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Spatial Analysis of Informal Settlement Growth and Disaster Management Preparedness: A Case Study in Honiara City, Solomon Islands

By
Reginald Reuben

A thesis submitted in fulfillment of the requirements for the Degree of Masters of Science in Climate Change

Pacific Center for Environment and Sustainable Development
Faculty of Science, Technology and Environment
The University of the South Pacific

July 2013

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Declaration

A Statement by the Author
I, Reginald Reuben, declare that this thesis is my own work and that, to the best of my knowledge, it contains no material previously published, or substantially overlapping with material submitted for the award of any other degree at any institution, except where duly acknowledgement is made in the text.

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A Statement by the Supervisor
The research in this thesis was performed under my supervision and to my knowledge is the sole work of Mr. Reginald Reuben.

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Abstract

In the Solomon Islands, natural hazards have their greatest impact at local level, especially on the lives of vulnerable people. Current natural hazards are exacerbated by climate change posing a greater potential for disasters in the future. This study has two goals: 1) it assesses the growth of informal settlements for 1984, 2003 and 2010 in relation to hazard areas, and 2) it examines the accessibility of the existing temporary evacuation facilities that would be used in the event of a disaster in Honiara City. The application of Geographic Information System (GIS) and remote sensing are used to achieve the study’s goals. Visual image interpretation is used to delineate and digitize informal settlements and buildings. Evacuation center service areas and GIS census data are used to assess the effectiveness of existing evacuation facilities and the composition of urban population vulnerable in the event of natural and climate change related disaster.

The study shows that informal settlements are growing, as well as expanding onto locations easily affected by natural and climate change related hazards. From 71 ha in 1984, the areas taken up by informal settlement has increased to 333 ha in 2003 and 721 ha in 2010. GIS network analysis (service area) shows areas served by the existing evacuation facilities. In a spatial analysis perspective, the existing evacuation facilities are ineffective to meet the needs of vulnerable urban population in the event of a natural and climate change related hazards. There are informal settlement areas on hazard zones which are under-served by the existing evacuation facilities.

Expansion of informal settlements onto hazardous areas, such as low-lying areas, floodplains, areas susceptible to liquefaction and steep slopes have also increased since 1984. For example, area taken up by informal settlements on floodplains has increased from 5 ha in 1984 to 46 ha in 2003 and 131 ha in 2010. Growth of informal settlements onto weak sediments (recently deposited sediments) areas has also increased from 67 ha in 1984 to 311 ha in 2003 and 806 ha in 2010. In a similar context, the number of houses built in areas susceptible to natural and climate change related hazards has increased. For instance, the number of houses built on low-lying area has increased from 113 houses in 1984 to 802 and 1278 houses in 2003 and 2010. On flood plain, the number of houses has increased from 36 houses in 1984 to 484 and 834 houses in 2003 and 2010. On recently deposited sediments (weak
sediments), the number of houses has increased from 427 houses in 1984 to 2342 and 3462 houses in 2003 and 2010.

Service area analysis shows ‘served’ and ‘under-served’ areas in Honiara City. This analysis indicates that informal settlements within the White River areas, Fishing Village and within Burns creek and Lungga informal settlements are outside the evacuation service areas. People living in these areas are ‘under-served’ in the event of natural and climate change related disasters. Existing evacuation facilities are not effective as accessing the facilities from under-served areas require more time. Facility 2 is not suitable for tsunami and storm surge making accessibility impossible for people living in west Honiara during these events.

GIS census analysis shows the percentage of age groups and gender that are adequately served by the existing service areas. More than 30 percent of the population within each evacuation facility’s service area is children below 14 years of age and 3 percent are older people above 60 years of age. Female makes up about 46 percent of the gender in each evacuation facility’s service area. There are more people living within Facility 1 service area followed by Facility 2 and Facility 3. About 9 percent of the total population in the study area is under-served. Additional evacuation facilities are needed to serve under-served areas at risk to natural and climate change related hazards.

The applications of Geographic Information Systems and Remote Sensing in urban growth mapping and facility service area analysis provide information needed to support decision making needed to minimize the impacts of natural and climate change related hazards. The outputs of this study will enable Honiara City planners, Honiara City Council, civic authorities, Guadalcanal Province and the National Government to ensure a sustainable urban growth in the face of increasing frequency and intensity of natural and climate change related hazards. In addition, the output of the study provides a basis for developing a strategic evacuation plan for disaster risk management for Honiara City. There are limitations in this study that need to be addressed to improve disaster management preparedness in Honiara City.
List of Abbreviations

AR4 – IPCC Fourth Assessment Report

DTM – Digital Terrain Model

EA – Enumeration Area

EEZ – Exclusive Economic Zone

ESCAP – Economic and Social Commission for Asia and the Pacific

EU – European Union

GCCA – Global Climate Change Alliance

GCS – Geographic Coordinate System

GIS – Geographic Information System

GNSS – Global Navigation Satellite System

GPS – Global Positioning System

IPCC – Intergovernmental Panel on Climate Change

NAPA – National Adaptation Program of Action

ND – Network Dataset

PACE SD – Pacific Center for Environment and Sustainable Development

PCCP – Pacific Climate Change Program

PCRAFI – Pacific Catastrophe Risk Assessment and Financing Initiative

RGB – Red Green Blue

RS – Remote Sensing

SHP – ArcGIS Dataset Format

SINU – Solomon Islands National University

SOPAC – Pacific Islands Applied Geoscience Commission

SPC – Secretariat of the Pacific Community
TAB – MapInfo Dataset Format
TAR – IPCC Third Assessment Report
TOL – Temporary Occupation License
UN – United Nations
UNEP – United Nations Environment Program
UNFCCC – United Nations Framework Convention on Climate Change
UNFPA – United Nations Population Fund
UNICEF – United Nations Children’s Fund
UNISDR – United Nations International Strategy for Disaster Reduction
US – United States
USP – The University of the South Pacific
UTM – Universal Transverse Mercator
WG 1 – IPCC Working Group One
WGS – World Geodetic System
WMO – World Meteorological Organization
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Chapter 1: Introduction

1.1. Introduction

Natural hazards affect many regions of the world, including urban areas. Natural hazards are natural processes or phenomena of earth systems that may constitute a damaging event (van Westen, 2002). The extent of the damage natural hazards cause often depends on the interaction between humans and earth systems, interactions between earth systems and humans and technology, or interactions within the human society itself (Cutter et al., 2009). The way hazards impact a given population, system, or place gives rise to the concept of vulnerability (Birkmann, 2006). Vulnerability is defined as the susceptibility of a given population, system or place to harm from exposure to natural and climate change related hazards (Birkmann, 2006; Cutter et al., 2009; UNISDR, 2004).

The impact of natural hazards on urban areas is exacerbated by unplanned land-use activities exposing natural and human systems to locations easily affected by natural and climate change related hazards (Srinivas, 2007; IPCC, 2012). It is becoming evident that cities and towns in developing countries are increasingly exposed to natural and climate change related hazards that increase their vulnerability and the potential of economic and human loss (Dickson et al., 2011). Natural hazards such as earthquakes and tsunamis have caused economic and human losses in both developed and developing countries. In addition, the increasing intensity of storms and tropical cyclones also cause human and economic losses. Unplanned urban growth, natural and climate change related hazards are converging in dangerous path exposing settlements, population and socioeconomic activities in urban areas (Ruth et al., 2011). Therefore, identifying the vulnerability of urban areas and their exposure to natural and climate change related hazards is important in disaster risk management and climate change adaptation (Dickson et al., 2011).

Approaches used to assess natural hazards are carried out at different scales ranging from the global to the community level with a focus on reducing the degree of exposure of a given population, a system, or a place, to the impacts of natural hazards. The use of Remote Sensing (RS) and Geographic Information Systems (GIS) has become an integrated, well developed and successful tool in such assessments (van
Westen, 2002). The use of RS and GIS in representing natural hazards, population and the local aspect of the environment spatially provides information needed to understand the impacts of natural hazards to the variables being studied.

1.2. **Problem Statement**

Honiara became the capital of the British Solomon Islands protectorate in 1946. Since then, Honiara’s population has been growing rapidly as people from other provinces of the Solomon Islands moved in and settle around the city. The growth of informal settlements in Honiara can be traced back to the 1970s, when a system known as the Temporary Occupation License (TOL) was established and implemented by the Government through the Ministry of Lands (Pende, 2009). Given such rapid growth, Honiara has been experiencing numerous development problems and these include water shortage, pollution, poor living conditions and people building their houses on steep slopes and other areas exposed to natural hazards. The urban growth problems of Honiara make many people highly vulnerable to potential natural hazards that are associated with global warming and climate change.

1.3. **Research Questions**

This study is designed to address two important questions:

a) Do informal settlement growths in Honiara City suggest that these settlements and the population are becoming established in areas of greatest risk to natural and climate change related hazards?

b) How well the existing temporary evacuation facilities do served Honiara City and meet the needs of the vulnerable urban population (accessibility) in an event of natural and climate change related hazard?

First, taking into consideration the potential impacts of natural hazards such as tsunami and tropical cyclones, this study examines the most vulnerable populations in Honiara City by focusing on the characteristics and growth of informal settlements, as these would have most of the vulnerable populations in the event of a natural hazard. Second, this study examines how well existing emergency evacuation centers meet the needs of populations in Honiara. Evacuation centers are intended for all people in Honiara in the event of an emergency, but knowing how well they meet the needs of
the most vulnerable is very important. Both research questions are addressed from a spatial analysis perspective.

1.4. Research Goals and Objectives

The two goals of this study are to: 1) assess how informal settlements (populations vulnerable to natural hazards) have changed over time, 2) assess how effective the existing evacuation facilities are for meeting the most vulnerable urban population’s needs. The objectives (a, b, and c) can be divided into the two but related research topics goals (1 and 2):

1) Research objectives for informal settlement assessment:

   a) To determine the growth and location of informal settlements.
   b) To determine the growth of informal settlements towards high hazard areas.
   c) To determine the number of buildings in hazard zones for 1984, 2003, and 2010.

2) Research objectives for existing evacuation centers assessment:

   a) To determine areas served by the existing temporary evacuation facilities within 30 minutes travel time by foot.
   b) To identify informal settlement areas that is under-served (not covered by the current temporary evacuation facilities.
   c) To determine the composition of vulnerable population within the areas served by the temporary evacuation facilities.

1.5. Thesis Organization

This thesis is divided into seven chapters. Chapter one is an introductory section, introducing the background of the study, statement of research problem, and research questions and objectives.

Chapter Two is a literature review that provides concepts linking natural and climate change related hazards and their impacts on urban areas, and the application of GIS and RS in addressing climate change challenges in urban areas.
Chapter Three gives an overview of Solomon Islands and Honiara City where the study is conducted.

Chapter Four briefly outlines the methodology used in this thesis. The chapter is divided into two sections addressing the two research questions dealt with by the study. The first outlines the methods used for visual interpretation of multi-temporal aerial images of Honiara for an assessment of informal settlement growth, and the second presents the network analysis methods used to identify service areas of existing evacuation centers.

Chapter Five provides the results of spatial analysis. The results of spatial analysis of informal settlements growth and the effectiveness of existing evacuation centers in Honiara City are presented.

Chapter Six provides a discussion of what is learnt from the spatial analysis of urban growth and informal settlements and the effectiveness of existing evacuation centers, and how these two topics provide helpful knowledge in natural hazard risk assessment.

Chapter Seven summarizes and concludes the key findings of this study. The main findings are summarized and recommendations are listed.
Chapter 2: Literature Review

2.1. Introduction

This section reviews fundamental concepts of climate change science, climate change challenges in the context of urban areas in the Pacific region, and the use of GIS and remote sensing in the study of urban areas, with a focus on GIS/RS applications in land-use change and emergency management and evacuation.

2.2. Climate and Climate Change: A Brief Overview

The terms climate and climate change are used widely in reports, literature and books that try to understand the dynamics of the earth’s climate system. The meanings of both terms are taken from the World Meteorological Organization (WMO) and Intergovernmental Panel on Climate Change (IPCC) reports. Climate is the average weather of a place or region which is derived from physical variables such as rainfall, temperature and wind including their range and patterns (Le Treut et al., 2007; IPCC, 2007a). It is the description of the state of the atmosphere and climate system. IPCC defines Climate change as the change in the state of the climate over time whether natural or as a result of human activity (IPCC, 2007a). This definition differs from United Nations Framework Convention on Climate Change (UNFCCC) definition which defines climate change as a change of climate as direct or indirect results of human interference to the composition of the atmosphere. Climate system changes in time under the influence of its own internal dynamics and due to changes in external factors such as solar variations including human activities that change the composition of the atmosphere (Le Treut et al., 2007).

The earth’s climate system is made up of atmosphere, oceans, terrestrial and marine biosphere, cryosphere and land surface and their interactions determine the earth’s surface climate (IPCC, 2007a; Forster et al., 2007). Interactions within the earth’s climate system are defined by the flow of energy in various forms within the earth’s climate system for instance, the exchange of water, gas and nutrients. The external source of energy that drives these interactions and the flow of energy is solar energy. Thus, the earth’s climate system is powered by the input of solar energy and this energy is balanced by the earth’s surface and atmosphere by emitting heat energy received from the sun back into space (Forster et al., 2007).
2.2.1. The Green House Gas Effect

It is important to understand that global temperature is determined by the energy received from the sun and the properties of the earth’s surface and its atmosphere (Solomon et al., 2007). These properties, such as reflection, absorption and emission of energy at the earth’s surface and in the atmosphere—are considered important as these can influence the earth’s energy budget, thus influencing the climate (Le Treut et al., 2007). For instance, the recent increase in greenhouse gas and aerosol concentration has influenced incoming and outgoing energy received from the sun by absorbing and redirecting it into space or back onto the earth’s surface (Solomon et al., 2007; Forster et al., 2007).

Figure 1: Earth’s mean energy balance. Source: (Le Treut et al., 2007).

The sun powers the earth’s climate by radiating energy at very short wavelength where more than two-third of this energy is absorbed by the surface and the atmosphere (Le Treut et al., 2007). On the earth’s surface, the energy causes surface heat and because the earth’s is much colder than the sun, it radiates the energy back into the atmosphere at much longer wavelengths balancing the incoming energy. Within the atmosphere, much of the thermal radiation is absorbed reradiated the energy back to earth (Le Treut et al., 2007). Certain naturally occurring gases within the atmosphere have the ability to trap long wave radiation emitted from the earth’s surface reradiating the energy both up into space and the earth’s surface keeping the earth’s surface warmer (Forster et al., 2007). Thus the composition of the atmosphere
determines the amount of energy lost into space and how much is left to circulate through the earth’s system.

Figure 2: A model of the greenhouse gas effect. Source: (Le Treut et al., 2007)

2.2.2. Climate Systems and Human Interference

The Intergovernmental Panel on Climate Change Fourth Assessment Report, Working Group one (IPCC AR4 WG1) technical summary has noted that the warming of the earth’s climate is unequivocally a result of anthropogenic interference with the climate system. Humans have modified the earth’s climate through emissions of greenhouse gases and through land-use and land-cover change (Solomon et al., 2007). It is now evident from observations, such as increases in global average air and ocean temperatures, widespread melting of snow and ice sheets on land, and rising global average sea level (Rummukainen et al., 2010). Global average temperature has continued to increase as different global models all have shown consistent warming trends. For example, analyses of temperature from 1859 to 1899, 1901 to 2000, and 1906 to 2005 show a total increase in temperature of 0.76 degree Celsius (Solomon et al., 2007). The current rate of warming is larger compared to that of a 2001 Intergovernmental Panel on Climate Change Third Assessment Report (IPCC TAR).
The 2007 IPCC AR4 indicates that land regions warmed at a much faster rate than the ocean. With more warming, damages linked to climate change related hazards will accelerate.

Changes in extreme temperature and the intensification of extreme precipitation are expected to increase under warming climate scenarios influenced by humans. Extreme weather events can be described as the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of variables (Peterson et al., 2012). An example of such an event is the European 2003 heat wave, which can be characterized both by extreme daily maximum and minimum temperature, and by an extremely warm summer season (Zwiers and Hegerl, 2008). The intensification and frequency of extreme weather events is an expected consequence of human influence on climate system.

2.2.3. Natural and Climate Change related Hazards

It is evident that global climate change threatens to disrupt the economies, environmental and social order of many countries (UNISDR, 2004; IPCC, 2012). Significant impacts of climate change will occur regardless of future greenhouse gas reduction measures (Feiden, 2011). When greenhouse gases are released into the atmosphere, they will stay there for between 50 to 200 years hence, further warming are already in the pipeline even if we are to reduce greenhouse gas emission in the future (Commonwealth of Australia, 2003; IPCC, 2007b). The impacts of climate change are apparent and well documented in all Intergovernmental Panel on Climate Change (IPCC) reports. For example, rising sea level, rapid melting of Greenland ice and inland glaciers are correlated with the increasing global temperature (Commonwealth of Australia, 2003; IPCC, 2007b). The frequency and intensity of natural and climate change related hazards are likely to increase as a result (Trenberth et al., 2007).

The impacts of unabated climate change related hazards threaten to be a problem for developing countries already struggling to cope with their current climate. Most developing countries are geographically disadvantaged and are vulnerable to climatic shocks, as these have caused setbacks to economic and social development (Stern, 2007). For instance, in 2002 cyclone Zoe struck the remote islands of Tikopia and Anuta in the Solomon Islands, causing significant economic and environmental
damage, and disruption of access to food, water, health, and education (Dyoulgerov et al., 2011). In 1962, a cyclone hit Guam with terrifying force, killing 11 people and destroying most temporary buildings (Bettencourt et al., 2006). The resulting losses are usually unbearable for most developing countries, as they’re already struggling with socio-economic problems.

When associated with extreme weather events, tropical cyclone presents major hazards within the tropics. Tropical cyclone, which is common in all tropical regions, is usually associated with extreme wind velocity, torrential rain causing flooding and landslide, high waves and surges leading to extensive structural damage. For example, tropical cyclone Bhola and Katrina inflicted the highest death toll and damages on Bangladesh and the US respectively on record (Hallegatte and Williams, 2012; Lin et al., 2012; Peduzzi et al., 2012). Surges, wind velocity and torrential rain are responsible for much of the damage and loss of life associated with tropical cyclones passing over a region. In future tropical cyclones, warmer climate is projected to increase peak in wind intensity and increase mean and peak precipitation (Solomon et al., 2007). Even though the total number of tropical cyclones globally is projected to decrease, the proportion of very intense tropical cyclones is projected to increase in some regions. Therefore, tropical cyclone promises to be an even greater hazard within the tropical regions.

2.3. Urban Growth and Climate Change

2.3.1. Urban Climate Change Impacts

Projected climatic change will adversely affect cities with high concentrations of people, buildings and infrastructures. Most cities will become vulnerable to extreme climatic events if they are located near the coast, beside major rivers, on steep landscape and other risk-prone areas (Mutizwa-Mangiza et al., 2011; Dodman et al., 2012; Sherbinin et al., 2007). In addition, urban infrastructures such as power lines, water pipes, roads, schools and hospitals that provide basic services for urban population are also vulnerable to extreme climate related events such as flooding, storm surges and landslides (Dickson et al., 2011; Mutizwa-Mangiza et al., 2011). Location choices for socioeconomic development have influenced exposure to flooding, landslide and windstorm. In fact, socioeconomic development often increases the occurrence and degree of loss of life resulting from landslide, floods and
surges, and windstorm (Bouwer, 2011; Guha-Sapir et al., 2012; UNISDR, 2011). Thus, the increase in frequency and intensity of projected extreme events as a result of climatic change, will pose greater risks to cities, urban infrastructures and population in the future.

Risk associated with natural and climate change related hazards can increase or decrease over time according to a country’s ability to reduce its vulnerability and strengthen disaster risk management preparedness capabilities (UNISDR, 2011). History has revealed that on many occasions, governments have to adjust to natural hazards or even extreme climate events to reduce risks to populations, infrastructures and services. For instance, mortality risks relative to population size is falling in East Asia and the Pacific by a third of what it was in 1980 (UNISDR, 2011). Despite more and more people living in areas expose to natural and climate change related hazards, governments in all regions stepped up their capacity to reduce risks associated with natural and climate change related hazards.

Cities in low and medium-income countries will see adaptation as a more pressing concern than mitigation. These cities usually host the largest proportion of population and economic sectors most at risk from extreme weather events and sea-level rise (UNISDR, 2011; Dodman et al., 2012). For instance, as low and medium-income countries have become more urbanized, there has been an increased concentration of low-income urban residents occupying locations that are prone to flooding, landslides and other hazards (Dodman et al., 2012). “In many low and medium-income countries, the low-income group are vulnerable because they had greater expose to hazard, lack of hazard reducing infrastructures, less adaptive capability, less provision for government assistance in the event of a disaster and weaker legal and financial protection” (Dodman et al., 2012).

2.3.2. Urban Population Vulnerability

The unique physical, social, economic and environmental composition of a city influences the risk and vulnerability of its residents. Risks to urban populations will differ across cities based on factors such as topography, poverty levels, the pace of urbanization and the level of awareness about disaster risk or climate change (Dickson et al., 2011; IPCC, 2012). For example, coastal cities are at risk as they are often built on low-lying lands which are susceptible to climate change related
impacts, such as sea level rise, flooding and coastal erosion (Dickson et al., 2011). In the Least Developed Countries, many coastal cities are found in tropical areas with hot and humid climate and low-lying land, both of which heighten their vulnerability to extreme events.

An important aspect of many cities is that the poor often live in informal housing within informal settlements which are usually located within risk-prone areas (Mutizwa-Mangiza et al., 2011; Dodman et al., 2012; UNISDR, 2004). This means that poor people living in urban squatter settlements have higher level of everyday risk compared to other city residents and officials. The failure of governments to provide affordable housing, infrastructures and services for low income earners has resulted in a profusion of people living in informal housing.

2.3.3. Urban Growth and Vulnerability in the South Pacific

There is a gradual increase in the growth rate of urban population in most of the Pacific Island Countries. This rate of change in urban population is projected to be at 2.3 per cent from 2015 to 2020 (PCCP, 2011). From such a rate, it is estimated that by 2020, about 48 – 50 per cent of the total population of Pacific Island Countries is projected to be in urban areas, with a high proportion consisting of youths. Accommodating such growth in a fully occupied urban area means that further expansion will include areas that are vulnerable and exposed to natural and climate change related hazards.

The Pacific Island Countries are likely to be amongst the worlds’ most vulnerable to natural and climate change related disasters. Their size and remoteness, fragile biodiversity, widespread exposure to natural and climate change related hazards, low elevation, and higher concentration of their population living in coastal areas contribute to their vulnerability (Bettencourt et al., 2006; PCCP, 2011). Rising sea level has already affected low lying atolls causing erosion, flooding and inundation. More than 20 per cent of the urban population in the Pacific Island Countries lives within the coastal areas less than 10 meters above sea level (UN-Habitat, 2009). As more people will find it comfortable to live in such areas, extreme climate events and natural hazards are the main challenges likely to be faced in the future.
Sea level rise, severe storms surges, and climate variability exacerbated by climate change will see coastal urban areas within the Pacific Island Countries increasingly at risk. Reduced access to water and productive land will affect areas that are densely populated. Variation in rainfall patterns coupled with increasing water demands will severely stress local watersheds (Feiden, 2011). With sea level rise, inundation will increase the concentration of salt in the soil, making it difficult for farming. Extensive foreshore modifications are effective under normal conditions but these developments do not guarantee that coastal communities will be able to withstand cyclone-force waves, which also worsen coastal erosion under extreme conditions (PCCP, 2011).

Modern day urban areas in the South Pacific reflect the accelerated urban growth since the colonial administration. Usually started as colonial administrative centers with basic infrastructure such as roads and ports, these centers later expand into surrounding villages resulting in a clusters of villages growing into a town which become a modern day urban center (Jones, 2012). Establishments of urban centers attract rural population which accelerates rural urban migration. As more people moving into urban centers, the demand for suitable land as well as affordable housing increases forcing those who cannot afford high cost housing to live and work in locations easily affected by natural and climate change related hazards. A new type of housing area known as informal settlement emerged and blossom when demands for suitable land and affordable housing are not met (Miles et al., 2012; Jones, 2012).

Informal settlement has become a part of urban growth in the pacific and in most cases; it is unique as it comprises of different classes of people living together compare to formal residential areas. The expansion of informal settlements onto locations easily affected by natural and climate change related hazards expose inhabitants, their houses, and sources of livelihood to the path of natural and climate change related hazard (Bonapace et al., 2012). The growth of informal settlements onto flood plains, low-lying coastal areas, steep slopes, and into deep ravine makes informal settlements more vulnerable to natural and climate change related hazards (Cardona et al., 2012). Lack of affordable housing, increasing cost of living in urban areas and low paying job push people to occupy areas that are easily affected by natural and climate change related hazards.
2.4. GIS and Remote Sensing in Urban Study

Geospatial technologies are technologies used for collecting and analyzing geospatial information. They are concerned with the concepts of location, establishing methods of representing and investigating location and the properties of spatial interaction (Chang, 2008). The technologies include Geographic Information Systems (GIS), Remote Sensing (RS), and Global Navigation Satellite Systems (GNSS). Geospatial technology has become a powerful tool when addressing relationships that vary through time and space (van Westen, 2002). Its use has become wide spread in the last twenty years as a result of rapid development in computer systems and data availability (Goodchild et al., 1999; Sheppard et al., 1999).

The power of GIS comes from its ability to combine multiple diverse layers of data with their attributes over a defined space to provide new information and assist in decision making. Satellite navigation systems provide precise and timely information on locations on the earth’s surface. This is useful in terms of providing accurate measurements of locations and events on the earth surface (Goodchild et al., 2007).

Remote Sensing techniques are useful in mapping urban areas and provide data for analyzing and modeling urban growth and land-use change (Herold et al., 2003). The launching of airborne remote sensing systems expands the capability of GIS, as new sources of timely and accurate spatial information are made available. Conventional surveying and mapping techniques are expensive and time consuming, so GIS and Remote Sensing play important roles in monitoring and planning urban environment as they save time.

2.4.1. Remote Sensing for Urban Growth Mapping

Remote Sensing data has been used widely for land cover identification and classification of various features of the land surface from satellite or airborne sensor (Hasmadi et al., 2009). In most urban and land-use change studies, image interpretation and classification are used to determine the extent, rates, nature and the direction of land-use change and urban growth. Monitoring informal settlements growth in urban areas using remotely sensed data improve the understanding on the nature of growth providing an effective way for disaster management preparedness (Sun et al., 2013; Jat et al., 2008).
The use of remotely sensed data in assessing natural hazards in urban areas supports decision making before, during and after a natural hazard occurs (Taubenbock et al., 2011). GIS and Remote Sensing have the capability to delineate vulnerable areas before a natural hazard occurs. In addition, the spatial impacts of natural hazards during and after the event can be determined, projecting the likely damages caused by a particular natural hazard. A multi-sensoral approach using remotely sensed data for flood risk assessment in an urban area was done by Taubenbock (Taubenbock et al., 2011). The study identified exposed areas, things that are likely to be affected, the number of people and their age and the extent of the damage. The study also assessed urban growth over time, classified urban structures, and assessed building stability.

The growth of informal settlements in urban areas onto locations easily affected by natural and climate change related hazards is one of the concerned faced by civil authorities as population living in these areas are vulnerable to natural and climate change related hazards (Miles et al., 2012). Assessing the expansion of informal settlements provide information which can be used to manage the growth of informal settlements onto locations susceptible to natural and climate change related hazards. GIS Spatial analysis techniques such as digital image analysis (image classification) has been used in urban studies to assess the physical characteristics of urban areas and determine the locations and direction of expansion (Thomson and Hardin, 2000; Sun et al., 2013; Fan et al., 2009; Pham and Yamaguchi, 2011). Yet the application of remote sensing and the use of high-resolution remote-sensed data in urban areas of the Pacific Island Countries remained sparser.

Mapping urban areas (especially informal settlements) likely to be affected by natural and climate change related hazards using GIS and Remote Sensing increases knowledge about urban vulnerability. However, GIS and Remote Sensing are relatively new technologies in many developing countries including the Pacific Island Countries (Pene, 2006). Therefore, access to the needed data is limited and whatever data that are available, are inconsistent, unreliable, obsolete or non-existent (Krishnamurthy et al., 2011; Pene, 2006; Hurskainen and Pellikka, 2004). In such case, visual image interpretation becomes favorable over image classification for image analysis.
The idea of visual image interpretation is based on features that our brain is familiar with, enabling the image to be interpreted. Visual image interpretation can be defined as the science and art of observing images with the objective of identifying different objects and judging their significance (Hurskainen and Pellikka, 2004). Familiarity with the subject of interest when viewed from space is important in visual image interpretation. It is a tool both for interpreting image data fed into a computer as well as generating information from image data set. It represents information by recognizing, communicating and interpreting patterns and structure. Elements such as tone, texture, pattern, shape, size, shadow and relative location form the basis for visual image interpretation (Lindgren, 2010). Visual image interpretation is the simplest method used to extract meaning information from Remote Sensing data when the quality and quantity of remotely sensed data are lacking or does not meet the image classification requirements.

Information on growth and expansion of informal settlements in urban areas provides valuable information for city planners to learn from past mistakes and avoid repeating them (Hurskainen and Pellikka, 2004). The use of features and objects in image interpretation provide information needed to analyze the growth and expansion of informal settlement in urban areas. Knowledge base object-oriented image analysis and visual interpretation prove to be applicable in many developing countries where remote sensing data are inconsistent and unreliable (Hurskainen and Pellikka, 2004).

Hurskainen and Pellikka (2004) use panchromatic and colored aerial photographs and satellite imageries to study the growth and change of informal settlements. Knowledge base object oriented image analysis and visual interpretation are used to detect the growth of informal settlements. This method is chosen because it does not depend on pixel spectral values, which is essential when data consists of both panchromatic and true-color images (Hurskainen and Pellikka, 2004). Studies that use knowledge base object oriented image analysis and visual interpretation obtained detail information on urban growth including informal settlements growth (Hofmann, 2008; Herold et al., 2003; Busgeeth et al., 2008). Analyzing remotely sensed data from knowledge base object oriented analysis and visual interpretation improve the level of detail and accuracy of remote sensing data (Herold et al., 2003).
A similar approach used by Hofmann (2008) and Busgeeth et al., (2008) is used in this study to delineate informal settlements in Honiara City. Hofmann develops ontology of informal settlements based on its characteristics and definitions. The ontology is used as a guide to visually interpret informal settlements from satellite images. Busgeeth et al., (2008) develop a key to delineate informal settlements. The key being developed is based on the physical attributes and characteristics of informal settlements. The key is used as a guide to delineate informal settlements from the satellite images. The ontology and the key developed by Hofmann and Busgeeth et al are a knowledge base object oriented image analysis and visual interpretation approaches. The informal settlement assessment component of this study is more on knowledge base visual image interpretation as that of Busgeeth et al where a key is developed and used to delineate informal settlements from aerial photographs and satellite images.

2.4.2. GIS for Emergency Management and Evacuation

Emergency management and evacuation planning is an approach used in urban areas to minimize the impacts of natural hazards especially to people’s lives. Enhancing the ability to effectively respond to natural hazards protects lives and properties promoting sustainable socioeconomic development in urban areas (Ma et al., 2011). Evacuation is a procedure of relocating people and materials that may damage during natural hazards. The effectiveness of executing evacuation plans depends on how organized an urban area is, in terms of transferring people from affected locations to areas that are much safer. Effective emergency evacuation plans therefore, require organize information on routes and the time that it might take to safely arrived at a designated evacuation point (Church and Sexton, 2002).

The use of Geographic Information System (GIS) as a tool for emergency management and evacuation planning is considered to be very effective. GIS combines a powerful visualization environment with a strong analytical and modeling applications that generates spatial information and their attributes in an organize manner that supports strategic planning (Wu et al., 2001). A significant amount of research has been done on evacuation model analysis using GIS (Cova and Church, 1997; Yin et al., 2012; Ahola et al., 2007; Kar and Hodgson, 2008; Almeida et al., 2009). The targeted hazard can be different however; the approaches used are
somewhat similar. Most of these studies used GIS network analysis for evacuation modeling. Network analysis is a functional GIS tool which simplifies the solution of various location selection problems (Curtin, 2007).

Evacuation model analyses consider time, velocity, and distance as important factors (impedance) in determining the effectiveness of relocating goods and people between two or more points (Indriasari et al., 2010). In most cases, the distance component is usually constant as evacuation points are static. This means that the only variables that change are velocity and time. To further simplify this, the time it takes for goods and people to reach an evacuation point depends on how fast the movement of goods and people between two or more points. In an emergency situation, the velocity component is an important factor as it will determine the time taken to reach an evacuation point. In the case of automobiles, other factors also affect this relationship, for instance, the number of vehicles on the road during the evacuation period.

A methodology that examines evacuation routes in transportation network was proposed by Stepanov and Smith. The objective of their study was to design a model using egress route assignment in algorithms for evacuation in transportation network. The methodology involves an integer programming formulation for optional route assignment (Stepanov and Smith, 2009). The model considers time delay as a key factor that determines the effectiveness of evacuation on automobile transport network. The methodology allows policy and decision makers to cope effectively with mass evacuation while considering traffic congestion (Stepanov and Smith, 2009).

A similar approach as that of Stepanov and Smith was also proposed by Almeida et al (2009). This approach takes into consideration a number of factors including the number and location of evacuation points as well as the routes that linked them. It forms a model that incorporates these factors into a GIS providing a decision support system for planners and decision makers. The approach shows the number and locations of each evacuation point and the routes that the people should take to reach the closest point (Almeida et al., 2009). Knowing the shortest route to the nearest evacuation point is important during the time of a disaster.

The time and distance taken to reach the closest evacuation facility will be considered important during emergency evacuation if velocity is to be remained constant. This scenario should be considered when planning evacuation points and routes targeting
pedestrians in an urban area. In this scenario, the pedestrian walking pace and the distance to a nearby evacuation point are considered constant. The time taken to reach an evacuation point is usually represented by polygons known as service areas in GIS network analysis. In urban areas such as those in the Pacific Islands where most people don’t have automobile and traffic congestion a major problem, it is important to note that most people will be evacuating on foot rather than automobile thus, routing across network model is the GIS network analysis application considered useful for emergency management and evacuation planning. Routing across network is the act of selecting a course of travel and is the most fundamental logistical operation in GIS network analysis (Curtin, 2007).

Routing across network analysis prioritize minimizing the cost of the route. Cost in this case, can be measured as a function of distance, time or impedance in crossing the network (Curtin, 2007). There are fundamental operations that can be performed, all of which are functions of routing across network analysis. Determining the service area of a facility and finding the closest facility across the network, are two related functions of routing across network analysis that can be used for emergency management and evacuation planning in the Pacific Island Countries. When considering urban population evacuating on foot, determining the service area and finding the closest facility is applicable since there’s no model developed to simulate evacuation scenario in the Pacific Island Countries.

In any evacuation facility modeling, the main objective is to minimize losses (Indriasari et al., 2010). The spatial dispersion of population and the optimal locations of the evacuation facilities can influence this objective (Case and Hawthorne, 2013; Church and Sexton, 2002; Indriasari et al., 2010). There are studies that integrate GIS into location and service area coverage to address location problems such as accessibility which is also applicable to evacuation facility modeling (Murray and Tong, 2007; Liu et al., 2006; Lee et al., 2013; Indriasari et al., 2010). However, not all of these models are applicable to all evacuation scenarios as the objectives of the model and the nature of the facility services could be different (Indriasari et al., 2010).

Two related GIS service area models; Maximal Service Area and Maximal Covering Area, address accessibility by taking into account road access, barriers and road
network attributes (Indriasari et al., 2010; Church and ReVelle, 1974). There are more than one methods used to define service areas (Figure 3). The model that generate service areas as travel time zones is considered applicable for evacuation facilities since emergency scenarios are modeled under time or distance constraint (Indriasari et al., 2010). A maximal service area is developed by Indriasari et al. (2010) to generate service areas of evacuation facilities as travel time zones. The main objective of maximal service area model is to determine the total areas that can be reached from the facility within a specific distance, time or cost (Indriasari et al., 2010). This study adopted the Maximal Service Area model by Indriasari et al., (2010) to determine the maximum service area of the evacuation facilities as travel time zones to determine the accessibility and effectiveness of existing evacuation facilities in Honiara City, Solomon Islands.

![Image](image_url)

**Figure 3: Methods used to define service area. Source: (Indriasari et al., 2010)**
2.5. Conclusion

Natural and Climate change related hazards pose significant challenges to urban centers. This chapter briefly stated the projected impacts of anthropogenic climate change related hazards on urban areas as urban centers continue to grow. Identifying areas, population, and settlements that are likely to be affected by natural and climate change related hazards is important. The application of geospatial technology in climate change vulnerability and hazard assessments provides cost-effective information that can be used to save lives.
Chapter 3: Study Area

3.1. Introduction

This chapter outlines a brief overview of the Solomon Islands and Honiara City where the study was conducted.

3.2. Solomon Islands and Honiara City

3.2.1. Location of Solomon Islands in the Pacific Region

The Solomon Islands (Figure 4) is located between the latitudes $5^\circ 10'$ and $12^\circ 45'$ south and longitudes $155^\circ 30'$ and $170^\circ 30'$ east in the South Pacific Ocean, encompassing a total land area of 28 785 square kilometers and an EEZ of 1.34 million square kilometers (Pende, 2009; Solomon Islands NAPA, 2008). It is the third largest archipelago in the South Pacific Ocean, comprising 6 major islands and approximately 1000 smaller islands and low lying atolls, which are dispersed over 1300 square kilometers of ocean (Solomon Islands NAPA, 2008; Pende, 2009).

![The Map of Solomon Islands](image)

Figure 4: The double chain islands of the Solomon. Malaita, Santa Isabel and Choiseul make up the northern chain while Makira/Ulawa, Guadalcanal and Western make up the southern chain.
3.2.2. Geographical Setting of Areas around Honiara

The general topography around Honiara (Figure 5) is like that of a series of low, dissected plateaus, sloping down from a height in the area south of Mbelapoke Hill of about 700 to 800 meters above sea level towards the Northeast Coast (Hackman, 1979). In most of the areas around Honiara, the plateaus are quite rough, deeply dissected and are not well-defined, due to land-use change. But moving further south and away from the City, prominent surface features of marine erosion are evident, even at a height of 600 to 700 meters above sea level (Hackman, 1979).

The drainage pattern also aligns closely with the formation of the plateaus. Major rivers flow from a south-west to north-east direction. This drainage pattern is obvious for major rivers within the Honiara area. For example, the headwaters of the Lungga River and the Ngoti tributary of the Mataniko follow this pattern (Hackman, 1979).

The coastline within Honiara is both natural and artificial. Within the City itself (central Honiara), the coastline is mostly artificial. For example, the whole of the Point Cruz area is reclaimed. Jetties, gabions and sea wall are built within the reclaim areas, except the Mataniko River mouth, which is natural and flagged by informal settlements. At the western end of Honiara, the coastline is mostly natural and is backed by a narrow stretch of fringing reef that is covered with hard corals.

The study area was divided into West, Central, and East Honiara with a total area of more than 46 square kilometers (Figure 6). West Honiara includes White River, Tandai, upper Tasahe, Rifle Range, Nggosi and Rove. Central Honiara comprises of areas between Mbumburu in the west to Panatina Solomon Islands National University in the east. East Honiara is made up of informal settlement areas around Ranadi, Burnscreek, Lungga, and Henderson. The study area was indicated in the map by a white line extending from White River in the west, Gilbert Camp, Mamulele, Green Valley and Adaliua in the south and Henderson in the east.
Informal Settlements and Poverty

Most of the areas where Honiara’s informal settlements are found are within the study’s boundary (Figure 6). These areas are categorized as Temporary Occupation License (TOL) areas by the Ministry of Lands, Housing and Survey. In Honiara City, informal settlements are found located on sloping areas, between valleys, on river banks, and coastline. They are usually unplanned, densely populated, and lack basic services. In some settlements, for instance, Kobito 1, 2, 3 and Kobiloko, water is communally shared amongst the settlers. Provision of basic services such as water and sanitation, rubbish collection, and road maintenance is difficult, as most of these areas are either on steep slopes or scattered between deep valleys making accessibility impossible (Amnesty International, 2011; UN-Habitat, 2012; Maebuta and Maebuta, 2009).
Figure 6: The study area was zoned as West, Central and East Honiara.

The structural characteristics of informal settlements within Honiara City reflect the economic and income-earning status of its residents. Income generation is difficult and most residents are struggling to earn a living. Urban poverty and unemployment are highest in these informal settlements, since most residents depend on informal economic activities for their livelihood (UN-Habitat, 2012; Maebuta and Maebuta, 2009).

Honiara City’s formal sectors employ just over 27 per cent of the city’s residents, while the remaining residents are involved in unorganized and unregulated informal activities (UN-Habitat, 2012). A survey conducted by Maebuta and Maebuta indicate that apart from full-time and casual jobs, the most important sources of income in the informal settlements are roadside markets and street selling (Maebuta and Maebuta, 2009). It is becoming more common to see young males selling cigarettes, perfumes, knives, and wrist watches along major commercial centers as part of their casual job. Selling of betel-nut continues at the front and back of shops, even though a ban is in place for such activity within the city. Roadside markets also emerge at various
locations within the city. This indicates that the informal settlement residents are struggling to earn a living and meet their families’ needs.

Honiara City is located on a coastline that is fully exposed to the ocean and is susceptible to storm surges and extremely high waters. There are settlements, hotels and other important utilities that are located within the low-lying stretches of the coastline. Informal settlements such as Lord Howe (Mamana Water) and Fishing Village (Fishery) are the most vulnerable in the city as they are situated right on the coastline. Extreme high tide coupled with storm can inundate these settlements as they are only 5 meters away from the high tide water line (UN-Habitat, 2012). A profile study done for Honiara City by the UN-Habitat in 2011 acknowledges that natural disasters and climate related hazards are a serious concern in the city, because construction continues to take place on steep slopes, along river banks, and along shorelines that are prone to natural and climate related disasters (UN-Habitat, 2012).

Rural people moving into urban centers in search of better living standards are hoping to decrease their economic vulnerability, but they might be increasing their vulnerability to the adverse impact of natural and climate change related hazards. The degree of exposure and risk experienced by urban residents depend on various aspects of urbanization. These include settlement location, density, availability of appropriate infrastructures and housing stock. Furthermore, rapid urbanization can stress government’s efforts to create plans and build a resilient city, leading to increased vulnerability to the city’s residents (United Nations Population Fund, 2011).

3.3. Conclusion

This chapter provided a general description of the Solomon Islands and Honiara City where the study is conducted. Honiara City is located on the northern coast of Guadalcanal island. The geographical location of the Solomon Islands and the physical topography of Honiara City are briefly stated. A brief overview of informal settlements livelihood in the City and their vulnerability to natural and climate change related hazards are stated.
Chapter 4: Methodology

4.1. Introduction

This chapter gives an overview of the research methods used to achieve the objectives of the research project. It starts by briefly providing background on research methodology theory and presents the methodological framework within which this study is undertaken. Research approach is presented, including the research design, data sources and a detail explanation on data pre-processing. Methodological steps for the informal settlement and evacuation center analysis are presented.

4.2. Research Methods Theory

Methodological approaches used in a research project are determined by how a researcher thinks and the type of language the researcher intends to use in a particular field of interest (DePoy and Gitlin, 2005). In most cases, a methodological approach that would be relevant for a particular query in a research project, originates from two theoretical frameworks: experimental and naturalistic inquiries. In the former, a theory is specified before a hypothesis is developed linking the hypothesis to a theory. In the later, a theory is developed only after observations had been made (DePoy and Gitlin, 2005).

Experimental inquiry assumes that reality exists and can only be discovered given the right approach and design of methodology since the variables are independent from the researcher. A reality exists and can be discovered after a hypothesis is set up and tested with quantifiable experiments (Douthwaite et al., 2001; Pende, 2009). On the other hand, natural inquiry assumes that knowledge can only be maximized when the researcher gets involved in that phenomenon of interest (DePoy and Gitlin, 2005). This means that, to maximize knowledge, the researcher has to obtain information from individual who has experienced the phenomenon of interest. Therefore, natural inquiry seeks to get new knowledge by understanding the context of variables including human experiences.

In a few areas of study, neither any of these inquiries by themselves can generate explanations of reality nor the new knowledge needed from the field of interest. For instance, studies such as climate change and its associated impacts on people’s livelihood, their settlements, utilities, assets and infrastructures, might require both
approaches depending on the questions that need to be answered. A lot of such studies are based on modeling and observation. In this study, neither a purely experimental nor a purely naturalistic inquiry was involved in the research design. This study is an overlay of land areas susceptible to hazards with informal settlements growth data derived from visual image interpretation. Population and GIS network analyzes are the modeling components.

The study used image analysis (visual image interpretation), ground truthing and field observation, and analyzed acquire GIS and census data to generate new knowledge and needed information. Those information and new knowledge helped to answer questions on the growth of informal settlements and their susceptibility to natural hazards and the effectiveness of evacuation centers for emergency management in Honiara City. Visual image interpretation and analysis of acquired GIS and census data were done on the computer. Ground truthing and field observation were carried out in the field (study area) to verify visual image interpretation. GPS was used to help determined the surveyed areas on the images. There’s no quantitative and qualitative data were collected in the field during ground truthing and field observation. The intention of carrying out ground truthing and field observation is to verify and confirmed visual image interpretation.

4.3. Research Design

The design of this study was based mainly on ground truthing and field observation, visual image interpretation, and analysis of acquired GIS and census data (see Appendix A). The survey was carried out in the form of ground truthing, field observation and literature review. Passive observation was done by visually interpreting aerial photos and satellite images, and determining the characteristics of settlement types. Ground truthing was carried out purposely, to confirm or verify visual interpretation of the aerial photos and satellite images and to identify potential hazards likely to affect the locations on which informal settlements were expanding onto. In addition, Field observation and ground truthing were carried out to see the nature of the topography where informal settlements are located. The Steepness of slopes, flatness of low-lying areas, and the proximity of informal settlements to the coast and major rivers (flood plain) were determine during ground truthing and field
observation. The number and locations of previously used temporary evacuation facilities were also identified during ground truthing and field observation.

4.3.1. Visual Image Interpretation

Visual image interpretation was used to extract meaningful information from remote sensing data. Settlement types were one of information needed in this study thus; ontology of settlements within urban area was developed. This means that settlements were categorized into formal and informal settlement types and features typical to each type in urban areas, were sorted out and used as a basis to categorize them. The basis of ontology used in this study was derived from an object-based image analysis developed by Hofmann and Busgeet et al (Hofmann, 2008; Busgeeth et al., 2008). The method by Hofmann started off with a definition of informal settlement and a model consisting of features common to settlements in urban areas (Hofmann, 2008). From the model, a much more specific key was generated to help differentiate formal from informal settlements. The method by Busgeet et al started off with a list of urban settlement physical attributes before proposing a specific key to categorize formal and informal settlements (Busgeeth et al., 2008). The method used in this study was based on the approach used by Busgeeth et al (2008) (see Appendix B).

4.3.2. Ground Truthing and Field Observation

Ground truthing and field observation were carried out in the study area purposely to verify visual interpretation of aerial photos and satellite images. The study area covers more than 46 square kilometers. Ground truthing and field observation were employed to verify and characterize the types and locations of land-use, especially the settlement types since viewing and interpreting image from space only tells one side of the picture. Field observation and ground truthing enhances a 3D visualization of the subject of interest. For instance, it verifies the steepness of slope, how close or far apart the buildings were or other components of the building materials apart from roofing where it could not be viewed from space. Buildings used as temporary evacuation facilities in previous evacuation events were also verified during ground truthing and field observation (Figure 7).

It took a total of 3 weeks to survey the entire study area. Ground truthing was accomplished by walking. There were 12 administrative wards within the City boundary and those areas were covered on foot. A car was used to survey parts of the
study areas that were not within the City boundary. Those were areas east of the city boundary. A hand held GPS was deployed during ground truthing to obtain locations of areas surveyed. The accuracy of coordinates collected, ranges between 3 – 4 meters.

4.3.3. Hazard Identification

Hazards were identified based on historical occurrence of natural and climate change related hazards recorded in literatures and other government and non-government documents for the study site. Potential hazards likely to affect the locations of informal settlements in Honiara were categorized as geophysical and hydro-meteorological hazards (See Appendix D). Geophysical hazards linked to earthquakes while hydro-meteorology hazards linked to weather and climate. Potential hazards likely to affect the locations of informal settlements were earthquake, tropical cyclone/storm surge, and floods. Locations susceptible to those hazards were identified and digitized as layers in GIS. Locations susceptible to natural and climate change related hazards were low-lying coastal areas, flood plains, steep slopes and locations made up of sand and un lithified or recently deposited sediments.

4.3.4. Evacuation Facilities Identification

Evacuation facilities (Figure 7) were identified based on previous evacuation events. Major natural hazard events that prompted evacuation in Honiara City were 1986, 2009 and 2010 flood and 2007 tsunami. Other man made events that also trigger evacuation includes the 1998 – 2000 conflict and 2006 riot. During those events, the evacuees settled in temporary facilities within Honiara City. Three of the identified facilities were Solomon Islands National University’s Hall, the Multi-purpose Hall, and the Police Club. The University’s Hall was located east of the study area. The Multi-purpose Hall was in the center of the study area and the Police Club was located west of the study area. Evacuation facilities were identified and digitized as points. Those were later, used with street layer (Network Dataset) to create service areas for each facility during network service area analysis.
4.4. Data Sources

The research design determined the methods used to collect data. In this study, visual image interpretation, field observation and ground truthing, service area analysis and census modeling were used. Primary and secondary data were collected and used in this study. Refer to appendix E for further information on data sources and descriptions.

Primary data are data collected directly in the field during field work. GPS readings and information obtained during ground truthing and field observation were primary data used in this study. During the survey, sets of coordinates were gathered. A hand held Garmin GPS was used to collect the coordinates. The Garmin GPS was set to WGS84 and sets of coordinates were collected using this datum. The coordinates were collected randomly in the field. The accuracy of those coordinates was in meter (±3). Collection of data through informal enquiry was achieved when contacts were made during ground truthing and field observation. No prior arrangement was made. People within the surveyed areas provided the names of informal settlements needed to verify and confirm visual interpretation of aerial photos, satellite images and TOL areas.

Figure 7: Existing Evacuation Facilities identified and used in this study.
Secondary data are data that already exist. In this study, collecting information from those existing data followed two paths. Firstly, existing imagery (raster data), SHP files (vector data), and Population census data were obtained from the Agriculture and Planning division, the SOPAC and SPC in Solomon Islands and Fiji respectively. Secondly, SHP files (vector data) were created based on existing paper maps, aerial photos and digital satellite images. Those existing paper maps and aerial photos were scanned (600 dpi); georeferenced and the features of interest were digitized at a scale of 1: 4000 in ArcMap 10. In addition to paper maps and aerial photos, satellite images for 2003 and Google earth image for 2010 were used.

The procedure used to get a current (2013) Google earth image for the study area was tedious. Since a recent satellite image needed for the study area was expensive, the alternative to use Google earth image was chosen. To get an image resolution that would be suitable for visual image interpretation, the elevation was set at 1000 meters in the Google earth. ‘N’ key on the computer’s keyboard was pressed to align the Google earth image north before saving the images on the computer. Images for the entire study area were saved as subsets. Then each saved image was assigned with coordinate system in ArcMap 10 before being georeferenced and rectified. A 2003 satellite image was used as a base map to georeferenced and rectified each saved image with more than 10 control points were used. Each piece of the georeferenced image was then merged together to form a single image of the study area.

4.5. Data Pre-processing

Secondary data obtained from other organizations needed to be pre-processed to improve their quality before using them for analysis. In this study, the GIS data obtained from SOPAC, Pacific City Database (PCRAFI), Agriculture and Planning (Solomon Islands) and SPC were pre-processed before being used. GIS data pre-processing includes scanning, georeferencing, editing layers, changing the coordinate system (projection), merging images, clipping and extracting information from other layers, image analysis and creating SHP file layers.

Some of the GIS data obtained from SOPAC were pre-processed before using them. One of such data was the 1984 aerial photo, a single band (panchromatic) image. This was the earliest aerial imagery of the study area available. The image was in A4 size paper maps consisting of more than 10 subsets. To obtain the image in digital format,
the 1984 aerial photo paper maps were scanned at 600 dpi and the digital copy of the images were loaded onto a CD which later transferred onto a personal computer. The 1984 digital images came in four subsets covering the study area. Every subset required preprocessing before using them.

Firstly, each subset was registered using a 2003 satellite image as a base map. Georeferencing assigned real world coordinates to a number of features present on both images using a base map that was already georeferenced. Features that appeared on both maps such as the corner of buildings (roof), road junctions, and walking tracks were used as control points. Georeferencing was done in ArcMap using a georeferencing toolbar. Several steps were involved in georeferencing when using a base map in ArcGIS. A coordinate system was assigned to the scanned image subsets before being imported into the ArcMap. The projection and coordinate system (UTM zone 57S) as that of the base map was assigned to the scanned image before the 1984 and 2003 images were imported into the ArcMap to begin the georeferencing.

Apart from raster data, vector data were also pre-processed before using them for analysis. A road network layer for Guadalcanal was pre-processed using editor and clipping tools in ArcMap. For the purpose of this study, only the road networks within the study area was used. The clipping tool was used to extract network layers within the study boundary. Guadalcanal road was the input feature and the clipped feature was the study boundary. The output feature after the clipped process was the road network layer within the study boundary. The new road network layer was then edited to remove unnecessary road segments. In this case, the new road network layer was overlaid onto a recent satellite image and edited based on the road network on the recent image as a reference.

The formats, datum and projections used to generate secondary GIS data vary amongst different organizations. Data format depends on the GIS software used to generate the data. For instance, GIS data generated by MapInfo would be in a TAB file format and TAB files need to be converted into SHP files to be used in ArcMap. The coordinate systems used could also vary. In this study, ArcMap 10 was used and all TAB files were converted into SHP files. In addition, WGS84 and UTM was the datum and projection used in this study. Most of the GIS secondary data were in Geographic Coordinate System where latitude-longitude was the unit of measure. A
GCS was a global coordinate system and data with GCS were projected into UTM. All GIS layers used in this study were in UTM Zone 57S coordinate system.

### 4.6. Informal Settlements Analysis

Data needed for this analysis were informal settlements, buildings, and hazard layers. Sets of aerial images for 1984, 2003 and 2010 were used to obtain the needed data for informal settlements and buildings. The 1984 image was a single band image or black and white. Both the 2003 and 2010 images were 3 banded true color images. Informal settlements and buildings were digitized by visually interpreting the aerial image for each year based on the definition of informal settlement used in this study. A key was developed based on the physical attributes associated with informal settlements (See Appendices B).

Geological, hydrological, and meteorological hazards were considered hazards likely to affect certain locations in the study area. Locations susceptible to those hazards were digitized as polygon layers in GIS. A 5 meter contour for Honiara was used as a marker to delineate low-lying areas within Honiara City susceptible to flooding and inundation. Geology data for the study area was used to extract soil types and formations which were used to identify areas susceptible to the liquefaction during earthquake. In addition, a flood map for North Guadalcanal was used as a guide to digitize susceptible locations on flood plain. A Digital Terrain Model was used to generate slope’s steepness susceptible to landslide. Locations in the study area likely to be affected by natural and climate change related hazards were digitized as hazard layers.

#### 4.6.1. Digitizing Informal Settlements

Urban settlements had physical attributes which can be easily detected from aerial photographs and satellite images. Those spatial attributes were used as a key to differentiate formal from informal settlements (See Appendix B). Visual image interpretation used in this study, utilized those spatial attributes to delineate formal from informal settlements. Spatial features of settlements were identified and the characteristics and descriptions were given to those features. Features of settlements that could not be identified spatially were identified and confirm during ground truthing. What was common and typical to urban settlements were listed with their characteristics in a tabular form. The spatial attributes and characteristics of informal
settlements were used to develop an informal settlement identification key (see Appendix B).

Informal settlement was one of the urban features in Honiara City. The definition of informal settlement often varies across most disciplines depending on the subject of interest. Chand and Yala defined informal settlements as “groups of households in localities and in conditions that contravene the laws and regulations of state, specifically, those that relates to the physical planning and building requirements of urban authorities and other state agencies” (Chand and Yala, 2008). This definition mostly focuses on the importance of adherent to urban regulation and spatial planning.

The UN-Habitat, a governing body that looks after Human Settlements under the United Nations also provides definition for informal settlements derived from observed characteristics of informal settlements around the world. In their report on human settlements 2003, they defined informal settlements as “settlements that have inadequate access to safe water, sanitation, other urban basic services, overcrowding, insecure land tenure, and poor quality of housing” (UN-Habitat, 2003). Informal settlements can be described as low-income settlements with poor human living conditions (UN-Habitat, 2007). In developing countries such as the Solomon Islands, informal settlements can also be described as settlements that contain a wide range of socio-economic groups living together resulting in mixed types of buildings.

In this study, the approach taken to define informal settlements was based on both physical and social characteristics of informal settlements as the study’s objectives focused on the likely impacts of natural and climate related hazards to urban centers. Physical characteristics were based entirely on the evidence of spatial planning and building characteristics. This means that by visually interpreting satellite images, one can easy figured out physically planned areas from unplanned ones. Structures, colors and shape of roofs, arrangement of buildings and streets and the distance between buildings were some indicators used in defining the physical dimensions of informal settlements. The social characteristics on the other hand, were based on the inhabitants’ access to basics urban services to meet their needs. Overcrowding and a wide range of socio-economic groups living together within the same settlement area were used as an indicator of informal settlements. The social indicators were
determined during ground truthing and through reviewing literatures and government documents. Based on this definition, a key was developed to delineate informal settlements (Refer to the appendix B). Polygons representing informal settlements were then digitized based on the approach used by Busgeeth et al. (2008) which was knowledge-based visual image interpretation (See Appendix C).

Based on visual image interpretation, informal settlements were digitized as polygons. Those polygons were digitized at a scale of 1:4000 in ArcMap and this was done prior to ground truthing. A map of Temporary Occupation License (TOL) areas provided by the Lands Department was used as a reference to assist in visual image interpretation and polygons were digitized based on those as well. Ground truthing, field observation and literature review helped to confirm visual image interpretation.

4.6.2. Creating Hazard Layers

Areas below a 5 meter contour were considered low-lying thus, susceptible to flooding and inundation in this study. Informal settlements and buildings within this area were considered to be in a hazard zone. A 5 meter contour of the study area was used as a guide to digitize a low-lying area which represents a hazard layer. The 5 meter contour was overlaid onto the 2003 image before digitizing. A polygon layer representing low-lying areas was created by digitizing areas below the 5 meter contour line.

The occurrence of earthquake with a high magnitude could not be ruled out affecting the study area. Liquefaction was considered a hazard that could brought buildings, especially those with little planning, to the ground. Unconsolidated sediments were weak and easily liquefy under tremendous shaking. In this study, a geology layer of the study site was used. Recent sediments and sand were considered unconsolidated sediments in this case. Since the sediment types were already digitized into layers as polygon, the recent sediment and sand layer was isolated from the rest using a ‘select by attribute, function in ArcGIS 10. A new layer (recent sediments and sand) was created from the selected feature and exported as a new layer.

Rivers and streams were liable to flooding during extreme rainfall. Flooding was considered a hazard in the study area as it caused damage and even claimed lives in the past. A flood hazard layer was created based on the 1989 flood and landslide
mapping done on Northern Guadalcanal plain. The 1989 flood and landslide mapping was based on the cyclone Namu flooding and landslide devastating effects on the study area. The flood layer was digitized as polygons in ArcGIS 10.

All hazard layers were digitized as polygon using ArcGIS 10. Liquefaction layer was the only hazard layer that was already digitized. Another scenario was that, at certain degrees of elevation, slopes were considered not suitable for residential buildings. In this study, between 0° and 15° slopes were considered safe, 15° - 25° moderately safe, and greater than 25° were considered risky for buildings based on landslide hazard zone assessment for Castle Hill area in Queensland, Australia and North Guadalcanal in Solomon Islands (Coffey International, 2004; Trustrum et al., 1989).

A Digital Terrain Model for Guadalcanal (scale 1:50000) was used to create a slope layer with values in degrees. Since the DTM was for the entire island, the portion where the study area was located was extracted using the clipping tool in ArcGIS 10. The output of the clipping process was a 10 meter resolution DTM and this was used to create a slope layer with values in degrees. The slope tool was used to create a slope layer with values in degrees.

4.6.3. Intersecting Layers

Data analysis approach used in this section was the intersecting of features in the form of GIS layers to create new GIS layer with features or portion of features which overlapped in all intersected layers. The intersect tool in ArcGIS 10 was used for this purpose. The informal settlements and the buildings within the informal settlement layers were intersected with each hazard layer. The output layer showed informal settlement areas and the number of buildings in the informal settlements that were in the hazard area. Data for the output layer were stored in the attribute table as number.

The slope layer with values in degrees was clipped with the informal settlement layer to create a new layer consisting of features or portion of features which overlap in both layers. The new layer now consisted of both the informal settlement (polygons) and the slope values in degrees indicated by colors. Reclassify tool was used to categorize areas within the informal settlements that were considered safe (0° - 15°), moderate (15° - 25°) and high (25° - 50°) based on the Landslide assessment done for Castle Hill in Queensland, Australia and North Guadalcanal in the Solomon Islands.
The reclassify layer had 3 colors representing the 3 categories and the areas covered by those categories were recorded in the attribute table.

In the attribute table, proportion, area and hectare fields were created. Field calculator was used to calculate the values in each field. Formula for each parameter was inserted in the field calculator and the calculator calculated the values for each field automatically. The values provided useful information that was used to generate graphs. Formula inserted in the ArcGIS field calculator;

1. Proportion = \( \text{Count} \div \text{Total Count} \)

2. Area = \( 10 \times 10 \times \text{Count} \)

3. Hectare = \( 10 \times 10 \times \text{Count} \div 10000 \)
4.7. Evacuation Service area Analysis

The input GIS data used for this assessment was the Guadalcanal road layer and evacuation facilities. The road layer consisted of digitized lines representing the road network within Guadalcanal and Honiara City. Three temporary evacuation facilities were digitized as points in a GIS layer. Network analysis using GIS was used to generate and identify service areas for the evacuation facilities.

Before proceeding further into network analysis, topological errors was identified and corrected. A polygon that does not properly close, line that over extended or does not meet, and lines’ end that does not have nodes were edited as those were the sources of topological error. Spatial features such as line, polygons and points are related through connectivity, congruency, and continuity. Those were guided by certain rules that uphold the geometry of spatial features and do not allow them to change their shape (Chang, 2008).

In this assessment, the road network layer for Guadalcanal was used. Since the boundary of the study area only covers Honiara City, the same was applied to the road network layer. In this case, the roads within the study boundary were used. The clip (Analysis) tool in ArcGIS 10 was used to achieve this. The road layer being the input layer was clipped against the study boundary layer as the clipped feature. The output road layer only contain road network with the study boundary and this was used for network analysis to determine the service area. Validating the road layer using topology tool was done to ensure the layer was topologically correct.

4.7.1. Creating Network Dataset

The road network layer for Honiara City was used as a base data to generate a street layer used to perform GIS network service area analysis. Network Analysis tool in ArcGIS 10 was used to create the network dataset layer. In the Arc catalogue window, the new network data set was created. The network data set had three components; the road layer, ND junction, and ND edges.

Evacuation points were the other component of the dataset used in the analysis. There were three temporary evacuation facilities identified within Honiara City and those were usually used during disasters. Those evacuation facilities were digitized as points in a SHP file. Satellite image was used to identify and digitize the buildings.
used as temporary evacuation facilities. Those were; the Police Club at the western edge of the commercial district, Multi-purpose Hall within the commercial center, and the Solomon Islands National University (SINU) Pavilion Hall in the eastern edge of Honiara City.

### 4.7.2. Service Area Analysis

The network dataset and the evacuation facility SHP files were added onto the ArcMap interface. Study area SHP file was used as a background polygon for the analysis, was added onto the ArcMap interface. Network analysis tool was used to do the analysis for evacuation facilities service areas. A GIS network service area is a zone or region easily accessed by streets within specified time and distance. “It is an area that is closer in distance, time or cost to a particular facility than to any other facility or; the area that can be reached from the facility within a specified distance, time or cost” (Indriasari et al., 2010). In service area analysis, one of the main intentions was either to minimize cost or maximize benefits. For instance, emergency services such as fire service and ambulances considered respond time and distance travel as important in determining the effectiveness of the service. This means that, longer responses will result in more losses, indicating ineffective service. Conversely, quicker responses minimize losses and maximize benefits as it save lives and properties from losses (Indriasari et al., 2010). GIS through network analysis, allows service area to be created taking into account accessibility and the effectiveness of facilities through service area analysis.

GIS network analysis was used to create service area which can then be used to identify demographic distribution, amount of land which the service area covers and the distribution and allocation of resources within the service area. The study used GIS network analysis to visualize and measure accessibility to evacuation facilities in Honiara City. Service areas created for each facility was used to show the effectiveness of those evacuation facilities as well as, to calculate the percentage of population within the service areas consider vulnerable to natural and climate change related hazards. A detail analysis procedure can be seen in Appendix F.
4.7.3. Demography within Service Area Using Census Data

An analytical GIS model created using Model Builder was used to determine age groups and gender considered vulnerable to natural and climate change related hazards amongst the population within each evacuation facility’s service area. The census service area model consisted of ten basic processes including the output. The diagram of Figure 8 showed the general concept behind the census service area model.

**Inputs**
EAs 2009 age group
Facility service areas

**Model Processes**
Intersects inputs
Calculates proportion of intersected area
Sums population in intersected area for EA_1, EA_2, EA_3, and EA_4

**Output**
Calculated population served by Service Area.

*Figure 8: Basic concepts behind GIS census analysis including input data, analysis and output.*

The census service area model was built purposely to determine vulnerable populations (based on the census data) within each evacuation facility’s service area thus; the input data were EA census polygons of 2009 age groups and the network service areas for the evacuation facilities. The model assumed that population within the enumeration areas was evenly distributed. This means that the intersection of enumeration areas with network service areas represents certain proportion of the total population within the enumeration areas that fall within the network service area polygons.
The 2009 census data for Honiara enumerated areas was used. The census data was in the form of GIS polygons representing population within the enumeration areas. A new layer created from the 2009 census enumeration area was used as an input data for the model. The new layer consisted of age groups within the enumeration areas. The other input data for the model was the service area polygons from the evacuation facilities. The polygons were extracted from the network analysis output as separate layers. A total of three layers each were representing a 10, 20, and 30 minutes zones respectively was created and used as input data for the model. Those were the two input data for the model that was used in this study to determine age groups considered vulnerable to natural and climate change related hazards.

**4.8. Conclusion**

This chapter presents the methodological approach taken to achieve the objectives of this study. It highlights the methodological approach that was used for research design, data sources and collection. Sources of data, data collection, pre-processing, and analysis were fully explained. Approaches used to assess Informal settlement’s growth and evacuation centers are explained in detail.
Chapter 5: Results

5.1. Introduction

The results presented in this chapter, consist of informal settlement and evacuation facilities service area assessments. Results for the assessment of informal settlement growth consist of the total growth of informal settlements for 1984, 2003 and 2010. Growth of informal settlements onto hazard zones and the number of buildings being built within these zones are presented. The results for evacuation facilities assessment consist of spatial distribution of service of each facilities and the percentage of age groups and gender considered vulnerable to natural and climate change related hazards. The results of informal settlements assessment is presented followed by evacuation service area analysis.

5.2. Spatial Analysis of Informal Settlement

Visually interpreting informal settlements and buildings and digitizing them as GIS layers enable the analysis of growth onto hazardous areas. This helps to show the expansion of informal settlements into areas considered susceptible to natural and climate change related hazards. “Informal settlements are often located on land left vacant because of inherent risks, such as flood plain, steep slopes and low lying areas” (Doberstein and Stager, 2013). A report on human settlements 2011 has mention urbanization and physical exposure determines the vulnerability of a city to natural and climate change related hazard (UN-Habitat, 2011). The poor are often least able to cope and adapt with the impacts of climate change as they have few resources and tend to live in informal settlements which are usually located in the most hazardous areas in the city. Since natural and climate change related hazards are on the rise since 1950 coinciding with the rise in the world population in urban areas, hazard area analysis and risk mapping is important, especially on informal settlements (Joseph, 2013; UN-Habitat, 2011).

5.2.1. Growth of Informal Settlements

Figure 9 shows that informal settlements within Honiara have been growing over the years (1984 – 2010). Yellow polygons indicate the locations and areas taken up by informal settlements in 1984 while blue and red polygons shows the locations and areas taken up by informal settlements in 2003 and 2010 respectively. There are
existing informal settlements that continue to expand while new ones are also seen in areas previously avoided or not settled. These are the settlements that were digitized from the aerial photos from 1984, 2003, and 2010.

Figure 9: Map of the study area showing the locations of informal settlements

Figure 9 shows that the informal settlements are centered on the central and western parts of the study site in 1984. Around the year 2000, settlements were expanding in the eastern part of the study site. Apart from other new settlements, existing ones continued to expand as people turn previously unoccupied areas into settlements. The phase of informal settlement growth seen on the study site is determined by the availability of suitable areas needed for housing. Settlements tend to expand much faster into relatively flat land compared to steep terrain. Appendix G shows a larger map of Figure 9. Figure 10 shows the spatial location, growth, and the direction in which, informal settlements are expanding in West Honiara in 1984, 2003, and 2010. West Honiara includes White River, Tandai, upper and lower Tasahe, Rifle Range, Nggosi and Rove.
In the western part of the Honiara City (Figure 10), the growth of informal settlements is generally expanding inland towards steep slope areas. In addition, informal settlements are also expanding east from the existing 1984 settlements. The arrows indicate the directions of informal settlement growth. Most of the expansion seen is recent, as most of these areas only developed into settlement area around early 2000. White River is the existing informal settlement in west Honiara. Recent expansion is occurring around Wind Valley, Independence Valley and Lower Tasahe areas. Settlements in 1984 are represented by the yellow polygon. Settlements in 2003 and 2010 are represented by the blue and the red polygons respectively.

Most of the informal settlements in Honiara City are found in the central region (Figure 11). Central Honiara is made up of areas from Mbumburu in the west to Panatina Ridge in the east. The growth of informal settlements within this region is similar to that observed in west Honiara where most existing settlements are growing towards steep slope areas inland. Lord Howe settlement and Fishing Village both lies along the coast, are not expanding in areas but the number of building increases. Informal settlement areas around Kaibia, Kokomulevuha areas and Koa Hill are...
growing. There are recent settlements also establish and are growing in several areas within the central region. Other settlement areas that indicate rapid growth includes Aekafo, Cana Hill, Matariu, Ferakusia, Feralodoa, Fulisango, Green Valley, Mamulele, Kombito, Kofiloko, and areas surrounding Gilbert Camp.

![Informal settlements in central Honiara](image)

**Figure 11: The locations of informal settlements within central Honiara.**

Development of informal settlements in east Honiara occurred around 2000. Figure 12 has shown that informal settlements are also expanding in East Honiara. Apart from Lungga and Sun Valley informal settlements, most of the eastern parts of the Honiara City are recently occupied and there are settlements almost everywhere in this region. Informal settlements in East Honiara seem to be growing faster than West Honiara. In addition to existing settlements, new settlements continue to develop in other areas which give scattered-like characteristics as shown on Figure 12. A Larger part of east Honiara is the Lungga River Delta and the growth of informal settlements expands onto the flood prone plain. Most of these informal settlement areas are at risk to flooding.
Figure 12: Informal settlement growth East of Honiara City.

Figure 12 show the spatial locations and direction of growth of informal settlements. Areas surrounding Burns creek, Lungga and Henderson are some of the locations where informal settlements are growing recently. The results presented in the maps shows that informal settlements have been increasing over the years into hazards zones.

Another way of looking at informal settlements growth is to look at the area taken up by informal settlements in 1984, 2003, and 2010. For this analysis growth is determined by calculating the areas taken up by the informal settlements from 1984, 2003 and 2010. The area is presented in hectares as seen in the table (Table 1). These are later, used to show informal settlement’s growth on graphs.
Table 1: Areas taken up by informal settlements from 1984, 2003, and 2010. Areas are represented in hectare.

<table>
<thead>
<tr>
<th>District</th>
<th>Growth (Ha) 1984</th>
<th>Growth (Ha) 2003</th>
<th>Growth (Ha) 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Honiara</td>
<td>18.41</td>
<td>62.01</td>
<td>119.48</td>
</tr>
<tr>
<td>Central Honiara</td>
<td>51.76</td>
<td>232.53</td>
<td>415.09</td>
</tr>
<tr>
<td>East Honiara</td>
<td>1.47</td>
<td>38.6</td>
<td>186.81</td>
</tr>
<tr>
<td><strong>Total Area</strong></td>
<td><strong>71.64</strong></td>
<td><strong>333.14</strong></td>
<td><strong>721.38</strong></td>
</tr>
</tbody>
</table>

The table (Table 1) shows that informal settlements are growing. In 1984, a total area of 71.64 hectares is taken up by informal settlements. West and Central Honiara is where most informal settlements are found in 1984. Informal settlement however, has continued to expand taking up new areas in 2003 and 2010 with 333.14 hectares in 2003 and 721.38 hectares in 2010. Figure 13 presents these data as a graph.

Figure 13: Growth of informal settlements in 1984, 2003, and 2010.

5.2.2. Expansion of Informal Settlements into Hazards Zones

Growth of informal settlements onto areas easily affected by natural and climate change related hazards exposes the inhabitants of these settlements to risks related to these hazards. Locations that are easily affected by geophysical and hydro-
Meteorological hazards are potentially at risk to natural and climate change related hazards. Steep slopes, flood plains, low-lying areas and locations susceptible to liquefaction during earthquakes are areas easily affected by both natural and climate change related hazards. Table 2 shows informal settlement growth on low-lying areas, flood plains, and locations susceptible to liquefactions for 1984, 2003 and 2010. Informal settlement’s growths are in hectares. Figure 14 shows the graphical representation of the growth of informal settlements onto locations susceptible to natural and climate change related hazards.

Table 2: Informal settlements growth on locations easily affected by natural and climate change related hazards.

<table>
<thead>
<tr>
<th>Susceptible Locations</th>
<th>Year</th>
<th>Growth (Ha) West</th>
<th>Growth (Ha) central</th>
<th>Growth (Ha) east</th>
<th>Total Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-lying area</td>
<td>1984</td>
<td>14.49</td>
<td>10.6</td>
<td>0.74</td>
<td>25.83</td>
</tr>
<tr>
<td></td>
<td>2003</td>
<td>19.77</td>
<td>30.78</td>
<td>38.6</td>
<td>89.15</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>91.48</td>
<td>61.84</td>
<td>155.96</td>
<td>309.28</td>
</tr>
<tr>
<td>Flood Plain</td>
<td>1984</td>
<td>0</td>
<td>5.01</td>
<td>0</td>
<td>5.01</td>
</tr>
<tr>
<td></td>
<td>2003</td>
<td>0</td>
<td>10.33</td>
<td>35.92</td>
<td>46.25</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>0</td>
<td>12.92</td>
<td>118.58</td>
<td>131.5</td>
</tr>
<tr>
<td>Liquefaction</td>
<td>1984</td>
<td>18.41</td>
<td>48.73</td>
<td>0.73</td>
<td>67.87</td>
</tr>
<tr>
<td></td>
<td>2003</td>
<td>57.42</td>
<td>215.1</td>
<td>38.6</td>
<td>311.12</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>219</td>
<td>401.66</td>
<td>186</td>
<td>806.66</td>
</tr>
</tbody>
</table>

Growth of informal settlements onto low-lying areas increases from 25.83 hectares in 1984 to 309.28 hectares in 2010. More low-lying areas turned into settlements in east Honiara around 2003 and 2010. In addition, expansion of informal settlements onto flood plain has been increasing since 1984. In 1984, informal settlement area on flood plain is about 5.01 hectares compare to 46.25 and 131.5 hectares in 2003 and 2010. Table 2 shows East Honiara which is a flood plain, attracts more settlers around 2003 and 2010 as settlement development within the flood zone can only be observed in the 2003 and 2010 satellite images. Base on the soil formation data of Honiara, informal settlements’ growth onto locations susceptible to liquefactions also increased from 67.87 hectares in 1984 to 311.12 hectares in 2003 and 806.66 hectares in 2010. The graph (Figure 14) shows the growth of informal settlements onto locations susceptible to natural and climate change related hazards.
Building on steep slopes is risky as the ability of the soil to hold its particles together to support any structure built on the slope, is weaken during heavy rainfall as water that seeps through the soil disassociates the bond between soil particles. The weight of the saturated soil and structures that are built above the slope can generate landslides. Informal settlements found on steep slopes within these areas are considered to be susceptible to landslide in this study. As informal settlements expand in the central and western parts of Honiara City, buildings are built on slope areas considered susceptible to landslide during heavy rainfall. The table (Table 3) shows the areas in hectare, taken up by informal settlements which are considered risky for 1984, 2003 and 2010. The slope steepness considered susceptible to landslide ranges between 15° – 25° and 25° – 50° and 0° – 15° is considered safe in this study. Table 3 shows informal settlement growth (in hectare) onto slopes steepness considered safe, moderate, and high risk to landslide.
Table 3: Three categories of slope steepness and the areas taken up by the informal settlement for each category in 1984, 2003, and 2010.

<table>
<thead>
<tr>
<th>Steepness (Degrees)</th>
<th>Area (Ha) 1984</th>
<th>Area (Ha) 2003</th>
<th>Area (Ha) 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° – 15°</td>
<td>67.31</td>
<td>251.27</td>
<td>308.36</td>
</tr>
<tr>
<td>15° – 25°</td>
<td>5.57</td>
<td>33.66</td>
<td>41.23</td>
</tr>
<tr>
<td>25° – 50°</td>
<td>3.59</td>
<td>16.16</td>
<td>29.15</td>
</tr>
</tbody>
</table>

The level of risk is divided into three categories (Table 3). Slope steepness ranging between 0° - 15° is considered safe. It is very unlikely for landslide hazard to occur on slope where slope steepness is less than 15°. Slope steepness greater than 15° but less than 25° is considered moderate. It is considered moderate because it is unlikely for landslide hazard to occur between 15° to 25° but the possibility of it occurring is not ruled out. Slope steepness greater than 25° is considered risky as such steepness has the potential for landslide and mass movement.

Slope steepness greater than 15° are considered areas likely susceptible to landslide hazard. From the table, the moderate and risky categories are considered to be areas likely susceptible to landslide hazard. The number of hectares under moderate and risky categories is increasing during the three years. The graph (Figure 15) shows the increasing areas.

Figure 15: Informal settlement's growth onto slope steepness susceptible to landslide
5.2.3. Informal Settlement Buildings in Hazard Zones

Table 4 shows the number of buildings found within the hazard zones after intersecting building and informal settlement layers with the hazard layers. For the potential hazards being identified, there is an increase in the number of buildings in informal settlement areas built on hazard zones. The number of residential buildings visible in areas easily affected by natural and climate change related hazards is proportional to the growth of informal settlements. Growth of informal settlements into susceptible locations has been increasing as shown in table 2. The number of residential buildings being built on susceptible location has increased as shown in table 4.

Table 4: Residential buildings within the informal settlements found with the hazard areas in 1984, 2003, and 2010.

<table>
<thead>
<tr>
<th>susceptible locations</th>
<th>No. of houses in 1984</th>
<th>No. of houses in 2003</th>
<th>No. of houses in 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Lying</td>
<td>113</td>
<td>802</td>
<td>1278</td>
</tr>
<tr>
<td>Flood Plain</td>
<td>36</td>
<td>484</td>
<td>834</td>
</tr>
<tr>
<td>Liquefaction</td>
<td>427</td>
<td>2342</td>
<td>3462</td>
</tr>
</tbody>
</table>

Figure 16 indicates the trend at which buildings within the informal settlements were growing within the low lying area. Low lying areas are vulnerable from hydrological, meteorological and geological disasters. In the case of Honiara City, the growth of informal settlements has been increasingly pointed towards low-lying areas, especially in the eastern part of the study area.

Flood plain areas that have high (5% – 20 %) and very high (>20 %) annual probability of flooding are considered hazard zone. Most of the areas surrounding the Lungga River Delta have high and very high annual probabilities of flooding. Visual image interpretations confirm an increasing numbers of buildings erected within the areas considered high and very high annual flooding probabilities. The 2010 image showed a number of areas within this high and very high annual flooding probabilities being settled on. In addition, the map indicates that the Lungga River Delta was becoming a destination for settlers as other areas within the city’s boundary are already occupied. Ground truthing, visual image interpretation and GIS analysis
confirm the increasing number of residential buildings built on flood hazard zone east of Honiara City.

Recent sediments and sand are considered weak as they are usually unconsolidated thus can easily pull down structures built on it. The intersection of recent sediments and sand layer with the informal settlements and building layers showed that the number of informal settlement buildings found on recent sediments and sand layer are increasing from 1984 to 2010 (Figure 16). The largest area consisting of recent sediments and sand is the areas surrounding the Lungga River Delta in the eastern section of the study area. Visual image interpretation suggests that people started settling in these areas since the year 2000 and since then, the numbers of buildings erected are increasing. The GIS analysis confirms this as we see that there are 427 buildings within the recent sediments and sand layer in 1984 but the number has increased to 2,342 and 3,462 in 2003 and 2010 respectively.

![Graph showing the number of houses within susceptible locations (1984 – 2010)](image)

Figure 16: The number of buildings in locations easily affected by natural and climate change related hazards.
5.3. Evacuation Facility Assessment

As urban areas are increasingly vulnerable to natural and climate change related hazards such as tsunamis, earthquakes, cyclones and flooding, management strategies including plans to reduce risks are important. One of the important components of both disaster risk management and adaptation to climate change is the appropriate allocations of efforts in disaster management and risk reduction (Lavell et al., 2012). Disaster management refers to social processes and measures put in place to respond to natural and climate change related hazard events. Disaster risk reduction is instrumental in lessening the vulnerability of people, livelihoods, and assets (Lavell et al., 2012).

This section presents the results of a GIS network analysis that creates service areas for evacuation center facilities. In other words, network analysis is used to identify the area within a street network that would be served by a given evacuation facility. The street network is used because people accessing the evacuation center would get there via the streets or sidewalks. This section also presents the results of an analytical GIS model that was used to calculate the population served by each evacuation center. The network analysis was performed purposely to spatially visualize the distribution of evacuation points within the study area and to identify areas that are not within the range of each evacuation points. The analysis is done for pedestrian walking on foot towards an evacuation point during an emergency situation. Certain age groups of the population are considered vulnerable to natural and climate change related hazards, especially the younger and the older portion of the population. A model was used and the result is presented in this section.

5.3.1. Service Area Analysis

A total of 3 temporary evacuation Facilities are usually used by the National Disaster Council in Honiara City in the event of natural hazards on previous evacuation events. Two of these are sporting facilities while the third, is the Solomon Island National University hall. The two sporting facilities are the Multi-purpose sporting building which is situated at the center of Honiara City and the Police Club at the western edge of the commercial center. The SINU hall is situated at the eastern edge of Honiara City. The map (Figure 17) shows the locations of each evacuation center. On the map,
Evacuations facilities are represented by points colored pink while colored polygons represents service areas.

Service areas are represented by colored polygons spreading out from each evacuation facility. The polygons determine the time taken to walk to the evacuation points. Red, yellow and green colors represent polygons with different time taken to reach the evacuation facility at a time interval of 10 minutes. In this analysis, the maximum time taken to reach an evacuation point is 30 minutes which is represented by the green polygons and a minimum time is 10 minutes represented by the red colored polygons. The speed and distance parameters assigned to each road segments determined the time taken to reach each evacuation points. The service area analysis is for pedestrian evacuation with an average walking pace of 4 kilometer per hour. The map shows the output of the service area analysis spatially showing the locations of the evacuation points and the areas covered by each evacuation points. See appendix H for a larger map of evacuation facilities service area.

Figure 17: Service areas of existing evacuation facilities in Honiara City.

Figure 17 shows the location and spatial distribution of the temporary evacuation facilities within Honiara City. Facility 1 (Multi-purpose sporting complex) is about 281 meters from the exposed coastline while Facility 2 (Police Club) and Facility 3
Facility 2 is somewhat situated very close to the coast. The location of Facility 1 and 3 are suitable as they’re in a much safer place compared to Facility 2 in terms of distance from the coast. However, Facility 1 and 2 are less than 10 meters above sea level. There are ‘under-served’ areas indicating that the current distribution of the existing evacuation facilities is not sufficient to meet the needs of urban population.

Areas not covered by the network service area polygons are considered “under-served” areas. Informal settlements within these areas are more than a 30 minute walk to any evacuation point. GIS network service area analysis has helped identifies the under-served areas. Areas considered more vulnerable to natural and climate change related hazards are identified on the map (Figure 18) in the form of rectangles. In the western edge of Honiara City (Figure 18), most of the White River settlements are under-served. The low lying nature of the area, its closeness to the coastline and inaccessibility to evacuation facilities makes it more vulnerable to natural and climate change related hazards.

Fishing village is another informal settlement area that is identified on the map (Figure 18) as under-served. The settlement is situated right along the coastline and is more than 30 minute walk to Facility 1 and Facility 3 thus, it also exposed to natural and climate change related hazards. As similar to White River informal settlements, Fishing Village settlement is low lying, situated right on the coastline, and inaccessible to evacuation facilities thus making it more vulnerable to natural and climate related hazards. With little space for expansion, buildings are concentrated within the available area making it overcrowded.

Burns creek and Lungga which are located within the low-lying flood plain in the eastern part of Honiara City is the third informal settlement area that is under-served as seen on the map (Figure 18). The area which has an annual flooding probability of more than 20 percent is considered vulnerable. New informal settlements continued to be built onto the flood plain as demand for residential land increases. The closest evacuation facility for Burns Creek and Lungga/Henderson areas which is the SINU hall is quite far making accessibility difficult during evacuation. The flood plain area is completely out of reach of evacuation facilities and informal settlements are scattered onto the flood plain making them more vulnerable to natural and climate
change related hazards. The sporadic nature of the informal settlements onto the flood plain increases the vulnerability of its residents to natural and climate change related hazards.

Figure 18: Under-served informal settlement areas.

Blow up areas on the map (Figure 18) indicate informal settlements that are not covered (under-serve) by the existing evacuation facilities. Most of these informal settlements are situated on low-lying areas, quite close to the coastline and rivers. These informal settlement areas (White River, Fishing Village and Burns Creek, Lungga/Henderson) are considered vulnerable due to their location and their exposure to hazards such as storm surge, tsunamis and flooding. Other under-served informal settlement areas are those within the central part of Honiara City. Additional evacuation facility is needed to accommodate people living in areas not serve by the existing evacuation facilities.
5.3.2. Population Analysis

Using population data from the Solomon Islands 2009 census, it is possible to determine the composition of population within each facility’s service area. Age and gender are the demographics of the Solomon Islands 2009 census data used to assess proportion of urban population vulnerable to natural and climate change related hazards. Knowing the distribution and composition of age groups and gender considered vulnerable to natural and climate change related hazards is important in evacuation planning.

Age groups considered more vulnerable to natural and climate change related hazards are 0 – 14 and those above 60 years of age. The number of people within these age groups is determine from each of the three zone or service area polygon from each temporary evacuation facility. The service areas are categorized into 3 zones each representing a time interval of 10 minutes at pedestrian walking pace (4 km per hour). The 3 facilities in this section, refers to the 3 temporary evacuation facilities. Facility 1 is situated at the center of the study area while Facility 2 and Facility 3 are located west and east of Facility 1 respectively. Table 5 show the number of people from the vulnerable age groups within each zone of the 3 temporary evacuation centers.

Apart from vulnerable age group, male and female are also vulnerable to natural and climate change related hazards. Women and girls are often at greater risk of dying in a natural and climate change related hazards (Sultana, 2010; Cardona et al., 2012). Social norms and the responsibility play by male and female in the society determine their susceptibility and vulnerability to natural and climate change related hazards. The total number of male and female within the service areas of each evacuation facility is presented in a tabulated form. The representation or composition of male and female in each evacuation facility service area is in percentage presented by pie charts.

Table 5 shows the number of people age 0 – 14 and above 60 within the 3 temporary evacuation points. Each temporary evacuation point has 3 zones and the number of people is determined for each one using the output data of the census analysis model. The figures within the facilities’ column are taken from the attribute tables after the census model analysis for each zone is done. The total number of people is
determined for each facility after adding up the number of people in each zone for the 3 facilities respectively.

Table 5: Number of people aged 0 - 14 and above 60 for each zone of the evacuation facilities.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Zones</th>
<th>Facility_1</th>
<th>Facility_2</th>
<th>Facility_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 14</td>
<td>0 - 10 minutes</td>
<td>1283</td>
<td>956</td>
<td>677</td>
</tr>
<tr>
<td></td>
<td>10 - 20 minutes</td>
<td>3719</td>
<td>1799</td>
<td>1404</td>
</tr>
<tr>
<td></td>
<td>20 - 30 minutes</td>
<td>6003</td>
<td>3480</td>
<td>2640</td>
</tr>
<tr>
<td>Total (1 – 14)</td>
<td></td>
<td>11005</td>
<td>6235</td>
<td>4721</td>
</tr>
<tr>
<td>Above 60</td>
<td>0 – 10 minutes</td>
<td>167</td>
<td>85</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>10 – 20 minutes</td>
<td>439</td>
<td>178</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>20 – 30 minutes</td>
<td>613</td>
<td>319</td>
<td>212</td>
</tr>
<tr>
<td>Total ( &gt; 60)</td>
<td></td>
<td>1219</td>
<td>582</td>
<td>398</td>
</tr>
<tr>
<td>Total Pop.</td>
<td></td>
<td>35752</td>
<td>21157</td>
<td>15417</td>
</tr>
</tbody>
</table>

Table 5 shows the total age groups considered vulnerable to natural and climate change related hazards within the service area of each evacuation facilities. For age group 0 - 14, Facility 1 has 11005 children while Facility 2 and Facility 3 have 6,235 and 4,721 children respectively. Facility 1 has the highest number of young population followed by Facility 2 and Facility 3. For age group above 60 years, Facility 1 has the highest with 1219 older people then Facility 2 and Facility 3 with 582 and 398 older people respectively. The overall result shows that Facility 1 has more people for both age groups followed by Facility 2 and Facility 3. Representation of age groups within each facility is presented as the percentage of each age group to the total population within the service area of each evacuation facility. The chart (Figure 19) shows the representation of each age group.
Figure 19: Composition of age group vulnerable to natural and climate related hazards

Representations of age groups 0 – 14 and above 60 years are in percentage as shown. Facility 1 and Facility 3 have 31 percentage of their populations making up the 0 – 14 age group consider vulnerable. Facility 2 has 29 percent of its population making up the 0 - 14 age group. For above 60 age group, Facility 1 and Facility 2 have 3 percent of their population making up this group while Facility 3 has 2 percent of its population making up the above 60 age group. The result indicates that more than 30 percent of the population (0 – 14 and above 60 years) within the service area of each evacuation facility.

Gender representation in each evacuation facility’s service areas are presented in Table 6. Facility 1 has 16723 female and 19029 male. Facility 2 has 9604 female and 11553 male while Facility 3 has 7188 female and 8229 male. The results indicate that there are more people within Facility 1 service area which is followed by Facility 2 and Facility 3 service areas. The proportion of male and female within each evacuation facility service area is presented in percent and display by the pie chart (Figure 20). Table 6 shows the proportion of male and female within each evacuation facility service area.
Table 6: Gender representations in each evacuation facility service area.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Service Area</th>
<th>Facility_1</th>
<th>Facility_2</th>
<th>Facility_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>0 - 10 minutes</td>
<td>1979</td>
<td>1446</td>
<td>1101</td>
</tr>
<tr>
<td></td>
<td>10 - 20 minutes</td>
<td>5731</td>
<td>2836</td>
<td>2213</td>
</tr>
<tr>
<td></td>
<td>20 - 30 minutes</td>
<td>9013</td>
<td>5322</td>
<td>3874</td>
</tr>
<tr>
<td>Total Female</td>
<td></td>
<td>16723</td>
<td>9604</td>
<td>7188</td>
</tr>
<tr>
<td>Male</td>
<td>0 - 10 minutes</td>
<td>2165</td>
<td>1805</td>
<td>1266</td>
</tr>
<tr>
<td></td>
<td>10 - 20 minutes</td>
<td>6436</td>
<td>3343</td>
<td>2503</td>
</tr>
<tr>
<td></td>
<td>20 - 30 minutes</td>
<td>10428</td>
<td>6405</td>
<td>4460</td>
</tr>
<tr>
<td>Total Male</td>
<td></td>
<td>19029</td>
<td>11553</td>
<td>8229</td>
</tr>
<tr>
<td>Total Pop.</td>
<td></td>
<td>35752</td>
<td>21157</td>
<td>15417</td>
</tr>
</tbody>
</table>

The distribution of population concentrated more in the central part of Honiara City. Table 6 shows that Facility 1 which is in Central Honiara has the highest number of people within its service area. Facility 1 service area has a total population of 35,752 people. Facility 2 and Facility 3 services areas has a total population of 21,157 and 15,417 people respectively. For all evacuation facilities, there is more male compared to female.

Figure 20 presents the percentage of male and female. Female may be considered more vulnerable than males and knowing their composition within each evacuation service area is important in evacuation planning and disaster management before, during and after the occurrence of a natural or climate change related hazard. For the 3 evacuation facilities, female makes up 45 and 47 percent of the total population within each evacuation facility service area while male makes up 53 and 55 percent. The result indicates higher number of male than female in each evacuation facility service area.
Figure 20: The chart indicates the composition of male and female within each evacuation facility service area

5.4. Conclusion

This chapter presents the analysis of informal settlement growth and evacuation facility assessment in Honiara City and provides explanation to the output data. Data output are presented in the form of maps, tables, graphs and charts. Informal settlement analysis is made up of informal settlement growth and an assessment of expansion of settlements onto hazard areas for 1984, 2003, and 2010. Evacuation assessment analyzed the effectiveness of the existing evacuation facilities using service areas generated using GIS network analysis.

Visual interpretation of informal settlement’s growth in Honiara City using aerial imageries is important when given the quantity and quality of the available data. The analysis using GIS shows the spatial location of growth and the directions towards which, the informal settlements are growing. In addition, it also shows growth of informal settlements and the number of buildings being built onto areas identified as vulnerable to natural and climate change related hazards. Maps used in this section helps visualize the expansion of informal settlements while tabulated data provides
quantitative information. A bar graph used in this chapter presents tabulated data for slope analysis result in a form that it can be visualized.

A thorough strategic evacuation planning reduces the risk of a disaster from natural and climate change related hazards. This chapter analyzes and discusses accessibility to existing evacuating facilities and determines the vulnerable urban population served by the facilities. GIS Network Analysis generate network service areas indicating the accessibility to the evacuation facilities measured in minutes (time) or time taken to walk to the facilities. The network service area helps identify expose informal settlement areas as well as the number of people within the range of the facilities’ service areas. The facilities’ service areas and the population census data become the input of the census analysis model used to determine the vulnerable age groups of the population within each facilities’ service area. This shows that the use of GIS Network Analysis proves exceptionally useful in strategic evacuation planning.
Chapter 6: Discussion

6.1. Introduction

This chapter presents an interpretation and discussion of the results presented in chapter five. The discussion is divided into two parts. First, an interpretation of the informal settlement growth assessment as it relates to natural and climate change related hazards is presented and discussed. This is followed by a discussion of the analysis and assessment of effectiveness of evacuation facilities in Honiara City.

6.2. Discussion on Informal Settlement in Honiara City

The growth of informal settlements in Honiara can be traced back to the 1970s, when despite a system implemented by the government to control the growth of informal settlements, they began growing anyway (Pende, 2009). Growth, started in the 1970s, has continued through the 1980s and into the present. Rural-to-urban migration is one of the major factors that contributes to informal settlement growth within Honiara City (Maebuta and Maebuta, 2009). This is because social and economic amenities are not evenly spread throughout the country leading to rural population moving toward locations with these amenities.

6.2.1. Growth of Informal Settlements

Urban growth and informal settlements are socioeconomic phenomena that induce a general transformation of land-use at local level (Weber and Puissant, 2003; Ramachandra et al., 2012). Urban growth can be defined as the spread of new developments from an urban area onto surrounding lands (Dadhich and Hanaoka, 2011). Urban areas are growing over time as population and socioeconomic activities are becoming more concentrated within these areas. Urban growth shows a general switch from spread out structure of human settlements into a compact growth at a specific location (Ramachandra et al., 2012). Informal settlements are considered part of urban growth in developing countries like the Solomon Islands, however, it is unplanned and in most cases, basic urban services and infrastructures are not provided to the inhabitants. Lack of physical land-use planning capacity by the Lands Department has encouraged the growth and expansion of both the existing and the recently established informal settlements.
The spatial analysis on informal settlement’s growth in Honiara City shows that these settlements are growing over the years within the study area. A distinctive aspect of urban growth in Honiara City is the unplanned expansion of these settlements onto public and customary lands ignoring the suitability of these lands for residential purposes. A survey in 2006 showed that informal settlements were growing at 26 percent per year on public land (Maebuta and Maebuta, 2009; Solomon Islands Government, 2006). A major contribution of the study presented in this thesis is its investigation of informal settlements from a spatial perspective. Spatial analysis using Geographic Information System assessed informal settlements by their physical attributes (topology, geometry and geographical properties). Spatial analysis of informal settlement’s growth indicates three important things; it shows the actual location of informal settlements, the directions where these settlements are expanding and the areas being taken up by these settlements.

Spatial analysis of informal settlement’s growth using GIS has helped to locate the spatial locations and distribution of informal settlements, indicate the direction of growth and shows the areas taken up by informal settlements for the years assessed. Intersecting informal settlement and hazard layers helps to determine the growth and locations of informal settlements areas onto zones easily affected by flooding and inundation, landslide, and earthquake. The study has shown informal settlements expanding onto areas easily affected by natural and climate change related hazards. Most of these informal settlements are located on areas where the city’s boundary and customary land converges. A number of these informal settlements are expanding onto customary lands. In west and central Honiara, informal settlements are located behind formal residential areas between valleys, deep ravines and onto slopes. In east Honiara, informal settlements are located on low-lying areas and flood plain.

A physical factor that might also be influencing informal settlement growth is space availability and topography. Settlements tend to sprawl rapidly towards areas that are still spacious and into areas that are relatively flat. The maps in chapter 5 (Figure 9 – Figure 12) clearly showed that expansion occurs in spacious and relatively flat areas. In Honiara City, such areas are found in the eastern edge of the city in the flood plain of the Lungga River Delta. The satellite images for 2003 and 2010 showed that more and more settlements are popping up in this area. As urban centers grow, informal settlements also expand. In most cases, this expansion tends to occur on marginal land
or on areas that are prone to natural and climate change related hazards. As urban areas continue to expand, areas that are previously avoided due to their susceptibility to natural and climate change related hazards are now becoming settlement areas (van Westen, 2002).

The growth of urban areas and informal settlements becomes a major challenge to government, city councils and civic authorities and this will be exacerbated by the impacts of natural and climate change related hazards (UN-Habitat, 2011). In Honiara City, the provision of basic urban services such as water and sanitation, are one of the issues facing the government and the city council as accessibility to these areas is not possible. In most developing countries like the Solomon Islands, rapid urban growth is becoming more evident as the result of rapid population growth and socioeconomic development, and most of these are happening in informal settlement areas (UN-Habitat, 2011). “People arriving in already overstressed urban centers are forced to live in dangerous areas that are unsuitable for residential or industrial development; many have constructed their own houses on flood plains, in swamp areas, and on unstable hillsides, often with inadequate or completely limited infrastructures and basic services to support human life, safety and developments” (UN-Habitat, 2011).

The case study of Honiara City provides enough knowledge to understand the characteristics of urban growth and informal settlements in the context of developing countries like those in the South Pacific.

Assessment such as image analysis and interpretation made on historical and recent remotely sensed data taken from different years, provide information on the spatial characteristics of informal settlement growth in urban areas. The spatial nature and directions of informal settlement growth is visible when combining digitize informal settlements layers representing the years assessed, in a GIS environment where color coding is used to indicate the growth for each year. This has enabled the interpretations of informal settlement growth within Honiara City. Visually interpreting satellite images and aerial photo is a preferred approach of generating information in a developing country where GIS and Remote Sensing data are limited. Visual image interpretation has some advantages over automated image analysis in this study. The availability of remotely sensed data as well as the spatial nature of informal settlement growth in Honiara City, favors visual image interpretation than image classification analysis.
The applications of GIS and Remote Sensing in urban growth mapping provide needed information that supports decisions to enhance a sustainable urban growth. Remote Sensing data provide spatial information in the form of satellite images and aerial photographs while GIS provides the environment where these data can be analyzed generating meaningful information. These output information which are presented in the form of maps and tables, are useful in urban growth studies. Mapping informal settlement growth in Honiara City using GIS and Remote Sensing provides information in the form of maps which can be visualized showing the locations and directions of growth. The attribute table that associates with the map shows the quantitative information that also determines the growth of informal settlements. The applications of GIS and Remote Sensing in assessing informal settlement growth in Honiara City proved to be useful in this study.

6.2.2. Locations of Informal Settlements

The locations of informal settlements in relation to natural and climate change related hazard areas is important from a planning and disaster management preparedness perspective. Informal settlement areas considered likely to be impacted the most by natural and climate change related hazards when they are in low-lying areas, areas close to the coastline, in floodplains, in areas on weak sediments, and where slope steepness is greater than 15°. The study shows that as Honiara City continues to expand, informal settlements expand both horizontally and vertically. Vertical expansion is evident within the central and western parts of Honiara City where informal settlements are growing onto slopes susceptible to landslide. Expansions into relatively flat areas are evident in most informal settlements within Honiara City. A current horizontal expansion is more evident in the eastern part of the city as the presence of foothills and ridges within the central and western part of Honiara City limits such expansion (Pende, 2009). Regardless of the topography seen in west and central Honiara, existing informal settlements are expanding onto slope steepness susceptible to landslide. Recent informal settlements are growing into the low-lying areas as new settlements continue to appear on the floodplain in the eastern part of the City.

The eastern part of Honiara City is a low elevated area that is susceptible to flooding during cyclones and heavy precipitations. The entire area is a floodplain of the
Lungga River Delta and is about 2 – 3 meters above sea level. Impeded drainage and the flatness of this area does not encourage the flow of surface water as seen during cyclone Namu leading to flash flooding (Trustrum et al., 1989). The haphazard nature of the development of informal settlements seen within this area confirms that these settlements are expanding into areas previously avoided due to their susceptibility to natural and climate change related hazards. In central Honiara, the number of houses found within the low-lying Koa Hill area is increasingly spreading onto the Mataniko River flood plain as seen in the 2010 imagery. This trend suggests that as the urban center continues to grow, informal settlements also spread onto areas previously avoided due to their vulnerability to natural and climate change related hazards.

The other concern about low-lying areas is that the sediments are weak (mostly sand) if they are recently deposited. The recently deposited alluvial soil, mostly sand along the Lungga River Delta east of Honiara is several meters thick. “Since the mid-Holocene, the river has built a sediments pile 290 km² in area and up to 50 meters thick on a slowly subsiding shelf platform” (Gillie, 1992). Recently deposited sediments are poorly consolidated meaning that structures that are built on the sediments are easy to pull down during vigorous seismic activity. The GIS analysis in this study also shows an increasing informal settlement growth and buildings being built on weak sediments. It shows that as Honiara City continues to expand, informal settlements are also expanding onto areas likely to be impacted the most by natural and climate change related hazards.

The western and central portion of Honiara City is mostly made up of ridges and foothills. This study shows that most of the relatively flat areas below the foothills are already occupied leaving only the sloped areas for further expansion. The steepest elevated areas occupied by informal settlements within Honiara City are 47°. There is an increasing trend in areas taken up by informal settlements from 1984, 2003 and 2010 onto slope steepness considered susceptible to landslide. There is a possibility for landslide to occur with slope steepness greater than 15°. Relief and rainfall also play an important role in the occurrence of landslide. For Honiara City, there is a high possibility for landslides to occur during heavy rainfall. This has happened when cyclone Sandra, associated with heavy rainfall, triggered a landslide in the Koa Hill informal settlement area in central Honiara (Solomon Star, 2013). A partially built building was pulled to the ground as a result.
Hydro-meteorological hazards will be the most likely hazards to affect informal settlements in Honiara City. This study indicates that informal settlements are growing towards locations that are easily affected by hydro-meteorological hazards. Hydro-meteorological hazards, exacerbated by climate change, will likely increase their frequency and intensity. Heavy precipitation usually associated with tropical cyclones is likely to result in flash flooding as well as mass movement. Low-lying areas, flood plains and steep slopes are locations susceptible and the expansion of informal settlements onto these areas exposes the inhabitants and their sources of livelihood to the impacts of natural and climate change related hazards thus, increasing their vulnerability to natural hazards.

Informal settlements located between valleys and deep ravines as seen in the western and central regions of Honiara are at risk to flash flooding. Intense precipitation that usually coincide with wet season around December to March, will likely affect these informal settlement areas in the future. In addition to their susceptibility due to their locations, building materials used and the construction of houses seen within these areas might not able to withstand natural and climate change related hazards. The susceptibility of locations and poor quality of building structures will further increases the vulnerability of people living within these informal settlements. This means that in urban areas, people living in informal settlement areas are most vulnerable and are at risk to the impacts of natural and climate change related hazards especially settlements on locations easily affected by natural and climate change related hazards.

The socioeconomic status of informal settlement’s population determines their vulnerability to natural and climate change related hazards. Increasing the capacity of their socioeconomic status is essential in disaster management preparedness as this will reduce their vulnerability.
6.3. Discussion on Evacuation Facility Effectiveness

Reducing the impacts of natural and climate change related hazards on people’s lives involves the establishment of evacuation facilities with thorough evacuation strategic planning. The establishment of evacuation facilities, whether temporary or permanent, should consider site accessibility as well as suitability in terms of location and the area served by the facilities. The National Disaster Council in Honiara uses three temporary facilities to shelter people in the event of an emergency such as a tsunami, tropical cyclone, flooding or other natural disaster. This study examined the areas served by evacuation facilities using GIS service area analysis.

6.3.1. Evacuation Facility’s Effectiveness

An important consideration in the effectiveness of evacuation facilities is whether they are in the best location relative to natural hazards. An evacuation center is not effective if it is in a hazardous location. Figure 17 and Figure 18 show the location of each temporary evacuation center and the service area each one covers. The nature of Honiara’s coastline and exposure to the ocean is considered important when determining the site suitability during emergency evacuation. In addition, their location above sea level is considered important when determining suitable sites in the case of tsunamis. The spatial distribution of the service areas covered by each evacuation facility is also important when considering evacuation site suitability as it determines accessibility to the facilities.

Distance from the coast and elevation above sea level indicate that the location of Facility 1 (Multi-purpose Hall) and Facility 2 (west Honiara) cannot be accessed for certain natural and climate change related hazards such as storm surge and tsunamis. Both facilities are located within 10 meters above the mean sea level but are different in terms of distances from the coastline. Facility 2 which is 113 meters from the coastline should be considered unsuitable in the event of a storm surge and tsunamis. Facility 1 is within 10 meters above sea level but 280 meters from the expose coastline is considered safe as it is further away inland compare to facility two depending on the size and magnitude of the hazard. Facility 3 is suitable for all hazards and is considered safe as it is above 10 meters from the sea level and is located 850 meters away from the coastline.
Accessibility to these facilities in the event of a natural and climate change related hazard is important during an emergency evacuation (Indriasari et al., 2010). Accessibility to the evacuation facilities is determined by the time (minutes) it takes the residents to walk to the facilities. A maximum time of 30 minutes is used to determine the effectiveness of each facility during an emergency evacuation in terms of their accessibility. For this reason it is important to evaluate whether the service areas of the evacuation centers cover the most vulnerable populations—the informal settlements.

The distribution of the facilities and the service areas covered by each one shows that there are under-served areas on locations considered to be highly vulnerable to natural and climate change related hazards in this study. These areas are particularly vulnerable as they are exposed to hazards yet some are not within 30 minutes walking distance to an evacuation center. Figure 18 indicates some of these areas. Most of these areas are located on low-lying areas and within a major flood plain at the eastern edge of Honiara City where the current evacuation facilities’ service area does not cover. Additional temporary evacuation facility should be established to cover these under-served areas. This is important especially in the eastern part of Honiara City where the current expansion of informal settlements is occurring. The area is prone to annual flooding already claiming the lives of two children a few years ago as their parents tried to evacuate from the oncoming surges of flood water during the night (National Disaster Council, 2010). GIS can help to identify facilities and assess locations that are suitable for evacuation facility.

The evacuation facilities’ capability to accommodate the evacuees during an evacuation event also contributes to the facility’s effectiveness. The facilities’ capability to meet the needs of people being evacuated has not assessed in this study and it is important that each evacuation facilities have the capability to accommodate urban population. Not only to meet the needs of people being evacuated but also meet the special needs of most vulnerable people such as vulnerable age groups (children and older people) and mothers during and after the natural and change related hazards. Strategic evacuation planning if setup for Honiara City, should consider the capacity of each existing evacuation facility to accommodate urban population as well as to meet the special needs of most vulnerable proportions of urban population.
Evacuation planning should also consider ways in which the chances of a natural hazard turning into a disaster are minimized. The effectiveness of evacuation facilities is also determined by the quick responses from the urban population when evacuation instructions are sent. This can be achieved once each evacuation facility in Honiara City has an organize plan of coordinating the movement of urban population towards the evacuation facilities during an emergency or in the event of a natural hazard.

Sending out evacuation instructions to areas likely to be affected by an oncoming hazard, alert people within these areas to take extra measures or even vacated their settlements to minimize losses. Information such as where to go, which route to take and how to effectively communicate this information to those who will be affected, is yet to be addressed for evacuation facilities within Honiara City. In addition, assessing how well the urban population will respond to early warning systems is yet another component of monitoring the effectiveness of the evacuation plan for Honiara City. So far, Honiara City does not have either an evacuation plan or an early warning system in place and if it needs to have one, some of the things mentioned should be taken into consideration when setting up evacuation plan.

The application of GIS service area analysis helps to indicate two important things in this study; the spatial distribution of evacuation facilities with areas served and the locations of areas under-served. Served and under-served areas are important indicators of evacuation facility’s accessibility. It takes a lot of time and efforts for people living within under-served areas to walk to a nearby evacuation facility during an event of emergency than those living in areas that are served. The time the evacuees take to reach a nearby evacuation facility is essential when assessing the effectiveness of evacuation facilities and the areas served. Time is also important in disaster risk management as less time taken by evacuees to reach an evacuation facility minimizes losses to people’s lives in areas easily affected by natural and climate change related hazards. GIS application has enabled such assessment as well as, providing information on which routes to take, to minimize time thus, minimizing losses if service area and shortest route analysis are performed. This shows how useful GIS applications are in evacuation planning and disaster risk management for Honiara City.
6.3.2. Vulnerable Urban Population

Population vulnerability is defined as the characteristics of a person or group of people and their situation that influences their capacity to cope with, resist, and recover from the impact of a natural or climate change related hazard (Gero et al., 2010; Wisner et al., 2004). Urban population is at risk to natural and climate change related hazards as a result of increasing vulnerability of many urban areas in developing countries (van Westen et al., 2002; Feiden, 2011). In Honiara City, urban population is increasing annually as rural populations are attracted to social services, economic activities and environmental transformation happening in Honiara City (Pende, 2009; Maebuta and Maebuta, 2009). This case study assessed vulnerable population age groups and gender using 2009 census data. Vulnerable age groups are those from 0 – 14 years of age and those above 60 years. Female are considered more vulnerable than male in terms of gender.

This study examined vulnerable population groups that are served by the service areas of the evacuation facilities, and by default, reveals information about vulnerable populations not served by the facilities. First, the served vulnerable populations are discussed, followed by a discussion of vulnerable populations not served, or under-served by the three established evacuation facilities.

Urban populations whether served or under-served, depend on the distribution of evacuation facilities within Honiara City. GIS service area analysis indicates that the three existing evacuation facilities in Honiara City are aligned near the coastline and are adequately served the central parts of the City. However, there are settlements such as Fishing Village, White River, and the entire Burnscreek, Lungga and Henderson areas that are located in areas easily affected by natural and climate change related hazards are under-served. Prioritizing areas highly susceptible to natural and climate change related hazards is important in evacuation strategic planning for Honiara City. The evacuation facilities in Honiara City should serve urban populations living on locations easily affected by natural and climate change related hazards such as low lying coast areas and flood plains. People living on the Lungga Delta flood plains, Fishing Village and White River areas which are quite close to the sea and on flood plain, are to be prioritized as these locations are easily
affect by hazards. These are some of the most vulnerable part of urban population which is under-served in Honiara City.

The current evacuation facilities identified in this study, served the urban populations on low-lying areas in west and central Honiara which are considered vulnerable due to the susceptibility of their locations to natural hazards and climate change related hazards. People living in these areas are at risk to natural hazards such as tsunamis and storm surges and they need to be served by the evacuation facilities during and after a natural hazards event. Other areas located further inland in west and central Honiara districts are not served by the three facilities as they are further inland and away from the existing facilities which are also located near the coast. Portion of urban population living on low-lying areas along the coastline are the ones who will need evacuation facilities the most in Honiara. They are the vulnerable urban population which the existing evacuation facilities should serve.

Urban population east of Honiara City is under-served by the existing evacuation facilities and these are some of the most vulnerable people within the study area. The growth of Honiara City is moving into east Honiara where most of the areas are low-lying or less than 5 meters above the mean sea level. This area is annually hit by floods prompting massive evacuation in previous years. The biggest flooding to occur in this area occurs during cyclone Namu in 1986 where most of the areas on the flood plain under water (Trustrum et al., 1989). The current expansion of informal settlements onto this flood plain exposes people as well as their properties to flooding. Minimizing loss to people’s lives in east Honiara during wet seasons requires an evacuation facility that can serve people living within the flood plain of the Lungga River Delta. The study shows that population east of Honiara is under-served by the existing evacuation facilities and these are some of the most vulnerable people need to be served due to the susceptibility of that location to flooding.

In western and central Honiara, the evacuation facilities’ service area only served areas surrounding the facilities whereas, areas outside of the facilities’ service areas are not served. This means that not all the populations within the study area are served. The population analysis shows that 9 percent of the total populations in the study area are not served. The percentage of age groups and female considered vulnerable population not served by the evacuation facilities are unknown for this
reason. In addition, in some areas whether served or under-served, the urban populations may not necessarily need to be evacuated at all. Evacuation is not a major issue to people living in areas not easily affected by natural and climate change related hazards. In addition, people who live in durable housing and away from hazard’s path might not see evacuation as an issue. For urban population living along the coast, low-lying areas and on flood plains, evacuation facility is important to them than to others who do not live on locations or areas easily affected by hazards. In this case, the exact number of urban populations that need and those that do not need an evacuation facility is unknown or not fully accounted.

The GIS census analysis shows that population considered vulnerable; those below 14 years of age make up more than 30 per cent and those above 60 years of age is around 3 per cent of the population in areas served by the evacuation facilities. In addition, female make up of approximately 46 percent of urban population in areas served by the evacuation facilities. The general representation of vulnerable urban populations served by the evacuation facilities shows more people under the age of 14 years than those above 60 years of age. People under the age of 14 are also an important part of population in Honiara City as they need supervision when they are not at home or with their parents. The only part of the day where this age group is not at home or with their parent, is when they are in schools. Whether or not, the schools within Honiara City have their evacuation plan in place to evacuate their students during emergency events is not known.

The most vulnerable urban populations in Honiara City are those who reside on areas easily affected by natural and climate change related hazards as well as those who require special attention or supervision before, during and after a hazard event. The applications of GIS in service area and population census assessments give much of the needed information for disaster preparedness in Honiara City. The GIS service area analysis using street network dataset and evacuation facilities shows the spatial distribution of facilities’ service areas indicating areas under-served. GIS population analysis using census data has enabled to show the demographic characteristics and the distribution of urban population served by the existing evacuation facilities. The GIS application used in both assessments helped to indicate what these evacuation facilities will be expecting during an event of emergency evacuation. This is
important in terms of disaster risk management and preparedness in Honiara City when such information is integrated into strategic evacuation planning.

6.4. General Discussion

Heavily populated urban areas that are flagged by inadequate housing, poor living conditions, and insecure land tenure are known as informal settlements (UN-Habitat, 2003). The term ‘informal settlement’ has been used interchangeably in many reports however, the meaning remains the same. For instance, a 2003 UN-Habitat report used the term ‘slum’ to describe heavily populated urban areas with a wide range of low income settlement, inadequate housing and poor living conditions (UN-Habitat, 2003). Informal settlements are defined and delineated based on the typical characteristics of these settlements’ area. In most cases, the definition is based on physical, spatial and social attributes typical to informal settlements. Despite these attributes, informal settlements can also be defined based on local cultures and conditions, history or politics and the topography of a particular area (UN-Habitat, 2003).

The analysis of informal settlement growth in Honiara City indicates the spatial nature of growth and directions of expansion of informal settlements. Honiara City which is the largest urban areas in the Solomon Islands, shows that the informal settlement are growing rapidly moving onto areas easily affected by natural and climate change related hazards. In the developing countries such as those in the Pacific, people are attracted to urban areas seeking socioeconomic opportunities and benefits. Countries such as the Solomon Islands and Vanuatu where urban centers are located only on the main islands encourage people from the surrounding islands to converge to these urban centers contributing to the growth of informal settlements (Maebuta and Maebuta, 2009; Chung and Hill, 2002). In the case of Solomon Islands, Honiara City hosts most of the socioeconomic activities attracting rural populations to settle around Honiara City. Most of the recent expansions of informal settlements observed in Honiara City are rural population moving and settling around Honiara.

Urban growth and informal settlements are socioeconomic phenomena that induce a general transformation of land-use at local level (Weber and Puissant, 2003; Ramachandra et al., 2012). Urban growth can be defined as the spread of new developments from an urban area onto surrounding lands (Dadhich and Hanaoka,
Urban areas are growing over time as population and socioeconomic activities are becoming more concentrated within these areas. Urban growth shows a general switch from spread out structure of human settlements into a compact growth at a specific location (Ramachandra et al., 2012). Informal settlements are considered part of urban growth, however, it is unplanned and in most cases, basic urban services and infrastructures are not provided to the inhabitants.

Some of the factors that contribute to urban and informal settlement growth in developing countries as seen in the case of Honiara City, are natural increase in urban population, rural-to-urban migration, economic growth, and political patronage (UN-Habitat and ESCAP, 2010; Chand and Yala, 2008). Natural increase in urban population coupled with rural-to-urban migration has resulted in the spread of urban areas onto surrounding lands. Growth of socioeconomic activities and the provision of urban services in urban areas acted as bait to lure rural population to urban areas as the communities are becoming monetized. When a large portion of urban expansion occurring on state or Government owned land, maintaining a strong political support to politician becomes a form of land tenure security to people living in informal settlements (Chand and Yala, 2008). Even though political patronage has been offered to people living in informal settlement, provision of basic urban infrastructures and services are limited as these areas are unplanned thus, often neglected by civic authorities. Informal settlements are part of urban growth in most cities due to these factors.

In most developing countries, the growth of urban areas and informal settlements become a major challenge to government, city councils and civic authorities and this will be exacerbate by the negative impacts of natural and climate change related hazards (UN-Habitat, 2011). In most developing countries, rapid urban growths are becoming more evident as the result of rapid population growth and socioeconomic development and most of these are happening in informal settlement areas (UN-Habitat, 2011). “People arriving in already overstressed urban centers are forced to live in dangerous areas that are unsuitable for residential or industrial development; many have constructed their own houses on flood plains, in swamp areas, and on unstable hillsides, often with inadequate or completely limited infrastructures and basic services to support human life, safety and developments” (UN-Habitat, 2011).
The impacts of natural and climate change related hazards will exacerbate the vulnerability of human life, safety and development in the future.

Reducing the chances of natural and climate change related hazards turning into a disaster involve building the capacity of urban population to withstand these negative impacts. Increasing the capacity of urban populations can be done through awareness, improving land-use and building practices, and improving the accessibility to existing evacuation facilities in urban areas. In developing countries such as the Solomon Islands, the status of some of these building capacity initiatives still needs improvement to help increase the capacity of urban population to withstand the negative impacts of natural and climate change related hazards.

The study assesses the effectiveness of accessing the existing evacuation facilities in Honiara City during an event of a natural and climate change related hazard. There are existing evacuation facilities in Honiara City and accessibility is not effective. There are vulnerable urban population still living in areas which are under-served by the current evacuation facilities. Most of the low-lying areas east of Honiara City are under-served and this is the most vulnerable area identify in the study. In addition, strategic evacuation planning is not available to coordinate the movement of people from affected areas to the evacuation facilities. Strategic evacuation planning that links evacuation instructions to people in locations easily affected by natural and climate change related hazards is considered effective in coordinating the movement of people to evacuation facilities. The study shows that the link to transfer instructions to evacuate people who are at risk during an event of a natural and climate change related hazard has yet to be developed and implemented in Honiara City. Similar situations for evacuation facility’s accessibility in Honiara City can also exist in urban areas of other developing countries in the South Pacific.

The applications of GIS and Remote Sensing in assessing the physical characteristics of natural and human systems help to identify underlying factors contributing to their vulnerability. Given the right data, GIS has the capability to identify the physical characteristics of natural and human systems vulnerable to the impacts of natural and climate change related hazards. GIS and Remote Sensing applications increase the capacity of natural and human systems reducing their vulnerability to natural and climate change related hazards. In this way, GIS and Remote Sensing is like a
supportive tool that help governments, urban planners, civic authorities and disaster management bodies to prioritize policies, actions and strategic planning. It also generates information and awareness to systems whether natural or human, increasing their capacity to minimize loss and maximize benefits.

In this study, the applications of GIS and Remote Sensing has helped identify physical characteristics of natural and human systems vulnerable to natural and climate change related hazards providing information and awareness to vulnerable systems. Locations easily affected by natural and climate change related hazards are identified. Informal settlements growing onto these locations are exposed to natural and climate change related hazards increasing the vulnerability of human systems. Apart from providing information and awareness to natural and human systems, the study also provides information on the effectiveness of existing temporary evacuation facilities. The information can be used to increase the effectiveness of existing temporary evacuation facilities as well as, improving evacuation strategic planning for the study area.

6.5. Limitations

To fully understand the nature of informal settlement growth in Honiara City, both the physical and socioeconomic attributes and factors that contribute to growth and expansion should be assessed. GIS assessed the spatial nature of growth indicating the locations of informal settlements and the directions of expansion in this study. In addition, it also identifies physical attributes or characteristics of urban landscape or land-use that define formal from informal settlements. However, it is very challenging to use GIS to incorporate both physical and socioeconomic attributes of informal settlements at once. This means that the socioeconomic aspects of informal settlement growth such as livelihood are not explained in this study. Integrating both the physical and socioeconomic attributes of informal settlement growth in urban areas like Honiara City into GIS will be a new step in the development and understanding of informal settlement growth and disaster risk management and preparedness. Future research will benefit from more fully integrating physical and socioeconomic attributes of informal settlement growth in Honiara City.

The methodological approach use to assess informal settlement growth in this study is quite general as it depends on GIS data available. Informal settlements and locations easily affected by natural and climate change related hazards are defined and digitized
as layers. These layers are intersected to show the locations and directions of growth and the growth onto susceptible locations. However, this methodological approach does not answer questions such as why and how these settlements, the people, and their socioeconomic activities are exposed and will be vulnerable to natural and climate change related hazards. In addition, the methodological approach does not measure, assess and rank vulnerability to determine population, locations of informal settlements, and socioeconomic activities at risk (low risk – highest risk). Thus, the current methodology can be improved with the integration of community participation involving people living within the study area, Honiara City Council and Government Departments that deals with land-use, disaster risk management, and infrastructure and planning.

A more precise analysis of informal settlement growth in Honiara City can only be achieved if data quantities and qualities meet the analysis requirement. There are limited number of aerial and satellite images available for Honiara City. Historical image data available from SOPAC library is the 1984 aerial photo and there’s no imagery for the years 1990 – 1999 and 1970 - 1979. Only the 2003 and 2010 satellite images are the colored while the 1984 is a panchromatic image (black and white). In addition, the 1984 aerial image and the 2010 satellite image are low resolution images. Low resolution and panchromatic characteristics of the 1984 aerial image makes visual image analysis a tedious task. Limitations on image data have limited the effort to understand the trend of informal settlement growth and project future growth of these settlements in Honiara City.

Defining and digitizing informal settlement present a unique challenge in this study. The characteristics of informal settlement vary with older ones showing more permanent buildings. Visual image interpretation was justified based on the evidence of spatial planning and physical attributes of informal settlements but may not be on tenure and socioeconomic characteristics. Since unplanned development expanding onto susceptible locations was the main concerned in this study, land tenure was not prioritized in defining informal settlements. The loss to natural and climate change related hazards was an issue of spatial relationship thus, evidence of spatial planning as well as physical attributes of informal settlements were considered important in defining informal settlements.
The quality, quantity and availability of GIS data posed a challenge to this study. GIS was still at its early developing stage in the Pacific and in some countries, the availability of GIS data was limited to the public. This means that those who generate those data viewed it as part of an income generation thus; accessing such data was closely regulated by those who generated them. However, even though if they were available, they were limited and the quality of the data might not that good and thus, need to be pre-processed before using them.

Accessibility to the evacuation facilities is determined from service area analysis in terms of served and under-served areas. Information on the capability of evacuation facilities to accommodate and provides the special needs of vulnerable urban population is either limited or not available in this study. Honiara City has three existing evacuation facilities however, whether these facilities are able to support or provide the special needs of vulnerable urban population before, during and after an emergency evacuation, is not available. Knowing the number of people each facility can accommodate as well as their capability to support vulnerable urban populations such as children, older people, and mothers (female) is also another way of looking at evacuation facilities’ accessibility.

In addition, accessibility to evacuation facilities involves coordination on the movement of people from areas easily affected by natural and climate change related hazards to safe areas or evacuation facilities. GIS service area analysis helps to identify areas that are under-served indicating that populations that are in areas under-served are having problem with accessibility. There is no available information on how the delivery of warning messages to areas under-served and the coordination of people’s movement out of the susceptible locations which are under-served. Thus, accessibility in this study is only determined by areas served and areas under-served. Information on the capability of the evacuation facilities to support urban vulnerable urban population as well as to coordinate the movement of people from susceptible areas to safe areas is not available.

Developing a network dataset for service area analysis require street layer or the road layer for the study area to have road information. Information such as velocity for road segments, directions of travel, street names, stops and turnings are important attributes to road layer. These are some of the information necessary to create a
network dataset needed for service area analysis. Most of the information is not available for the road layer used in this study. This can be improved if needed to do evacuation analysis for automobiles in Honiara City.

There’s limited knowledge available on spatial perspective of informal settlements’ growth and disaster management preparedness in the developing countries within the South Pacific. There’s no major study done on spatial analysis of informal settlements’ growth and disaster management preparedness in the context of urban areas in developing countries of the South Pacific using GIS applications. As previously mentioned, spatially analyzing informal settlements growth in Honiara presents a challenge in this study due to the unavailability and the quality of data. A method used in this study to assess informal settlement growth, can be improved based on the limitations mentioned in this section.

In addition, there’s no major study done on evacuation facilities’ effectiveness to generate knowledge on disaster management and preparedness in urban areas in developing countries of the South Pacific. Urban areas of the South Pacific have temporary evacuation facilities but there is limited knowledge on how effective these temporary evacuation facilities in the event of emergency evacuation. This study assesses effectiveness of evacuation facilities in Honiara City in a spatial perspective using GIS application. This application determines areas served and not served as there’s no existing method applicable to developing countries in the South Pacific. Limitations to this approach are mentioned in this section. This can be used to develop a new approach to fully assess the effectiveness to generate knowledge on disaster management and preparedness in urban areas in developing countries of the South Pacific.

### 6.6. Conclusion

This chapter provides both the discussions and in-depth interpretations of the results generated in this study. Informal settlements’ growth and disaster management and preparedness were the main focus of the discussion. The growth and expansion of informal settlements in Honiara City and their movement onto locations easily affected by natural and climate change related hazards was discussed. In addition, the effectiveness of the existing evacuation facilities was discussed. Evacuation facilities’ effectiveness is an important component of disaster management preparedness in
urban areas. Limitations faced with the study and how these can be overcome was mentioned providing baseline information on what needs to be improved if such study is to be replicated in the future. Discussion on informal settlements’ growth and disaster management preparedness indicates the status of these issues in developing countries of the South Pacific.
Chapter 7: Conclusion and Recommendation

7.1. Conclusion

The vulnerability of urban areas to natural and climate change related hazards has increased as services offered in urban centers attract rural population to move into urban areas. In addition, the expansion of unplanned developments, population and socioeconomic activities towards hazards prone areas exacerbate the existing vulnerabilities and exposures. In most cases, people moving into urban centers have limited information on the history of their settlements regarding the risks to natural and climate change related hazards. As the demand for residential land increases, settlements now expand onto areas that are previously avoided due to their association with natural hazards. This chapter summarizes the findings of this study after assessing the growth of informal settlements and population in Honiara City and their vulnerable to natural and climate change related hazards.

The study approaches urban vulnerability by looking at the likely impacts of natural and climate change related hazards on informal settlements and urban population within Honiara City. It determines the growth of informal settlements within Honiara City onto areas vulnerable to natural and climate change related hazards. With this objective, the study focuses on informal settlements’ growth from 1984 to 2010 identifying the direction of growth and determining the areas taken up by informal settlements. The number of residential dwellings within the informal settlement areas located in areas susceptible to natural and climate change related hazards are determined for 1984, 2003, and 2010. In addition, the study identifies temporary evacuation facilities and the service areas covered by each facility. Identifying temporary evacuation facilities and services areas help to determine informal settlement areas that are exposed or not accommodated by the service areas of each facility and thus, more vulnerable to natural and climate change related hazards.
7.3. Recommendations

These ideas are recommended for the National Government, Honiara City Council, Guadalcanal Province, and non-government agencies who are dealing with urban growth and disaster risks, and researchers who are interested in this area of study. Based on the findings of this study, the researcher’s experiences and observation during ground truthing, and supported document and literatures, these are the recommendations:

1. **Growth of informal settlements onto areas exposed to natural and climate change related hazards;**
   
   a) Government departments and civic authorities that deal with urban development activities should provide information to the public on disaster reduction options prior to construction and land sale. This means that Government Departments and civic authorities that deal with urban development should be knowledgeable about the land being developed and the likely risks it associated with in terms of geophysical and hydro-meteorological hazards.

   b) In addition, Government Departments and civic authorities that deal with urban development activities should develop criteria for selecting site suitable for residential. These criteria should include slope steepness, proximity of the site to nearby river and shoreline, and other sites consider sensitive to natural and climate change related hazards. In the case where some of these required criteria are not met and the site is susceptible to geophysical and hydro-meteorological hazards, building codes should be prioritize and enforced.

   c) The national Government, Honiara City Council and Guadalcanal Province should set up a team to plan and manage the expansion of informal settlements around the Lungga River Delta flood plain and Henderson areas. People settling in this area are amongst the most vulnerable portion of urban population. Now more people are moving into these areas. One of the important issues to consider is how to evacuate people from these settlements during flood events as most of these areas are prone to flooding. It is important to identify a temporary evacuation facility somewhere close to the settlements which can serve the Lungga – Henderson area. In addition, responsible
authorities should subdivide land in these areas to prevent unplanned development into hazard areas.

2. **Disaster Risk Management and Evacuation Planning;**
   a) Honiara City Council and the National Government should consider establishing an evacuation strategic plan for Honiara City taking into consideration buildings, working places, schools, and public transport and places. Planning should involve setting up assemblage points and exit routes for buildings, working places, schools and public transport and places including identifying accessible evacuation points.

   b) Identify and setup evacuation centers to cover expose areas (under-served areas) to accommodate population within these areas. Under-served areas that are vulnerable to natural and climate change related hazards are those along the coastline, low-lying areas, and flood plain. Setting up of temporary evacuation facilities should prioritize these vulnerable areas. In an event of emergency, these temporary evacuation facilities should be organized to provide the needs of the affected population including the vulnerable population groups.

   c) Government departments, Government owned firms, Honiara City Council and other organizations that have GIS data should link up with the National Disaster Management Office sharing their data and technology. There are few GIS technical individuals in the National Disaster Management Office but there is no GIS data available. This requires a memorandum of understanding to be developed between Government Departments, Government own firms, Honiara City Council and other organizations that have GIS data with the National Disaster Management Office.

3. **Further Research should address some of these;**
   a) The ability to measure, assess, and rank vulnerability is seen as a key step towards effective risk reduction as the frequency and intensity of natural and climate change related disaster increases. There is a need to understand vulnerability and exposure to natural and climate change related hazards in the human and social context. This study identifies locations and their susceptibility and exposure to specific hazards and determines the growth of informal settlements into these areas. However, it does not address the
socioeconomic and human aspects of people living in the informal settlements which are also important in understanding vulnerability.

b) Honiara City needs to have well-planned evacuation routes including assemblage and exit points. Since children are the largest part of vulnerable population, a research project should consider setting up evacuation route, assemblage, and exit points for all schools leading to a nearby evacuation facility. The evacuation facilities should be opened and accessible (no blockage) during evacuation.

c) Honiara City should have early warning system managements that will oversee the deliveries of information and movement of people in an event of a natural and climate change related hazards. Further studies should consider generation and transfer of information and warnings as well as linking this information to those at risk prompting them to response to these information base of the severity of the warning being issued.
Bibliography


Pende, L. 2009. *Impact of Urban Growth on Water-Supply and Sanitation: A Case Study of Honiara City, the Solomon Islands*. MSc, University of the South Pacific.


Solomon Star. 2013. Hillsides are not safe to build a home, a Koa Hill Resident warned. The Solomon Star.


Appendices

Appendix A: General Overview of Research Procedure

Define Informal Settlement
- Digitizing Buildings
- Digitizing Informal Settlements
- Intersecting GIS layers
- Maps & Attribute Tables

Define Hazards
- Digitizing Informal Settlements
- Digitize locations at risk to Hazards
- Reklass (Slope + Informal Settlements)
- Maps & Attribute Tables

Identify & Setup Evacuation centers
- Generate Slopes’ steepness
- GIS Network Analysis
- Census Analysis
- Maps & Attribute Tables
Appendix B: Informal Settlement Identification Key

Urban Area

Infrastructure

Buildings

Roads

Residential

Tar or gravel road. Road width = > 5m

Formal street

House > = 40 sq. meters

Uniform or different size of house

Irregular gravel road or foot path/tracks

Street has no pattern

House < = 30 sq. meters

Different sizes of house

Formal settlements

Informal settlements

Presence of infrastructures

Urban Services provided

High - low housing density. Bright roof

Simple to complex roof design

High quality material used

Poor infrastructure

Poorly or no service

Scattered to high density housing

Simple or no roof design. Dual colored roof

Cheap materials

Formal township suburbs

Traditional formal settlements

Modern housing estate

Recent informal settlements

Village
Appendix C: Informal Settlement (polygons) and buildings (points)
Appendix D: Defining Natural and Climate Change related Hazards.

Natural and climate change related hazards

Geophysical
- Earthquake
  I. Landslide
  II. tsunami

Hydrological
- Flood
  I. General flood
  II. Flash flood
  III. Storm surge/coastal inundation
- mass movement (wet)
  I. Landslide

Meteorological
- Storm
  I. Tropical cyclone
  II. Extra-tropical cyclone
  III. Local storm

Climatological
- Extreme events
  I. Extreme temperature
  II. Drought
  III. rainfall
## Appendix E: Data Sources and Description

<table>
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<tr>
<th>Data</th>
<th>Data Type</th>
<th>Data Source</th>
<th>Spatial Reference Used</th>
<th>Resolution</th>
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<td>WGS_1984_UTM_zone_57S</td>
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<td>5 Meter Contour</td>
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<td>Guadalcanal Road Layer</td>
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Appendix F: Service Area Analysis

GIS Network analysis tool was used to do the service area analysis. The tool was found and activated in the toolbars upon clicking customize on the menu bar. The tool bar opened in the ArcMap interface and was dragged to the menu bar before the analysis was performed.

New service area was selected in the network analysis dropdown list. And the service layer was visible in the table of content. The show/hide network analysis window was selected by clicking, and a list of information was given. Facilities were selected by right clicking onto the facilities in the network analysis window. In the dropdown window, load location command was selected by clicking onto it and a dialogue box opens. The evacuation points SHP file was selected from the list of SHP files. Location 1, 2, and 3 were visible under facilities in the network analysis dropdown window.

The general output characteristics of the service area were determined from the service area properties and this was found on the right corner of the network analysis dropdown window. Service area properties dialogue box was opened by clicking the ‘service area properties’ button on the right top corner of the network analysis dropdown window. Polygon generation, analysis setting, accumulation and line generation were checked.

In the polygon dialogue box, generate polygon was checked and generalized was selected for polygon type. Overlapping was chosen for multiple facilities options and rings for overlap type. Minutes was selected as impedance in the analysis setting dialogue box and the minute interval breaks were set at 10, 20, and 30 (10 minutes interval). Direction was set at away from facility and invalid locations were ignored. U-turns were allowed at junctions. The service area was created by clicking the solve function in the network tool bar docked in the main menu bar. A selection of colors can be found in the property layer of the polygon in the table of content.
Appendix G: Map of Informal Settlements
Appendix H: Areas Served by the existing Evacuation Facilities

Legend:
- Hon_2010_Info_settlement
- Polygons
- 10 Minutes
- 20 Minutes
- 30 Minutes
- Evacuation_Facilities
- Guadalcanal_coastline
- Study_boundary

Evacuation Facilities Service Area