in the preceding sub-section and the spatial distribution of the points are shown in (Figure 6-5).

Most of the respondents gave several reasons that resulted to the occurrence of the highest flood depth in their houses. Majority stated that it was due to rainfall, while 26% mentioned that is was caused by a river outbreak from the Ravine Trou à l'eau (Figure 6-6). The flood duration of the highest flood depth in the houses lasted from 30 minutes to 72 hours.

During the interviews and general conversation with the people, knowledge about their perception on causes of flood and practices that exposes them to flood in the study area was gained. One respondent mentioned that some people still construct their buildings in the high flood prone area without raising the heights of the first floor well above the ground. Consequently, such people will be more affected by flooding. Another respondent mentioned that garbage from the hills settles and clogs the nearby drain to his house, which in turn obstructs the free flow of water and increases the amount of flood water. During site inspection to some of the drains the researcher also discovered that they were filled with silt (see Figure 6-7).

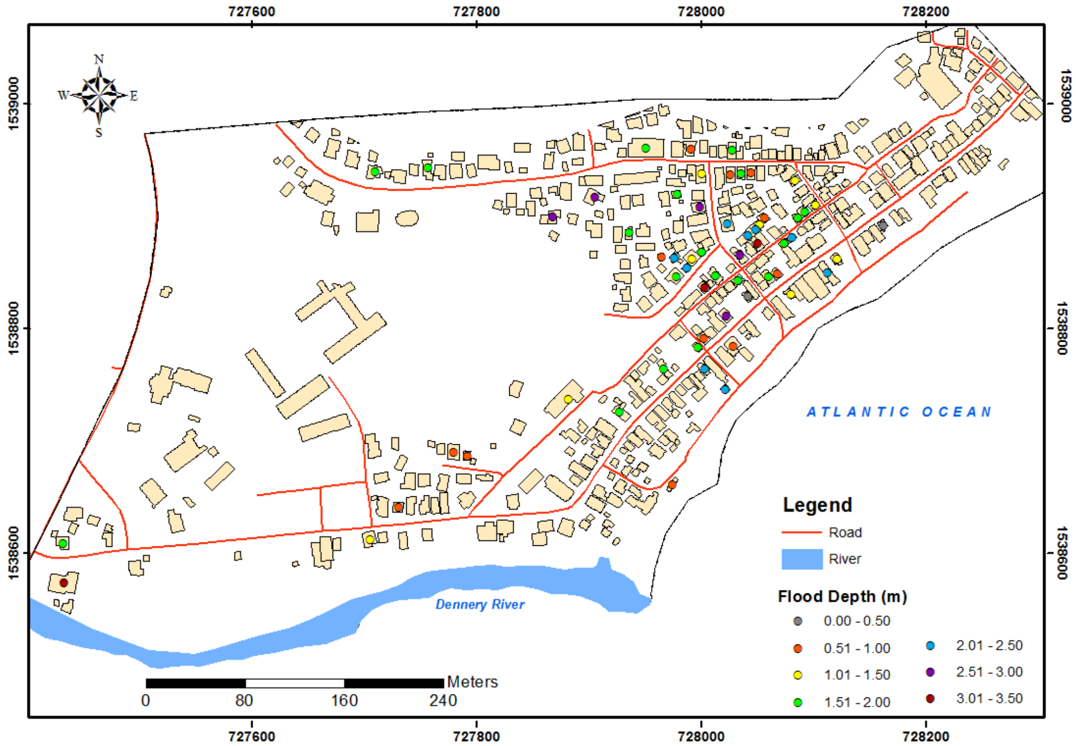


Figure 6-4: Distribution of the maximum flood depth points in respondents houses

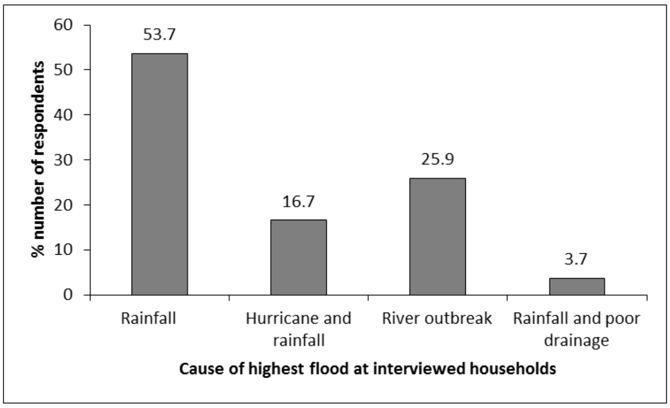


Figure 6-5: Respondents perception on the cause of highest flood in their houses

Figure 6-6: Drains filled with silt

6.2.3. December 2013 flood depth from openLISEM

The December 2013 event at the study area was also, simulated using an openLISEM model. This model was used to generate flood hazard information at the national scale and on more detailed scales in the island, for the CHARIM project. The input parameters used for simulating the event with the model includes rainfall data, Digital Elevation Model (DEM), soil data and land use/ cover map. The model map was obtained with the aim of using it to assess the exposure of buildings and people at the study area, during the event. Also, to ascertain if the flood depth produced by the model corresponds with the flood depths derived during household interviews at the fieldwork.

The rainfall data that was used in simulating the December 2013 storm event for the study area was derived from the Caribbean Agricultural Research and Development Institute (CARDI) rainfall station (it is outside the boundary of the study area). According to the rainfall data, the peak (maximum) intensity for the event was 120mm/hr (see Appendix 14).

When the model map (Figure 6-7) was obtained, it was adjusted to the same spatial reference of the December 2013 flood depth map (field measured map) because there was a shift between both maps. It should be noted that the spatial resolution of the model map is 10 meters while the maps used in this research is 0.5 meters. In order to obtain the flood depth points of those houses that were flooded during the event, those houses were overlaid on the model map. After that the flood depths (Figure 6-8) were extracted from the model map in ArcGIS.

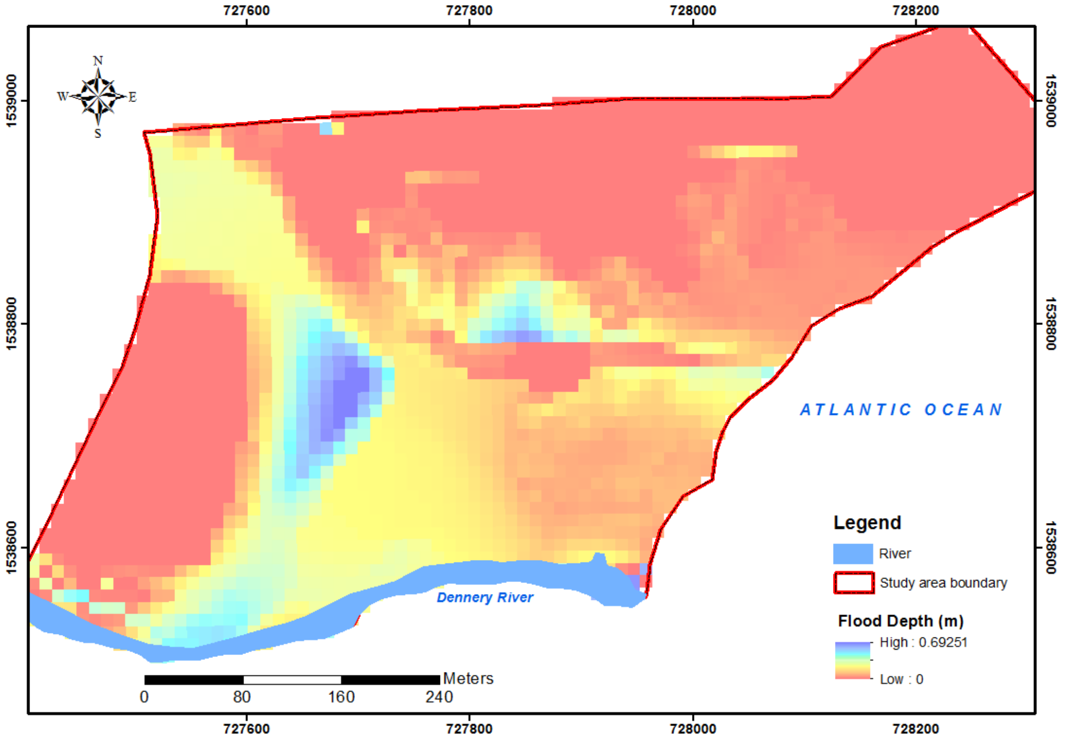


Figure 6-7: December 2013 flood map from openLISEM

Source: Jetten (2015)

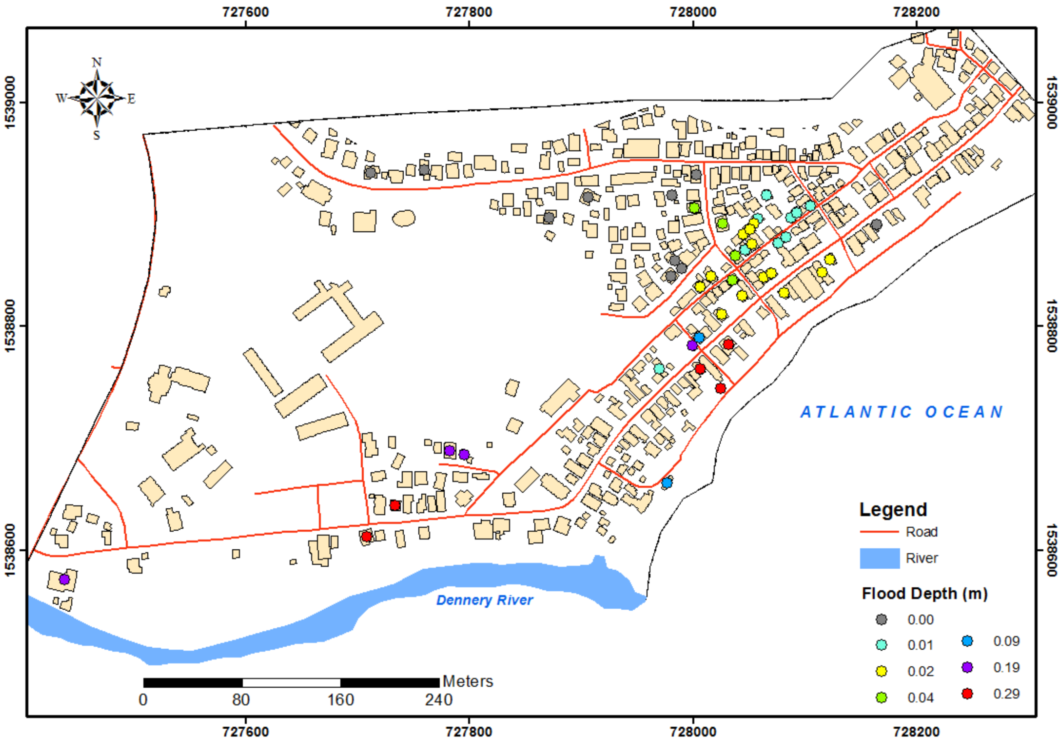


Figure 6-8: Distribution of December 2013 flood depth points from the openLISEM model

The result (model map) shows that the maximum flood depth in the houses of the respondents during the event was 0.29 meters. Also, some of the flooded houses from the household interviews were not flooded.

In order to compare the level of correlation of the flood depths from the model map and the field measured flood map, a correlation test was performed using SPSS software. The input data (flood depths) that was used for this analysis is shown in Appendix 15; and a scatter plot of the flood depths is presented in Figure 6-9. From the test result, the correlation coefficient was -0.15 (Figure 6-10), which means that there is a poor correlation between the flood depth of both maps.

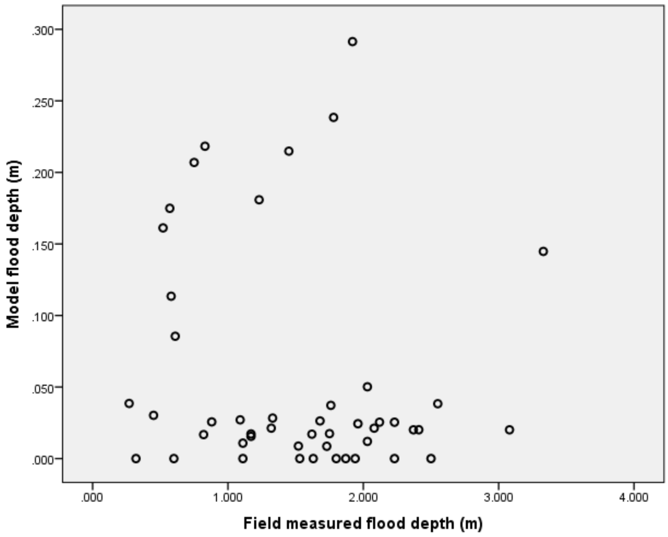
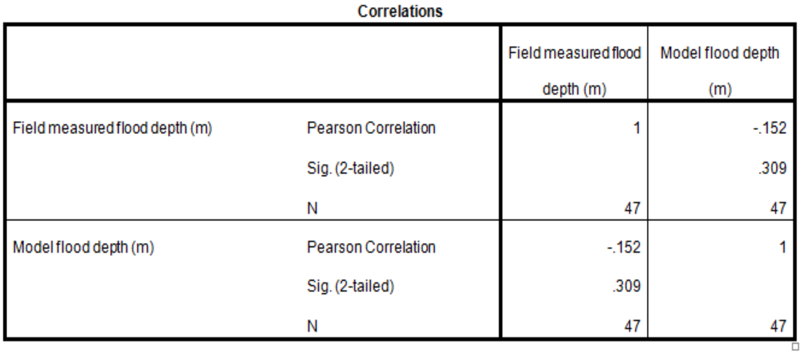


Figure 6-9: Scatter plot of field measured flood depth and model flood depth



Correlations

		Field measured flood depth (m)	Model flood depth (m)
Field measured flood depth (m)	Pearson Correlation	1	-.152
	Sig. (2-tailed)		.309
	N	47	47
Model flood depth (m)	Pearson Correlation	-.152	1
	Sig. (2-tailed)	.309	
	N	47	47

Figure 6-10: Correlation test for flood depth values derived from the field and model

6.3. Flood Level analysis

The flood level analysis was performed for the two scenarios, using the flood depth points (i.e. the final flood depth in the houses that includes the addition of the height of the foundation to the measured flood depths) obtained during the household interviews. The aim was to get the flood level of the houses above mean sea level.

6.3.1. December 2013 flood level

The actual flood level for 47 households that were affected by the December 2013 flood was derived by adding the terrain height of each house to the flood depth points obtained during the interviews. The terrain height was obtained by extracting the height above mean sea level of each house from the DTM. The spatial distribution of the flood level points is shown in Figure 6-11.

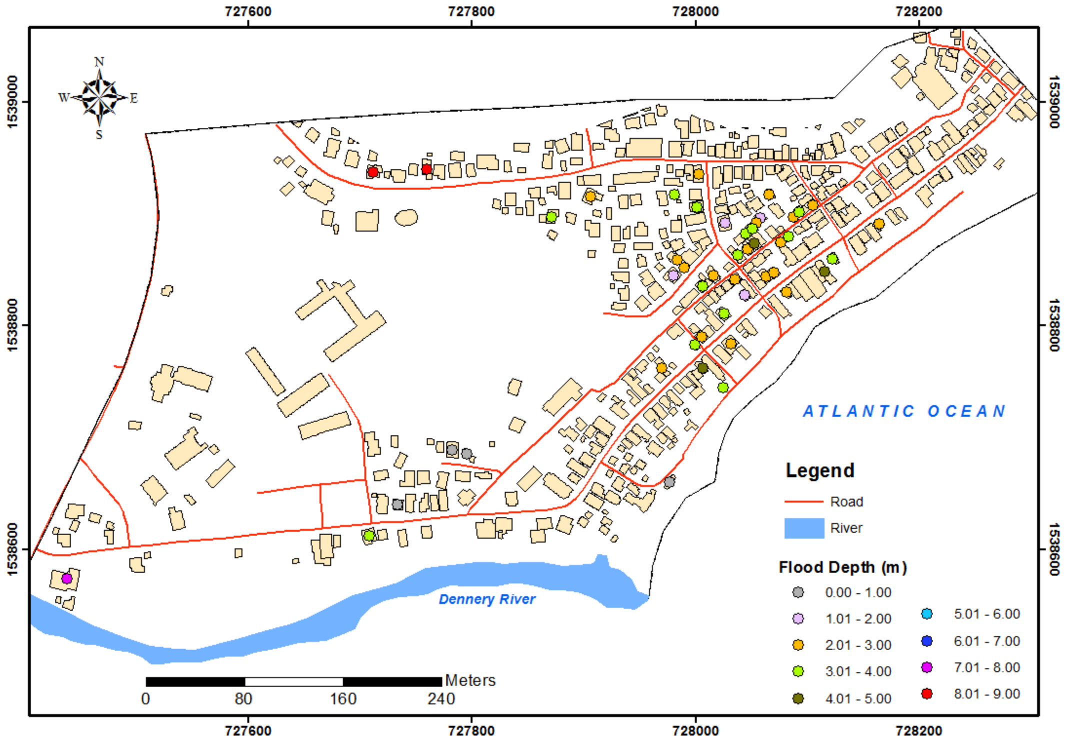


Figure 6-11: Distribution of the December 2013 flood level points in respondents houses

6.3.2. Maximum flood level

The flood depth point data from 59 households that indicated the highest flood heights to their houses was used to generate the actual flood level for those houses. The terrain heights of each house was added using the same procedure explained in section 6.3.1; and the spatial distribution of the flood level points are shown in Figure 6-12.

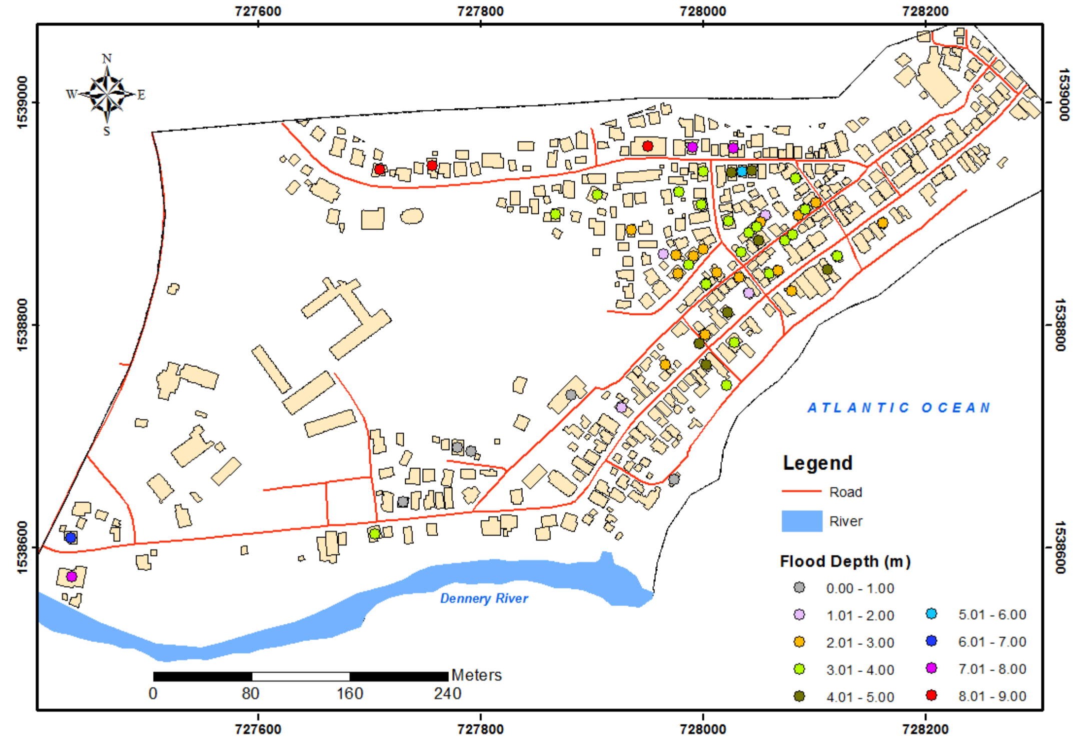


Figure 6-12: Distribution of the maximum flood level points in respondents houses

6.4. Assessing the exposure of buildings and population

The exposure analysis for the December 2013 event was conducted for the entire study area. The aim was to assess the amount of buildings and population that had a low, moderate, and high exposure during the event. The data that was used for assessing the exposure of buildings was derived from the 339 buildings that were surveyed during the inventory. In terms of exposure of population, the data was obtained from the 94 households that were interviewed.

Before the exposure analysis, a classification scheme (Table 6-2) from a study conducted by (Cooper & Opadeyi, 2006) on flood hazard assessment for the island was adopted to classify the flood depths of the model map into low, moderate, and high classes. This classification scheme was adopted because data on class boundaries (i.e. low, moderate, and high) for flood depths could not be obtained from the people during the fieldwork, due to time constraint.

Flood hazard class	**Depth (in meters)**
Low	<0.91
Moderate	0.91-1.37
High	>1.37

Table 6-1: Classification of flood hazard according to depth

Source: Cooper & Opadeyi (2006)

The exposure was performed by an overlay (spatial join) of the provided flood model map with the elements at risk (buildings and population) map. The result showed that the exposure of all the buildings and population during the December 2013 flood event, in the study area was low.

6.5. Discussion

In this chapter, the flood events, flood depth and level analysis, comparison of the December 2013 field measured flood depth and model flood depth, and exposure analysis of the elements at risk has been explained.

From the findings during field work, several factors namely, natural events such as hurricanes which often leads to rainfall; low capacity of the drains to direct the flow of water through the channel to the outlet (sea, or river); garbage; river outbreak; causes flooding in Dennery Village.

The differences in flood depths between the December 2013 field data map and the model map, for the flooded houses were in general high (as shown in Appendix 15). The highest deviation (difference) of 3.19 meters is at 'Point 46', where the flood depth from the model is 0.15 meters while the flood depth from the field data is 3.33 meters. This difference could be from the parameterization and (or) quality of the input data that was used for simulating the event with the model.

The result of the flood level analysis of both scenarios showed that the level of flood depth was not the same between some houses that were close to each other. This may be due to the following reasons: A)Wave action of water, with the possibility that maybe the water entered into respondent A's house when it was at the peak (crest) and the next house (respondent B) when it was at the trough. With the result that respondent A had more water depth than respondent B, assuming all other factors are equal. B) The quality of the DTM: if a DTM gives wrong estimates of the terrain values it will in turn lead to inaccurate result of the flood level. C) Incorrect information of flood depth by the respondents during the interviews. Sometimes people tend to mix up the flood depths for different events especially when there are several flood events in the area. D) The flood depth data was collected in collaboration with the volunteers; and there is a possibility that measurements of water depths may have been taken from different reference points e.g. from heights indicated by respondents to level of first floor, or to the foundation, or to the ground. It is concluded that the quality of the results from all the analysis performed in this chapter relies greatly on the quality of the input data.

Regarding the exposure analysis, the model map fell into the low flood hazard class because the highest flood depth of the map was 0.69 meters. Consequently, the entire buildings and population in Dennery Village had a low exposure during the December 2013 flood event. This result does not correspond with the information derived from the people during the field survey. The exposure result presented can be improved by a calibration of the model to produce a better result (flood depth map) for the December 2013 event and other flood maps (e.g. 1- 5 year, 1-10 year, 1-20 year, etc.) for the study area. An improved flood map (s) can lead to a better estimation of the exposure of elements at risk in the study area. Furthermore, information derived from this analysis can aid in identifying the areas of high flood water depths; and the number of people, age structure, occupancy types, type of material used for construction of buildings, etc. in such areas can be assessed. The information can aid in the implementation of effective plans on reducing the level of exposure of the elements at risk. Also, during flood events, emergency responders will be able to know the high, moderate, and low flood depth areas, for proper response and evacuation of the people.

7. ANALYSIS OF PHYSICAL VULNERABILITY TO FLOOD

This chapter describes the flood physical vulnerability assessment for both study areas (Castries old CBD and Dennery Village). The first part consists of the physical vulnerability assessment using the depth-damage method at Dennery Village, for buildings that were flooded during the December 2013 event. The second part is an assessment of the physical vulnerability of buildings in both study areas using the indicator (SMCE) method. The concluding part shows the comparison of physical vulnerability assessment using the depth-damage and indicator (SMCE) method at Dennery Village. Flood depth and damage to buildings structure data was obtained from the respondents during household interviews at Dennery Village; weights assigned to selected indicators for the indicator method (SMCE) were derived from inputs by experts from Saint Lucia.

7.1. Assessing vulnerability of buildings using Depth-Damage method

Kelman & Spence, (2004) noted that damage to buildings from flood water includes wall failure, glass breaking, roof collapsing, foundations being undermined, or doors being forced open. Therefore, in assessing the physical vulnerability of buildings, it is important to consider parts of the building structure such as wall, floor, doors, windows, roof, etc. that could be damaged by flood.

In this research, depth-damage assessment of building structure was examined considering only the wall, floor and roof material. The vulnerability of structural type of buildings was expressed as the percentage of damage to the wall, floor, and roof at different flood depths on a scale of 0 (no damage) to 1(total damage).

In order to obtain the various degrees of damage to the selected materials of building structure a classification of the damage grade (degree) into Nothing Happen (NH), Half Collapse (HC), and Collapse (C) was made (Table 7-1). This damage classification was adapted from Sagala (2006). During the household interviews, the damage to each building structure (wall, floor and roof) at certain flood depth was obtained from the respondents using the damage classes; Nothing Happen for 0% damage, Half Collapse for 50% damage, and Collapse for 100%.

Vulnerability	Description
Nothing Happen (NH)	If materials do not get damaged due to certain level of flood depth.
Half Collapse (HC)	If the materials get damaged by half due to flood, and money is needed for repairing it.
Collapse (C)	If the material is totally damaged from a certain level of flood depth and needs to be replaced.

Table 7-1: Definition for Vulnerability of structural type of building

Source: Adapted from Sagala (2006)

Damage data for building contents could not be collected during the interviews due to some of the reasons outlined by the respondents, as explained in Section 4.2.4. However, damage was assessed using the information derived from damage to structural parts of the buildings.

Vulnerability scale used in this research is similar to that of Maiti (2007). All possible combinations of damage classes (NH, HC, C) to wall, floor, and roof materials was analysed, and the outcome was ten combinations (see Table 7-2).

No.	Damage combination of wall, floor, and roof material
1	Nothing Happen to wall, floor, and roof materials
2	Nothing Happen to two materials but one material has Half Collapse
3	Nothing Happen to two materials but one material has Collapse
4	Nothing Happen to one material but two has Half Collapse
5	Half Collapse to three materials
6	Half Collapse to two materials, and one material has Collapse
7	Nothing Happen to one material, Half Collapse to one material, and Collapse to one material
8	Nothing Happen to one material but two materials has Collapse
9	Half Collapse to one material but two has Collapse
10	Collapse of the three materials

Table 7-2: Combinations of damage classes

From the data derived during the household interviews, seven, namely, 1, 2, 3, 4, 7, 8, and 10, out of the above combinations (shown in Table 7-2) of damage classes were applicable. The vulnerability scale developed from these combinations is shown in Table 7-3, below.

Vulnerability	Description
0 (No Damage or Nothing Happen to wall, floor, and roof materials)	• If the wall, floor and roof materials were not damaged (Nothing Happen) due to certain level of flood depth.
0.2	• If two materials were not damaged (Nothing Happen) and one material has half damage (Half Collapse) due to certain level of flood depth; and repairing cost is needed.
0.4	• If two materials were not damaged (Nothing Happen) and one material has total damage (Collapse) due to certain level of flood depth; and replacement is needed. • If one material is not damaged (Nothing Happen) and two materials have half damage (Half Collapse) due to certain level of flood depth; and repairing cost is needed.
0.6	• If one material is not damaged (Nothing Happen), one material has half damage (Half Collapse), and one material has total damage (Collapse) due to certain level of flood depth; and repairing or replacement cost is needed.
0.8	• If one material is not damaged (Nothing Happen) and two materials have total damage (Collapse) due to certain level of flood depth; and replacement cost is needed.
1 (Collapse or total damage to wall, floor, and roof materials)	• If three materials have total damage (Collapse) due to certain level of flood depth; and total replacement is needed.

Table 7-3: Vulnerability scale of structural type of building

Levels of damage and flood depth for the four common structural types were plotted into curves. The input data used for plotting the curves is shown in Appendix 16. Also, the flood depth used for plotting the curves are the depths measured inside the respondent's house. The average vulnerability curve for each common structural type of building is explained below:

1. Structural Type 1

Houses with structural type 1 are made from the combination of wood wall-wood floor-galvanized iron sheet roof material. This structural type is very vulnerable to flood water. During the interviews, one respondent mentioned that his wall was swollen and the floor sank due to water. It should be noted that the various types of wood wall materials found in the study area were classified as 'wood'. The analysis of the data shows that damage to this structural type starts from water depths of 32cm (see Figure 7-1), and at a water depth of 48 cm the vulnerability reaches 0.2 (low damage). Furthermore, at water depths of around 130 cm, this structural type is half damaged; and at around 185 cm the materials have almost total collapse.

2. Structural Type 2

Houses with structural type 2 are made from a combination of concrete block wall-ceramic tiles floor-galvanized iron sheet roof. During the interviews, one respondent mentioned the wall of her house cracked due to exposure to flood water, while another indicated that the tiles in his house were raised. Based on the analysis of the interview data, damage to this structural type starts from water depths of approximately 90 cm (see Figure 7-1); and at water depth of 144 cm the vulnerability reaches 0.2 (low damage). When the water increases to 265 cm the vulnerability reaches almost half damage.

3. Structural Type 3

Houses with structural type 3 are made from a combination of concrete block wall-concrete floor-galvanized iron sheet roof. At water depths of approximately 40 cm (see Figure 7-1), damage to this structural type starts; and at water depth of 122 cm vulnerability reaches 0.2 (low damage). When the water increases to 183 cm the vulnerability reaches almost half damage.

4. Structural Type 4

Houses with structural type 4 are made from a combination of concrete block wall-ceramic tiles floor-painted steel sheet roof. One of the respondents mentioned that there was no structural damage to the house except deposition of mud due to the flood. Damage to this structural type starts from around 125 cm and at water depth of 183 cm vulnerability reaches 0.2 (low damage). When the water depth increases to 203 cm the vulnerability increases to almost half damage (see Figure 7-1).

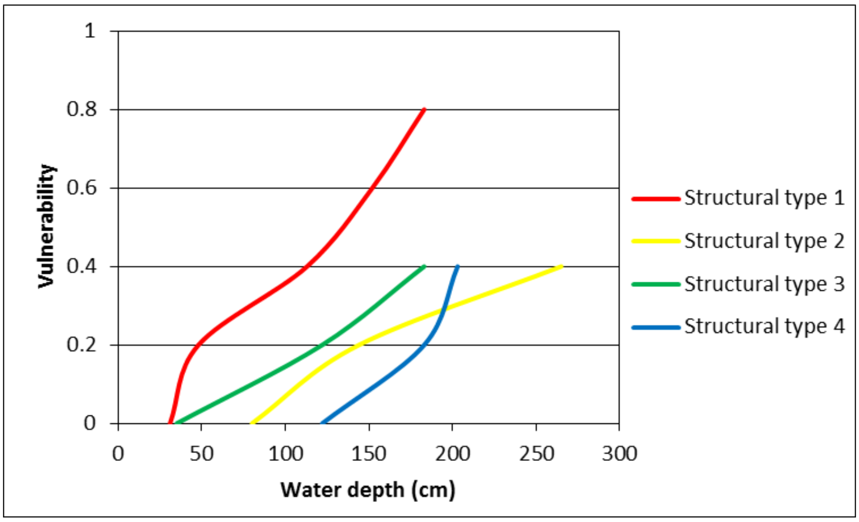


Figure 7-1: Comparison of vulnerability curves for the structural types

A comparison of the vulnerability curves for the four common structural types indicates that houses with structural type 1 are the most vulnerable (as shown in Figure 7-1). From the household interview data, the vulnerability of houses with structural types 2, 3, and 4 does not exceed almost half damage (0.4). However, the least vulnerable among all structural types of houses in the study area is structural type 4.

The final depth-damage vulnerability map for the structural types of building (Figure 7-2) was obtained after a classification of the vulnerability values into four categories, namely, no vulnerability, low vulnerability, moderate vulnerability, and high vulnerability (see Table 7-4). The slicing operation in ILWIS was used for the classification.

Vulnerability class	Vulnerability value
No Vulnerability	0
Low Vulnerability	≤ 0.3
Moderate Vulnerability	≤ 0.6
High Vulnerability	≤ 1

Table 7-4: Depth-damage vulnerability class for structural types of household buildings

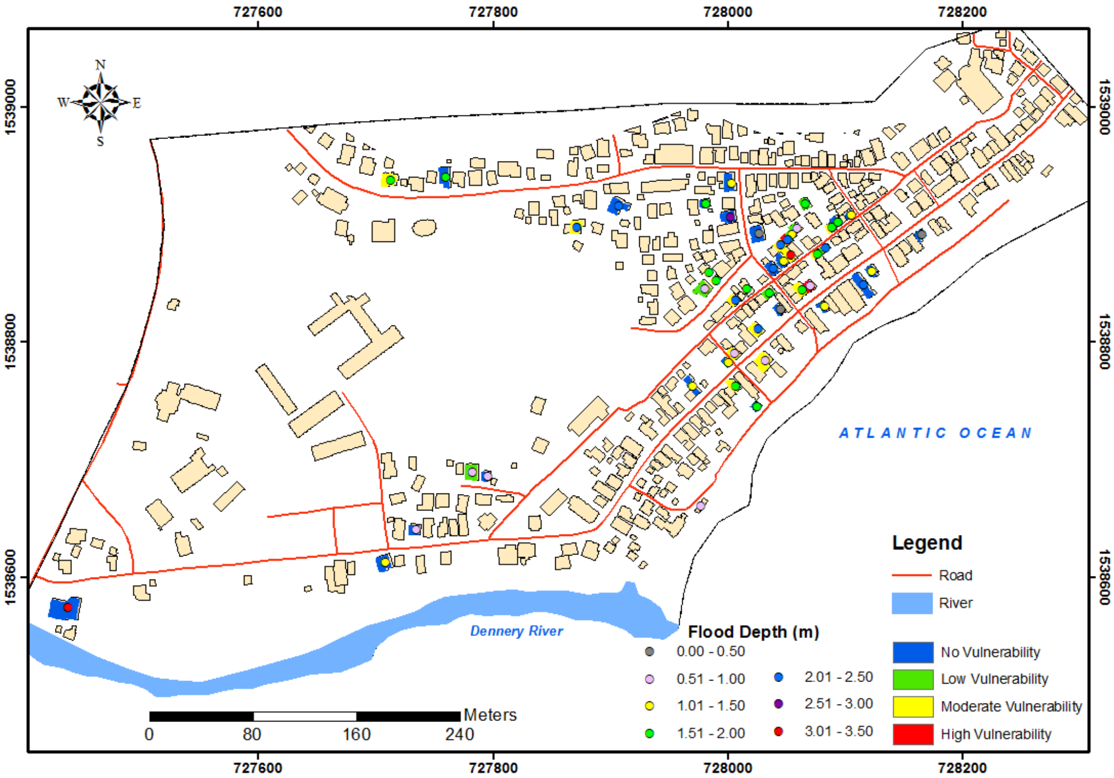


Figure 7-2: Vulnerability map of building structure for Dennery Village (Depth-damage method)

7.2. Assessing vulnerability of buildings using Vulnerability Indicators (SMCE)

The physical vulnerability assessment using SMCE was conducted for both study areas (Castries old CBD and Dennery Village). For the Dennery Village, the assessment was conducted in two parts. The first part is an assessment of the entire buildings. While the second is for those buildings that were flooded during the December 2013 event; that will be used for the comparison of depth-damage and SMCE methods of physical vulnerability assessment. The procedure that was used for the assessment is explained in this section.

The defined main 'goal' of this analysis is to perform a physical vulnerability assessment of buildings to flood using selected building characteristics. The selected factors for the assessment include wall material, height of building above the ground, number of floors, and maintenance. In this research, selection of the factors (indicators) was partly influenced by the responses derived during the household interviews, and from previous related studies by (Kappes et al., 2012; Thouret et al., 2014). From the research questionnaire data, wall material had the highest score for the most important characteristic of a building for flood damage. These factors were entered into the criteria trees of the study areas.

For the comparison of depth-damage and SMCE method, the factor 'age' was added to the aforementioned factors. It was not added to the physical vulnerability assessment of the entire buildings in both study areas because data on age of buildings was collected for only those buildings that were sampled during the household interviews at Dennery Village. Additionally, a 'constraint' was included to the aforementioned factors with the aim of selecting only the buildings that were affected during the December 2013 flood in Dennery Village. This constraint was applied in order to compare the vulnerability map derived using indicator method (SMCE) with the vulnerability map obtained using vulnerability curves (for Dennery Village study area).

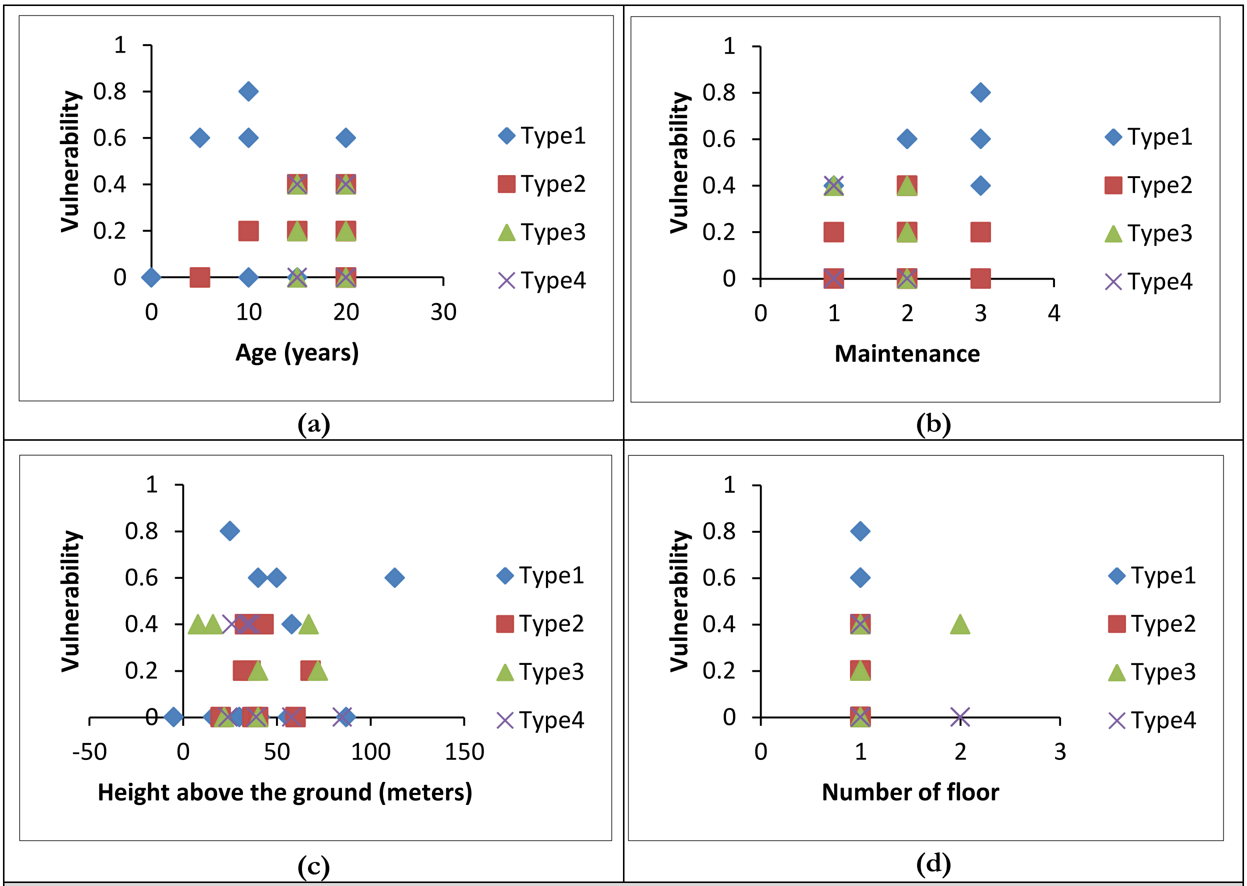
After the selection of factors, scores were assigned to the criteria (selected factors). The rating scale that was used in assigning scores to the criteria are values between 0 and 1, while the 'true' and 'false' was used for the constraint. All the factors used in this research had a 'class' domain while the constraint had a 'bool' domain. Each factor was standardized using the values between 0 and 1 so that the factors can be compared with each other. It should be noted that in this research, high score means high vulnerability while values (scores) close to zero means low vulnerability.

The next step was assigning weights to the factors. Weighting of the factors was performed with experts (stakeholders) from Saint Lucia that came for a workshop to the Faculty of Geo-Information Science and Earth Observation (ITC) in February 2015. The aim of the participatory session (Figure 7-3) was to assign weights to the classes of each factor, and among the various factors based on their expertise and experience in flood hazard and vulnerability of buildings during disasters in the island. The expert group consists of a planner - Mrs Karen Augustin (Ministry of Physical Development, Housing and Urban Renewal); an engineer - Mrs Renata McKie (Ministry of Infrastructure, Port Services and Transport); and a water resource technician - Mr Mervin Engeliste (Watershed Management Authority).

Figure 7-3: Participatory session with experts from Saint Lucia

Before the participatory session, an analysis was performed by the researcher to determine the extent of damage for the selected factors to various degrees of flood depth. In other words, to ascertain if there is a relationship between the different classes of each selected factors and damage to various degrees of flood depth. The input data that was used for the analysis was the depth-damage to the common structural types of buildings (Type 1, 2, 3, and 4) from the interviewed households.

In terms of age, it was observed that older buildings were generally more vulnerable than newer ones; but on the contrary, wooden buildings from 10 years were more vulnerable than concrete block buildings from 15 years (see Figure 7-4a). For maintenance, the result showed that poorly maintained buildings were more vulnerable than moderate and good types. In terms of building height above the ground, buildings at lower elevations showed more vulnerability than those on higher elevations. Finally, buildings with 1-floor were more vulnerable than 2-floor buildings. These findings were presented and explained to the experts before the weight assignment of the factors. It should be noted that the weights assigned by the experts for the various classes and factors were assigned with the assumption that the physical vulnerability assessment of buildings is for floods in general (i.e. not taking into consideration the different types of flood, such as flash flood or river flood).



(a) (b) (c) (d)

-In (a) 0 means 0-5 years, 5 means 5-10 years, 10 means 10-15 years, 15 means 15-20 years, 20 means 20 years and above.
-In (b) 1 means Good, 2 means Moderate, and 3 means Poor.
-Type 1, 2, 3, and 4 are structural types derived from interviewed households, as explained in section 5.2.5.

Figure 7-4: Degree of damage to selected factors (a) Age (b) Maintenance (c) Height of building above the ground (d) Number of floor

During the participatory session, it was also observed that the different experts have a more or less, different preferences in terms of indicating the relative importance (weight assignment) of the various classes in a factor. For example, for wall material each expert assigned different weight values (see Table 7-5) to concrete block class (type). In general, the more vulnerable classes were given higher weight values while the less vulnerable were assigned lower weight values. However, at the end, the experts agreed and came up with a final weight for the classes (see Table 7-6), which corresponded more or less with the scores (Table 4-3) that was obtained during fieldwork from a session with Mr Junior Mathurin.

Wall material types	**Weights**		
	Planner	**Engineer**	**Water Resource Technician**
Concrete Block	0.05	0.08	0.01
Wood	0.29	0.25	0.25
Wood and Concrete Block	0.21	0.21	0.25
Glass and Concrete Block	0.08	0.11	0.14
Stone	0.02	0.02	0.00
Brick	0.06	0.06	0.07
Brick and Stone	0.05	0.05	0.10
Galvanized iron Sheet	0.23	0.23	0.15
Total	**1.00**	**1.00**	**1.00**

Table 7-5: Different preferences on weight assignment to wall material classes by the experts

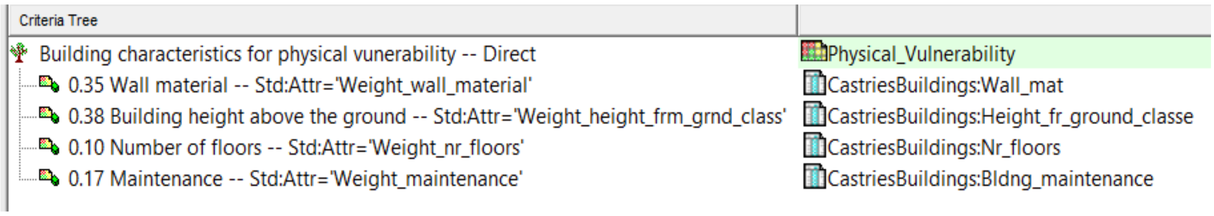
For the factors, the experts gave the highest weight to height of building above the ground; which means that it is the most important building characteristics that affects its vulnerability to flood. According to the experts, a wooden building that is elevated to, for example, 3 meters above the ground in a flood plain is less vulnerable than a concrete wall building that has an elevation of 0.6 meters in the same location. Also, the weights assigned to the various classes of each factor by the experts were similar to the earlier plotted degree of damage for each factor. The weights assigned to the selected factors and classes by the experts are presented in Table 7-6.

Factors	**Building characteristics classes**	**Final Weights**	**Factor Weights (1)**	**Factor Weights (2)**
Wall material types	Concrete Block	0.03	0.27	0.35
	Wood	0.28		
	Wood and Concrete Block	0.20		
	Glass and Concrete Block	0.10		
	Stone	0.01		
	Brick	0.07		
	Brick and Stone	0.06		
	Galvanized Iron Sheet	0.23		
Height above the ground (in meters)	<0-0.0	0.28	0.3	0.38
	0.1-0.5	0.21		
	0.6-1.0	0.18		
	1.1-1.5	0.14		
	1.6-2.0	0.10		
	2.1-2.5	0.06		
	2.6-3.0	0.04		
	>3.0	0.00		

Factors	Building characteristics classes	Final Weights	Factor Weights (1)	Factor Weights (2)
Number of floors	1	0.49	0.07	0.1
	2	0.22		
	3	0.17		
	4	0.12		
	5	0.00		
	6	0.00		
Age (in years)	0-5	0.00	0.22	NA
	5-10	0.13		
	10-15	0.19		
	15-20	0.31		
	>20	0.37		
Maintenance	Good	0.00	0.13	0.17
	Moderate	0.33		
	Poor	0.67		
Factor Weight (1)- For the comparison at Dennery Village Factor Weight (2)- For the entire buildings at both study areas				

Table 7-6: Weights assigned to the classes and factors by experts

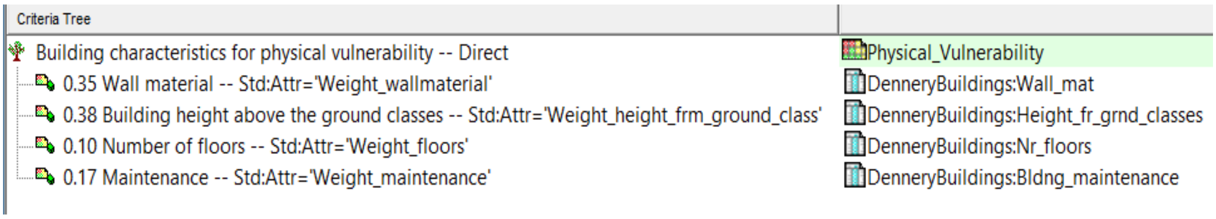
After the participatory session, the researcher used the 'direct' method option to assign the specified weights by the experts to the classes in each factor and among the factors in the criteria trees (Figure 7-5, 7-6 and 7-7). Then, the composite index map was generated.



Criteria Tree

Building characteristics for physical vunerability -- Direct	Physical_Vulnerability
0.35 Wall material -- Std:Attr='Weight_wall_material'	CastriesBuildings:Wall_mat
0.38 Building height above the ground -- Std:Attr='Weight_height_frm_grnd_class'	CastriesBuildings:Height_fr_ground_classe
0.10 Number of floors -- Std:Attr='Weight_nr_floors'	CastriesBuildings:Nr_floors
0.17 Maintenance -- Std:Attr='Weight_maintenance'	CastriesBuildings:Bldng_maintenance

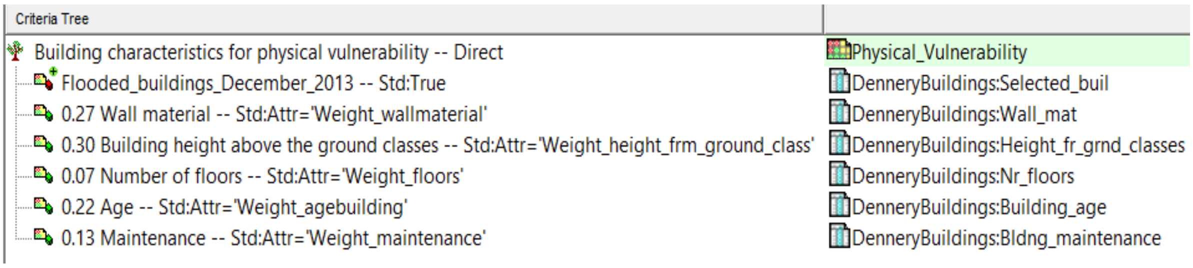
Figure 7-5: Weight values of selected factors for physical vulnerability of buildings to flood in Castries old CBD (for the entire buildings)



Criteria Tree

Building characteristics for physical vulnerability -- Direct	Physical_Vulnerability
0.35 Wall material -- Std:Attr='Weight_wallmaterial'	DenneryBuildings:Wall_mat
0.38 Building height above the ground classes -- Std:Attr='Weight_height_frm_ground_class'	DenneryBuildings:Height_fr_grnd_classes
0.10 Number of floors -- Std:Attr='Weight_floors'	DenneryBuildings:Nr_floors
0.17 Maintenance -- Std:Attr='Weight_maintenance'	DenneryBuildings:Bldng_maintenance

Figure 7-6: Weight values of selected factors for physical vulnerability of buildings to flood in Dennery Village (for the entire buildings)



Criteria Tree

Building characteristics for physical vulnerability -- Direct	Physical_Vulnerability
Flooded_buildings_December_2013 -- Std:True	DenneryBuildings:Selected_buil
0.27 Wall material -- Std:Attr='Weight_wallmaterial'	DenneryBuildings:Wall_mat
0.30 Building height above the ground classes -- Std:Attr='Weight_height_frm_ground_class'	DenneryBuildings:Height_fr_grnd_classes
0.07 Number of floors -- Std:Attr='Weight_floors'	DenneryBuildings:Nr_floors
0.22 Age -- Std:Attr='Weight_agebuilding'	DenneryBuildings:Building_age
0.13 Maintenance -- Std:Attr='Weight_maintenance'	DenneryBuildings:Bldng_maintenance

Figure 7-7: Weight values of selected factors for physical vulnerability of buildings to flood in Dennery Village (for the comparison)

To derive a meaningful classification of the upper bound values for the vulnerability classes (i.e. low, moderate, and high) of the composite index map, the standard score (z value) method was applied. Firstly, the pixel values of the composite index maps were obtained from the histogram of each map. Secondly, the standard scores (z value) of the pixel values of each map were calculated to derive the deviation from the mean of each value, using the equation below. Lastly, the positive standard score values (+1) were classified as high vulnerability while the negative standard score values (-1) were classified as low vulnerability. All the standard score values of zero (0) were classified as moderate.

Standard Score, $z = \frac{x-\mu}{\sigma}$

Where,

μ= mean
x= score
σ= standard deviation

The final physical vulnerability map (composite index map) for Castries old CBD and Dennery Village are shown in Figure 7-8, 7-9, and 7-10 respectively. The maps were obtained after a classification of the composite index map values into three classes, namely, low vulnerability, moderate vulnerability, and high vulnerability (see Table 7-7); using the slicing operation in ILWIS.

Structural Vulnerability class	**Vulnerability values**		
	Castries old CBD (for the entire buildings)	**Dennery Village (for the entire buildings)**	**Dennery Village (for the comparison)**
Low Vulnerability	≤0.39	≤0.31	≤0.48
Moderate Vulnerability	≤0.76	≤0.75	≤0.81
High Vulnerability	≤1	≤1	≤1

Table 7-7: SMCE vulnerability class for structural types of buildings

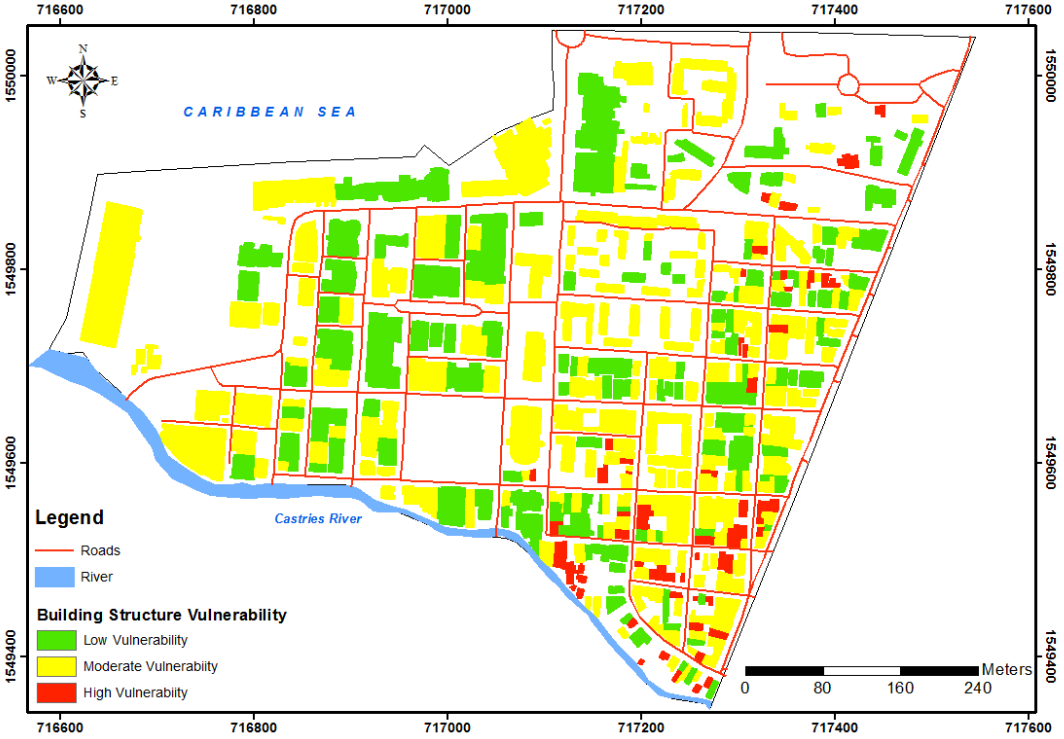


Figure 7-8: Vulnerability map of building structure for Castries old CBD (entire buildings)

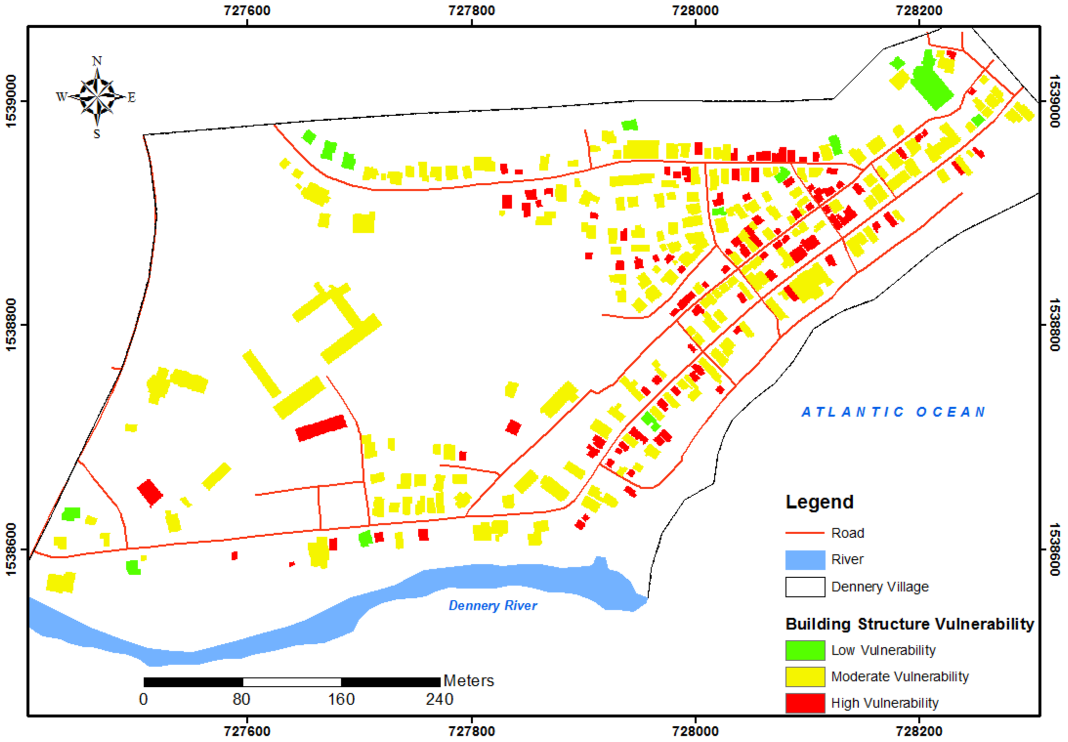


Figure 7-9: Vulnerability map of building structure for Dennery Village (entire buildings)

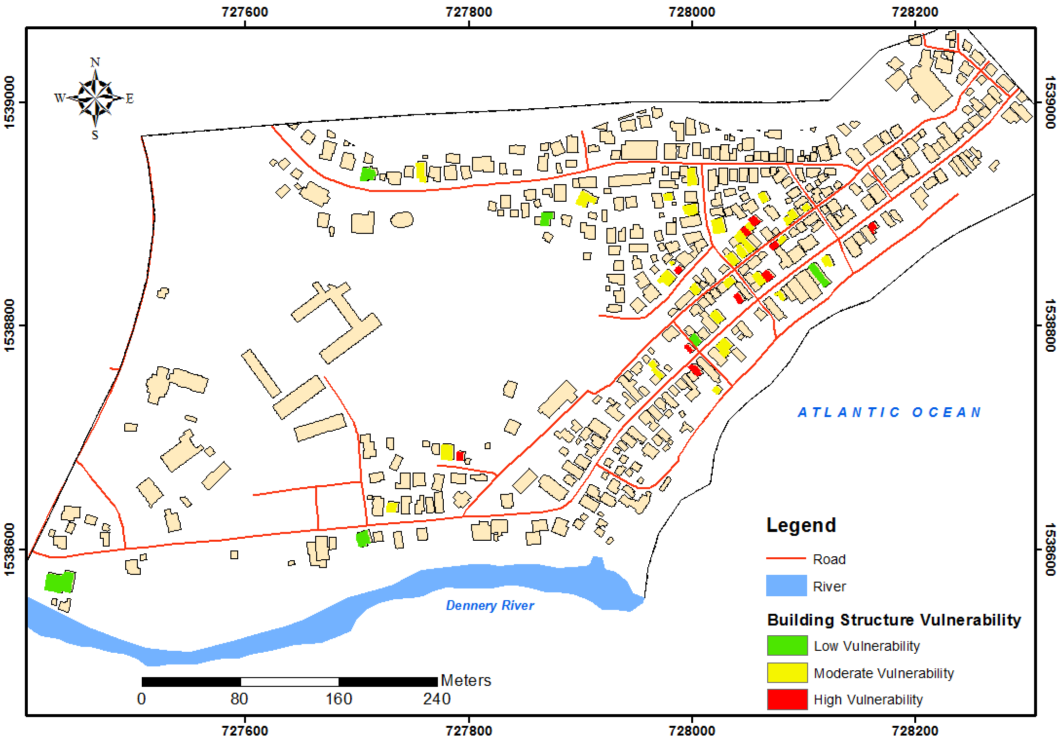


Figure 7-10: Vulnerability map of building structure for Dennery Village (for the comparison)

After the final physical vulnerability maps were derived, an analysis was performed to calculate the percentage of buildings that have low, moderate and high vulnerability to floods, for both study areas. The outcome of the analysis is presented in Figure 7-11. Additionally, the percentage of the occupancy type of buildings in the high vulnerability class was analysed for both study areas, and the result is presented in Table 7-8. It is important to note that the physical vulnerability map of Dennery Village that will be used for the comparison of both methods was not included in this analysis. This is because, the purpose of generating the vulnerability map is to compare if the results from the depth-damage and SMCE methods are similar.

Figure 7-11: Physical vulnerability of buildings in Castries old CBD and Dennery Village

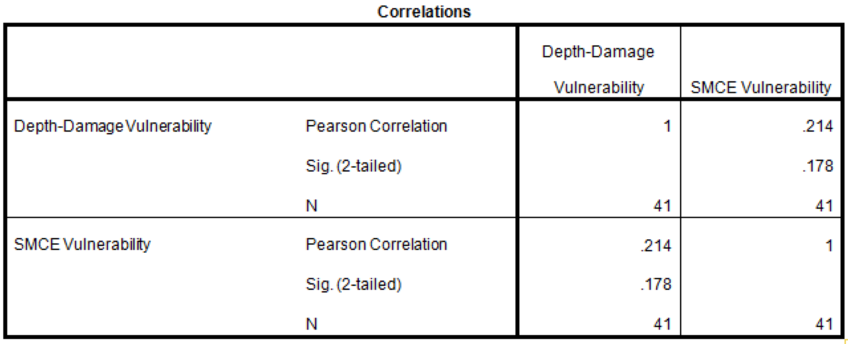
Occupancy type	**Castries old CBD**	**Dennery Village**
	Percentage of buildings (%)	**Percentage of buildings (%)**
Single dwelling	28.8	59.6
Retail trade (e.g. shops)	21.9	6.7
Residential/Commercial	12.3	1.0
Vacant abandoned	9.6	20.2
Specialty store (e.g. barbers shop, hairdressers, repair shop, etc.)	8.2	2.9
Squatter	8.2	0.0
Restaurant/bar/tavern	5.5	1.9
Vacant building	1.4	3.8
Professional services (e.g. offices such as dentist's office, lawyer's office, insurance agencies, etc.)	1.4	0.0
Government office	1.4	0.0
Meeting hall	1.4	0.0
Multiple dwelling	0.0	1.9
Schools	0.0	1.0
Church	0.0	1.0
Total	**100**	**100**

Table 7-8: Occupancy type of buildings in high vulnerability class

7.3. Comparison of the physical vulnerability maps

The comparison of the physical vulnerability of buildings for the depth-damage map (Figure 7-2) and the SMCE map (Figure 7-10) was performed using the vulnerability values (see Appendix 17) obtained from the generic maps (i.e. the output map before the classification of both maps into low, moderate, and high classes). The final vulnerability maps were not used because they have been classified into various vulnerability classes with different thresholds (class boundaries).

For the comparison, the vulnerability values of both maps were plotted into a scatter plot in SPSS software to determine the relationship of the values (see Figure 7-13). After that a correlation test was performed to ascertain the level of correlation between the values of both maps. From the test result, the correlation coefficient was 0.21 (Figure 7-12) which indicates that there is a poor correlation between both maps.



Correlations

		Depth-Damage Vulnerability	SMCE Vulnerability
Depth-Damage Vulnerability	Pearson Correlation	1	.214
	Sig. (2-tailed)		.178
	N	41	41
SMCE Vulnerability	Pearson Correlation	.214	1
	Sig. (2-tailed)	.178	
	N	41	41

Figure 7-12: Correlation test for vulnerability of buildings from Depth-damage and SMCE methods

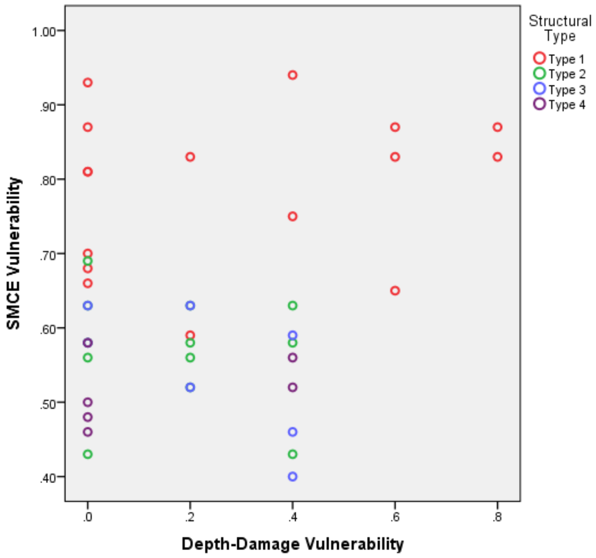


Figure 7-13: Scatter plot showing the vulnerability of buildings from Depth-damage and SMCE methods

Furthermore, another correlation analysis was performed in order to ascertain the difference in vulnerability values derived from both maps, for each structural type (1, 2, 3, and 4) of building. Firstly, all the samples (buildings) were grouped according to their structural types; and the corresponding vulnerability values from both maps were entered for each sample. Then, for each structural type, the vulnerability value from both maps was subtracted for each sample, to get the difference in values. Lastly, the values obtained were added and the total sum was divided by the total number of buildings within the same structural type. The result that was obtained is presented in Table 7-9 below.

Structural type	**Difference in Vulnerability values**
Type 1	0.50
Type 2	0.40
Type 3	0.32
Type 4	0.38

Table 7-9: Difference in vulnerability values between depth-damage and SMCE maps

7.4. Discussion

This chapter has explained the physical vulnerability assessment of buildings at both study areas, and the two different methods that was used. In the last section, the comparison of the generic vulnerability values of the depth-damage and SMCE methods for buildings that were flooded during the December 2013 event at Dennery Village was discussed.

The vulnerability assessment of buildings using the depth damage method at Dennery Village indicated that among the four common structural types of buildings from the interviewed households, structural type 1 is the most vulnerable to flood. The type of materials used for the wall and floor easily absorbs flood water, and in most scenarios when the materials are exposed to flood water for a long period of time it becomes weak or distorted in shape. Consequently, such structural types have more damage than the other structural types. Also, during floods, the other structural types have a better capacity to withstand the impact of the hydrodynamic forces, and (or) the impact forces associated with floating debris from moving water, than structural type 1.

In the vulnerability assessment of the entire buildings at both study areas using the SMCE method, the result shows that majority of the buildings in Castries old CBD (55%) and Dennery Village (64%) have moderate vulnerability to floods. Also, the percentage of buildings that are highly vulnerable to floods in Castries old CBD and Dennery Village is 14% and 32%, respectively. Furthermore, there is a spatial pattern observed in the distribution of the highly vulnerable buildings in Castries old CBD. Those buildings are located at the north-eastern and south-eastern parts of the city. Among the buildings that are highly vulnerable to floods, the highest percentage of the occupancy type of such buildings is 'single dwelling'- residential buildings, for both study areas. Vacant abandoned buildings are the second highest in Dennery Village, while retail trade (e.g. shops) are the second highest in Castries old CBD.

For the comparison of depth-damage and SMCE vulnerability maps at Dennery Village, it was observed that some buildings had zero vulnerability values in the depth-damage map while the SMCE vulnerability values for those buildings was within the range of 0.43 to 0.93 (see Figure 7-13). Also, from the analysis, the difference in the vulnerability values of both maps was highest for structural type 1. In general, the vulnerability values for both maps are different. Consequently, the physical vulnerability assessment results (i.e. the final vulnerability maps) produced by the two methods are not comparable. This may be attributed to the different approach and (or) different ways of expressing vulnerability by the two methods. For example, in depth-damage method, the degree of damage from the impact of a certain intensity of hazard (flood) is assessed using only, one characteristics of a building e.g. structural type; while the SMCE method considers the intrinsic factors such as height of building, age, wall material, etc., that can influence the vulnerability of a building to flood.

It is suggested that comparison should be made between methods that use a similar approach. For example, a comparison between stage-damage function methods like depth-damage and depth-velocity-damage; or a comparison with two indicator-based methods e.g. SMCE and Papathoma Tsunami Vulnerability Assessment (PTVA) used by (Kappes et al., 2012).

8. CONCLUSION AND RECOMMENDATION

This chapter concludes the research by answering the research questions stated at the beginning of the research, and it includes recommendation for future research.

8.1. Conclusion

1) Is the use of voluntary mapping for collecting the characteristics effective?

The characteristics of the elements at risk that was used in the exposure and physical vulnerability assessments, was collected through the use of voluntary mapping by the local people at both study areas. During the fieldwork, the volunteers (local people) were given a short training on the procedure of data collection and documentation. Through the participation of the volunteers it was possible to collect the characteristics of 536 buildings and 339 buildings at Castries Old CBD and Dennery Village, respectively. Additionally, data on building and population characteristics was collected from 94 households during the household interviews at Dennery Village. In this research, the use of voluntary mapping has been proven to be an effective approach for collecting the required characteristics of the elements at risk.

2) How is the exposure of buildings and population in Dennery Village to the December 2013 flood event?

The exposure analysis was conducted using a provided openLISEM flood map. The flood depths of the map were classified into low (<0.91 meters), moderate (0.91-1.37 meters), and high (>1.37 meters) classes using the class boundaries from a previous study on flood hazard assessment at the island. Consequently, the model map fell into the low flood hazard class because the highest flood depth of the map was 0.69 meters. From the exposure analysis, all the buildings and population in Dennery Village had a low exposure to floods, during the December 2013 event. The result obtained from the assessment is not satisfactory.

3) Which structural type of buildings are the most vulnerable in Dennery Village?

It was discovered from the vulnerability assessment that the vulnerability of the structural types to flood is influenced by the materials (such as wall, floor, and roof) of the house. Although, there are eight common structural types of buildings in the entire study area, four structural types from the interviewed households was used for the assessment. The relationship between flood depth and damage for the four structural types was plotted into a vulnerability curve.

The most vulnerable structural type of building from the households that were interviewed is structural type 1 (the combination of wood wall-wood floor-galvanized iron sheet roof). Houses with structural type 2 (the combination of concrete block wall-ceramic tiles floor-galvanized iron sheet roof) and structural types 3 (the combination of concrete block wall-concrete floor-galvanized iron sheet roof) are less vulnerable to floods than structural type 1. However, houses with structural type 4 (the combination of concrete block wall-ceramic tiles floor-painted steel sheet roof) are the least vulnerable. From the vulnerability curves (see Figure 7-1), structural type 1 is almost half damaged at a water depth of around 130 cm, while at a water depth of 203 cm structural type 4 is almost half damaged.

4) What percentage of building structures is highly vulnerable in Castries old CBD and Dennery Village?

Assessment of the physical vulnerability of buildings in both study areas was conducted using the SMCE method. The weight assigned to the selected 'factors' and 'classes' was derived during an expert session with stakeholders (experts) from the island. The vulnerability assessment of the entire buildings in both study areas indicated that 14% and 32% of the buildings in Castries old CBD and Dennery Village, respectively, are highly vulnerable to floods. Furthermore, in Castries old CBD, 31% and 55% of the buildings have a low and moderate vulnerability, respectively. On the other hand, 4.3% and 64% of the buildings in Dennery Village have low and moderate vulnerability to floods, respectively.

5) Are the results derived from physical vulnerability assessment of buildings using both methods comparable?

Damage to buildings that were flooded during the December 2013 event at Dennery Village was conducted using two approaches, namely, stage-damage (depth-damage) and vulnerability indicator (SMCE). The physical vulnerability maps produced from both methods were used for the assessment. A correlation test was performed to ascertain the level of relationship of the physical vulnerability values from both maps. The result (correlation coefficient of 0.21) showed that there is a poor correlation between both maps. After this investigation it was concluded that the results produced from the depth-damage and SMCE method are not comparable.

8.2. Recommendation for futher research

- If participatory approaches (e.g. voluntary mapping) is adopted as the method of data collection, quality checks should be implemented on ensuring that there is a uniformity in the data collected (e.g. when taking measurements of flood depths from different reference points). Apart from that efforts should be made on ensuring that the accurate information is documented. Also, a sampling method that will lead to obtaining a representative sample of the 'population' to be investigated in a research should be implemented during data collection.

- More research should be conducted on improving the result of the exposure analysis of the elements at risk at Dennery Village. This can be achieved through the collection of more flood depth data from the households, for the generation of a field survey flood depth map for the December 2013 event. On the other hand, the model should be calibrated to produce a better flood depth map of the event.

- The depth-damage physical vulnerability assessment conducted in this research should be improved through the inclusion of more representative data (water depths) of the entire structural types of buildings in Dennery Village. Furthermore, addition of the data on damage to building contents will lead to a better result, because during the field work majority of the houses did not have any damage to the building structure but their properties were damaged. For the SMCE, a sensitivity analysis should be carried out to test the influence of the weights assigned to the various 'classes' and 'factors', towards the physical vulnerability map.

- One of the challenges encountered during this research was time constraint, during fieldwork. Consequently, some data that could have been used for the various analyses were not collected. In future studies, enough time should be allocated during the data collection phase.

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APPENDIX

Appendix 1: Building Survey Form

DISTRICT: …………………………………………… STREET………………………………………………… DATE……………………

ID	UTM Coordinates	Occupancy Type	Wall Material	Floor Material	Roof Material	Number of Floors	Height above the ground (m)	Building Function	Maintenance	Built-up/Columns

Appendix 2: Questionnaire

Research Title: Assessment of physical vulnerability to flood in Saint Lucia. Case studies: Castries old Central Business District and Dennery Village.
Researcher: Anne Uwakwe
Contact: a.c.uwakwe@student.utwente.nl

This information will only be used for scientific research. We thank you for your help and cooperation.

Questionnaire number ………………………………….	Date …………………………………
Address …………………………………………………	UTM Coordinates: X……… Y………..

1. General Information

1.1 Respondent's profile

Respondent's name : ……………………………………………………………………………..
Gender : Male…………. Female……………

1.2 Building Information

Building age	0-5 years	5-10 years	10-15 years	15-20 years	>20 years
Building size	≤ 50m²	51m² - 100m²	101m² – 200m²	>200m²	
Ownership	Own	Rent			
Flood Insurance	Yes	No			

2. Elements at Risk

2.1 Building characteristics *(Please specify)*

Building function	1).Shop	2).School	3).Church	4).House	5).Hotel
	6).Factory	7).Other			
Floor material	1).Wood	2).Ceramic tiles	3).Concrete	4).Other	
Wall Material	1).Galvanized iron sheet	2).Concrete block	3).Wood	4).Brick	5).Stone
	6).Other				
Roof material	1).Concrete	2).Galvanized iron sheet	3).Painted steel sheet	4).Asphalt Shingles	5).Other
Number of floors	1	2	3	4	>4
Height of ground floor (m)					
Height from foundation (m)					
Height from road (m)					
Height of window (m)					
Type of window					
Type of door					

2.2 Population characteristics

Number of people per household					
Age distribution (*How many*)	0-4 ( )	5-14 ( )	15-24 ( )	25-39 ( )	40-54 ( )
	55-64 ( )	65-79 ( )	>80 ( )		
Number of people during the day	6-9am ( )	9-12pm ( )	12-3pm ( )	3-6pm ( )	
Number of people at night	6-9pm ( )	9-12am ( )	12-3am ( )	3-6am ( )	

3. Floods

3.1 Cause of flood

What is the cause of flooding based on the household's perception?

1).Excessive rainfall	2).Garbage
3).Uncontrolled city development	4).From the sea: high water level
5).Hurricane with excessive rainfall	6).Water pumping capacity, too low
7).Other	

3.2 Flood Occurrence

How high was the level of flood water in December 2013? (cm)		
How long was the duration in December 2013? (hr)		
What was the cause?		
How did the water enter your house?	1).Front door	2).Back door
	3).Window	4).Roof
	5).Other……………………	
What is the maximum height that has happened in this building? (cm)		
When? (dd/mm/yy)		
How long was the duration? (hr)		
What was the cause?		

3.3 Flood proofing structure

Is there any flood proofing structure?

Raised houses	Shutters for the doors	Dyke	Stilts	Other

4. Damage and losses

4.1 Damage to Building Structure

What is the maximum damage to building structure within the last 10 years?

Item	Depth	Damage	Depth	Damage	Depth	Damage
Floor						
Wall						
Door						
Window						
Roof						

Note: C=Collapse HC=Half Collapse NH=Nothing Happen

How much is the cost to repair the damage?

Item	Depth	Cost	Depth	Cost	Depth	Cost
Floor						
Wall						
Door						
Window						
Roof						

Note: in money (Eastern Caribbean Dollars)

4.2 Damage to Building Contents

What kind of building contents have been damaged due to of flood within the last 10 years? *Please indicate.*

Total building content	Depth	Damage (percentage)	Depth	Damage (percentage)	Depth	Damage (percentage)

What are the two most important characteristics of the building to flood damage?

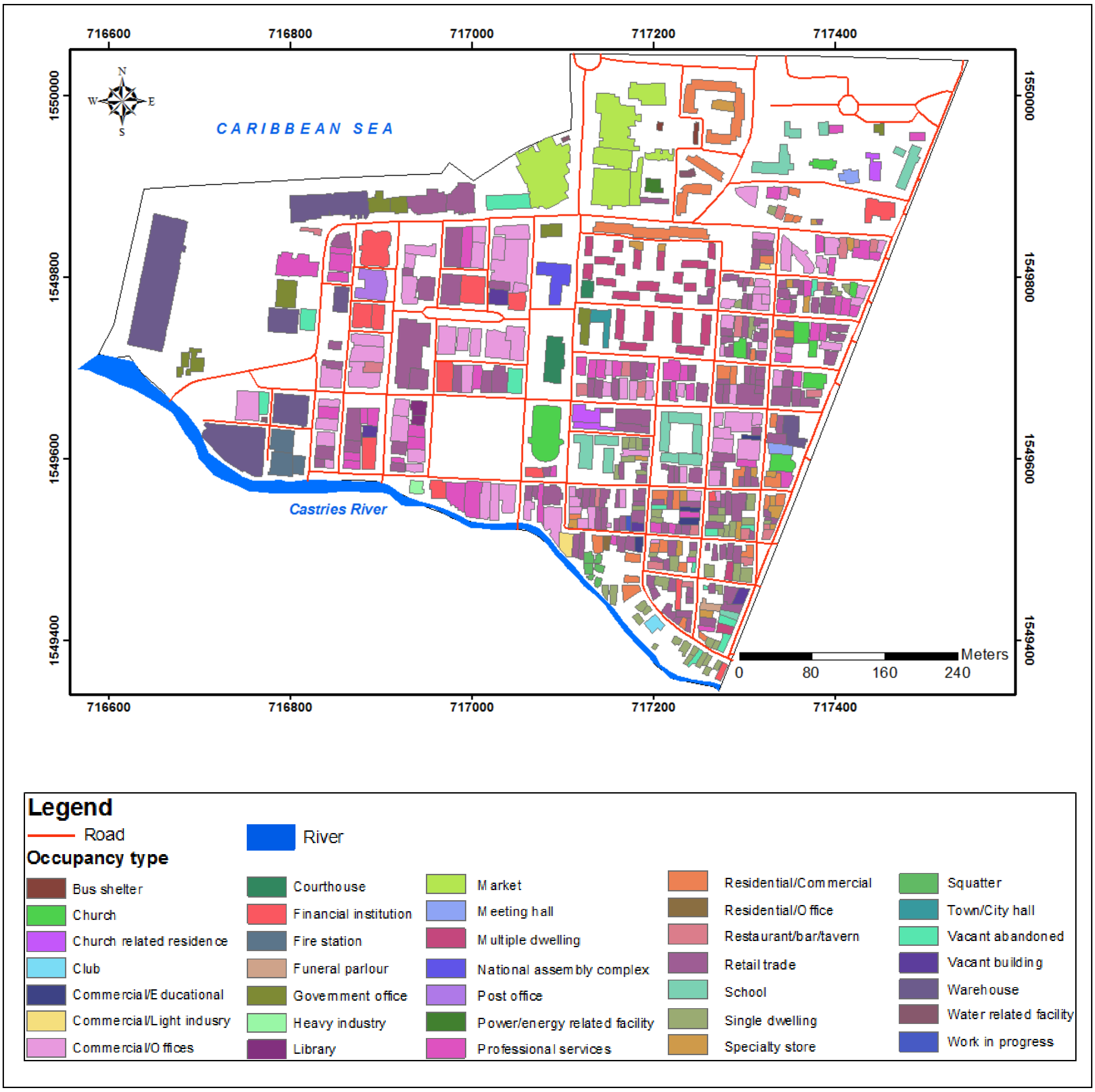
………

………

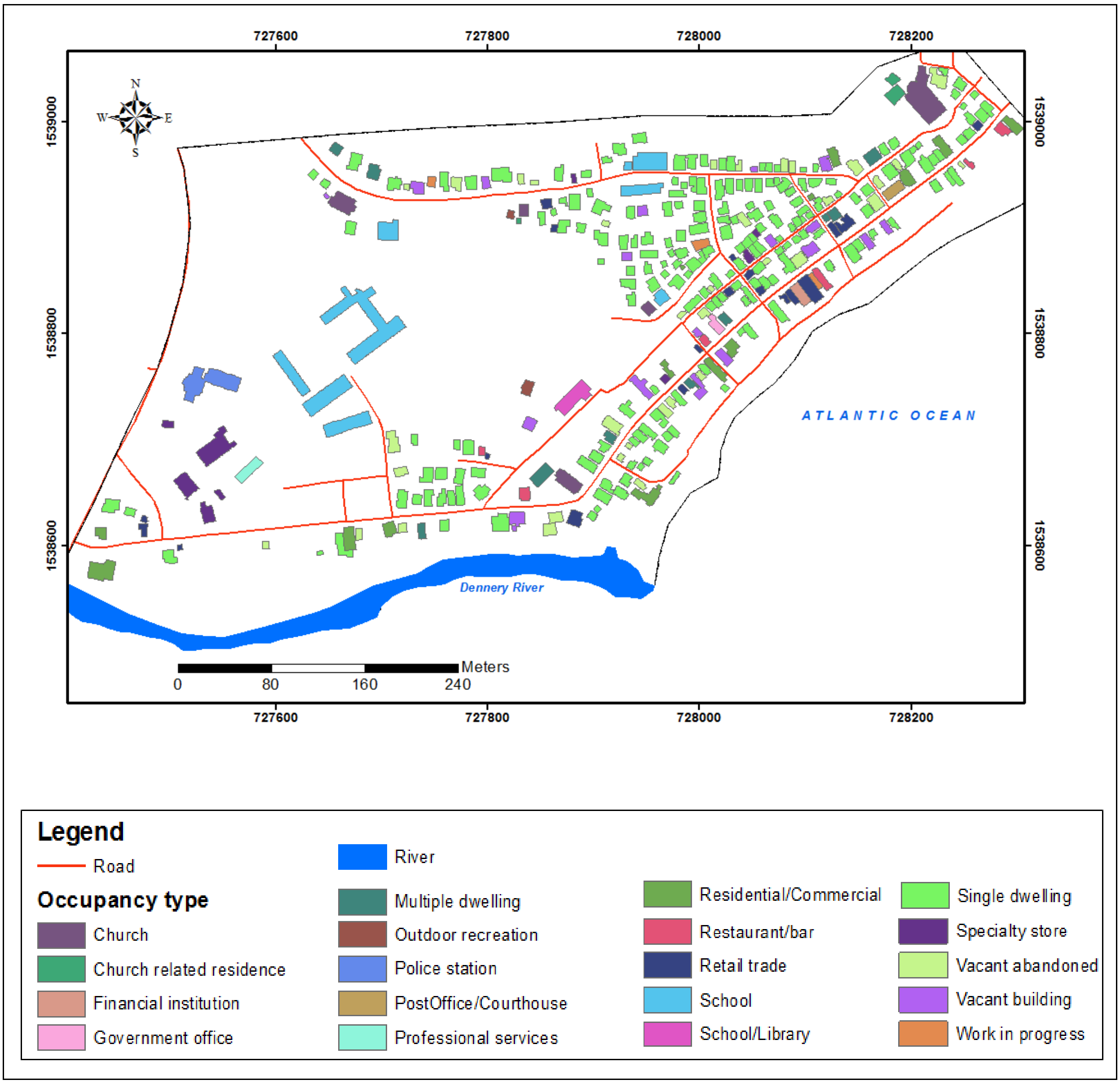
Appendix 3: List of institutions visited for Focus group discussion

No	Institution	Contact person
1	Physical Planning Department-Ministry of Planning Development Housing and Urban Renewal (MPDHUR)	David Desir
2	Survey and Mapping Department (MPDHUR)	Philip Hippolyte; and David Alphonse
3	Ministry of Finance, Economic Affairs Planning and Social Security National Reconstruction	Elizabeth Charles-Soomer
4	Ministry of Infrastructure, Ports Services and Transport	Renata McKie
5	Water Resources and Environmental Management	Farzana Yusuf-Leon
6	National Emergency Management Agency (NEMO)	Vela Joseph; and Iraline Joseph
7	St. Lucia Fire Service	Lambert Charles
8	Housing Department-MPDHUR	Susanna Aurelien
9	Central Statistics Office	Aurelia Jacinta Francis; and Sherma Lawrence

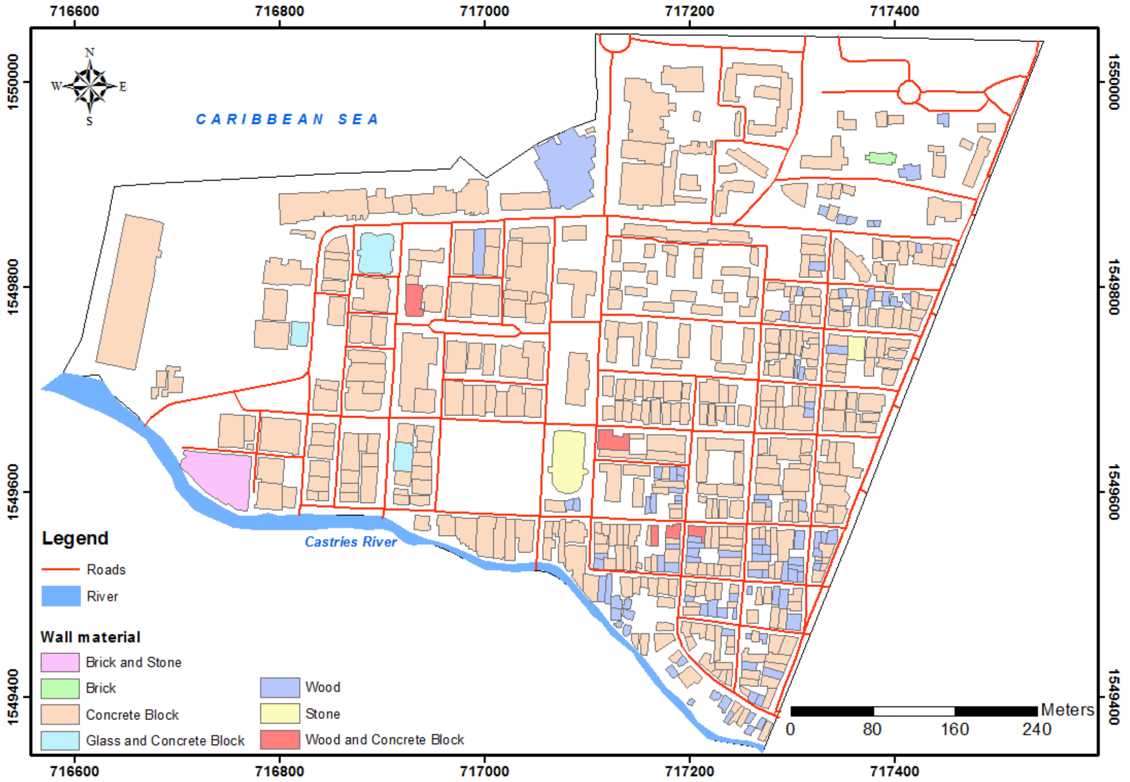
Appendix 4a: Distribution of occupancy types in Castries old CBD



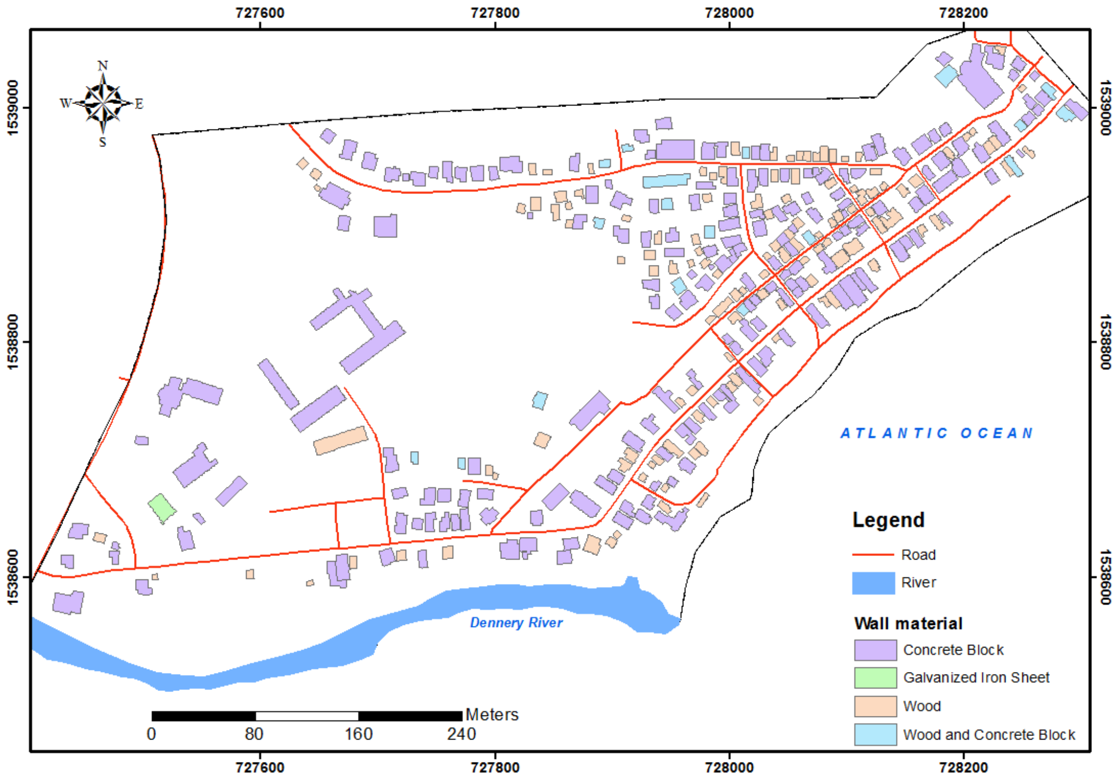
Appendix 4b: Distribution of occupancy types in Dennery Village



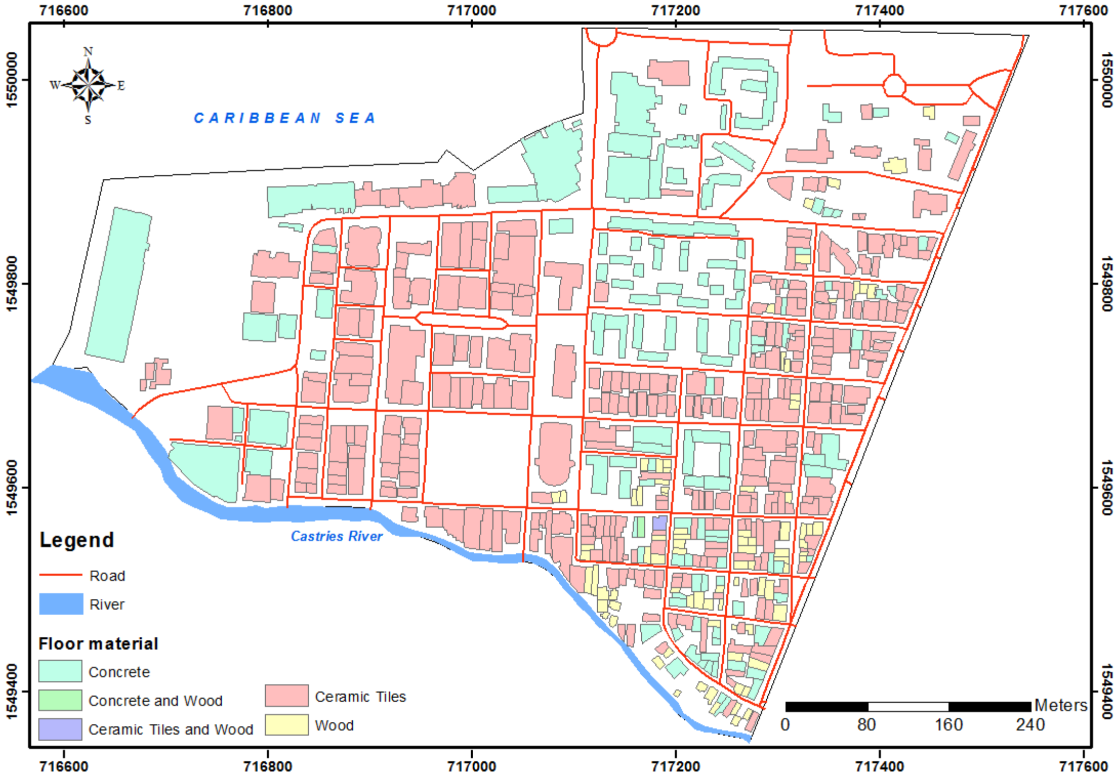
Appendix 5a: Distribution of wall types in Castries old CBD



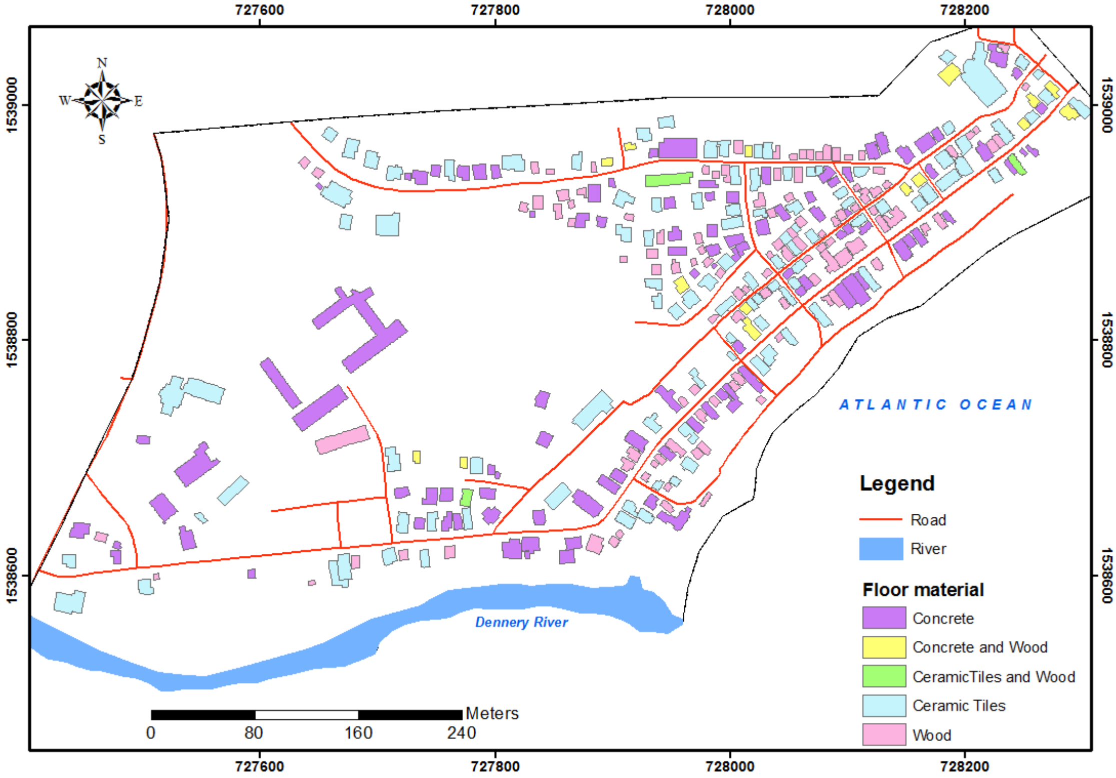
Appendix 5b: Distribution of wall types in Dennery Village



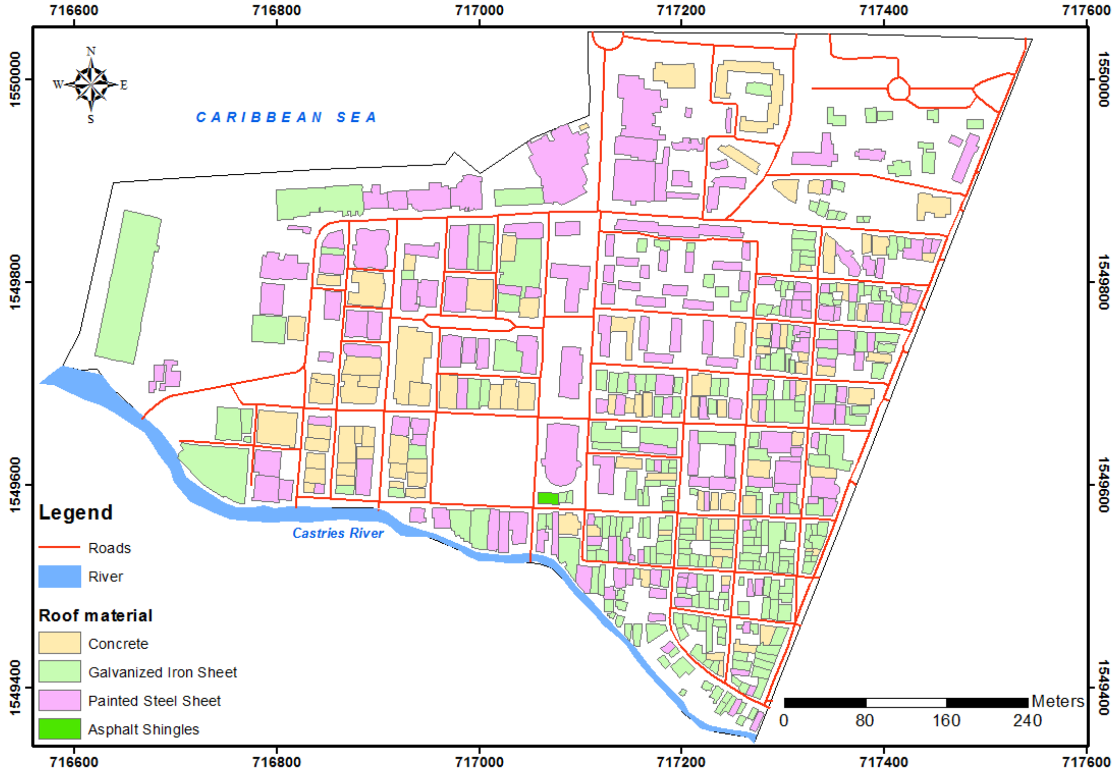
Appendix 6a: Distribution of floor types in Castries old CBD



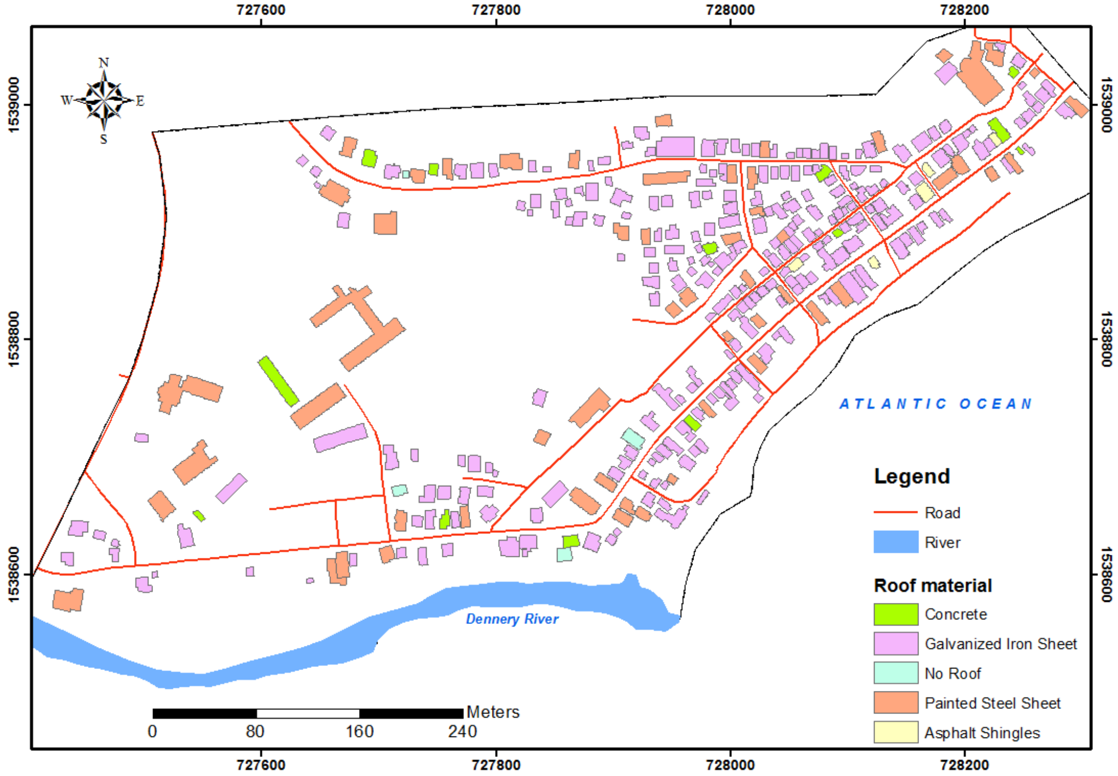
Appendix 6b: Distribution of floor types in Dennery Village



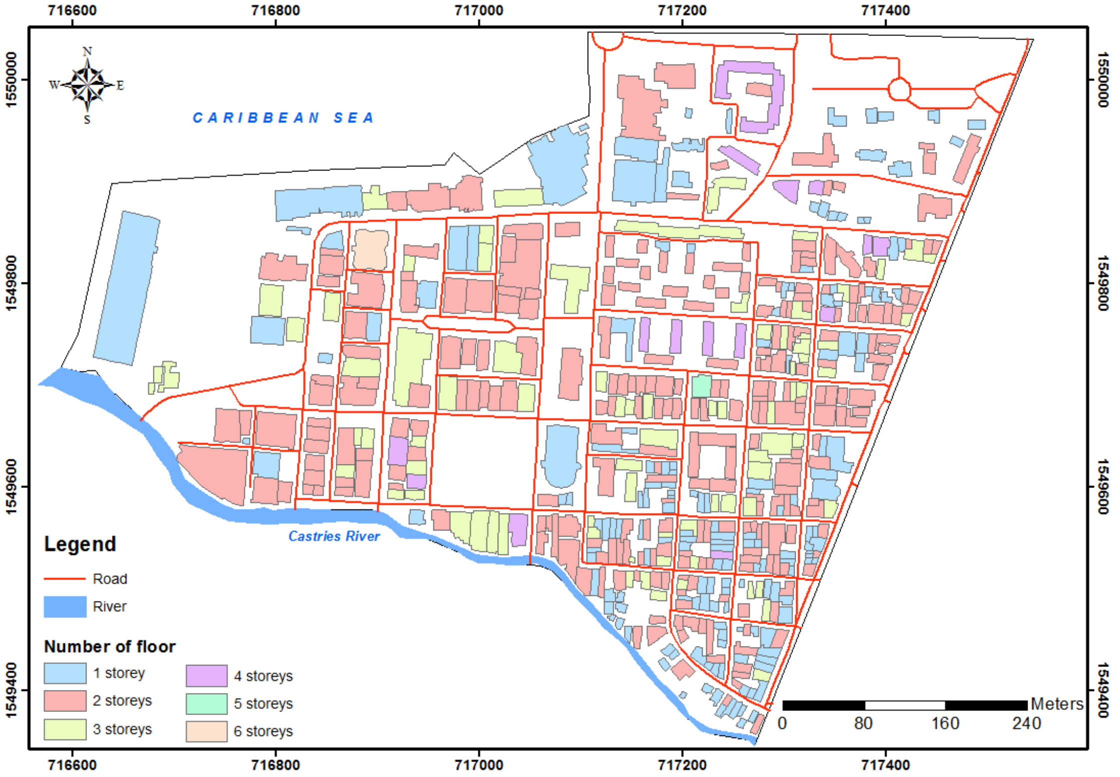
Appendix 7a: Distribution of roof types in Castries old CBD



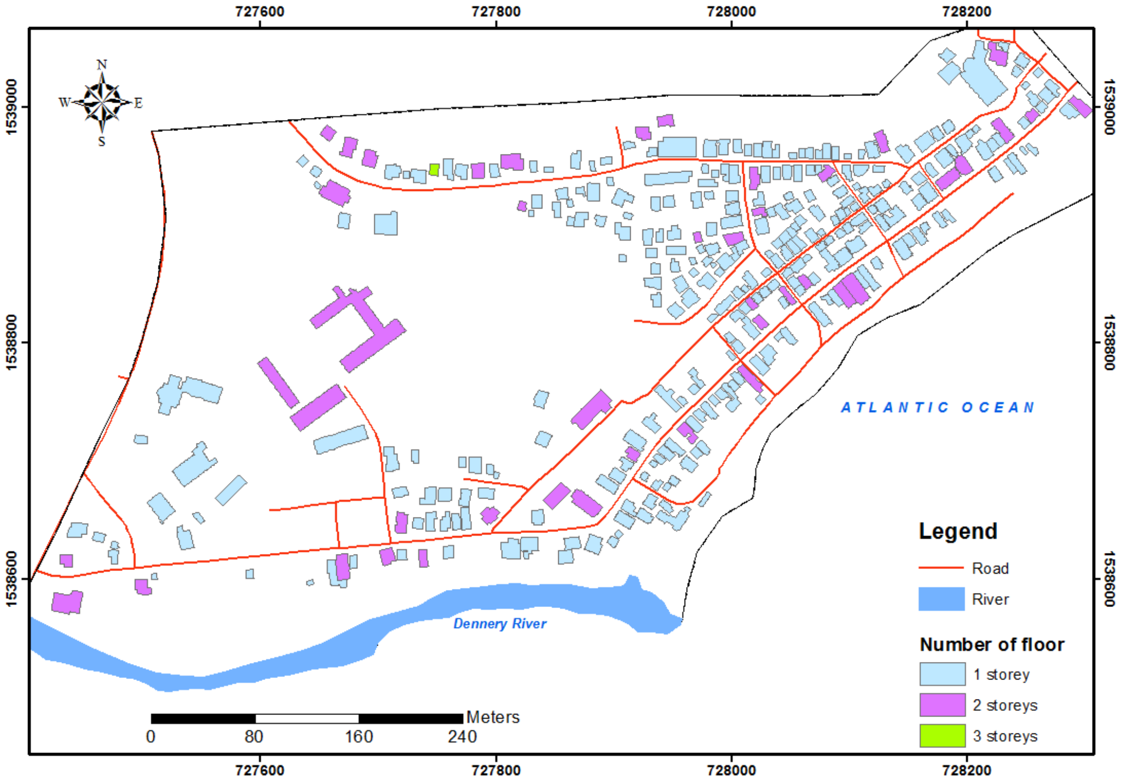
Appendix 7b: Distribution of roof types in Dennery Village



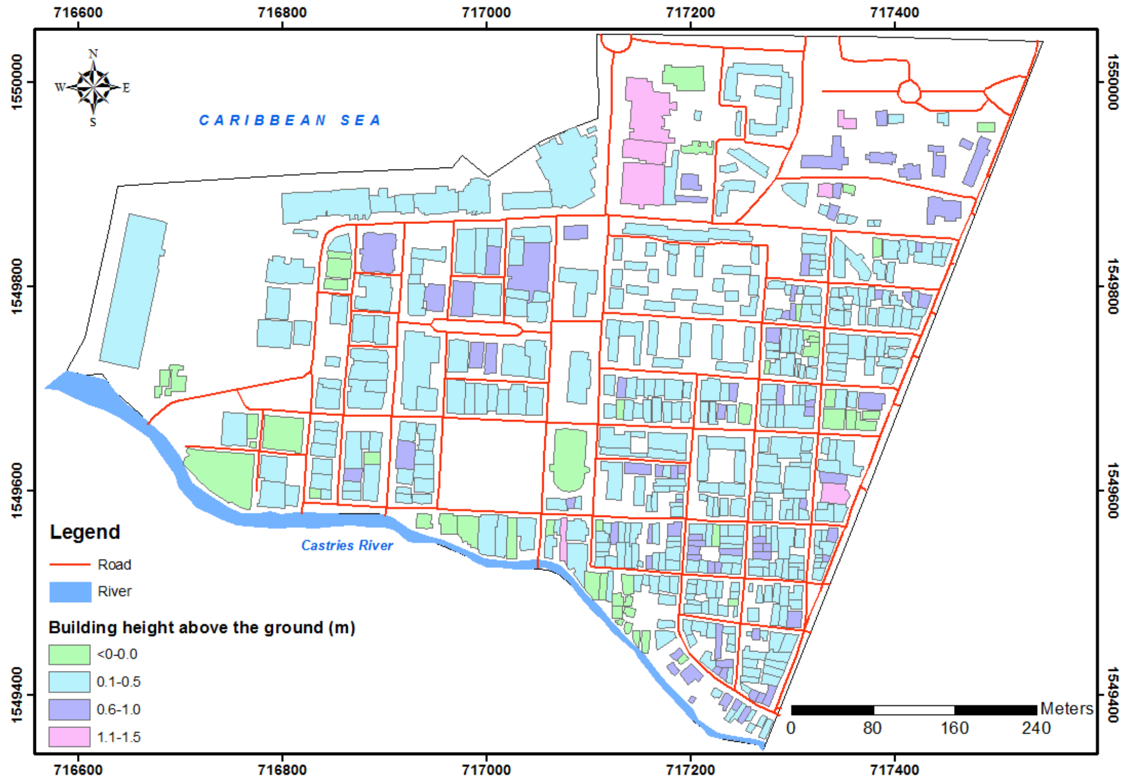
Appendix 8a: Distribution of number of floor types in Castries old CBD



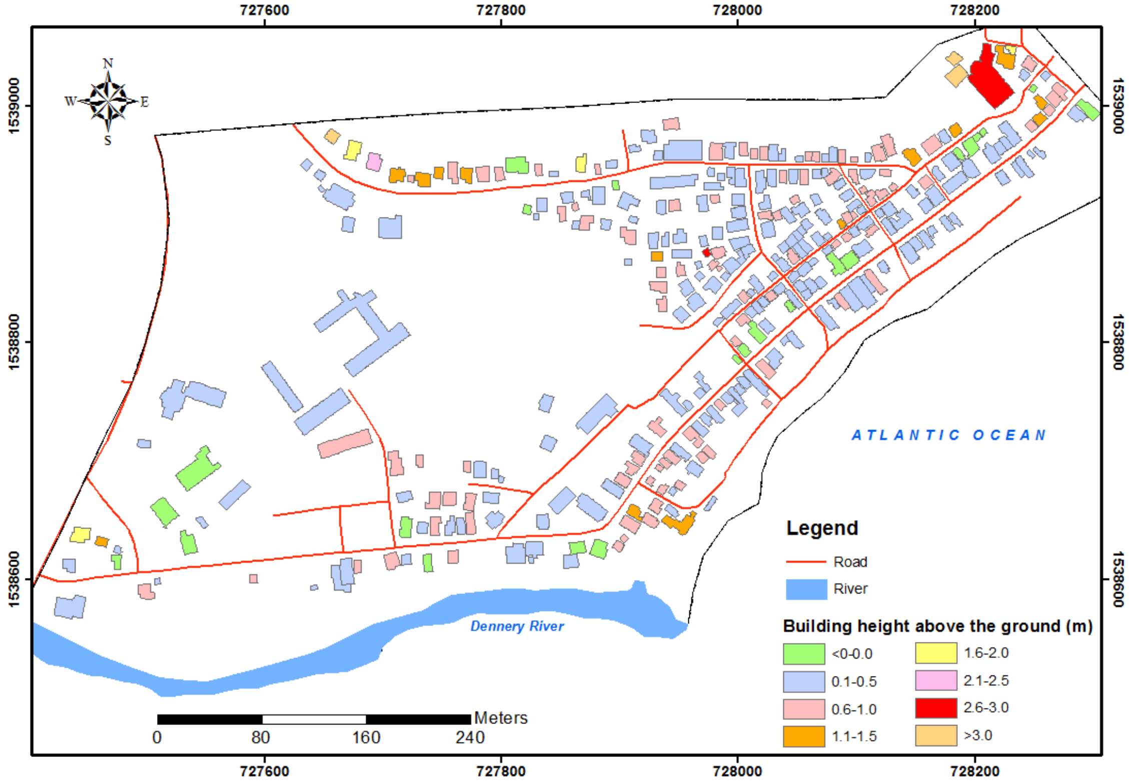
Appendix 8b: Distribution of number of floor types in Dennery Village



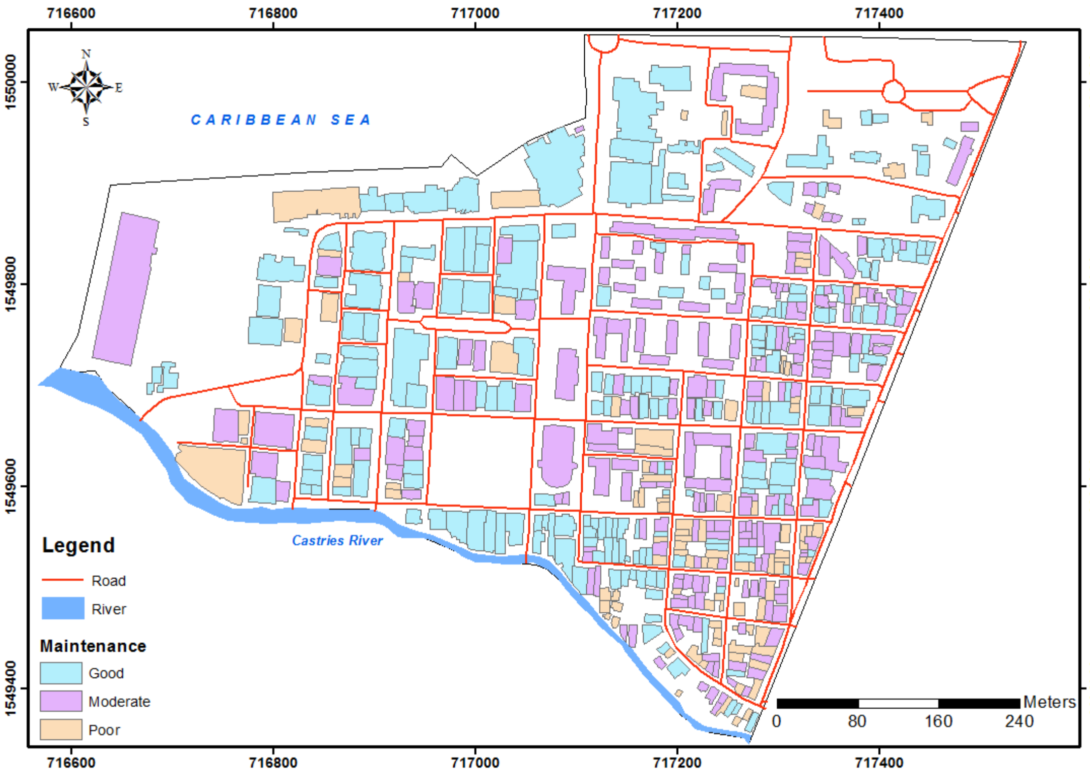
Appendix 9a: Distribution of building height above the ground in Castries old CBD



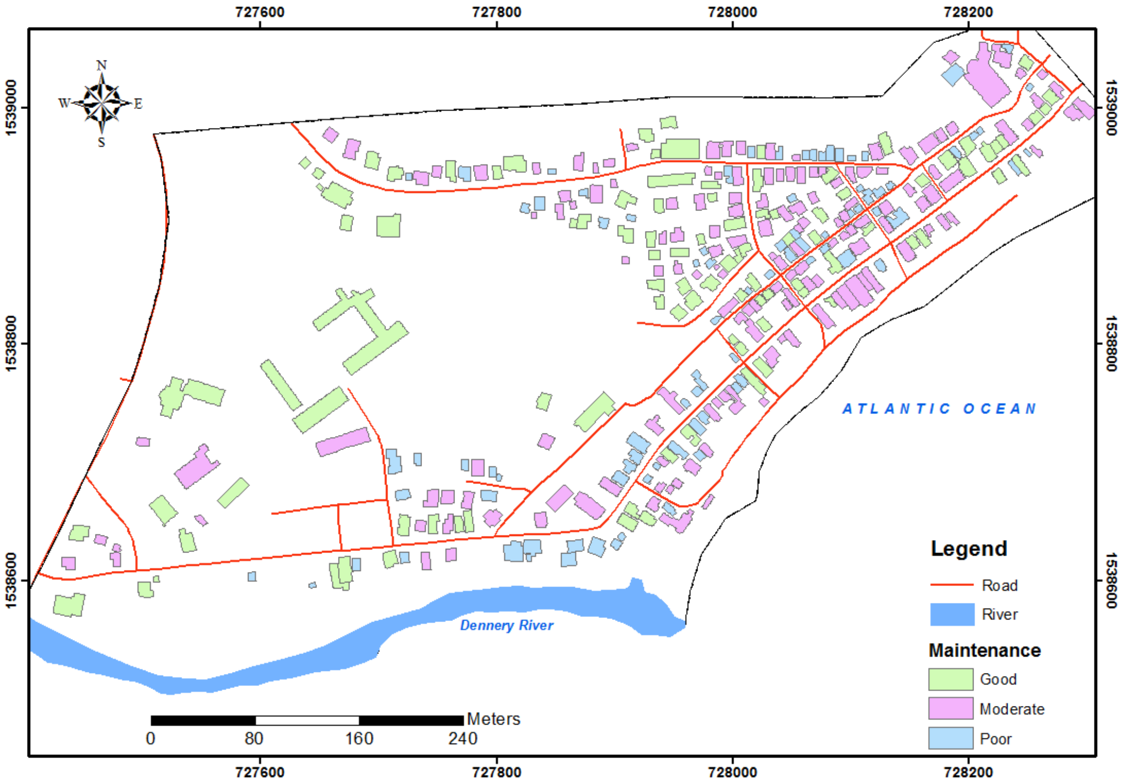
Appendix 9b: Distribution of building height above the ground in Dennery Village



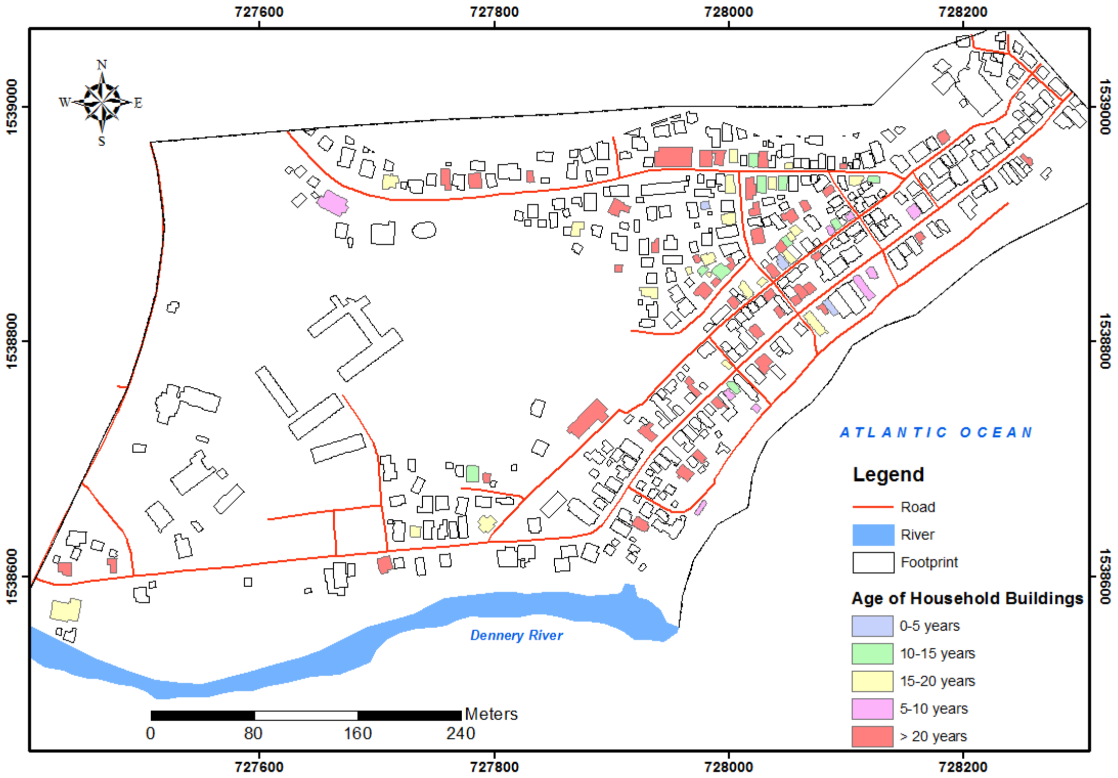
Appendix 10a: Distribution of maintenance types in Castries old CBD



Appendix 10b: Distribution of maintenance types in Dennery Village



Appendix 11: Distribution of the age of household buildings



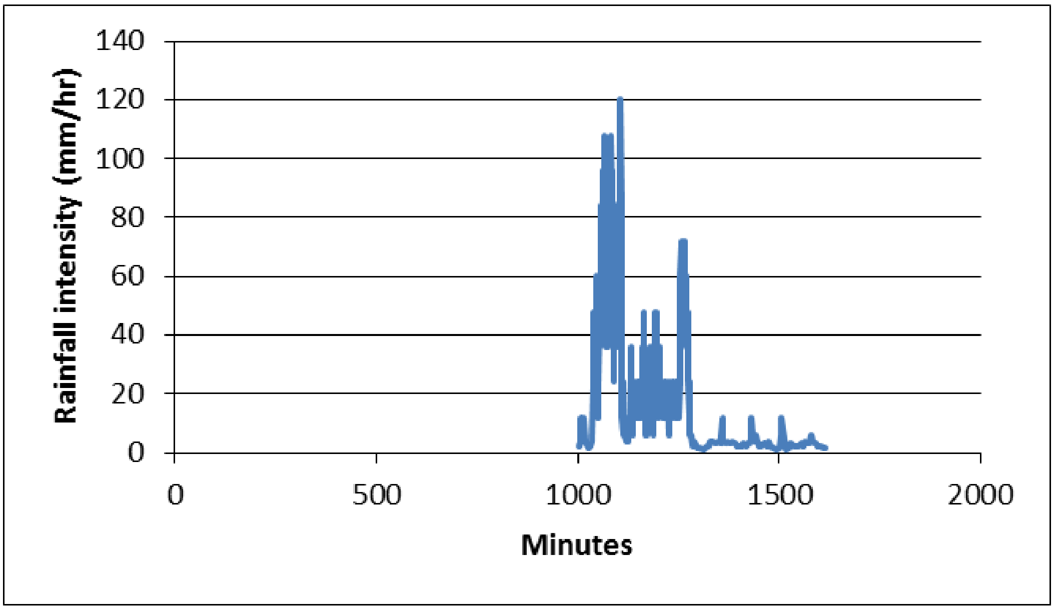
Appendix 12: Combination of wall, floor, and roof material of interviewed households

Wall material	Floor material	Roof material				Total
		Concrete	Galvanized Iron Sheet	Painted Steel Sheet	Asphalt Shingles	
Concrete Block	Concrete	1	16	0	0	17
	Concrete and Wood	0	0	0	0	0
	Ceramic Tiles	0	24	14	0	38
	Ceramic Tiles & Wood	0	0	0	0	0
	Wood	0	0	0	0	0
Galvanized Iron Sheet	Concrete	0	0	0	0	0
	Concrete and Wood	0	0	0	0	0
	Ceramic Tiles	0	0	0	0	0
	Ceramic Tiles & Wood	0	0	0	0	0
	Wood	0	0	0	0	0
Wood	Concrete	0	4	0	0	4
	Concrete and Wood	0	0	0	0	0
	Ceramic Tiles	0	1	0	0	1
	Ceramic Tiles & Wood	0	0	0	0	0
	Wood	0	33	0	1	34
Wood and Concrete Block	Concrete	0	0	0	0	0
	Concrete and Wood	0	0	0	0	0
	Ceramic Tiles	0	0	0	0	0
	Ceramic Tiles & Wood	0	0	0	0	0
	Wood	0	0	0	0	0
Total		**1**	**78**	**14**	**1**	**94**

Appendix 13: Combination of wall, floor, and roof material of all buildings from the inventory

Wall material	Floor material	Roof material					Total
		Concrete	Galvanized Iron Sheet	No Roof	Painted Steel Sheet	Asphalt Shingles	
Concrete Block	Concrete	10	64	4	11	1	90
	Concrete and Wood	0	2		0	0	2
	Ceramic Tiles	3	54	0	41	2	100
	Ceramic Tiles & Wood	0	1	0	0	0	1
	Wood	0	1	0	0	0	1
Galvanized Iron Sheet	Concrete	0	0	0	1	0	1
	Concrete and Wood	0	0	0	0	0	0
	Ceramic Tiles	0	0	0	0	0	0
	Ceramic Tiles & Wood	0	0	0	0	0	0
	Wood	0	0	0	0	0	0
Wood	Concrete	0	8	0	1	0	9
	Concrete and Wood	0	2	0	0	0	2
	Ceramic Tiles	0	2	0	0	0	2
	Ceramic Tiles & Wood	0	0	0	0	0	0
	Wood	0	111	0	0	2	113
Wood and Concrete Block	Concrete	0	4	0	0	0	4
	Concrete and Wood	0	11	0	0	0	11
	Ceramic Tiles	0	1	0	0	0	1
	Ceramic Tiles & Wood	0	0	0	2	0	2
	Wood	0	0	0	0	0	0
Total		**13**	**261**	**4**	**56**	**5**	**339**

Appendix 14: December 2013 rainfall event



Appendix 15: Difference in Flood model depth values and December 2013 (field measured) depth values

FID	Shape *	FLOOD_HEIG	Model flood depth (m)	Field measured flood depth (m)	Deviation
0	Point	0.6	0.215	1.450	1.235
1	Point	0.35	0.207	0.750	0.543
2	Point	0.31	0.086	0.610	0.524
3	Point	0.34	0.161	0.520	0.359
4	Point	0.07	0.175	0.570	0.395
5	Point	1.22	0.238	1.780	1.542
6	Point	1.52	0.291	1.920	1.629
7	Point	0.8	0.015	1.170	1.155
8	Point	1.22	0.181	1.230	1.049
9	Point	0.5	0.218	0.830	0.612
10	Point	0.7	0.113	0.580	0.467
11	Point	1.83	0.025	2.230	2.205
12	Point	0.5	0.030	0.450	0.420
13	Point	0.94	0.028	1.330	1.302
14	Point	1.83	0.020	2.410	2.390
15	Point	1.44	0.037	1.760	1.723
16	Point	1.52	0.026	1.680	1.654
17	Point	0.72	0.026	0.880	0.854
18	Point	0.2	0.000	0.600	0.600
19	Point	1.6	0.024	1.960	1.936
20	Point	1.37	0.000	1.870	1.870
21	Point	1.52	0.025	2.120	2.095
22	Point	1.22	0.000	1.940	1.940
23	Point	0.57	0.027	1.090	1.063
24	Point	1.83	0.050	2.030	1.980
25	Point	0.6	0.017	1.170	1.153
26	Point	1.13	0.009	1.520	1.511
27	Point	2.65	0.020	3.080	3.060
28	Point	1.35	0.012	2.030	2.018
29	Point	2.03	0.020	2.370	2.350
30	Point	0.48	0.017	0.820	0.803
31	Point	0.1	0.000	0.320	0.320
32	Point	0.05	0.039	0.270	0.231
33	Point	0.6	0.009	1.730	1.721
34	Point	0.96	0.021	1.320	1.299
35	Point	1.83	0.000	2.500	2.500
36	Point	0.88	0.017	1.750	1.733
37	Point	2.04	0.038	2.550	2.512
38	Point	0.7	0.011	1.110	1.099
39	Point	0.96	0.000	1.630	1.630
40	Point	1.22	0.017	1.620	1.603
41	Point	1.83	0.000	2.230	2.230
42	Point	0.72	0.000	1.110	1.110
43	Point	0.07	0.000	1.530	1.530
44	Point	1.22	0.000	1.800	1.800
45	Point	1.83	0.021	2.080	2.059
46	Point	3.09	0.145	3.330	3.185

Appendix 16: December 2013 flood depths at sample locations (interviewed households)

UTM (X-Y) Coordinates	Structural Type	December 2013 Flood depth (m)	Damage
(727457.07, 1538576.84)	Type 4	3.09	0.0
(727705.09, 1538612.11)	Type 4	0.60	0.0
(727728.51, 1538637.90)	Type 3	0.35	0.0
(727950.06, 1538656.21)	Type 1	0.31	0.0
(727772.97, 1538682.77)	Type 2	0.07	0.2
(727993.01, 1538733.54)	Type 1	1.22	0.0
(727976.23, 1538749.89)	Type 1	1.52	0.6
(727942.41, 1538750.14)	Type 2	0.80	0.0
(727999.09, 1538768.22)	Type 2	0.50	0.4
(727975.56, 1538774.57)	Type 3	0.50	0.4
(727993.28, 1538793.20)	Type 4	1.83	0.4
(728011.06, 1538808.62)	Type 1	0.50	0.0
(728045.61, 1538810.58)	Type 1	0.94	0.0
(727975.70, 1538816.05)	Type 1	1.83	0.4
(728002.90, 1538821.71)	Type 2	1.44	0.2
(728027.43, 1538824.60)	Type 3	1.52	0.4
(728034.72, 1538826.88)	Type 1	0.72	0.8
(727952.68, 1538824.94)	Type 2	0.2	0.2
(727985.09, 1538825.80)	Type 4	1.60	0.4
(727961.48, 1538831.55)	Type 1	1.37	0.6
(728075.31, 1538828.17)	Type 2	1.52	0.0
(727956.51, 1538837.41)	Type 3	1.22	0.2
(728004.86, 1538841.93)	Type 2	1.83	0.0
(728013.24, 1538846.89)	Type 1	0.60	0.0
(728040.16, 1538851.69)	Type 1	1.13	0.4
(728019.21, 1538851.40)	Type 2	2.65	0.4
(728046.51, 1538856.31)	Type 1	1.35	0.2
(728011.11, 1538857.85)	Type 4	2.03	0.4
(728024.08, 1538872.07)	Type 1	0.48	0.2
(728120.69, 1538865.90)	Type 1	0.10	0.0
(727994.45, 1538867.33)	Type 3	0.05	0.0
(728051.11, 1538871.91)	Type 1	0.60	0.6
(728020.29, 1538866.66)	Type 2	0.96	0.2
(727853.12, 1538873.44)	Type 3	1.83	0.4
(728056.82, 1538876.94)	Type 1	0.88	0.0
(727971.72, 1538880.81)	Type 2	2.04	0.0
(728066.05, 1538882.43)	Type 1	0.70	0.0
(728031.41, 1538890.86)	Type 3	1.22	0.2
(727887.33, 1538889.28)	Type 2	1.83	0.0
(727973.42, 1538908.11)	Type 4	0.72	0.0
(727709.32, 1538909.32)	Type 2	0.07	0.4
(727751.81, 1538912.44)	Type 4	1.22	0.0
(728017.18, 1538862.71)	Type 1	1.83	0.8

Appendix 17: Vulnerability values of buildings for the depth-damage and SMCE methods

UTM (X-Y) Coordinates	Depth-Damage Vulnerability	SMCE Vulnerability	Structural Type
(727457.07, 1538576.84)	0.0	0.48	Type 4
(727705.09, 1538612.11)	0.0	0.46	Type 4
(727728.51, 1538637.90)	0.0	0.58	Type 3
(727993.01, 1538733.54)	0.0	0.68	Type 1
(727942.41, 1538750.14)	0.0	0.69	Type 2
(728011.06, 1538808.62)	0.0	0.93	Type 1
(728045.61, 1538810.58)	0.0	0.81	Type 1
(728075.31, 1538828.17)	0.0	0.43	Type 2
(728004.86, 1538841.93)	0.0	0.63	Type 2
(728013.24, 1538846.89)	0.0	0.66	Type 1
(728120.69, 1538865.90)	0.0	0.87	Type 1
(727994.45, 1538867.33)	0.0	0.63	Type 3
(728056.82, 1538876.94)	0.0	0.70	Type 1
(727971.72, 1538880.81)	0.0	0.58	Type 2
(728066.05, 1538882.43)	0.0	0.81	Type 1
(727887.33, 1538889.28)	0.0	0.56	Type 2
(727973.42, 1538908.11)	0.0	0.58	Type 4
(727751.81, 1538912.44)	0.0	0.50	Type 4
(727772.97, 1538682.77)	0.2	0.52	Type 2
(728002.90, 1538821.71)	0.2	0.63	Type 2
(727952.68, 1538824.94)	0.2	0.56	Type 2
(727956.51, 1538837.41)	0.2	0.52	Type 3
(728046.51, 1538856.31)	0.2	0.59	Type 1
(728024.08, 1538872.07)	0.2	0.83	Type 1
(728020.29, 1538866.66)	0.2	0.58	Type 2
(728031.41, 1538890.86)	0.2	0.63	Type 3
(727999.09, 1538768.22)	0.4	0.63	Type 2
(727975.56, 1538774.57)	0.4	0.40	Type 3
(727993.28, 1538793.20)	0.4	0.52	Type 4
(727975.70, 1538816.05)	0.4	0.75	Type 1
(728027.43, 1538824.60)	0.4	0.59	Type 3
(728040.16, 1538851.69)	0.4	0.94	Type 1
(728019.21, 1538851.40)	0.4	0.58	Type 2
(728011.11, 1538857.85)	0.4	0.56	Type 4
(727853.12, 1538873.44)	0.4	0.46	Type 3
(727709.32, 1538909.32)	0.4	0.43	Type 2
(727976.23, 1538749.89)	0.6	0.83	Type 1
(727961.48, 1538831.55)	0.6	0.87	Type 1
(728051.11, 1538871.91)	0.6	0.65	Type 1
(728034.72, 1538826.88)	0.8	0.87	Type 1
(728017.18, 1538862.71)	0.8	0.83	Type 1