THE VULNERABILITY OF TONGATAPU COASTAL ZONE TO LOCAL IMPACTS OF CLIMATE AND SEA LEVEL RISE RELATED RISKS

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ABSTRACT

Tongatapu coastal zone vulnerability assessment study was conducted to examine the degree of current and future risks of projected climate change and sea level rise on the coastal zone of the main island of the Kingdom of Tonga-Tongatapu. Inundation, and flooding hazards generated by tropical cyclone storm surges are the common threats to Tongatapu coastal towns and villages because of their low-lying settings. Flooding problems are exacerbated by the social trends of population growth and migration from the outer islands of the Kingdom, to Tongatapu the main island where the capital town of the Kingdom, Nuku'alofa is located. Other threats include beach erosion, saltwater intrusion, and seawater spraying of coastal vegetations and properties. A survey of the local people of Tongatapu, mapping of vulnerable areas with GIS, and using my local knowledge of the island coastal zone were the three methods were used to conduct this study. The main objective of this research was to assess the vulnerability of the coastal zone of Tongatapu to local impacts of inundation and flooding hazards associated with climate and sea-level rise related risks. The results of the survey indicated that more than 95% of the respondents agreed that the coastal zone of Tongatapu is vulnerable to inundation and flooding risks generated by tropical cyclones that visit Tongatapu coastal water every year, based on their recollection, knowledge, and experienced of the past storm events that hit Tongatapu. GIS work showed that those coastal towns and villages of Tongatapu that are located in areas less than 5 meter above sea level are vulnerable to the local impacts of inundation and flooding hazards. It is concluded that the yearly visited tropical cyclones to Tonga that are actually hit Tongatapu coastal zone had increasing the vulnerability of the coastal towns and villages of Tongatapu that are located in areas below 5 meters above sea level to inundation and flooding hazards associated with climate change and sea level rise related risks. Other possible cause might be the gradual uplifted of the south coast of Tongatapu due to ongoing earthquake activities in Tonga since the last 200 years. But in facts more research it has to be done to confirm this argument. The response to the local impacts of inundation and flooding hazards in the coastal zone of Tongatapu should be focused on adaptation, risk and hazard management.

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CHAPTER 1

INTRODUCTION

1.1 Location of Tonga

The Kingdom of Tonga is a small island country located in the Central South Pacific. It lies between 15° and 23° 30' south of the Equator and 173° and 177° west of Greenwich. Tonga is about 1,700km northeast of New Zealand and about 700km southeast of Fiji (Figure 1.1).

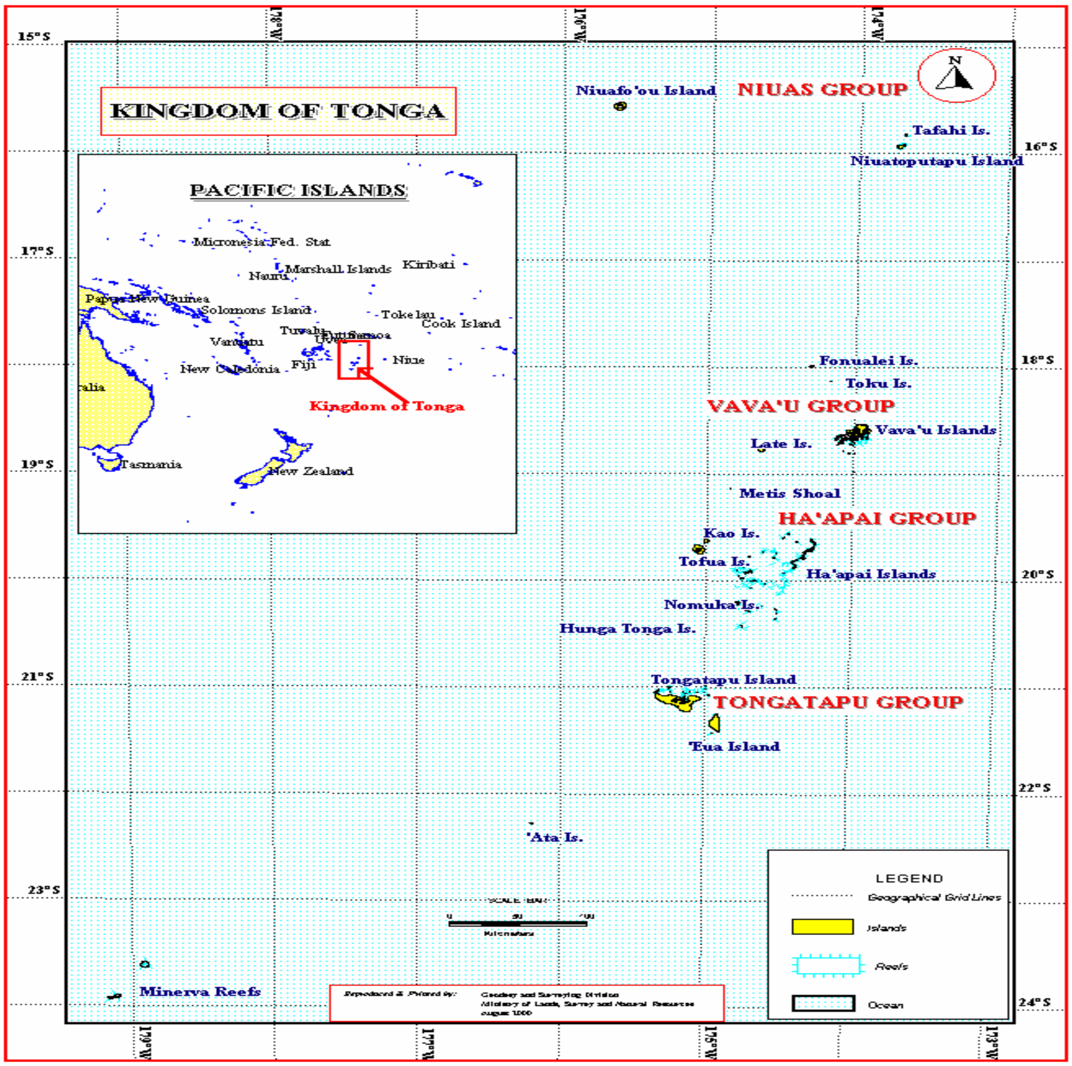


Figure 1.1: Location Map of the Kingdom of Tonga

Source: Geodesy & Surveying Section [Ministry of Lands, Survey & Natural Resources], TONGA.

Tonga has a combined land and sea area of 720,000 km². It is an archipelago of 172 named islands with an area of 747 km² of which 36 islands are inhabited with an area of 670 km² (Fifita et al. 1992).

The Kingdom of Tonga is divided into 4 main island groups (Figure 1.1) which extend over a north-south axis: Tongatapu and ‘Eua in the south; Haápai in the middle; Vavaú in the north; and the small Niuas group in the far north. Tongatapu is the southern-most island group of the Kingdom (Thistlethwaite et al.1993). The Tongan archipelago lies on the western side of the Tonga Trench, a major area of lithospheric plate convergence in the South Pacific. Along the Tonga Trench, the Pacific Plate in the east is being thrust beneath the Indo-Australian Plate in the west (Gatliff, 1990).

1.2 Population and Economy of Tonga

Tonga had a total population of 97,784 recorded in the 1996 census (Tonga Department of Statistics, 1999). Tonga’s 1996 population census was divided into five divisions (Tongatapu, Vavaú, Haápai, Éua and the Niuas). Tongatapu was the most populous and has the highest population density. Tongatapu population totaled 66,979 (69% of the total population), 15715 (16%) for Vavaú, 8138 (8%) for Haápai, 4934 (5%) for Éua, and 2018 (2%) for the Niuas (Tonga Department of Statistics, 1996).

Tonga has a high level of educational achievement with 98.5 % literacy. The Government of Tonga provides primary schools for every inhabited island. Strategic Development Plan seven reaffirms the Governments commitment to high quality universal education reaching Form 6 and the development of technical and vocational education training (Tonga Department of Statistics, 1996).

Tonga’s economy grew at the average annual rate of 1.8 per cent during the period 1970-1995. Real GDP grew at the annual rate of 2.2 per cent in the seven-year period from June 1994 to June 2001 (Tonga Department of Environment, 2005).

Agriculture has been the primary sector of the economy and remains the primary source of livelihood for two-thirds of the population. However; tourism, fisheries, and small industry are becoming important. The agriculture sector is an important source of domestic food supply, employment, cash income, foreign exchange earnings, and raw materials for processing and handicrafts. There are few remaining natural forests in Tonga and the remaining forests are limited in extent, primarily restricted to steep, remote, and inaccessible areas, uninhibited islands, coastal areas, swamps and mangroves (Thistlethwaite et al. 1993).

The sea and coastal resources have provided for the livelihood of Tongans. Coastal development is the driving force that has shaped the coastal areas. The main environmental components of the coast include coral reefs, mangroves, and beaches. Beach sand has been mined for construction and other development purposes in Tonga. Some of the critical habitats of the coastal areas, including coral reefs and mangroves, are important fisheries ecosystems (Thistlethwaite et al. 1993). There are three categories of marine fisheries resources in Tonga including offshore, bottomfish and inshore resources. They differ in magnitude and are subjected to different levels of exploitation (Tonga Department of Environment, 2002).

Tonga’s main energy sources are indigenous biomass and imported petroleum products. In 1992, indigenous biomass accounted for 56 % of total energy consumed while imported petroleum represented the remaining 44 %. By 2001, imported petroleum products captured 54 % of total energy and biomass accounted for 43 %. Tonga has potential to develop use of solar, wind and wave energy in the form of solar photovoltaic power and hydro-electricity power. Tonga’s geographical location, proximity to the Equatorial region of the Pacific, and its vast area of oceanic territorial waters are considered viable future potential sources of renewable energy. Renewable energy use has risen from less than 1 % in 1990 to 2 % in 2003 (Tonga Department of Environment, 2002).

Transportation in Tonga is managed under three different bodies. Land transport is managed by the Ministry of Works; sea transport is managed by the Ministry of

Marine and Ports and air transport is managed by the Ministry of Civil Aviation (Tonga Department of Environment, 2002).

The two main sources of water in Tonga are from rainwater collected and stored in cisterns as well as groundwater from the porous limestone substrate. Surface water resources are not commonly present in Tonga with the exception of ‘Eua (Coral island) and a number of volcanic islands include Niuafo’ou and Tofua (Haápai island).

According to the 1996 census there were 16,194 households in Tonga. Eighty-five percent of households (13,705), had access to piped water supply, 58.3 % (9,444 households) had their own tanks, 2.4 % (393 households) had their own wells, 1.1 % (175 households) had other sources of water supply (Tonga Department of Environment, 2002, 2005).

There were five leading causes of death in Tonga from 1989-2003; acute respiratory infection, Influenza, Broncho pneumonia, Diarrhea (infants) and Pneumonia (adults). Year 2000 had the highest reported incidences of all diseases. Diseases of the respiratory and circulatory systems were the two main causes of death in 2002. There was an increase in the number of cases of dengue fever (a mosquito borne disease) reported between 1983 and 1990. Food and water borne diseases are also reported in Tonga (Tonga Department of Environment, 2005).

1.3 Objectives

The main objective of this research was to assess the vulnerability of the coastal zone of the main island of the Kingdom of Tonga – Tongatapu, to local impacts of flooding hazards associated with climate and sea level rise related risks.

Specific objectives include:

(1) Conduct literature review of the vulnerability of the coastal zone sector of the main island of the Kingdom of Tonga – Tongatapu to flooding hazards

associated with climate and sea level rise related risks; specifically focusing on;

- Coastal zone areas inundation and flooding
- Beach erosion
- Tsunami

(2) Conduct a survey of the local people to obtain views and memories of the past and present impacts of storm events on the coastal zone of Tongatapu Is.

(3) Develop a Geographical Information System (GIS) that shows:

- Tongatapu Island coastal zone topography
- Vulnerable coastal areas of Tongatapu coastal zone
- Distribution of coastal towns/villages settlement areas in Tongatapu

1.4 Methods

The work undertaken in this thesis comprised two parts:

(1). A Survey

(2). Use of Arc View GIS to assess the local impacts of potential sea level rise

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

2.1 The Study Area

2.1.1. Introduction

Tongatapu is the main island of Tonga where the capital Nukuálofa is located is the focus of in this study (Figure 2.1). It is the most populous island among Tonga's island groups.

Figure 2.1 Map shows the location of Tongatapu in the Kingdom of Tonga (Source: Ministry of Lands, Survey & Natural Resources, 2001)

Tongatapu is also the home to the current King of Tonga, Taufaáhau Tupou IV, as well as numerous Tongan historical sites. The capital, Nukuálofa, has seen a more rapid economic development than other islands and is thus a commercial hub, attracting many immigrants from outer islands.

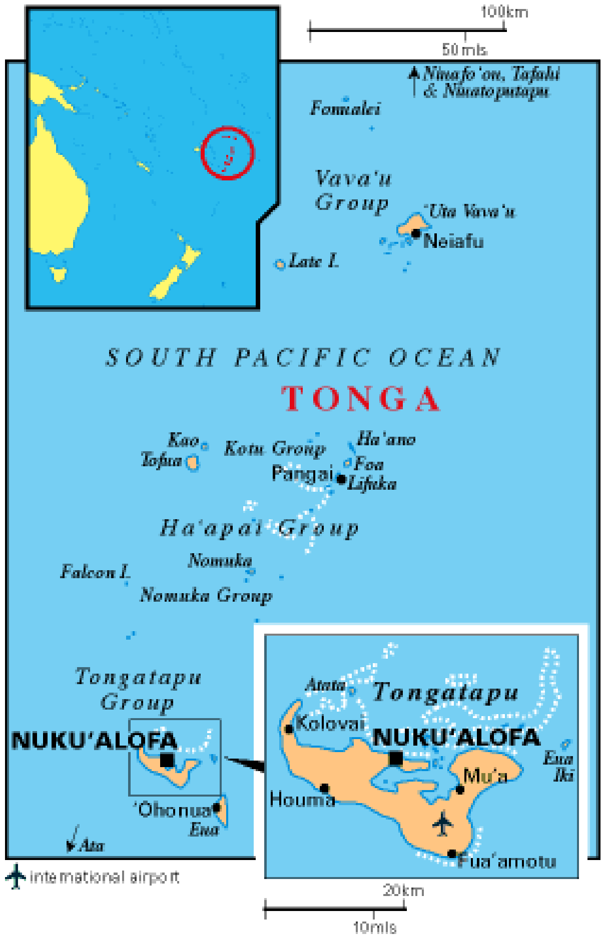


Figure 2.2 Map shows the location of Tongatapu in the Kingdom of Tonga, Pacific Ocean.
(Source: Ministry of Lands, Survey & Natural Resources Tonga, 2006)

Nukuálofa, population 22,400 (Department of Statistics, 1996), is the capital of Tonga. The city is located on the coast of Tongatapu island. It is the most important commercial, transport and social center of Tonga. It comprises about 35% of the Kingdom's population. All of the government buildings and office headquarters are located in Nuku'alofa (Figure 2.1).

2.1.1.1. History

The word Tonga means "south" in numerous Polynesian languages. Some scholars believe the inhabitants originally came from the islands now known as Samoa. Archaeological evidence indicates that the Tonga islands have been settled since at least 500 B.C., and local traditions have carefully preserved the names of the Tongan sovereign for about 1,000 years. The power of the Tongan monarchy reached its height in the 13th century. At the time, chieftains exercised political influences as far away as Samoa (Parsonage, 1941; Wood, 1972; Martin, 1991; Campbell, 1992; Spennemann, 1997).

During the 14th century, the King of Tonga delegated much of his temporal power to a brother while retaining the spiritual authority. Sometime later, this process was repeated by the second royal line, thus resulting in three distinct lines: the Tuí Tonga with spiritual authority, which is believed to have extended over much of Polynesia; the Tuí Haátakalaua; and the Tuí Kanokupolu. The latter two had temporal authority for carrying out much of the day-to-day administration of the Kingdom (Wood, 1972; Campbell, 1992).

Dutch navigators in 1616 were the first Europeans to sight the Tongan archipelago. The main island of Tongatapu was first visited by Abel Tasman in 1643 (Wood, 1972; Martin, 1991; Campbell, 1992). Continual contact with Europeans did not begin until more than 125 years later. Captain James Cook visited the islands in 1773 and 1777 and gave the archipelago the name “the Friendly Islands” because of the gentle nature of the people he encountered (Wood, 1972; Bott, 1982; Martin, 1991; Campbell, 1992). He, of course, was never aware of the acrimonious debate that raged among contending nobles over who should have the honor of attacking Cook’s tiny fleet and killing its sailors (Parsonage, 1941; Wood, 1972; Siers, 1978, Bott, 1982; Martin, 1991; Campbell, 1992). In 1789, the famous mutiny on the British ship, Bounty, took, place in the waters between the Haápai and Nomuka island groups (Parsonage, 1941; Wood, 1972; Bott, 1982; Martin, 1991; Campbell, 1992).

Shortly after Captain Cook’s last visit, warfare broke out in the islands as the three lines of kings contended for dominance (Wood, 1972; Bott, 1982; Campbell, 1992). At about the same time, young Tongan nobles serving as mercenaries took Tongan culture to Fiji’s most eastern island group, the Laus (Wood, 1972). The first missionaries, attached to the London Missionary Society, arrived in Tonga in 1747 (Parsonage, 1941; Wood, 1972; Campbell, 1992). A second missionary group followed in 1822, led by Walter Lawry of the Wesleyan Missionary Society (Parsonage, 1941; Wood, 1972; Campbell, 1992).

They converted Taufaáhau, one of the claimants to the Tuí Kanokupolu line, and Christianity began to spread throughout the islands (Parsonage, 1941; Wood, 1972; Bott, 1982).

At the time of his conversion, Taufaáhau took the name of Siaosi (George) and his consort assumed the name Salote (Charlotte) in honor of King George III and Queen Charlotte of England (Parsonage, 1941; Wood, 1972, Bott, 1982; Campbell, 1992). In the following years, he united all of the Tongan islands for the first time in recorded history (Parsonage, 1941; Wood, 1972; Bott, 1982). In 1845, he was formally proclaimed King George Tupou I and the present dynasty was founded (Wood, 1972). Siaosi Taufaáhau Tupou I established a constitution and a parliamentary government based, in some respects, on the British Model (Parsonage, 1941; Wood, 1972; Bott, 1982, Campbell, 1992). In 1862, he abolished the existing system of semi-serfdom and established an entirely alien system of land tenure (Wood, 1972). Under this system every male Tongan, upon reaching the age of 16, was entitled to rent – for life and at a nominal fee – a plot of bush land (called "api") of 8.25 acres, plus a village allotment of about three-eights of an acre for his home (Parsonage, 1941; Luke, 1954; Wood, 1972; Campbell, 1992; Pulea, 1992; Thistlethwaite *et al.,* 1993).

Tonga concluded a treaty of friendship and protection with the United Kingdom in 1900 and came under British protection (Parsonage, 1941; Luke, 1954; Wood, 1972; Campbell, 1992). Tonga retained its independence and autonomy, while the United Kingdom agreed to handle its foreign affairs and protect it from external attack (Parsonage, 1941; Luke, 1954; Wood, 1972; Campbell, 1992).

Tonga joined the Commonwealth of Nations in 1970 and the United Nations in September 1999. While exposed to colonial forces, Tonga has never lost indigenous governance, a fact that makes Tonga unique in the Pacific and gives Tonga much pride, as well as confidence in their monarchal system. However, that pride and confidence is lost in Tonga today due to its people blamed the King and his royal family for corruption, mismanagement of government funds and properties, and the deterioration of the Tonga economy.

2.1.1.2. Geology

The Tongan archipelago is formed as the western edge (Figure 2.3) of the western Pacific Plate collides with and slides below the Indian/Australian Plate (Scholl and Vallier, 1985; Gatliff, 1990, Fifita *et al.*, 1992; Thistlethwaite *et al.*, 1993; Stevenson *et al.,* 1994; Mimura and Pelesikoti, 1997; Department of Environment, 2005).

There are two parallel lines of islands (Figure 2.3): the western line consists of volcanic islands, and the eastern line, coral islands (Wood, 1972; Scholl and Vallier, 1985; Gatliff, 1990; Fifita et al., 1992; Thistlethwaite et al., 1993; Stevenson *et al.,* 1994; Mimura and Pelesikoti, 1997). East of the coral islands is the deep Tonga Trench, (Figure 3) which extends at times to a depth of 10,500 m (Wood, 1972; Scholl and Vallier, 1985; Gatliff, 1990; Fifita et al., 1992; Thistlethwaite *et al.*, 1993; Stevenson, *et al.*, 1994).

The islands that are located along the north west – south west drawn red line (Figure 2.3) (e.g. Niuafoóu island (north west) to Áta island (south east), of Tonga are composed of fresh volcanic islands, and the islands that are located along the north east – south east drawn black line (Figure 2.3) are uplifted limestone islands (e.g. Vavaú Groups main island (North east) to Éua island (south east) (Scholl and Vallier, 1985; Stevenson *et al.,* 1994). The limestone islands, while founded on older volcanic substrates, are formed from coral (Scholl and Vallier, 1985, Stevenson et al., 1994; Fifita *et al.,* 1992; Mimura and Pelesikoti, 1997).

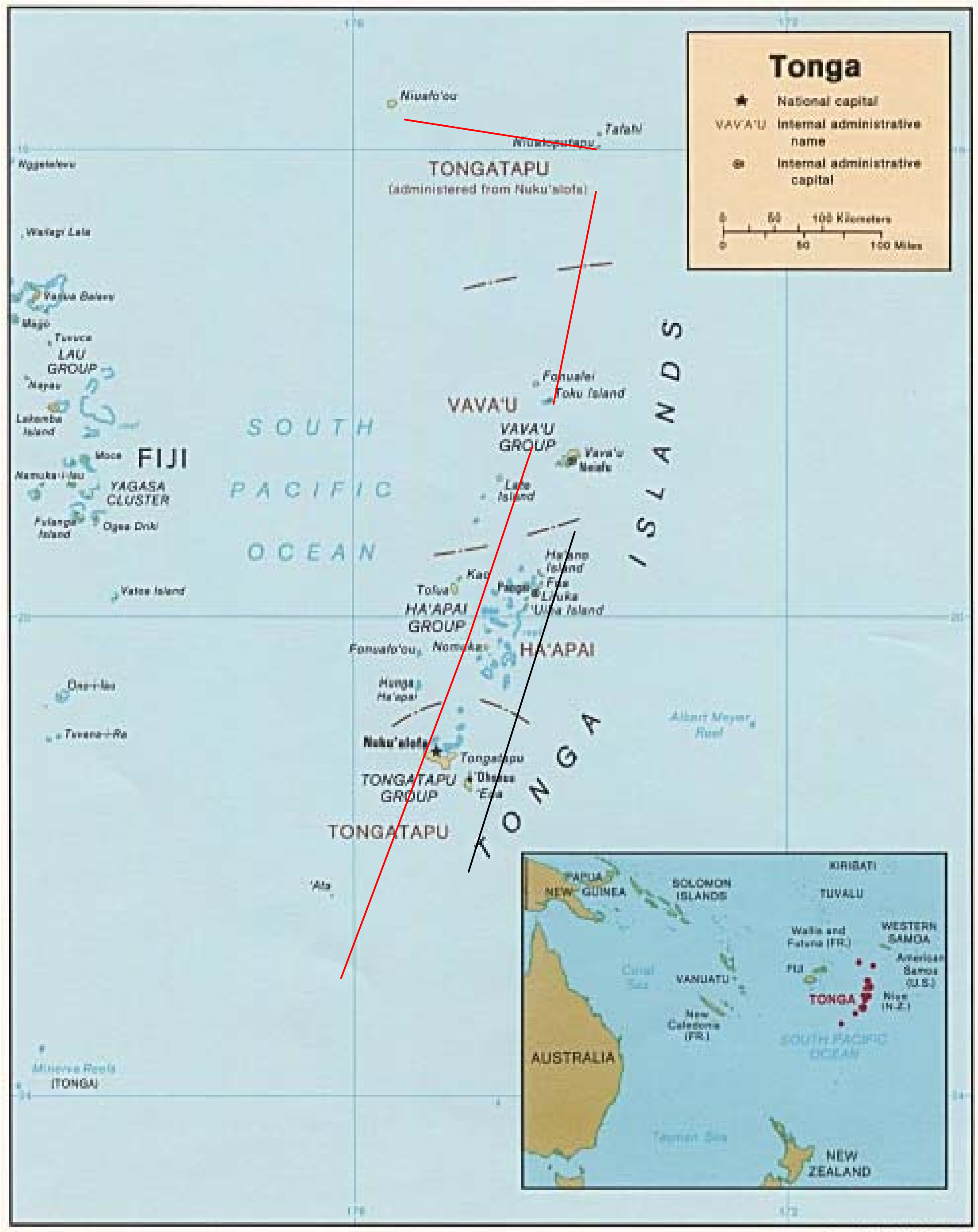


Figure 2.3: Map of the Kingdom of Tonga Island Groups.

Source: Ministry of Lands, Survey & Natural Resources, Nukuálofa, Tonga, 2001.

Apart from the young volcanic chain, the islands divide naturally into four geographical groups along the Tonga platform – each group representing the highest points on a respective block, with each block separated by major WNW-ESE faults.

Tonga Island groups (Figure 2.3) consist of the Niuas Group in the far north, Vavaú Group in the north, the central groups of Haápai and Nomuka, and the Tongatapu Group in the south (Scholl and Vallier, 1985).

2.2. Physical characteristics of the Study Area

2.2.1. Topography of Tongatapu

Tongatapu Island (Figure 2.4) extends 40 km long from east to west and is 20 km at its widest (Nunn, 1988; Fifita et al**.,** 1992; Nunn and Waddell, 1992; Nunn, 1994). It is generally flat, but slopes from a maximum elevation of 65m in the southeast to sea level along the northern coast. Given that, the sea penetrates inland to form a large, shallow lagoon, Fangaúta, that is 27 km^2 (see Figure 2.4.).

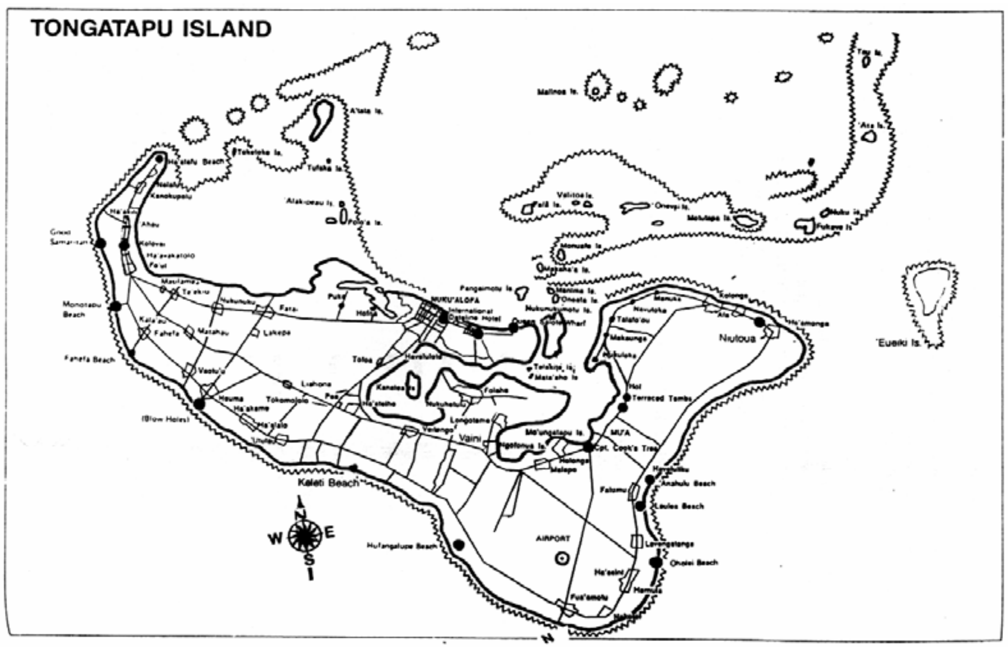


Figure 2.4: Topographic Map of Tongatapu Island

Source: Douglas, and Douglas, 1989.

Nukuálofa is located on a flat peninsula between the lagoon and the ocean (Figure 2.4). Most of the urban area of Nukuálofa has an elevation of 0.5 to 1.5m above mean sea level, and many parts of the city are below 0.5 m (Nunn, 1988;

Spennemann, 1988; Fifita et al., 1992; Nunn and Waddell, 1992; Mimura and Pelesikoti, 1997; Nunn and Mimura, 1997; Mimura, 1999).

Because the Tonga Island groups are on the edge of an active plate, strong uplift may occur. Taylor and Bloom (1976) have argued that there has been no net uplift or tilting of the Tongatapu Group at least in the last 125,000 years. However, on-going tectonically activity since 1853, may pose a possibility that uplift on the southern coast (Figure 2.5) and at Tongatapu lowering on the northeast coast (Figure 2.6, 2.7, 2.8) could contribute to the present vulnerability of the Tongatapu coastal zone to inundation.

Figure 2.5 Blow Holes at Houma village on uplifted coastal platform, Southern coast of Tongatapu (2006).

2.2.2. Natural and Artificial Coast

The island of Tongatapu has broad tidal flats, coastal swamps, and mangrove forests along the northern edge (Figure 2.6, 2.7, 2.8). A narrow fringing reef surrounds the east, south, and west coasts (Figure 2.5, 2.6, 2.7, 2.8, 2.9). The coral reefs extend northward from the north coast of the island along an extensive submerged terrace

(Figure 2.9). Apart from that, between the two coral ridges is a large harbor with deep entrances from the north and the east (Figure 2.6, 2.7, 2.8, 2.9). In addition, the extensive shallow lagoon in the central part of the island is Fangaúta (Figure 2.9). Mangrove forests fringe the lagoons and the north coast (Figure 2.6, 2.7, 2.8, 2.9, 2.10) of Tongatapu (Nunn, 1988; Spennemann et al., 1988; Fifita et al., 1992; Nunn and Waddell, 1992).

Figure 2.6: **Coast of Kanokupolu village, Northwest Tongatapu**

Source: Photographs taken by T. Kula, 2002.

Figure 2.7: Coast of Sopu village, Northwest Nukuálofa (North Tongatapu)

Source: Photographs taken by T. Kula, 2004.

Figure 2.8: Coast of Popua village, Northeast Nukuálofa (North Tongatapu), 2006.

Map of Fangaúta and Fangakakau lagoon, (Central Tongatapu)

Figure 2.9: Fangaúta and Fangakakau lagoon, (Central Tongatapu)

Source: Adopted from the Department of Environment, 2002.

Figure 2.10: Coast of Nukuleka village, Northeast Tongatapu

Source: Photographs taken by T. Kula, 2004.

Figure 2.11: Coast of Manuka village, Northeast Tongatapu

Source: Photograph taken by T. Kula, 2004.

Furthermore, Tongatapu has more than 10 sandy beaches (Figure 2.10, 2.11), some of which are pocket beaches. Most of the popular beach areas have been stripped of sand (Figure 2.12) because of the high demand for construction material (Figure 2.13), which exceeded the potential for sand regeneration (Nunn, 1988; Spennemann, 1988; Fifita et al., 1992; Nunn and Waddell, 1992). The length of each type of coast is summarized in Table 2.1.

Figure 2.12: Lavengatonga Beach, East coast Tongatapu

Source: Photographs taken by T. Kula, 2004.

Table 2.1 Physical characteristics of the coasts in Tongatapu Island

Coastal type		**Length of coastline (km)**
Natural coast	Mangroves	60
	Sandy beach	26
	Cliff	5
	Cliff and sand	2
	Others – lagoon, estuaries	74
Artificial coast	Seawalls	3.4
	Others	**4 wharfs**
Local subsidence		Negligible
Average tidal range		1.1 m (Nuku'alofa)
Design high water level		2.8 m above DL Nuku'alofa
Average significant wave height		0.5 m
Design wave height		2.0 m

Source: Fifita et al., 1992.

Figure 2.13: Government sand depot of beach sand in Nukuálofa-there are 5 others around Tongatapu. (**Source**: Ministry of Lands, Survey & Natural Resources, 1991).

Waterfront development in Tongatapu has been limited to the construction of wharfs, and jetties (Figure 2.14, 2.15) adjoining major towns and villages, and housing development in mangroves swamps (Figure 2.16, 2.17).

Figure 2.14: Extended of Queen Salote Wharfs container stockpile site, North Coast Tongatapu, 2006.

Figure 2.15: Masefield Naval Base at Touliki, Northeast Nukuálofa, North Tongatapu, 2006.

Figure 2.16: Coast of Sopu village, Northwest Nukuálofa (North Tongatapu), 2006.

Figure 2.17: Coast of Popua village, Northeast Nukuálofa, North Tongatapu, 2006.

The Nukuálofa foreshore protection (Figure 2.18) was reconstructed following damage from the tropical cyclone Isaac of 1982 (Ministry of Works, 1983; Fifita et al., 1992). In 1986, 3,400 m of protective wall were completed (Fifita et al., 1992).

Figure 2.18: Coastal Foreshore Protection Wall at Nukuálofa Waterfront
Source: Ministry of Lands, Survey & Natural Resources, 2003.

Apart from that, the Queen Salote Wharf complex , and the Faua Fisheries harbor (Figure 2.19) were completed in 1986 and 1987, and two other wharfs are on the fringing reef flat at Nukuálofa (Fifita et al., 1992).

Figure 2.19: Faua Fisheries Harbor, Northeast Nukuálofa, North of Tongatapu, 2006.

2.2.3. Tide and Design Water Level

Fifita et al. (1992) report that from the existing studies, the tidal range of the spring tide was found to be 1.1 m for Nukuálofa. This indicates that the tidal motion at Nukuálofa is not very strong. As for the design water level, the high-water level induced by cyclone should be taken into account. A detailed survey was carried out by the Tonga Ministry of Works to find out the maximum water level along the shoreline of Nuku'alofa during Tropical cyclone Isaac in 1982 (Fifita et al., 1992), revealing that the water level reached 2.50 to 2.75 m (above chart datum) over the whole length of approximately 8 km of the north coastline of Tongatapu. Furthermore, on the basis of this survey, Tonga Ministry of Works local civil engineers with the assistance of a foreign technical consultant concluded that a design water level of approximately 2.8 m would include most of the risk, which should be considered for design purposes under the current sea level (Fifita et al., 1992). Generally, all the present coastal road, wharf, and foreshore protection structures that were constructed along the coastline of the capital town of Nuku'alofa since Tropical cyclone Isaac (1982), were kept to the 2.8 m design water level. (pers com, I. Pulini, 2006).

2.2.4. Waves

When designing the foreshore protection work, design wave characteristics were determined by a wave forecast (Fifita et al., 1992). The winds blowing from the north to the waterfront of Nukuálofa are usually calm (Fifita et al., 1992). Toward the northeast and northwest coastline of Tongatapu is sheltered by the chain of islands and protected by vast fringing and isolated reefs (Fifita et al., 1992). Because of such sheltering effects, the significant wave heights can be estimated to be less than 0.5 m under ordinary conditions (Fifita et al., 1992). Fifita et al. (1992) also report that in the case of a cyclone, higher wave height in deep water and a rise in sea level due to wave action on the reef should be taken into account.

2.2.5. Climate

a. Temperature and rainfall

The climate of Tonga is tropical. It lies within the southeast trade wind zone of the South Pacific. Tonga's annual rainfall can be defined by two seasons, the wet and dry seasons (Thistlethwaite et al. 1993). The wet season is also known as the cyclone season and it is noticeable from November to April. The dry season runs from May to October. The wettest months are January, February, and March during which time rainfall may exceed 250mm per month. During the dry season, the rainfall is usually less than 250mm per month. The mean annual rainfall for the major island groups of Tonga was calculated from the 1947-2001, as 1753mm in Nuku'alofa, 1689mm in Lifuka, 2185mm in Neiafu (Tonga Meteorological Service, 2002). The annual precipitation trends in Tonga were also studied. Trends indicate a general decrease in annual rainfall in central and southern parts of Tonga particularly since the 1970s (Tonga Department of Environment, 2005). Tonga has a subtropical maritime climate, which is mild to warm, humid and moderately wet throughout the year. For instance, from Tongatapu islands in the south to the Niuas in the north, the mean annual minimum temperature increases from 20.7 to 23.7 °C, the mean annual maximum temperature increases from 27.1 to 29.8°C, and the mean annual rainfall increases from 1719 to 2356 mm (Tonga Meteorological Services, 2002).

The mean annual temperatures in Tonga vary from 26°C at Niuafoóu and Niuatoputapu to 23°C on Tongatapu. During the hot wet season (November-April) the average temperature ranges from 25-26°C whereas in the dry cool season (May-October) the average temperature ranges from 21-24°C. Climatic data records date back to 1949 for Nuku'alofa, Haápai, Vavaú and Niuatoputapu. Trends suggest an increase of 0.4-0.8°C in mean annual temperature throughout the island groups since the 1970s (Tonga Department of Environment, 2005).

b. Tropical Cyclone

Tonga experienced tropical cyclones mainly during the hot wet season. In addition, between 1960-2004, there have been 32 tropical cyclones impacted the whole of Tonga island groups included Tongatapu (Table 2.2).

Table 2.2 Tropical cyclones that have impacted Tonga (1960-2004)

Month/Year	Total Number of Cyclones	Strength of Cyclone/intensity	Name of Cyclones
January-60 March-61 November-64 February-69	**4**	Storm Severe Gale Gale	Nil Nil Nil Nil
April-73	**1**	Storm	Juliette
February-81 March-82 March-84		Gale Hurricane Gale	Betsy Isaac Nil

January-85 February-86 April-86 February-89 April-89	**8**	Storm Storm Gale Gale Storm	Drena Keli Martin Nil Kerry
Jan–Feb-90 February-90 November-90 December-90 December-91 December-92 Dec 92-Jan 93 Dec 92-Jan 93 February-93 March-97 June-97 January-98 December-98	**13**	Hurricane Gale Hurricane Gale Storm Storm Hurricane Storm Gale Hurricane Storm Hurricane Storm	Ofa Nil Sina Nil Val Joni Kina Nina Mick Hina Keli Ron Cora
March-00 March-01 Dec 01-Jan 02 January-03 March-03 January-04	**6**	Gale Hurricane Hurricane Hurricane Hurricane Hurricane	Mona Paula Waka Ami Eseta Heta

Source: Tonga Meteorological Services, 2004.

Key:	
Gale:	winds of 34-47 knots (63-87 km/hr)
Storm:	winds of 48-63 knots (88-117km/hr)
Hurricane:	winds of 64 knots or more (>117km/hr)

On average, Tonga is affected by 1 tropical cyclone annually (Department of Environment Tonga, 2002, 2005). Most of the tropical cyclones that damage the island groups of Tonga in the past cost million of dollars. For example, tropical cyclone Isaac, 1982 damaged the island groups of Tongatapu and Haápai. The total cost for the damage inflicted was T$18.7 million. In addition to that, tropical cyclone Cora, 1998 hit Tongatapu, Haápai, and Éua groups and damages cost T$19.6 million.

2.2.7. Sea Level

Department of Environment Tonga (2005) reported that the sea level trend (Figure 2.20) suggests a general increase in sea level in order of 14mm/yr since records started in 1993 up to 2001 as compared to a global average of 1-2mm/yr. However, the magnitude of the trend continues to vary widely from month to month. For example, the result of August 2004 shows a trend of +11.6mm/yr (AMSAT Tonga Country Report – Sea Level: Present State, 2004).

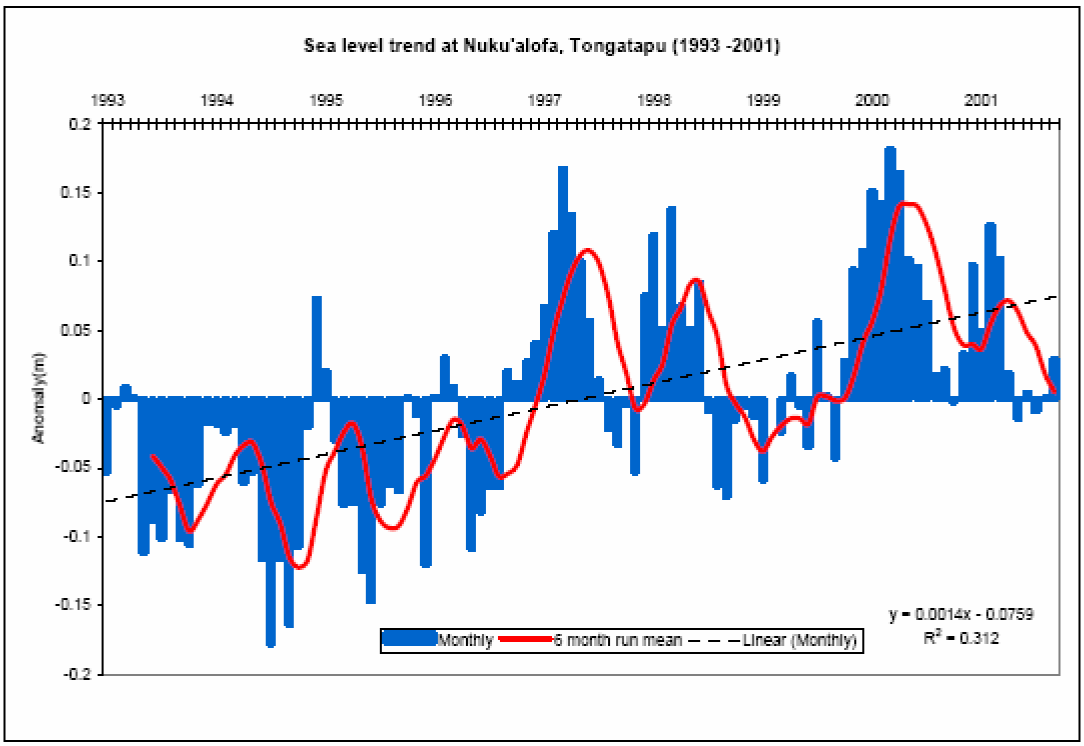


Figure 2.20: Sea level trend for Nukuálofa, Tongatapu

Source: Adapted from AMSAT, 2004.

Department of Environment Tonga (2005) also argues that it should be noted however that the data recorded is far too short to suggest a true representation of sea level rise in Tonga. In addition, the IPCC suggests a minimum of 30 years of monitoring is a useful benchmark to develop trends (IPCC, 1996a, b; 2001a, b). In contrast, a longer term data record is desirable to ensure noise from the ENSO cycles and various local atmospheric, oceanographic and geodetic processes are limited before better estimate can be made (AMSAT, 2004). Apart from that, to consider this kind of limitation, it is still constructive to consider that data obtained from tide gauge thus far signifies a positive sea level trend. Not to forget that the projected sea level rise accompanying climate changes due to the enhanced greenhouse effect are expected to adversely affect almost all the coastal areas of Tonga (Department of Environment Tonga, 2005).

2.2.8. Conclusion

The selection of Tongatapu coastal zone to be the focus of this study was based on the facts, that many parts of the coastal areas of the island has been observed by the local people and reported by many previous studies that the coastal areas of Tongatapu and its resources may potentially be seriously affected by the local impacts of climate change and sea level rise related risks in the next 100 years. Amongst all the coastal areas in Tonga, the northern low-lying coastal areas of Tongatapu are most vulnerable to climate change and sea level rise related risks. Therefore, this study has been selected the coastal zone of Tongatapu as the case study area of this research, is aiming to find out more evidence on the present and future trends of the vulnerability of the coastal zone of Tongatapu to the local impacts, and adverse effects of climate change and sea level rise related risks.

CHAPTER 3

LITERATURE RIVIEW: Potential impacts of changes in climate and sea - level rise on Pacific Islands, with particular regard to Tonga

3.1 Introduction

The literature from previous studies that have been conducted in the main island of the Kingdom of Tonga – Tongatapu - since 1988 (Nunn, 1988, 1994, 1997; Fifita et al., 1992, 1994; Nunn and Waddell, 1992; Mimura and Pelesikoti., 1997; Nunn and Mimura, 1997; Mimura, 1999; Department of Environment Tonga, 2005) is reviewed. The first assessment study of the vulnerability of the coastal zone sectors of Tongatapu Island to the impacts of climate change and sea level rise was conducted under a collaboration of Tongan and Japanese researchers in 1992 (Fifita et al., 1992, 1994; Mimura and Pelesikoti., 1997; Nunn and Mimura, 1997; Mimura, 1999). The second study, was conducted in 2005, by Tongan people from various government of Tonga ministries/ departments/ statutory boards, and NGOs under the supervision and co-ordination of the Tonga Department of Environment, as part of the preparation of their initial national communication country report to the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (Department of Environment, Tonga 2005).

The studies have identified some parts of the coastal areas of Tongatapu Island that are vulnerable to the impacts of climate change and sea-level rise. The coastal areas are vulnerable to tropical cyclones, storm surges, drought, inundation and flooding (Fifita et al. 1992, 1994; Mimura and Pelesikoti, 1997; Nunn and Mimura, 1997, Mimura, 1999. The vulnerability of the Tongatapu Island coastal zone sector is principally due to its physiographic, socioeconomic and ecological characteristics (IPCC, 1992; Fifita et al. 1992, 1994; Mimura and Pelesikoti, 1997; Nicholls, 1995; Nunn and Mimura, 1997; Department of Environment, 2002, 2005).

3.2. Concept and Definition of Vulnerability

Vulnerability is an important concept in the United Nations Framework Convention on Climate Change (UNFCCC) (IPCC, 1991, 1992, 1996, 2001: Klein, 2002). The UNFCCC main scientific body known as the Intergovernmental Panel on Climate Change (IPCC), in its Second Assessment Report, Intergovernmental Panel on Climate Change (IPCC), 1996a, 1996b) defines vulnerability as "the extent to which climate change may damage or harm a system". It adds that vulnerability "depends not only on a system's sensitivity, but also on its ability to adapt to new climatic conditions" (Watson et al. 1996:23). In a presentation made at the Sixth Conference of the Parties to the UNFCCC (COP-6), Robert T. Watson, Chair of the IPCC, defined vulnerability as:

> "the extent to which a natural or social system is susceptible to sustaining damage from climate change, and is a function of the magnitude of climate change, the sensitivity of the system to changes in climate and the ability to adapt the system to changes in climate. Hence, a vulnerable system is one that is sensitive to modest changes in climate and one for which the ability to adapt is severely constrain" (IPCC, 2000).

The IPCC report, *The Regional Impacts of Climate Change: An Assessment of Vulnerability* (Watson et al. 1998), argues that the vulnerability of a region depends to a great extent on its wealth, and that poverty limits adaptive capabilities. According to the Second Assessment Report, vulnerability depends on the level of economic development and institutions. The report argues that socio-economic systems "typically are more vulnerable in developing countries where economic and institutional circumstances are less favourable" (Watson et al. 1996:24). The report continues that vulnerability is highest where there is "the greatest sensitivity to climate change and the least adaptability".

Looking at vulnerability from the food security point of view, the FAO publication *The State of Food Insecurity in the World* (1999), defines vulnerability as "the presence of factors that place people at risk of becoming food insecure or malnourished. Clearly, this definition encompasses causes of food insecurity other than climate (e.g. armed conflict, landlessness, etc.). Nevertheless, the concept of vulnerability includes hunger vulnerability – which refers to the vulnerability of individuals or households rather than that of regions or economic sectors."

A common theme in the climate change impacts and vulnerability literature is the idea that countries, regions, economic sectors and social groups differ in their degree of vulnerability to climate change (Bohle et al. 1994). This is due partly to the fact that changes in temperature and precipitation will occur unevenly and that climate change impacts will be unevenly distributed around the globe. It is also due to the fact that resources and wealth are distributed unevenly. Though vulnerability differs substantially across regions, it is also recognized that "even within regions…impacts, adaptive capacity and vulnerability will vary" (IPCC, 2001:15).

Blaikie et al. (1994) define vulnerability as "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard". The same authors argue that vulnerability "is a measure of a person or group's exposure to the effects of a natural hazard, including the degree to which they can recover from the impacts of that event".

Kelly and Adger (2000:328) define vulnerability as "the ability or inability of individuals or social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being." Their approach focuses on existing "wounds" (or prior damage), which might limit capacity to respond to stresses and are independent of future threats.

Intergovernmental Panel on Climate Change (IPCC), (1992) defines the vulnerability of coastal zones as "the degree of incapability to cope with the consequences of climate change and accelerated sea-level rise". This definition implies that vulnerability is a composite measure of anticipated impacts of climate change and the extent to which systems can adapt to these impacts. It is consistent with earlier conceptual work on vulnerability, which usually presents vulnerability as a reverse function of a system's ability to cope with stress and shock (Timmerman, 1981; Smith, 1992).

3.3. Vulnerability of the coastal zone of Tongatapu Island and the rest of the coastal areas of Tonga to the impacts and adverse effects of Global Warming and Sea level rise

3.3.1. Impacts of Global warming

Tonga and the other small island states of the world account for less than 1% of global Green House Gas (GHG) emissions but are among the most vulnerable of all areas to the potential adverse effects of climate change and sea-level rise (Jones, 1998; Nurse *et al.,* 1998). It has been established that there already is a global commitment (i.e. refers to those countries of the world who agreed, signed and ratified the 1997 Kyoto Protocol and targets) to climate change and sea-level rise as a result of green house gas forcing arising from historic emissions (Warwick *et al*., 1996; Jone, 1998; Nicholls *et al.,* 1999; Parry *et al.,* 1999). Moreover, analysis has shown that even with a fully implemented Kyoto Protocol, by 2050 warming would be only about 1/20th of a degree less than what is projected by the IPCC (Parry et al., 1999). Therefore, climate change impacts are likely to continue to occur.

3.3.2. Impacts of Global Sea Level Rise

Based on Global sea-level rise scenarios produced by the Hadley Centre (HADCM2 and HADCM3), Nicholls et al. (1999) estimate that global sea levels are expected to rise by about 38 cm between 1990 and the 2080s. They project that many coastal areas are likely to experience annual or more frequent flooding, with the islands of the Pacific (e.g. Tonga), Caribbean, and the Indian Oceans facing the largest relative increase in flood risk. It projected out to the 2080s; the number of people facing high flood risk from sea level rise in these regions would be 200 times higher than in the case of no climate change (Nicholls *et al*., 1999).

Although the severity of the threat will vary regionally, sea-level rise of the magnitude currently projected is expected to have disproportionately greater effects on the economic and social development of many small island states like Tonga (Granger, 1997; IPCC, 1998). Coastal land loss from annual and decadal periodic effects of inundation and flooding are already projected to have widespread adverse consequences. Land loss from sea-level rise, especially on atolls (e.g., in the Pacific and Indian Oceans) and low limestone islands (e.g., in the Caribbean), is likely to be of a magnitude that would disrupt virtually all economic and social sectors in these countries (Leatherman, 1997). For example, recent estimates indicate that with an increase of between 0.3 and 1m in mean sea level (MSL) would cause land loses of 3.1 and 10.3 km^2, respectively, or 1.1 and 3.9% of the total low-lying coastal areas in Tongatapu Island, Tonga, would be lost to the effects of annual and decadal periodic coastal inundation, flooding, and beach erosion (Fifita et al., 1992; Mimura and Pelesikoti, 1997).

3.3.3. Storm Surge and Flood Risks

The changes in the highest sea levels at a given locality will result from the change in mean sea level at that location and changes in storm-surge heights. If mean sea level rises, present extreme levels will be attained more frequently, all else being equal. The increase in maximum heights will be equal to the change in the mean, which implies a significant increase in the area threatened with inundation (e.g. northern low-lying coastal areas of Tongatapu Island). This will be especially true in areas with a small surge envelope (e.g. Tongatapu Island), which is typical in most small island states like Tonga. For example, in the case of Tongatapu Island, recent estimate predicted that land loss in the coastal zone sector of the island would increase to 37.3 km^2 (14%) with storm surge superimposed on a 1-m sea-level rise scenario (Mimura, 1999). Even incrementally small elevations in sea level potentially have severely negative effects on low-lying coastal areas of high islands (e.g. northern side of Tongatapu Island), atolls, and low islands (Forbes and Solomon, 1997; Nicholls *et al*., 1999).

Increases in storm –surge heights would result from alterations in the occurrence of strong winds and low pressures. Tropical cyclones are the major cause of storm surges that impact small islands in the Pacific (e.g. Tongatapu Island), Atlantic, Caribbean, and Indian Oceans. Moreover, the changes in the frequency and intensity of tropical cyclones could result from alterations to Sea Surface Temperature (SST), large scale atmospheric circulation, and the characteristic of ENSO (Pittock *et al*., 1996).

3.3.4. Beach and Coastal Changes

A wide range of beach types and characteristics are represented in the coastal areas of Tongatapu Island. Coastal erosion is a common problem in most small Pacific island states and evidently may be exacerbated by sea level rise or an increase in storminess (Fifita *et al*., 1992, Mimura and Pelesikoti, 1997, Mimura, and Nunn, 1998, Mimura, 1999). The particular coastal erosion problems that occur in most parts of the coastal areas of Tongatapu Island are partly the result of human activities such as sand mining (Gillie, 1997; Ragoonaden, 1997).

In the northern low-lying coastal areas of Tongatapu Island, and many atolls (in the Pacific), and low reef islands (in the Caribbean), carbonate beaches are maintained by sand produced from productive reefs whose degradation already is causing accelerated beach erosion (Nunn, 1988, Leatherman, 1997). Similarly, in the Mediterranean Sea, where the islands are periodically susceptible to flooding and scour from storm surges, an increase in storminess would further stress natural and human systems located at the coast (Nicholls and Hoozemans, 1996).

Nunn and Mimura (1997) report that the coasts of some islands in Fiji have retreated by more than 30m in the past 70 years due to erosion. In the specific case of Viti Levu and Taveuni, Fiji, beach erosion has been attributed to a combination of human-induced causes (including loss of the mangrove fringe and other natural protection) and elevated sea level, which has been rising at a rate of approximately 1-1.5 mm yr^{-1} since 1960 in Fiji (Forbes ad Solomon, 1997; Nunn and Mimura, 1997).

Beach erosion is occurring on Tongatapu Island. Many coasts on the limestone islands of Tonga are high and cliffed and appear to resist marine erosion quite effectively, at least compared to a human lifespan. But on the low-lying coasts, particularly the densely-populated north coast of Tongatapu, considerable inundation and erosion has probably occurred in recent decades, associated in places with mangrove clearance and beach-sand mining (Nunn and Mimura, 1997).

3.3.5. Human Vulnerability

The most-threatened populations are in low-lying areas, which are already under stress because of overcrowding, frequent inundation (during storms), and other environmental problems (Nunn and Mimura, 1997). On high islands formed on older volcaniclastics like Vavaú, populations will not be affected by sea-level rise although many of their neighbors in the low Haápai group may be displaced with a 0.5 m rise. The problems associated with displaced peoples will have to be addressed alongside the question of land tenure (Nunn and Mimura, 1997). "If the King and his nobles are not prepared to release more land to commoners for settlement, trouble may arise" (Nunn and Mimura, 1997).

Many of the coastal roads in the northern low-lying coastal towns and villages of Tongatapu are threatened by flooding and inundation. Most of the coastal communities settlements and roads are located within 100 metres of the coast and, in places are less than 5 m above sea level. The coastal villages on the northern coast of Tongatapu are particularly vulnerable to inundation and flooding. The major port facilities in Nukuálofa are likely to be under serious threat if sea level rises as predicted. For example, a 0.5m rise of sea level would inundate approximately 16% of the existing Nukuálofa port area (Nunn, 1988).

The Government of Tonga is contemplating relocating some of its departments to higher ground in the southeast coast of Tongatapu, particularly to Fuaámotu areas where Tonga international airport is located, to reduce their vulnerability to potential flooding and inundation (Nunn and Mimura, 1997).

3.3.6. History of the effects of Tsunami in the coastal zone of Tongatapu

Tongatapu coastal zone is also vulnerable to Tsunami. A historical account has reported an earthquake that tilted Tongatapu on Christmas Eve 1853 (Nunn, 2001). Resulted in the north east end of the island subsided causing up to 2 miles of inundation. This subsidence diminished along the eastern coast as far as Nuku'alofa, where at least one waterfront property was submerged. Uprooted of a tree was grew within a garden and destroyed of a house by this particular Tsunami event was reported. As a result of that Tsunami event, the western coast of Tongatapu at that time was reported to be risen to some feet, and also a spring of water was observed to be sunk below the surface (Nunn, 2001). Apart from that, is the 1865 earthquake that hit Tonga included Tongatapu, that was identified as the only tsunami had generated far field from Tonga subduction zone was observable without instruments. For example, the run up heights reached 2 m in Rarotonga and 80 cm in Marquesas Islands (Okal et al., 2003). These reported historical events signified the higher degree of Tongatapu coastal zone vulnerability to possible future Tsunami event. These events suggest that the estuary to the east of Nukuálofa is possibly linked in part to these tsunami events. Further, the seismic informatiom suggests that earthquakes of this magnitude may be sufficiently frequent that coseismic subsidence represents a greater threat to the coastal towns and villages of Tongatapu than sea level rise due to global warming (pers com, W. de Lange, 2006).

CHAPTER 4

SURVEY OF TONGATAPU LOCAL PEOPLE

4.1. Introduction

The main objective of a survey of the local people of Tongatapu was to collect their traditional knowledge and memories of the past, of the localized impacts and adverse effects of extreme events like flooding and inundation of the low-lying coastal villages of the island causing by prolonged heavy rainfall period, tropical cyclone storm surges, and shoreline erosion. The survey intended to help overcome the shortage of data on the vulnerability of the coastal zone sectors of the island to localized flood events. Indigenous people who have been living in the same coastal villages at Tongatapu have observed environmental changes for generations.

For the purposes of this study various senior experts from selected government agencies; (Tonga Meteorological Services, Department of Environment, Ministry of Fisheries (Research Division), Tonga Water Board (Research Division), Ministry of Marine & Ports, Ministry of Lands, Survey & Natural Resources (Geology, Mapping, Surveying, and Energy Planning Division), Ministry of Works (Tonga National Disaster Management Office, Civil Engineering Division), Ministry of Agriculture & Food (Research Division), Ministry of Forestry, Ministry of Finance, Department of Statistics, Department of Central Planning), and the local coastal landowners of the coastal villages of Tongatapu, were approached and interviewed.

4.2. Survey Method

4.2.1. Survey Methods limitations

The survey of Tongatapu local people had some difficulties and limitations. Availability of the selected officials/local coastal landowners of Tongatapu to be interviewed at a secured booking time was not always the case. For example, some of them would call me at the last minute, and change our appointment for some other time, or otherwise they would apologise and say they couldn't make it at all. In that case, I looked for another person as a replacement, which required extra transportation and communication costs. The surveys were all conducted orally in the Tongan language. The forms given below were used to guide the discussions.

4.2.2. Survey Technical Equipments

The following equipment was used to undertake the survey;

1. 1/SONY Mini - Tape Voice Operated Cassette Recorder
   (Powerful Sound) – 350Mw

2. 1/ACER Laptop Computer (Aspire 3002WLMi)

4.2.3. University of Waikato Ethics Approval

Prior to the commencement of the survey an ethical approval from the University of Waikato Ethnics Committee had to be obtained (Appendix I). Both taped, a written materials and any information produced by the research were securely locked in my desk at the Earth Science MSc Graduate Student Room. D.G.01 at the Department of Earth and Ocean Sciences, University of Waikato. Interview scripts and data will be destroyed two years after the submission of my thesis.

The participants' informed consent (Appendix III) were included as part of the letter sent to each participant. This Informed consent was discussed when the interview time was arranged and as part of the introductory section to the interview.

The identified potential harm to the participants was loss of their time used in the interview. Interview time was kept to a minimum of no longer than 45 minutes unless the participant wanted to continue for longer. In a small island such as

Tongatapu it is possible that readers were able to identify those involved in the study through their role. Care was taken to report data so as to minimize the readers' ability to identify the role of the data source. Data were presented with due regard to the potential impact on participants. Specific and relevant aspects of the collected historical information, and memories of extreme climatic events that are potentially contentious, will be returned to the participants for checking.

1). Participation is voluntary

2). Participants have the full right to decline to answer questions at any stage during the interview.

3). They may decline the inclusion of aspects of the data provided when they review their interview transcript.

The data and finding obtained were used for completing the course requirements for my MScREP Earth Sciences thesis. In addition, they may be used in seminars, conference presentation and research publications.

4.2.4. Questionaire development

The development of an open questionnaire interview form for Tongatapu local people survey which was made up of 12 major questions. The full survey form is included in (Appendix IV). The rationale of each question is discussed below.

Question 1. How long have you been staying in this coastal town/village?
This question gives an indication of the range of direct memory the respondent would have for the past storm and flooding events.

Question 2. How far is the location of your house from the coastline?

This question gives a guide to the level of direct experience participants would have with the impacts of storm and flood events.

Question 3. What storm events can you remember?

This question assesses which events the participant will be able to discuss and describe.

Question 4. What happened?

While participants often gave long descriptive answers to the question regarding effects of the major cyclones the following specific questions were included to attempt to elicit some answers that could be compared between survey participants.

Question 5. Do you know exactly what year that Tropical cyclone Isaac, Hina, and Cora were visited Tongatapu?

Assess accuracy of participants' recollections.

Question 6. Can you please give me an approximation of how many people would be at risk in the coastal villages of Tongatapu if a series of tropical cyclone events like Isaac, Hina, and Cora will be revisited Tongatapu coastal zone today?

To get a direct estimation of the magnitude of damage occurred during a cyclone storms could be remember by a respondent.

Question 7. Can you please give me an approximation of how effective and strong the construction of the past/present existing seawall at the coast of Tongatapu?

To get a fair idea of what can remember by a respondent of what had happened to these seawalls during the past storm events.

Question 8. Can you give me an approximation of how effective is the past/present existing coastal reforestation protection project has been implemented in Tongatapu?

To get direct information on what each individual respondent could remember about what really happening in the coast during cyclone season.

Question 9. Do you thinks there are ways we can build a coastal defence structures to prevent similar events in the future?

To get a direct information from the respondents on what they could remembered it was happened to these coastal structures during past storm events.

Question 10. Can you please give me an approximation of how much has already been spent by the Government of Tonga on sea wall construction in Tongatapu (1977-2006)?

To get a direction information of what can remember by the respondents on the type of design used and damage level.

Question 11. Who pays for the costs of the construction of the foreshore protection structures established in the north coastline of Tongatapu since 1986?

To get a direct information of what the respondents could remember of what type of coastal design and engineering they used.

Question 12. Is there any new coastal protection structure development projects that are being implemented here in Tongatapu at the present time?

To get a direct information on what the respondents could remember of any current storm events impacts on the coast of Tongatapu.

4.2.5. Procedure for recruitment and interview of participants

The Secretary for the Ministry of Lands, Survey & Natural Resources (Government of Tonga), approval for this study was sought through a letter sent as soon as the research was approved by the University of Waikato Research Ethics Committee. The order of contact was government officers were approached firstly, and then finally the town officers and local coastal landowners were contacted.

Appointments were set up with selected participants from government departments/ministries (Table 4.1).

Table 4.1: List of the officials interviewed between the 15/12/2005 – 16/01/2006.

Government Agencies/officials interviewed	**Date**	**Location**	**Number of officials interviewed per Gov't Agencies**
1. Ministry of Lands, Survey & Natural Resources - Secretary & Surveyor General - Head of Coastal Division - Head Geodetic Survey Division - Assistant Geodetic Surveyor - Head of GIS Mapping Division - Assistant GIS Mapping Officer - Head of Geology Division - Senior Geological Officer (1) - Senior Geological Officer (2)	 15/12/05 16/12/05 19/12/05 20/12/05 21/12/05 05/01/06 06/01/06 09/01/06 10/01/06	 Office, Nukuálofa Office, Nukuálofa Office, Nukuálofa Office, Nukuálofa Office, Nukuálofa Office, Nukuálofa Office, Nukuálofa Office, Nukuálofa Office, Nukuálofa	(9)
2. Tonga Meteorological Services	11/01/06	Office, Fuaámotu International Airport	(1)
3. Ministry of Works - Head of Civil Engineering Division - Head of Tonga National Disaster Emergency Management Office	 12/01/06 13/01/06	 Office, Nukuálofa Office, Nukuálofa	(2)
4. Department of Environment - Co-ordinator Tonga National Climate Change Enabling Activity Project	 16/01/06	 Office, Nukuálofa	(1)
13			

Appointments were made with the town officers of selected low-lying coastal towns/villages. The purpose of the first formal contact with each town officer was: to personally address an invitation for their respective villages to be part of the research; to request permissions to access their respective villages; and to seek their advice on who would be the most suitable senior expert people in their villages, in matters related to past flood events, that were available to be interviewed. Letters were sent to inform the respective town officers of the coastal towns/villages before my initial visit to them. One person from each of 25 coastal towns/villages was interviewed in their own homes (Figure 4.1). Representatives of the following villages were interviewed:

Table 4.2: List of selected vulnerable coastal villages and numbers of selected coastal landowners interviewed between the 17/12/05 – 10/02/06.

Name of villages		**Date**		**Location**	**Total number of person interviewed per coastal villages**
1. Kanokupolu		17/12/05		Home	1
2. Sopu		24/12/05		Home	1
3. Hala-ó-Vave		31/12/05		Home	1
4. Hala Ano		07/01/06		Home	1
5. Main town Nukuálofa		14/01/06		Home	1
6. Fasi		17/01/06		Home	1
7. Maúfanga		18/01/06		Home	1
8. Houmakelikao		19/01/06		Home	1
9. Patangata		20/01/06		Home	1
10. Popua		21/01/06		Home	1
11. ‘Anana		23/01/06		Home	1
12. Ngeleía		24/01/06		Home	1
13. Pahu		25/01/06		Home	1
14. Fanga		26/01/06		Home	1
15. Kolomotuá		27/01/06		Home	1
16. Vaololoa		28/01/06		Home	1
17. Haveluloto		01/02/06		Home	1
18. Tofoa Coastlines		02/02/06		Home	1
19. Pea		03/02/06		Home	1
20. Haáteiho		04/02/06		Home	1
21. Nukuleka		06/02/06		Home	1
22. Makaunga		07/02/06		Home	1
23. Talafoóu		08/02/06		Home	1
24. Manuka		09/02/06		Home	1
25. Niutoua		10/02/06		Home	1
Total number of selected coastal towns/villages coastal landowners were interviewed					25

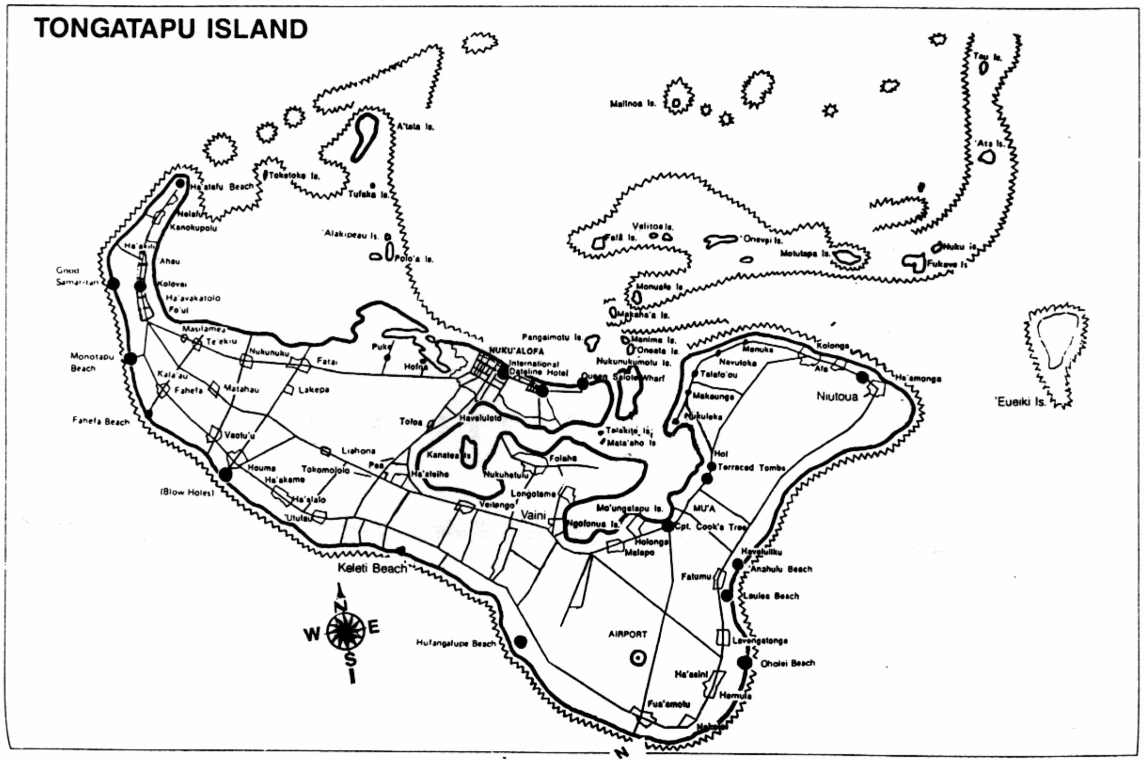


Figure 4.1: Map of Tongatapu shows the names and locations of the surveyed coastal villages (**Source**: Douglas, and Douglas, 1989).

The participants were involved in an interview of at least 45 minutes. The interviews were generally at 5.00 pm so as not to encroach on people's work time. The interview was audio-tape recorded with the participant's permission.

4.3. RESULTS

Over a period of eight weeks and two days, from 15th December 2005 – 10th February 2006, 38 respondents from Tongatapu were interviewed; 13 from government agencies, and 25 from local low-lying coastal villages. All of the respondents were coastal landowners. The results for each question are as follows:

4.3.1. Personal Background:

Question 1. How long have you been staying in this coastal town/villages?

Most of the respondents had stayed in their villages for their whole life.

More than half of the respondents (67%) had stayed in their village for between 50 and 75 years , 28 % of respondents between 25 and 50 years. Four percent of respondents were over the age of 75 years, and about 1% of the respondents were less than 25 years old or had lived in their current villages for less than 25 years. (Figure 4.2).

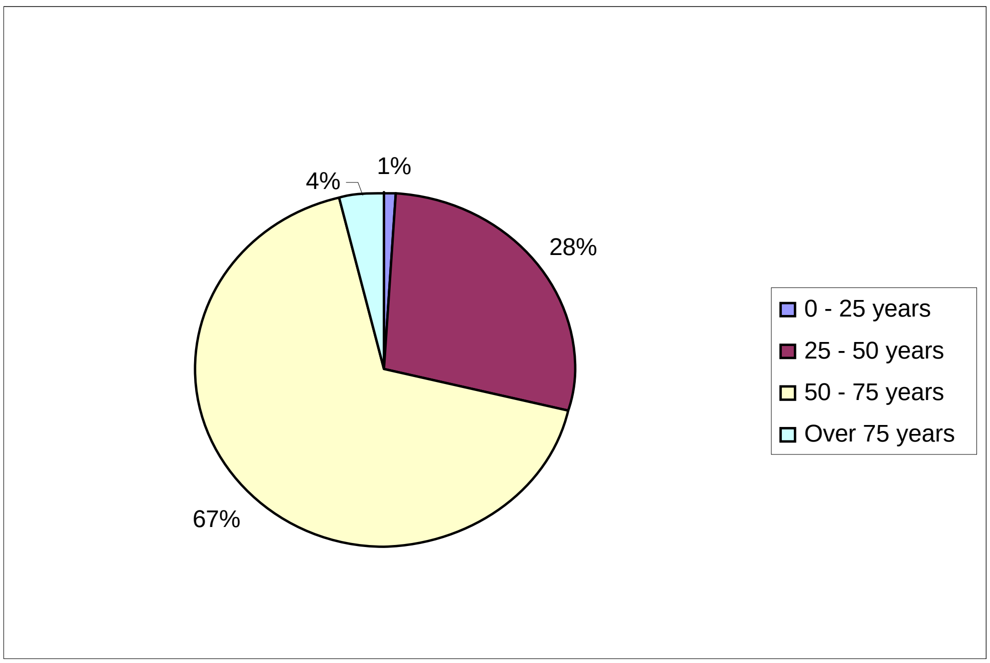


Figure 4.2 Percentage of the respondents and the length of time in years they had resided in their current village.

Question 2. How far is the location of your house from the coastline?

About 75% of the respondents had built most of their houses within and around 10m from the coast, and 18% at 10 – 25m, 4% at 25 – 50m, 2% at 50 – 75m, and less than 1% of the respondents built their houses over 100m away from the island coastlines. Generally, Ninety three percent of the respondents lived less than 25 m from the coast.

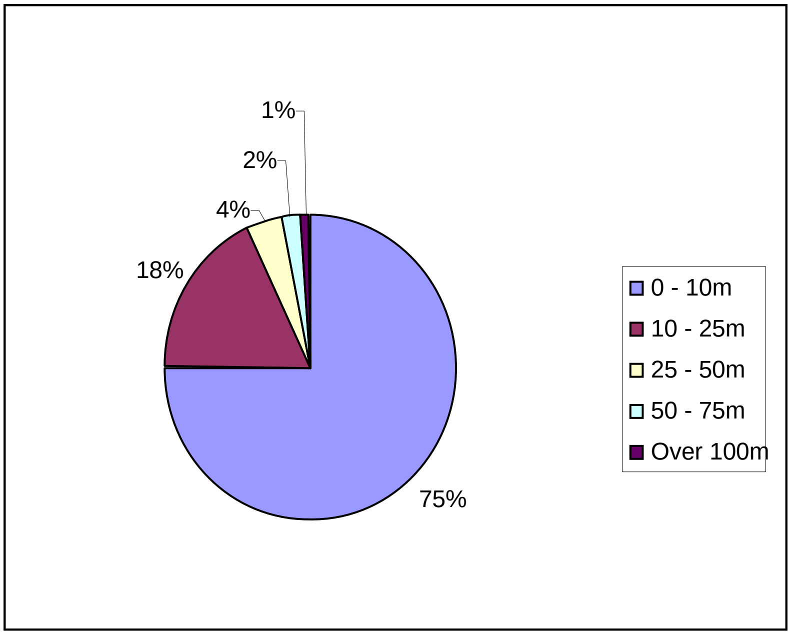


Figure 4.3 Percent of Respondents' houses within each distance from the coastline.

4.3.2. Knowledge, experiences, and Memories of Past Extreme Events (e.g. Tropical cyclone, Flood events):

Question 3. What storm events can you remember? (E.g. Tropical cyclone)

Out of the 3 major storm events that hit the coastal zone of Tongatapu during the last 26 years, more than 95% of the respondents still remembered and considered Tropical Cyclone Isaac (1982), as the biggest ever storm event to hit Tongatapu coastal zone, and 3% remembered Tropical Cyclone Hina (1997), and 2% for Cora (1998). Generally, ninety nine percent of the respondents remembered Isaac, Hina (100 %) and Cora too. Less than fifty percent remembered any other severe storm events.

Question 4. What happened?

The respondents view of the sea level changes during cyclone Isaac (1982), Hina (1997), and Cora (1998). Ninety two percent of the respondents reported that storm surge level was up to 3 meter or more in the Northern coast of Tongatapu during cyclone Isaac of 1982, and less than 5% claimed that it was not that worst during during Tropical cyclone Cora and Hina it was less than 2 meter above high-water mark, and less than 2% they don't really remembered what had happened. The north coast of Tongatapu especially the main town of Nukuálofa, Kanokupolu village (north Tongatapu), Sopu, and Popua villages located surrounded Fangaúta lagoon are the lowest lying part of Tongatapu.

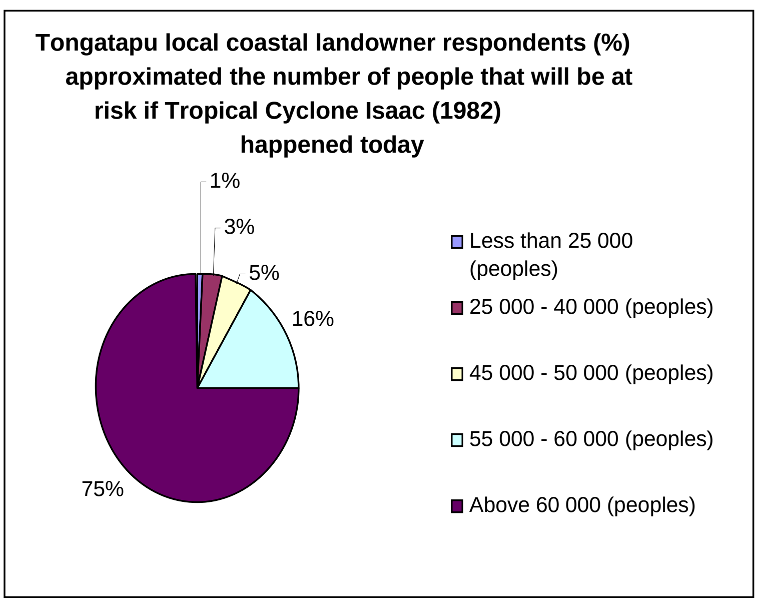
Question 5. When was it?

The most common date of storm events that more than 83 percent of the total respondents could remember shown below, and less than 4% remember other storm event, and more than 2% of the respondents cannot remember any storm event..

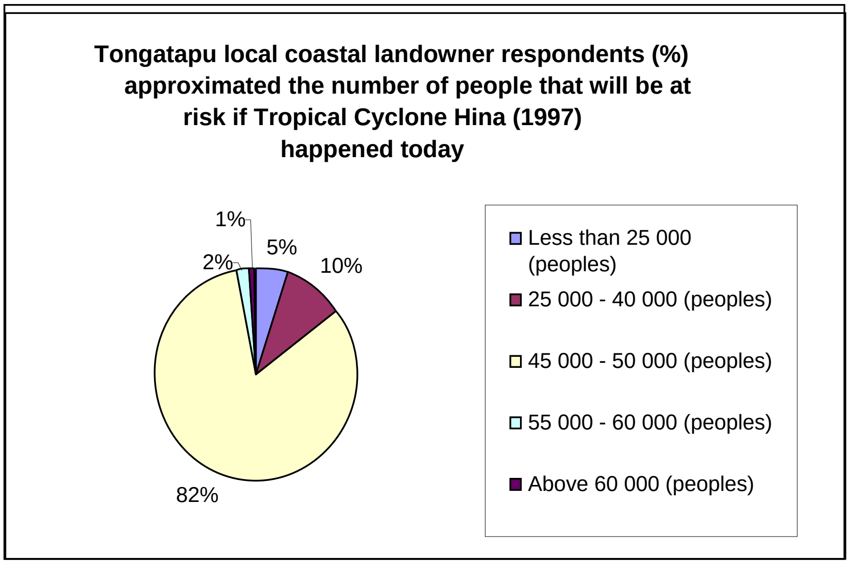
Tropical Cyclone Isaac – 1982
Tropical Cyclone Hina – 1997
Tropical Cyclone Cora – 1998

Question 6. If similar event happened now how many people would be at risk?

A. Tropical Cyclone Isaac (1982)



B. Tropical Cyclone Hina (1997)



C. Tropical Cyclone Cora (1998)

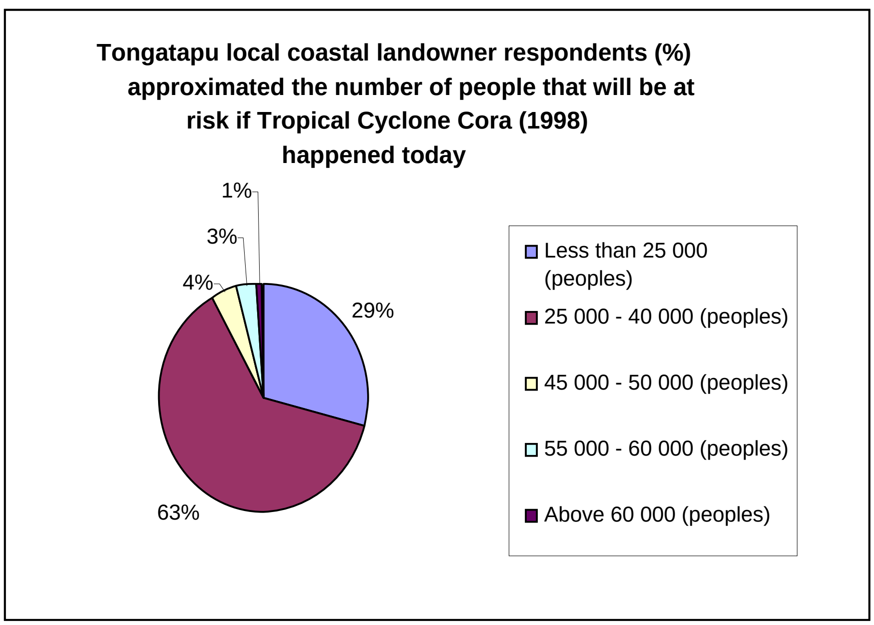


Figure 4.4. **A**. Tropical Cyclone Isaac (1982), **B**. Tropical Cyclone Hina (1997), **C**. Tropical Cyclone (1998).

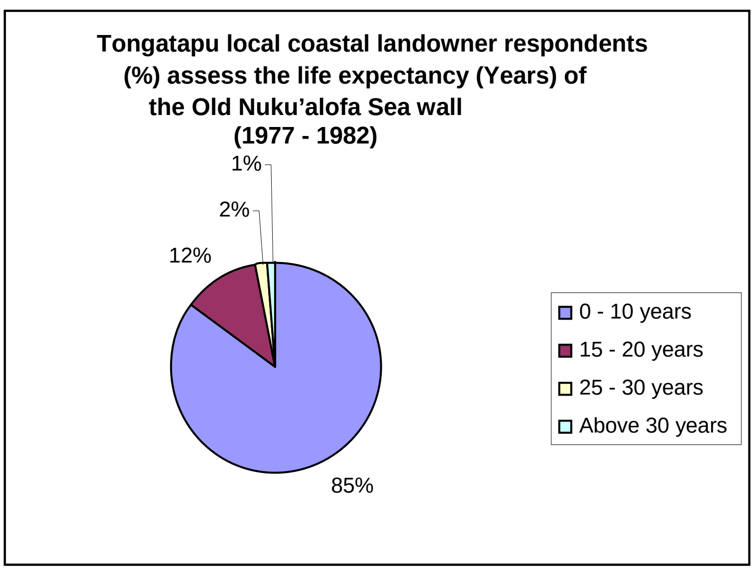
Seventy five percent of the respondents claimed that if Tropical Cyclone Isaac (1982) happened today, there would be more than 60 000 peoples that will be at risk in the low-lying coastal areas of Tongatapu. Eighty two percent of Tongatapu local coastal landowner respondents claimed that if Tropical Cyclone Hina (1997) happened today, approximately there would be between 45 000 – 50 000 people that would be at risked in the low-lying coastal areas of Tongatpu (Figure 4.4B). Sixty three percent of Tongatapu local coastal landowner respondents claimed that if Tropical Cyclone Cora (1998) happened today, approximately there will be between 25 000 – 40 000 people that would be at risk in the low-lying coastal areas of Tongatapu (Figure 4.4C).

C. Past/Present Adaptation Approaches (e.g. built of sea wall and foreshore protection structures)

Question 7. How effective were the past/present existing seawalls/foreshore protection development projects in the protection of the low-lying coastal towns/villages of Tongatapu?

Eighty five percent of the respondents claimed that the old Nukuálofa sea wall was ineffective due to poor planning and failure engineering design. Ninety four percent claimed that the new constructed Nukuálofa sea wall was the best due to good planning and improved coastal engineering design.

A. Old Nuku'alofa Sea wall (1977 – 1982)



B. Modern-Day Nuku'alofa Sea wall (1986 -)

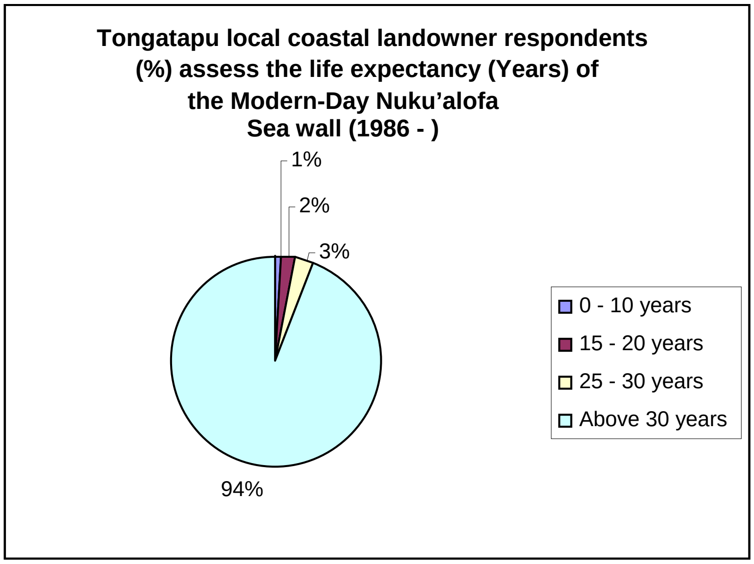


Figure 4.5. **A**. Tongatapu local coastal landowner respondents (%) assess the degree of the effectiveness of the Old Nuku'alofa Sea wall (Built before Tropical Cyclone Isaac, 1982) in the protection of the low-lying coastal areas of Nuku'alofa, **B**. Tongatapu local coastal landowner respondents (%) assess the degree of the effectiveness of the Modern-Day Nuku'alofa Sea wall in the protection of the low-lying coastal areas of Nuku'alofa.

Eighty five percent of Tongatapu local coastal landowner respondents assessed the effectiveness of the Old Nuku'alofa Sea wall in terms of its life expectancy (Years) and they claimed that the Old Nuku'alofa Sea wall life time was less than 10 years (Figure 4.5A). In contrast, Modern-Day Nuku'alofa Sea wall, ninety four percent of Tongatapu local coastal landowner respondents claimed that it will last for more than 30 years (Figure 4.5B).

Question 8. How effective is the past/present existing coastal reforestations development project in the protection of the coastal gardens and peoples properties from seawater spraying and soil erosion?

Tongatapu local coastal landowner respondents (%) assess the effectiveness (i.e. Categories 1 – 5) of the following four major coastal reforestation development projects implemented at Tongatapu since the last 20 years in the protection of the coastal gardens, and the people properties from seawater spraying and soil erosion.

Forty six percent of respondents ranked the Nuku'alofa Waterfront coastal tree replanting project at Category 4, forty three percent ranked the Houma village coastal tree replanting project at Category 3, ten percent ranked the Fanga'uta low-lying coastal areas mangrove tree replanting project at Category 2, and also one percent ranked Kanokupolu village coastal tree replanting project at Category 1.

Question 9. Are there any new coastal protection structure development projects that are being implemented here at Tongatapu at the present time?

More than 95% of the respondents remembered the developed of the Kanokupolu village foreshore protection structure (2003 - 2005) which is located along the North west coast of Tongatapu, and less than 5% they remember others, and more than 3% don't know anything.

4.4. DISCUSSION

4.4.1. Tongatapu local coastal landowner respondents' background

The personal background of the Tongatapu local village coastal landowner respondents was used as an indicator to measure how long they had observed the short and long term local impacts of storm and flood events amongst their own coastal towns/villages, by taking into consideration the approximate number of years they had stayed in a coastal village, and also the distance in meters of the actual location of their houses from the sea. These two factors clearly explained how much they can remember of what had been happened in the past/present storm or flood events based on what they observed before, during, and after a storm or flood event. The result of this survey has highlighted that those respondents had lived in coastal towns/villages for many years, and their house located close to the sea had a good general knowledge of the impacts of storm and flood events in the coast.

When asked how long they had been staying in most of their coastal town/villages, I found that more than 67% of the respondents were staying in their respective villages for more than 65 years, and most of their homes were located in and around less than 100 m from the coastline. Less than 1% of the respondents they don't know much about their village, because they just only migrated to Tongatapu since the last 10 years.

4.4.2. Knowledge, experiences, and memories of the past extreme events (E.g. Tropical Cyclones, Flooding events)

Out of the three major storm and flooding events that hit the coastal zone of Tongatapu during the last 26 years, more than 95% of the respondents still remembered and considered Tropical Cyclone Isaac (1982), as the biggest ever storm event to hit Tongatapu coastal zone.

4.4.3. Past/Present Adaptation Approaches to Tongatapu Coastal Zone (E.g. built of sea wall and foreshore protection structures)

The Tongatapu local coastal landowner respondents were asked to assess and compare how effective the past and present coastal protection structure has been built in the coastal zone sector of Tongatapu (e.g. Nukuálofa sea wall) since 1970. Eighty five percent of respondents assessed the effectiveness of the Old Nukuálofa sea wall (1977 – 1982) in terms of its life expectancy (years) and they claimed that the old Nukuálofa sea wall life time was less than 10 years, due to the lack of technical expertise and financial resources to built or to design a coastal defense structure that will withstand the strong force of the ocean waves during the tropical cyclone season (November – April). As compared to the existing state of the art Modern-Day Nukuálofa sea wall which was built by the Japanese and the Australians since 1986, 94% of the Tongatapu local coastal landowner respondents claimed that it will last for more than 30 years , due to the availability of the right technical expertise, technology, and financial resources. The Tongatapu local coastal landowner respondents were asked to give an estimate of how much money has been spent by the Government of Tonga on sea wall construction in Tongatapu (1977 – 2006). Seventy eight percent of the respondents estimated that more than T$6 million Paánga has been spent by the government on sea wall construction in Tongatapu alone since 1977. It was reported that the Government of Tonga annual budget allocation for development of coastal infrastructure like sea wall can't afford to build a major sea wall like the size of the existing Nuku'alofa foreshore protection structure that was built by the Japanese and the German in 1986. Even though more than 94% of the respondents agreed that there are always ways that the people and the Government of Tonga can find to develop or build coastal defence structures to prevent similar events on the coastal zone of Tongatapu in the future.

In addition, respondents were asked to give an estimation by ranking (i.e. scores range from 1 to 5, 1 = lowest, 5 highest), how effective the existing coastal forest replanting programmes were currently implemented in the coastal zone of Tongatapu. The results are as follow; 46% of the respondents ranked the Government of Tonga Nuku'alofa waterfront coastal tree replanting project at Category 4, 43% for Houma village coastal tree replanting project at Category 3, 10% for the Fangaúta lagoon community mangrove replanting project, at Category 2, and 1% ranked Kanokupolu village coastal protection replanting project at Category 1. It was reported that the success and effectiveness of these above coastal protection replanting programmes is entirely dependant on the availability of funds and seedlings.

Generally, the results of this survey suggested that the past and present adaptation approaches to build strong and effective kind of coastal protection structure systems for the coastal zone sector of Tongatapu, either replanting of coastal protection trees (e.g. soft adaptation option) or built a sea wall (hard adaptation option) are hampered by the lack of technical expertise and financial resources. The results of this survey suggested that the people and the Government of Tonga really need the technical and financial supports from its foreign counterparts, regional and international organizations, and local and international financial institutions to help finance and develop its local adaptation programme.

4.5. Conclusion

The people who lived amongst those coastal towns/villages of Tongatapu had observed better the localized impacts and the adverse effects of storm or flooding events like a tropical cyclone, on their villages and their properties, than those people who lived in the interior of the island. Tongatapu village coastal communities had knowledge, and experience of the localized impacts of those tropical cyclones that hit the Tongatapu coast in the past 100 years. They were the first people to observe the negative and positive impacts of the tropical cyclone wind/wave force on the coastal zone of the island every year. The people who lived in those coastal towns/villages of Tongatapu for many years had a good observation of the localized impacts of the past and present storm or flooding events on the coastal zone of Tongatapu. They had an accurate and consistent recollection of the local extent of the impacts and damage to the island shoreline caused by storm or flooding events in the past. They have recognized those places of the island coastal zone that have been damaged and destroyed by those cyclones of the past. They still keep some of their traditional knowledge and skills of weather forecast from the past such as looking to the colour of the cloud cover in the sky, and the height of the ocean waves, they received daily on their villages coastline, and they can easily predict the situation of the weather in the next 24 hours, whether it is going to rain or either a tropical cyclone is on it way to the island. They had a good daily observation of the local impacts of the strong force of the wind and ocean waves on the shoreline of Tongatapu. They had a vast knowledge and skills on how to adapt to major extreme events like tropical cyclone, such as build of a special kind of temporary shelter, and the preservation of water and food supply for families for the cyclone season. Generally, the memories and experiences of people living in long-established local coastal settlements within the main island of the Kingdom of Tonga – Tongatapu are an effective source of information to help scientists, planners, civil engineers, and decision-makers to fill the gap of information that they were usually required to conduct or complete a standard and professional assessment study of the overall vulnerability of an island coastal zone sector like Tongatapu to the localized impacts of the global climate change and sea level rise.

CHAPTER 5

USE OF GIS TO ASSESS THE VULNERABILITY OF COASTAL TOWNS AND VILLAGES OF TONGATAPU

5.1. Introduction

Tongatapu has sixty coastal towns and villages that are located adjacent to its coastal zone. There were about 15 coastal towns including Nuku'alofa the capital, and 45 coastal villages that are located in Tongatapu. More than 40 of these coastal towns and villages are located on the north coast of Tongatapu and about 1 town and 14 villages are located to the south coast of the island. The objective of this chapter was to use GIS to assess the local topography and identify areas that were close to sea level and there vulnerability to flooding. The populations of each coastal town are more than one thousand people but for the coastal villages they have only a population of less than a thousand. Amongst these 15 coastal towns and 45 coastal villages they are all vulnerable in various ways and different scales to the local impacts of the flooding hazards associated with climate change and sea level rise related risk that occurred during the cyclone season in Tonga (November – April) every 1 year or 2.

5.2. Construction of GIS Database

A GIS database was constructed at the University of Waikato using ArcView GIS software. The data incorporated includes:

- A 2001, 5 meters (line interval) contour map digital geotiff file of Tongatapu from the Government of Tonga Ministry of Lands, Survey & Natural Resources
- Tongatapu Aerial photographs from 1968, 1979, 1981, 1990, and 2000 combined digital geotiff file from the Government of Tonga Ministry of Lands, Survey & Natural Resources

- A 2000 satellite image of Tongatapu digital geotiff file from NIWA
- A 2007 Google Earth Satellite image digital geotiff file of Tongatapu from Google Earth 2006 Europa TerraMetric Image Technologies.
- Interpretations of the coastal flooded area and main features

The GIS was used to store data and to extrapolate a 1 meter (line interval) contour map of Tongatapu to assist the developed and the interpretation of a future climate and sea level scenarios for the coastal zone of Tongatapu.

To create the database the following steps were followed:

1. A digital geotiff files of the 2001 existing 5 meters contour map of Tongatapu, a satellite image of Tongatapu in 2000 from NIWA, and also a 2007 Google Earth satellite image of Tongatapu from Google Earth was imported to ArcViewInfo GIS 9.0

2. Using ArcViewInfo GIS 9.0 software:

The newly drawn 1 meter contour map of Tongatapu was processed through extrapolation the original 2001, 5 meters contour map of Tongatapu using ArcViewInfo GIS 9.0. The maps georeferenced (rectified) using the 2000 satellite image from NIWA, 2007 Google Earth Satellite image, and the 1968, 1979, 1981 and 1990 aerial photographs, and also using my own local knowledge of the relief and topography of Tongatapu island.

3. The extrapolated 1 meter (line interval) contour map images of Tongatapu were imported into the ArcViewInfo GIS 9.0 and overlaying it with the 2000 satellite image of Tongatapu from the NIWA to rectify the possible error and distortion of the newly drawn 1 meter (contour line interval) contour map in comparison with the original 2001, 5 meters contour map of Tongatapu. This process also marked and traced the number of towns and villages that are located in the most vulnerable areas of the coastal zone of Tongatapu.

4. Finally the aerial photographs and satellite image were interpreted and correlated with the new extrapolated 1 meter contour map of Tongatapu to identify changes taking place within the coastal area over the time span of the data used.

GIS Structure

The GIS folders were constructed on a temporal basis with folders for the rectified map images of the newly extrapolated 1 meter contour map, existing rectified aerial photographs, and satellite images of Tongatapu. Workspace was created for the extrapolated 1 meter rectified contour map images of Tongatapu.

Within each folder there are MapInfo tables with interpreted information such as coastline features, coastal towns and villages, and newly drawn 1 meter contour map line intervals which range from 1m to 5m in height above sea level, to assist the accurate marking of the areas of the coastal zone of Tongatapu that are currently predicted to be affected by the on-going impacts and adverse effects of climate change and sea-level rise related risk.

In the interpretation each time series data set is distinguished by one colour although where necessary the shade of colour varies to identify individual features.

5.3. Development of local sea level Scenario for Tongatapu Coastal Zone.

5.3.1. Local Coastal Sea-level Scenarios

In order to assess the vulnerability of the coastal zone of Tongatapu to the local impacts of climate change and sea level rise related risks, a scenario had to be developed and assumed. To do that various coastal sea level conditions are taking into account.

The increase in sea level by storm surge has positive and negative impacts on the coastal zone of Tongatapu. Therefore, the effects of storm surge in the coastal areas of Tongatapu are very important parts of this particular scenario.

The 1 meter contour map of Tongatapu was extrapolated from the original 2001 modified topographical map of Tongatapu (Ministry of Lands, Survey & Natural Resources, 2001) shows the relative elevation of the coastal areas of Tongatapu that are located in areas less than 5 meters above sea-level.

Storm surge level caused by cyclone Isaac (1982) was reported to be more than 3 meters above the island coastline. The elevation of coastline is usually determine by the high water level. However, the 1-meter contour map line interval was assumed to be the coastline in this assessment. For the assessment of the vulnerability of Tongatapu coastal zone to local impacts of climate change and sea level rise related risks, the following water levels were used to take into account the effects of storm surge.

a. High water level (Coastline) — 1.0 meter above sea level of today

b. Storm-surge level — 3 meters above sea level of today

c. Sea-level rise — 0.4 and 1.0 meter above sea level of today

The area below the storm-surge level can be considered as area at risk for flooding, while the area below high-water level may be regarded as areas at loss by inundation (Table 5.1).

Table 5.1 Scenarios for local coastal sea levels

Sea level conditions	Present condition	Sea level rise 1	Sea level rise 2
Normal condition (High-water level)	1.0 m	1.0 + 0.4 = 1.4 m	1.0 + 1.0 = 2 m
Extreme event (Storm surge)	3 m	3 + 0.4 = 3.4 m	3 + 1.0 = 4 m

*Coastal elevations are based on the 2001 modified topographical map of Tongatapu (Ministry of Lands, Survey & Natural Resources, 2001). 1 – meter contour nearly corresponds to the high water level, i.e. the present coastline.

For instance, if a storm surge of the highest level would occur under the situation of 1-meter sea level rise, the water level could reach 4 meter above the present coastline. Even for the normal condition, the high-water level would become 1.4 m for 0.4 m rise in sea level and 2 m for 1-meter rise. Other consideration is the possible uplift of the south coast of Tongatapu due to on-going earthquake activities in Tonga since the last 200 years. But in facts, I believe that more research is needed to be done in the near future to confirm this argument. Therefore, this scenario is focus only in the anticipated sea-level rise effects.

5.4. GIS generated contour map for Tongatapu

Another necessary material to the assessment of the vulnerability of the coastal areas of Tongatapu to local impacts of climate change and sea level rise related risks is the drawn of this 1 – meter contour map line interval for Tongatapu by GIS (Figure 5.1) to help the assessment of the possible impacts of climate change and sea level rise related risks in the coastal areas of Tongatapu..

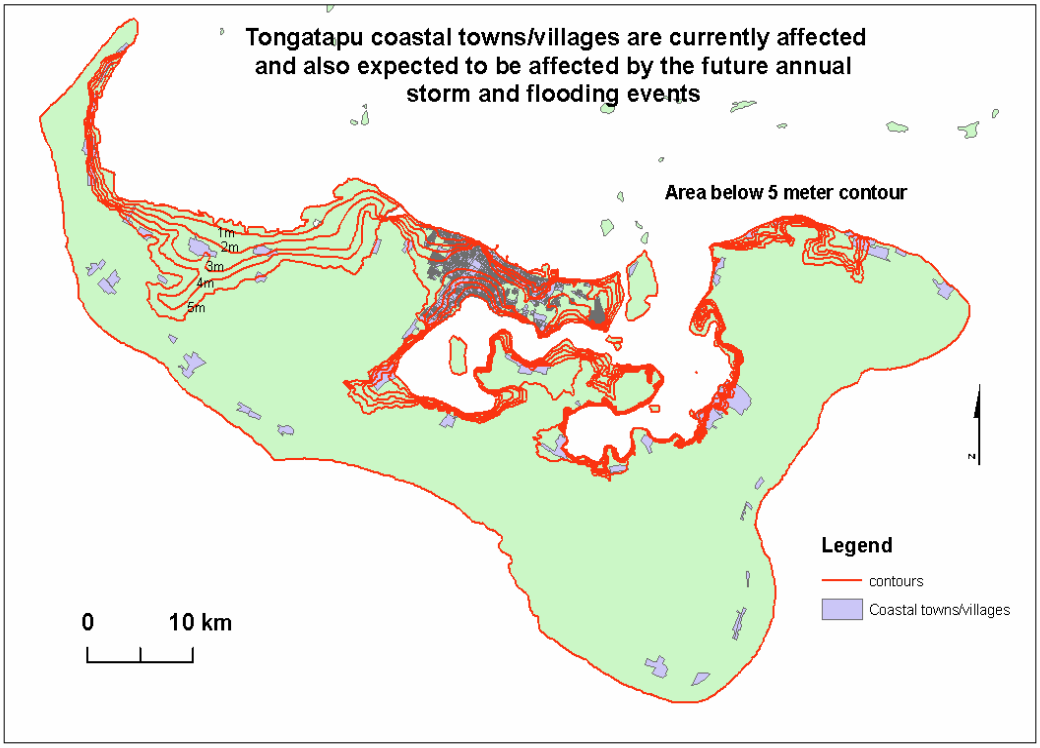


Figure 5.1 Map that shows the coastal areas of Tongatapu that are located below 5 meter above sea level.

5.4.1. Areas and population affected by inundation and flooding

Figure 5.2 shows the distribution of residence areas in the coastal zone of Tongatapu island. Since the population of each coastal towns and villages is known by the Tongan Government National census (1996), and the percentage of the affected areas were known, by using of the ArcView GIS measurement Ruker and Area function to trace the areas of the coastal zone of Tongatapu that located in areas less than 5 meter above sea level based on the extrapolated 1-meter contour map of Tongatapu.

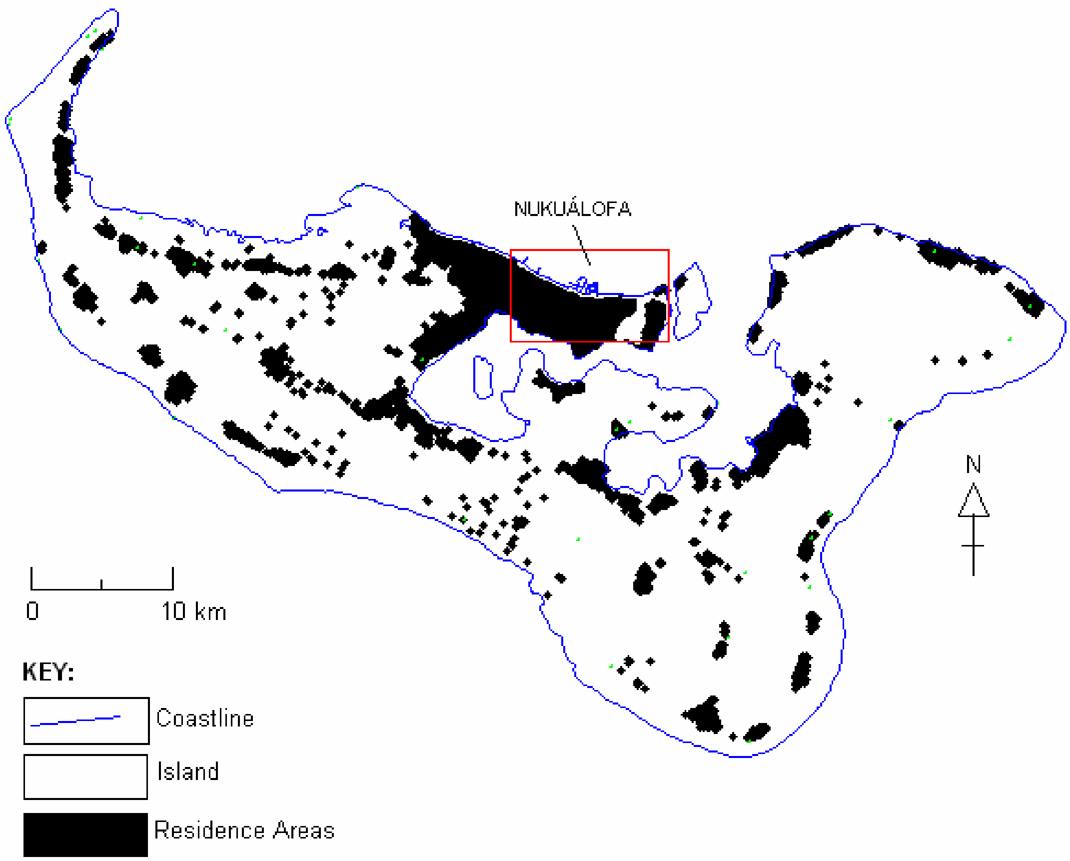


Figure 5.2 Distribution of coastal residence in Tongatapu island.

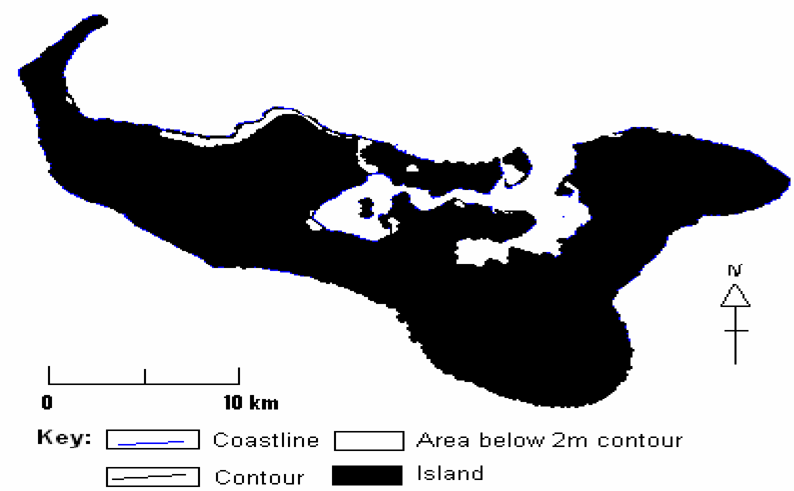
Table 5.2 Distribution of Tongatapu coastal populations within areas that less than 5 meter above sea-level.

Elevation above high – water level (present coastline)	Inundation Area		Affected residence area	Affected population	
	(km^2)	(%)	(km^2)	(People)	(%)
1 m	12.2	5.8	4.3	6052	16.1
2m	28.5	12.1	10.5	8421	37.5
3m	42.1	17.1	16.0	9563	51.3
4m	60.1	23.8	20.8	12741	65.1

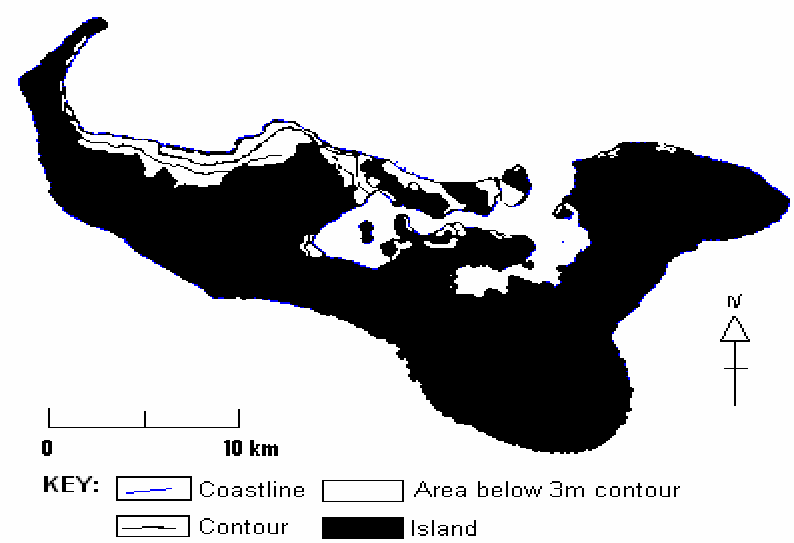
*Percentages of the affected areas and populations are based on the Ministry of Lands, Survey & Natural Resources Tonga, Tongatapu land statistic 2001, and the Government of Tonga national human population census, 1996.

Figure 5.3 shows the area below the 2 to 5 meters contours, which correspond to the elevation of 1 to 4 meter. The whole Nukuálofa town areas and the surrounding coastal villages of the Fangaúta lagoon and northern coastline of Tongatapu areas are located in areas less than 5 meter above sea level.

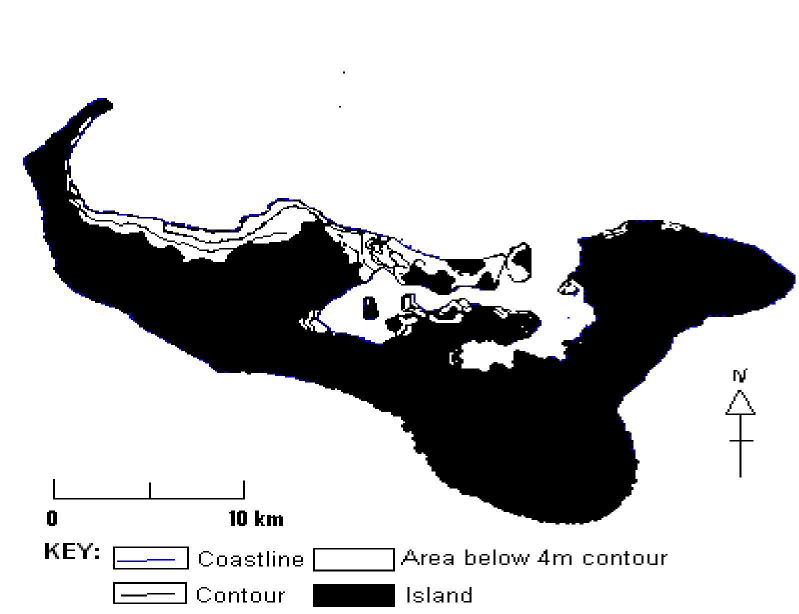
(a).



(b).



(c).



(d).

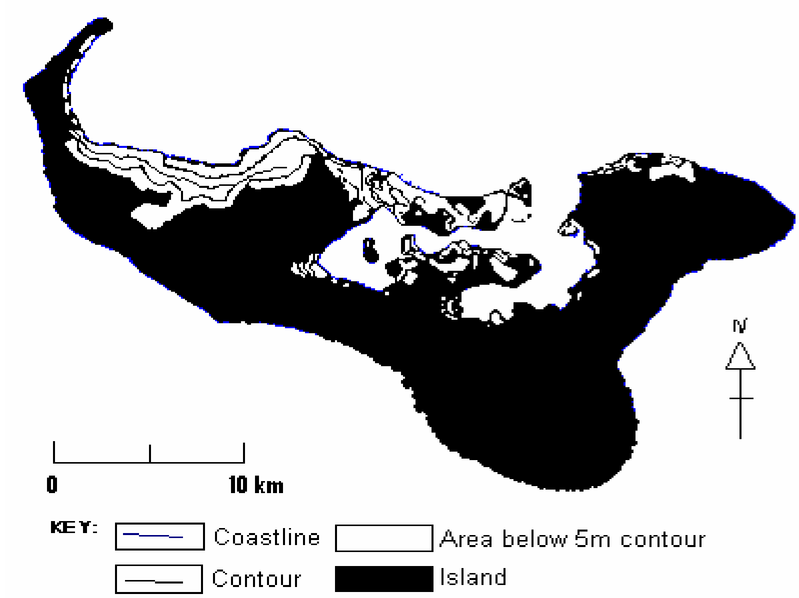


Figure 5.3 Tongatapu coastal areas to be affected by inundation and flooding.

5.5. Discussion/Conclusion

The areas of the coastal zone of Tongatapu that is located within areas that are less than 2 meters above sea level is the most vulnerable parts of the coastal zone of Tongatapu to coastal inundation and flooding risks. While the areas that located in places that are less than 5 meters above sea level are affected by extreme storm surge during cyclone season.

CHAPTER 6

6.1 SUMMARY AND CONCLUSION

- More than 95% of the respondents agreed that the coastal zone of Tongatapu is highly vulnerable to inundation and flooding risks generated by the tropical cyclones that visit Tongatapu coastal water every year, based on their recollection, knowledge, and experienced of the past storm events that hit Tongatapu.

- GIS work showed that those coastal towns and villages of Tongatapu that are located in areas less than 5 meter above sea level are the most vulnerable parts of the island coastal zone to inundation and flooding hazards associated with climate and sea level rise related risks.

- The village of Kanokupolu (North west coast Tongatapu), Sopu, Hala ó Vave (North west coast Nukuálofa), Popua, Patangata (North east Nukuálofa), are found to be located in areas less than 3 meter above sea level.

6.2 Conclusion

The results suggest that sea level rise will increase the vulnerability of the coastal zone of Tongatapu to coastal inundation and flooding hazards considerably, by increasing the areas that are exposed to the highest coastal inundation and flood risk, hence increasing the number of critical facilities, properties, and people to the risk of coastal flooding. Comparing the upper and lower bound sea-level rise scenarios indicates that poorly managed coastal development could increase the island's coastal zone vulnerability to storm and flooding events. These results suggest that decision-makers could reduce Tongatapu coastal zone vulnerability to local impacts of climate and sea level rise related risks by making choices that steer development away from high risk areas.

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APPENDIX I

The University of Waikato

Application for Ethics Approval

Human Research Ethics Committee

1 Title of Project

Climate Change and Sea-Level Rise Impacts on the main island of the Kingdom of Tonga - Tongatapu: A Vulnerability Assessment.

2 Researcher(s) and Contact Details

a Name of applicant

Mr. Fine Faitehina Tutu'u Lao

b Program of study (if applicable)

Master of Science (Resources and Environmental Planning)

c Course number (if applicable)

ERTH594-05C

d Department/Centre/Unit

Department of Earth Sciences

e Contact Address

Department of Earth Sciences, University of Waikato, Private Bag 3105, Hamilton, New Zealand.

f Phone number

(07) 0211493114 (Mobile) or (09) 274 9663 (Home)

g Qualifications

Master of Science (Resources and Environmental Planning)

h Supervisor

Dr. Megan Balks
Dr. Willem de Lange

3 Description of Project

The focus of this research is on the assessment of the vulnerability of the low-lying coastal zone sectors of Tongatapu, the main island of the Kingdom of Tonga, to the degree of current and future risks induced by climate and sea level changes. For the purposes of this study various individual senior expert peoples from selected government agencies; (Tonga Meteorological Services, Department of Environment, Ministry of Fisheries (Research Division), Tonga Water Board (Research Division), Ministry of Marine & Ports, Ministry of Lands, Survey & Natural Resources (Geology, Mapping, Surveying, and Energy Planning Division), Ministry of Works (Natural Disasters, Relief and Rehabilitation Division), Ministry of Agriculture & Food (Research Division), Ministry of Forestry, Ministry of Finance, Department of Statistics, Department of Central Planning), and the local coastal landowners of Tongatapu, will be approached through interviewing of each potential government officers from each respective selected government departments/ministries and local coastal landowners of Tongatapu, to seek for valuable historical information of their memory of the past and present extreme events like tropical cyclones and sea level changes impacts on the coastal zone sectors of Tongatapu.

It is anticipated that the research findings will not only contribute towards the requirements for my program of study but also that the knowledge gained will make a useful contribution to the Government of Tonga, Coastal Landowners, Fisheries Managers, Tourism and Hotel Managers, Harbour Masters, Civil Engineers, Coastal Managers, Environmental Planners, and Town Planners of the Kingdom and abroad for the conceptualization, design, and implementation of their current and future integrated coastal management plans. However, for my results to be of use it is imperative to work in close cooperation with government agencies and the local coastal communities of Tongatapu.

a Procedure for recruitment of participants and obtaining informed consent

Getting the overall permission for the study to be conducted.

The Secretary for the Ministry of Lands, Survey & Natural Resources (Government of Tonga), approval for this study to be conducted within the low-lying coastal zone sectors of the main island of the Kingdom of Tonga - Tongatapu will be sought through a letter sent as soon as the research is approved by the Research Ethics Committee (see Appendix 1). Further information required will be clarified once the response from the Secretary for the Ministry of Lands, Survey & Natural Resources received.

The order of contact is government officers will be approached firstly, and then finally approaching the town officers and local coastal landowners.

Access to participating officials from the following selected Government of Tonga Agencies.

An appointment will be set up with each of the potential participants from the:
(1) Tonga Meteorological Services
(2) Department of Environment
(3) Ministry of Fisheries
(4) Ministry of Works
(5) Ministry of Lands, Survey & Natural Resources
(6) Ministry of Marine & Ports

(7) Department of Statistics
(8) Tonga Water Board
(9) Ministry of Agriculture & Food
(10) Ministry of Forestry
(11) Ministry of Finance
(12) Department of Central Planning

Those from government agencies will include:

- Director of Tonga Meteorological Services
- Secretary for Lands, Survey & Natural Resources
- Director of Environment
- Secretary for Fisheries
- Secretary for Marine & Ports
- Director of Works
- General Manager – Tonga Water Board
- Director for Agriculture & Food
- Director for Forestry
- Secretary of Finance
- Director of Planning
- Chief Statistician

The main purpose of being setup an appointment firstly with those above-stated head of government departments, is to seek for their approval and advice on who are the most appropriate senior officers from each of their respective departments that I should approach in the course of my research seeking for existing information and data on the impacts of climate and sea level changes in Tongatapu.

Access to low - lying coastal villages (Tongatapu):
An appointment will be set up with each respective low-lying coastal village town officers. The purpose of the first formal contact with each town officers is two fold: introduction and to personally address an invitation for their respective villages to be part of the research by allowing access to their respective villages, and also seek for their kind advice on who are the most suitable senior expert peoples in their villages in those matters related to climate and sea-level changes are available to be interviewed. Letters will inform the respective town officers of these coastal towns/villages accordingly on the inception stage of this research (see Appendix 2).

b Procedures in which research participants will be involved
The participants will be involved in an interview of no more than 45 minutes. The interview will be at a place and time most convenient to each participant. The interview will be audio-tape recorded with the participant's permission. Participants' informed consent will be sought prior to the interview time. See Appendix 3) for possible interview questions.

c Procedures for handling information and materials produced in the course of the research

Both taped, written materials and any information produced by the research will be securely locked in my desk at the Earth Sciences MSc Graduate Student Room. DG.05 at the Department of Earth Sciences, University of Waikato, and in my filing cabinet at home while in Tonga. Interview scripts and data will be destroyed two years after the submission of my thesis.

4 Ethical Concerns

a Access to participants

Selected Government Agencies

Selected participants will be personally invited to participate in the research. The invitation will also be formalised through a letter given to them in the meeting time. Interested participants will be contacted at a later date to set up time for the interview.

Low-lying coastal villages of Tongatapu

It is intended that access to participants from each respective low-lying coastal villages will be via town officers, will be invited to participate in the research through a letter sent to them. Interested participants will be contacted at a later date to set up time for the interview.

b Informed consent

The participants' informed consent (Appendix 4), will be included as part of the letter that will be sent to each. This will also be discussed when the interview time is arranged and as part of the introductory section to the interview.

c Confidentiality

Participants from the selected Government Agencies.

Names will not be disclosed by any means in the research report. Any transcript and reporting of data would by no means use names; codes and pseudonyms will be used instead. Care will be taken to report data so as to minimize the readers' ability to identify the role and hence identity of the data source. Data/information provided will be kept strictly confidential.

Participants from the low-lying coastal villages (Tongatapu)

Participants and their villages will not be identified in any written materials. Any transcript and reporting of data would by no means use names; codes and pseudonyms will be used instead. In addition, the assurance of participants' identity and data being strictly kept confidential will be addressed in the participants' letter of informed consent.

d Potential harm to participants

The identified potential harm to the participants could be losing their time for the interview. Interview time will be kept to a minimum (no longer than 45 minutes).

In a small island such as Tongatapu it is possible that readers would be able to identify those involved in the study through their role. Care will be taken to report data so as to minimize the readers' ability to identify the role of the data source. Data will be presented with due regard to the potential impact on participants, only specific and relevant aspects of the expecting collected historical information and memories of extreme climatic events to my thesis topic, that are potentially contentious will be returned to the participants for checking.

e Participants right to decline

1). Participation is voluntary

2). Participants have the full right to decline to answer questions at any stage during the interview.

3). They may decline the inclusion of aspects of the data provided when they review their interview transcripts.

f Arrangements for participants to receive information

A copy of the thesis will be made available through the main Library of the Geology & Mineral Resources Division of the Ministry of Lands, Survey & Natural Resources which will be accessible to all.

g Use of information

The data and findings obtained will be used for completing the course requirements for my MScREP Earth Sciences thesis. In addition, they may be used in seminars, conference presentations and research publications.

h Conflicts of interest

None anticipated.

i Other ethical concerns relevant to the research

Not applicable.

j Procedure for resolution of disputes

In any dispute that may arise as result of this research, the participants may approach me, and if their situation is not resolved they may approach my supervisor (details provided a letter).

5 Ethical Statement

The project will follow the University of Waikato Human Research Ethics Regulations 2000 and the ethical guidelines of the NZARE and include the following. Informed consent of participants will be obtained, without coercion. Exploitation (or perception of exploitation) of researcher-participant relationship will be prevented. Privacy and confidentiality will be respected. The participant will own the raw material collected, and their requests regarding the material will be honored. Participation in the research will not impact professionally on the participants.

6 Legal Issues

a **Copyright**
Participants will own their own raw data. The researcher will own the data analysis.

b **Ownership of materials produced**
The data produced both by audio taped recording and through verbal conversation with the participants are acknowledged owned by participants. Any further correction or amendments that would be needed either by the researcher's or his supervisor to any aspects of these collected historical informations, specific participant's approval will be sought. The researcher is the owner of the data analysis.

c **Any other legal issues relevant to the research**
No

7 **Place in which the research will be conducted**
Tongatapu – this is where participants such as the selected government agencies, Directors/Secretaries and Senior Expert officials have their offices.

Low-lying coastal towns/villages – specifically with town officers and elderly local coastal landowners (Tongatapu).

8 **Has this application in whole of part previously been declined approval by another ethics committee?**
No

9 **For research to be undertaken at other facilities under the control of another ethics committee, has an application also been made to that committee?**
Not relevant

10 **Is any of this work being used in a thesis to be submitted for a degree at the University of Waikato?**
Yes

11 **Further conditions**
In the event of this application being approved, the undersigned agrees to inform the Human Research Ethics Committee of any change subsequently proposed.

12 **Applicant Request for Approval of Ethics Application**

Signed by the Applicant ______________________________

Date	
Signed by the Supervisor	
Date	
Signed by the Chairperson/Director	
Date	

The ethics application is approved/requires further work

Signed on behalf of the Committee	**(Chairperson of the Committee)**
Date	

APPENDIX II

MSc Research Proposal

Research objectives

The main island of the Kingdom of Tonga – Tongatapu is like many small island developing countries in the Pacific Ocean is highly vulnerable to the adverse effects of climate variability, sea level rise and climate changes. Tongatapu vulnerability is principally due to its physiographic, socioeconomic and ecological characteristics (Tonga Department of Environment, 2005). The effects of climate variability are manifested by tropical cyclones, storm surges, drought, inundation and flooding (Mimura & Pelesikoti 1997). International Climate Scientists have reported that anthropogenic climate change will exacerbate the aforesaid effects (IPCC, WGI, 2001).

The specific aims of this research is to find out the overall vulnerability of, and possible impacts of climate change and sea level rise on the coastal zone sectors of the main island of the Kingdom of Tonga – Tongatapu.

Specific objectives include:

(4) Conduct literature review of the vulnerability of the coastal zone sectors of the main island of the Kingdom – Tongatapu to climate change and sea level rise:
  - Inundation and flooding
  - Global warming (Human Enhanced Green House Gases Emission)
  - Beach erosion
  - Saltwater intrusion
  - Impacts on infrastructure and society

(5) Develop a Geographical Information System (GIS) that shows:
  - Topography and bathymetry of the island
  - Land use types and changes
  - Human population distribution and density
  - Infrastructures (e.g. roads, power supply, sewage disposal, Port facility)
  - Coastal features

(6) Develop potential future climate and sea level scenarios and interpret with regard to GIS to assess its potential impacts at each scenario.

Focus of the Study

This research will focus only on the coastal zone sectors of the main island of the Kingdom of Tonga – Tongatapu (Figure 1). The Kingdom of Tonga lies between 15º and 23º50’ south of the Equator and 173º to 177º west of Greenwich in the South Pacific Ocean. The Kingdom is divided up into 4 main island groups which extended over a north-south axis: Tongatapu and ‘Eua in the South; Ha’apai in the middle; Vava’u in the north; and the small Niuas group in the far north. Tongatapu is the southern-most island Group of the Kingdom (Figure 1).

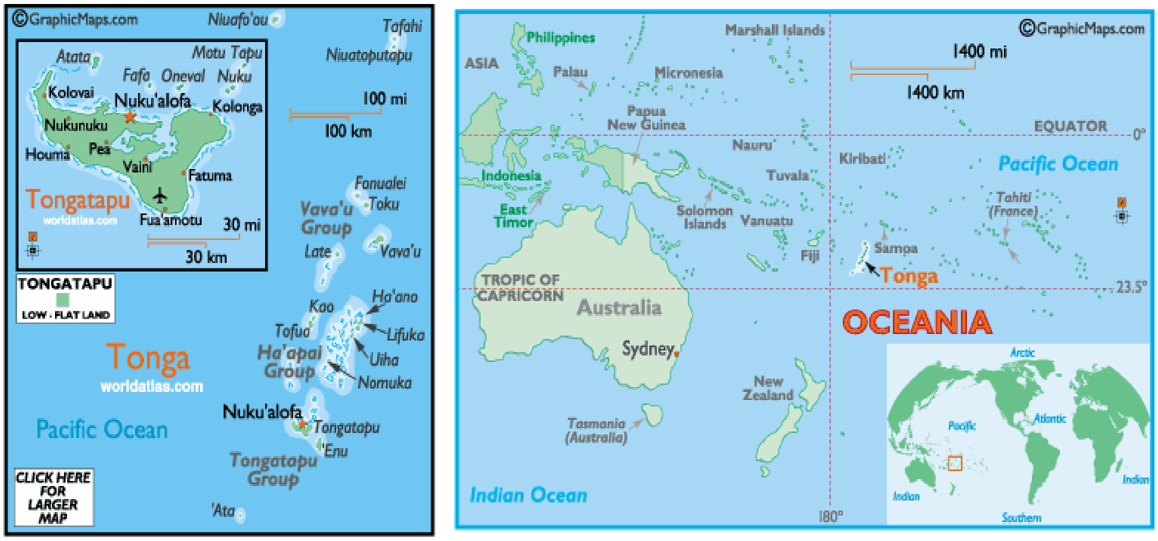

Figure: 1 Tongatapu’s Location

Research Methodology

The Intergovernmental Panel on Climate Change (IPCC) Common Methodology (IPCC CZMS 1991) will be considered to be the framework for the proposed vulnerability assessment study of the main island of the Kingdom of Tonga – Tongatapu, in which a set of specific data for natural and socio-economic conditions is required and the impacts are often evaluated on an economic basis using gross domestic product (GDP) as a typical index. However, we also considered in this research some of the problems that was pointed out by previous studies that have been done in Tonga and around many island countries in the Pacific, like the lack of data, such as topographic maps with precise contours, historical records of climate and mean sea level, land use pattern, and so forth – a constraint that is common in developing countries. In addition, the monetary economy is only a part of a country’s economic system, and a subsistence economy still prevails in the main island of the Kingdom of Tonga – Tongatapu. These factors restricted the direct application of the IPCC Common Methodology to assess the vulnerability of the coastal zone sectors of Tongatapu to current and future climate and sea level change.

An important aspect is to use the traditional knowledge and memories of the local people to overcome the shortage of data. Indigenous people who have been living in the same villages at Tongatapu have observed environmental changes for generations. The memories and experiences of people living in long-established local settlements within the main island of the Kingdom of Tonga – Tongatapu, are an effective source of information. Based on such recognition, a semi-empirical method will be developed to enable systematic analysis of the vulnerability of the coastal zone sectors of the main island of the Kingdom of Tonga – Tongatapu, to climate change and sea level rise by expert judgment. Due to the coastal nature of the main island of the Kingdom – Tongatapu, this proposed method classifies the coastal system of the island into 6 subsystems – natural, human, infrastructural, economic, institutional, and cultural (Figure 1), and evaluates their resilience and vulnerability to changes in external forces, such as sea level rise (Kay & Hay 1993).

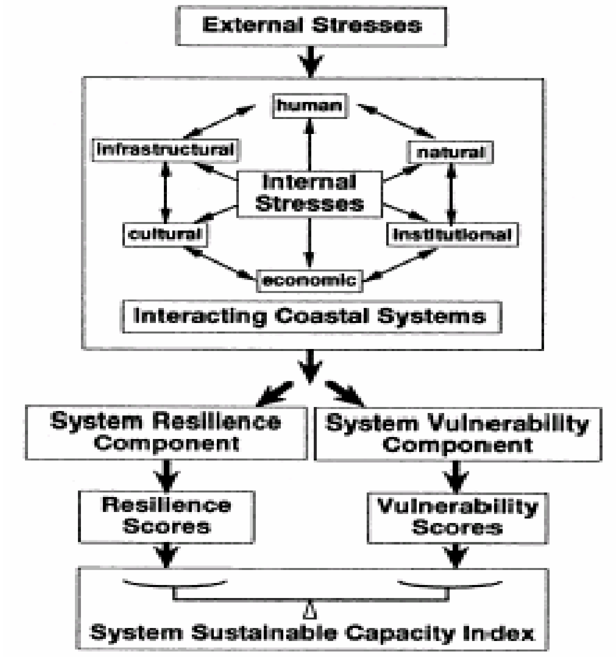

Figure 1. Framework of the semi-empirical assessment method
(Source: Kay and Hay, 1993).

A set of criteria for expert judgment will be established to evaluate the degree of vulnerability and resilience of the subsystems on a common basis (Parry and Carter, 1998). This method will allow us to draw an overall picture of the vulnerability of the entire island.

A similar approach will be applied to the analysis of beach erosion. Interviews regarding beach erosion and coastal protection practices will be carried out with elderly people in the local villages of Tongatapu. On the basis of the information will be collected from these interviews, a long-term trend in beach erosion will be analyzed from the view-point of the future sea level rise and climate change.

In addition to assessing impacts qualitatively, analytical science and engineering tools are also expected to be applied. Storm surge, wave height and run-up, and wave forces on wharfs, seawalls, and concrete blocks will be estimated using coastal engineering to evaluate the changes in external forces and their likely consequences.

Arc/Info 9.0 a Geographical Information System (GIS) computer programmes owned by the Geography Department of the University of Waikato, School of Arts & Social Sciences will be applied for the study of the vulnerability of Tonga to future sea-level rise and climate change, and also used to classify the coastal zones of the island in terms of vulnerability indexes, and economic evaluation, and to analyze the costs of countermeasures of sea level rise in Tongatapu.

The methods will be developed during the course of this study is combined experience-based and scientific ones. Using such a combination, we can reveal the overall vulnerability qualitatively, while evaluating the impacts on some coastal systems quantitatively. This approach will be so helpful to compensate for the lack of data (Mimura, 1999). However, the proposed methods do not cover all the related sectors in the coastal zone sectors of Tongatapu. To develop a response strategy for the main island of the Kingdom of Tonga – Tongatapu, based on the estimate of all the possible threats, we will need a set of quantitative methods and the relevant data for Tongatapu (Mimura and Pelesikoti, 1997).

Data Sources

Data and information will be utilized in this vulnerability assessments are expected to be collected from the following sources:

- South Pacific Sea Level and Climate Monitoring Project
- Ministry of Marine & Ports
- Ministry of Defence (Tonga Royal Navy)
- Ministry of Works
- Ministry of Lands, Survey & Natural Resources
- Ministry of Fisheries
- Department of Environment
- Department of Statistics
- Tonga Meteorological Services
- Tonga Water Board
- Tonga Visitors Bureau
- Ministry of Agriculture and Food
- Ministry of Forestry
- Personal view and judgment of the author
- Interview with elderly local coastal landowners, and experts from government
- Literature review of research articles, theses of special publications, national, regional an international reports
- Expert judgment of the author

Work plan

This research will take about 17 months:

Month/Year	Activity
Oct, 2005	• Finalise my thesis topic proposal • Abstract submission • Attend Graduate students conference – Poster Presentation
Nov, 2005	• Complete chapter 1

	• GIS – Learn a bit of how to use • Try to get base maps of Tongatapu sorted out • Literature review • Start write up first draft of the literature review
Dec, 2005	• Complete first draft of the literature review • Visit Tonga – Data collection • Holiday for 2 weeks
Jan, 2006	• Visiting government agencies • Interview local villages coastal communities elderly population
Feb, 2006	• Re-visit – University of Waikato, NZ • Working on - GIS application
March, 2006	• First draft – methods
April, 2006	• Develop scenarios • Sort which areas • How to apply to data
May, 2006	• On-going
June, 2006	• On-going
July, 2006	• First draft of GIS results
August, 2006	• Checking further data acquisition
Sept, 2006	• First draft of scenarios
Oct, 2006	• First draft of the discussion/conclusion
Nov, 2006	• Second drafts of all chapters at latest
Dec, 2006	• Third final draft of all chapters
Jan, 2007	• Dr. Megan Balks – visit the Antarctica • Dr. Willem de Lange – Annual leave

Feb, 2007	• 1 Feb – final discussion completed/Abstract • 10 Feb – final collation • 20 Feb – send Thesis to binder

This research design proposal is acceptable

Signed by the Applicant	
Date	
Signed by the Supervisor (if applicable)	
Date	

APPENDIX III

THE PARTICIPANT CONSENT FORM

UNIVERSITY OF WAIKATO
School of Science & Engineering
Department of Earth Sciences
Private Bag 3105, Hamilton

"Climate Change and Sea-Level Rise Impacts on the main island of the Kingdom of Tonga – Tongatapu: A Vulnerability Assessment"
Research Project for ERTH594-05C

Fine F Tutu'u Lao (Ph: 00 676 27514)/E-mail: fftl1@waikato.ac.nz or finelao@yahoo.com
Supervisor: Dr Megan Balks (Ph: 64-7-838 4024)/E-Mail: m.balks@waikato.ac.nz

CONSENT FORM

1. I am undertaking this research project as to complete the course requirements for my MScREP Earth Sciences thesis. The aim of the project is to collect the traditional knowledge, experiences, and memories of the local people of Tongatapu concerning the vulnerability of the coastal zone sectors of the island to climate and sea level changes.

2. I would like to interview you about your knowledge, experiences, and memories of how the coastal zone sectors of Tongatapu vulnerable to climate and sea level changes.

3. The interview will take about 45 minutes.

4. I would like to tape record the interview for transcription. I will produce a verbatim (word for word) transcript of the interview, which I will show you. You may add to the transcript or edit parts from it if you wish. My supervisor will have access to the edited transcript, but no one else will see it.

5. When I am not using them for writing my thesis, the tape recording and transcript will be securely locked in my desk at the (Earth Sciences MSc Student Graduate Room. DG.05) at the Department of Earth Sciences, University of Waikato and in my filing cabinet at home while I am here in Tonga. You may choose to have your tape recording and interview transcript given to you after my thesis has been completed and assessed. Otherwise, they will be destroyed in two years later.

6. If material from the report is published in an academic article, care will be taken to ensure that your anonymity will be preserved.

7. If you agree to take part in this interview, you have the following rights:
a) To refuse to answer any particular question, and to terminate the interview at any time.
b) To ask any further questions about the interview or research project that occurs to you, either during the interview or at any other time.
c) To provide information on the understanding that is confidential to the interviewer and the supervisor.
d) To remain anonymous - anything that might identify you will not be included in the write up of my thesis.
e) To read and add to the transcript of the interview, and to indicate any part of it that you do not wish to be used. You may withdraw your consent, and be given all material relating to you, at any time up until you have approved your transcript.
f) To discuss further the conditions of your consent at any stage.
g) To access the copy of the thesis will be available for all in the Geology & Mineral Resources Division of the Ministry of Lands, Survey & Natural Resources main Library.
h) To take any complaints you have about the interview or the research project to the Supervisor or to the Dean of the School of Science and Engineering.

"I consent to be interviewed for this research on the above conditions"
Signed: *Interviewee* ___________________________ Date: ____________

"I agree to abide by the above conditions"
Signed: *Interviewer* ____________________________Date:______

APPENDIX IV

Survey of Tongatapu local people Interview Questionnaire

Name of Interviewer:………………………**Date:**…………………**Time:**…………………….

Respondent No.:…………………………**Location:**…………………………………………...

Type of Respondents: (Government/local village residents): …………………………………………..

The following surveys main intention is to interview you about your local knowledge, experience, and memory of the past and present extreme events like tropical cyclones and sea level rise localized impacts on the coastal zone sector of Tongatapu. Approximated figures based on previous studies that were conducted in Tongatapu in the past were given to refresh the memory of the randomly selected respondents. Any explanation given by the respondents were falling within the range of these given approximated figures will be recorded or marked by ticking with a blue/black pen by the interviewer during the course of the interview for further information.

1. How long have you been staying in these coastal town/villages?

□ 0 – 25 years

□ 25 – 50 years

□ 50 – 75 years

□ Over 75 years

2. How far is the location of your house from the coastline?

□ 0 – 10m

□ 10 – 25m

□ 25 – 50m

□ 50 – 75m

□ Over 100m

3. What storm events can you remember? (E.g. Tropical Cyclone)

Name of tropical cyclone event	Year
1. …………………………….	…………
2. …………………………….	…………
3. ……………………………	………….
4. ……………………………	………….

4. What happened?

(A).Coastal average sea level (m)?

(a). Tropical Cyclone Isaac (1982)?

□ 0 – 1.5m

□ 1.5 – 2m

□ 2.5 – 3m

□ Above 3m

(b). Tropical Cyclone Hina (1997)?

□ 0 – 1.5m

□ 1.5 – 2m

□ 2.5 – 3m

□ Above 3m

(c). Tropical Cyclone Cora (1998)?

□ 0 – 1.5m

□ 1.5 – 2m

□ 2.5 – 3m

□ Above 3m

(B). Coastal storm surge wave strength/height/width (m)

(i). Coastal storm surge wave strength (m)?

Can you please rank the coastal storm surge wave strength in terms of the approximated distance (m) of it inland encroachment to the low-lying coastal areas of Tongatapu from lowest to highest rank (*i.e. Category 1 – 5) during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998) if you know anything about it?
*Tropical Cyclone Coastal storm surge wave strength (m) Categories:
1=lowest rank, 5=highest rank

1 – Less stronger	(0 – 50m)
2 – Stronger	(50 – 100m)
3 – Very stronger	(100 – 150m)
4 – More stronger	(200 – 300m)
5 – Extremely stronger	(>300m)

1. Tropical Cyclone Isaac (1982)

□ Category 1

□ Category 2

□ Category 3

□ Category 4

2. Tropical Cyclone Hina (1997)

□ Category 1

□ Category 2

□ Category 3

□ Category 4

☐ Category 5

☐ Category 5

3. Tropical Cyclone Cora (1998)

☐ Category 1

☐ Category 2

☐ Category 3

☐ Category 4

☐ Category 5

(ii). Coastal storm surge wave height (m)?
Can you please give me an approximation of the average coastal storm surge wave height in meters in the coastline of Tongatapu during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998) if you know anything about it?

1. Tropical Cyclone Isaac (1982)

☐ 0 – 1.5m

☐ 1.5 – 2m

☐ 2.5 – 3m

☐ Above 3m

2. Tropical Cyclone Hina (1997)

☐ 0 – 1.5m

☐ 1.5 – 2m

☐ 2.5 – 3m

☐ Above 3m

3. Tropical Cyclone Cora (1998)

☐ 0 – 1.5m

☐ 1.5 – 2m

☐ 2.5 – 3m

☐ Above 3m

(iii). Coastal storm surge wave width (m)?

Can you please give me an approximation of the average coastal storm surge wave width in meters in the coastline of Tongatapu during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998) if you know anything about it?

1. Tropical Cyclone Isaac (1982)

☐ 0 – 150m

☐ 150 – 200m

☐ 250 – 300m

☐ Above 300m

2. Tropical Cyclone Hina (1997)

☐ 0 – 150m

☐ 150 – 200m

☐ 250 – 300m

☐ Above 300m

3. Tropical Cyclone Cora (1998)

☐ 0 – 150m

☐ 150 – 200m

□ 250 – 300m

□ Above 300m

(C). Can you please give me an approximation of how many houses were affected and damaged during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998) amongst the following four major divisions of Tongatapu; Greater Nuku'alofa, East Coast Tongatapu, North East Coast Tongatapu, and the North West Coast Tongatapu?

1. Tropical Cyclone Isaac (1982)

1. Greater Nukuálofa

□ 0 – 750 houses

□ 750 – 800 houses

□ 850 – 900 houses

□ Over 900 houses

2. East Coast Tongatapu

□ 0 – 750 houses

□ 750 – 800 houses

□ 850 – 900 houses

□ Over 900 houses

3. North East Coast Tongatapu

□ 0 – 750 houses

□ 750 – 800 houses

□ 850 – 900 houses

□ Over 900 houses

4. North West Coast Tongatapu

□ 0 – 750 houses

□ 750 – 800 houses

□ 850 – 900 houses

□ 900 houses

2. Tropical Cyclone Hina (1997)

1. Greater Nukuálofa

□ 0 – 750 houses

□ 750 – 800 houses

□ 850 – 900 houses

□ Over 900 houses

2. East Coast Tongatapu

□ 0 – 750 houses

□ 750 – 800 houses

□ 850 – 900 houses

□ Over 900 houses

3. North East Coast Tongatapu

□ 0 – 750 houses

□ 750 – 800 houses

□ 850 – 900 houses

□ Over 900 houses

4. North West Coast Tongatapu

□ 0 – 750 houses

□ 750 – 800 houses

□ 850 – 900 houses

□ 900 houses

3. Tropical Cyclone Cora (1998)

1. Greater Nukuálofa

□ 0 – 750 houses

□ 750 – 800 houses

2. East Coast Tongatapu

□ 0 – 750 houses

□ 750 – 800 houses

□ 850 – 900 houses
□ Over 900 houses

□ 850 – 900 houses
□ Over 900 houses

3. North East Coast Tongatapu
□ 0 – 750 houses
□ 750 – 800 houses
□ 850 – 900 houses
□ Over 900 houses

4. North West Coast Tongatapu
□ 0 – 750 houses
□ 750 – 800 houses
□ 850 – 900 houses
□ 900 houses

(d). Can you please give me an approximation of the total physical damage to the old Nukuálofa sea wall foreshore protection caused by Tropical Cyclone Isaac (1982) in monetary values (T$million Paánga)?

1. Tropical Cyclone Isaac (1982)
□ T$1 – 2 million
□ T$2 – 3 million
□ T$3 – 4 million
□ T$4 – 5 million
□ Over T$5 million

(e). Can you please give me an approximation amongst those four major coastal divisions of Tongatapu; Greater Nukuálofa, East Coast Tongatapu, North East Coast Tongatapu, and North West Coast Tongatapu which one of them was the most severely affected divisions by beach erosion and saltwater intrusion during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998)?

1. Tropical Cyclone Isaac (1982)
□ Greater Nukuálofa
□ East Coast Tongatapu
□ North East Coast Tongatapu
□ North West Coast Tongatapu

2. Tropical Cyclone Hina (1997)
□ Greater Nukuálofa
□ East Coast Tongatapu
□ North East Coast Tongatapu
□ North West Coast Tongatapu

3. Tropical Cyclone Cora (1998)
□ Greater Nukuálofa
□ East Coast Tongatapu
□ North East Coast Tongatapu
□ North West Coast Tongatapu

5. Do you know exactly what year that Tropical Cyclone Isaac, Hina, and Cora were visited Tongatapu?

1. Tropical Cyclone Isaac

2. Tropical Cyclone Hina

3. Tropical Cyclone Cora

☐ 1997 ☐ 1998 ☐ 1982

☐ 1982 ☐ 1997 ☐ 1998

☐ 1996 ☐ 1995 ☐ 1999

6. Can you please give me an approximation of how many people would be at risk in the coastal villages of Tongatapu if a series of Tropical cyclone events like Isaac, Hina, and Cora will be revisited Tongatapu coastal zone sector today?

1. Tropical Cyclone Isaac (1982)

☐ < 25 000 (peoples)

☐ 25 000 – 40 000 (peoples)

☐ 45 000 – 50 000 (peoples)

☐ 55 000 – 60 000 (peoples)

☐ Over 60 000 (peoples)

2. Tropical Cyclone Hina (1997)

☐ < 25 000 (peoples)

☐ 25 000 – 40 000 (peoples)

☐ 45 000 – 50 000 (peoples)

☐ 55 000 – 60 000 (peoples)

☐ Over 60 000 (peoples)

3. Tropical Cyclone Cora (1998)

☐ < 25 000 (peoples)

☐ 25 000 – 40 000 (peoples)

☐ 45 000 – 50 000 (peoples)

☐ 55 000 – 60 000 (peoples)

☐ Over 60 000 (peoples)

7. Can you please give me an approximation of how effective and strong (life expectancy in years) the construction of the past/present existing sea walls/foreshore protection systems at the waterfront of Nukuálofa in the protection of the low-lying coastal towns/villages of Northern coast Tongatapu?

1. Old Nukuálofa Sea wall (1977)

☐ 0 – 10 years

☐ 15 – 20 years

☐ 25 – 30 years

☐ Over 30 years

2. Modern-Day Nukuálofa Sea wall (1986)

☐ 0 – 10 years

☐ 15 – 20 years

☐ 25 – 30 years

☐ Over 30 years

8. Can you please give me an approximation of how effective is the past/present existing coastal reforestations development project has been implemented in Tongatapu in the protection of the coastal gardens, and people properties from seawater spraying and soil erosion by ranking them in order of effectiveness start from 1 = lowest rank to 5 = highest rank? *Tongatapu local past/present coastal reforestation development projects effectiveness are measured in terms of its wind/wave protection strength by taking into consideration the duration of its growing period (years). Local coastal reforestation development projects wind/wave protection strength categories (Years):

1=lowest rank, 5=highest rank

1 – Less protective 0 – 5 years

2 – Protective 5 – 10 years
3. – Very protective 15 – 20 years
4. – Highly protective 20 – 25 years
5. – Extremely protective Over 25 years

1. Houma village coastal tree replanting project (1993) (South coast Tongatapu)

□ Cat 1 □ Cat 2 □ Cat 3 □ Cat 4 □ Cat 5

2. Fangaúta lagoon community mangrove replanting project (1999)

□ Cat 1 □ Cat 2 □ Cat 3 □ Cat 4 □ Cat 5

3. Nukuálofa waterfront coastal protection tree replanting project (1986)

□ Cat 1 □ Cat 2 □ Cat 3 □ Cat 4 □ Cat 5

4. Kanokupolu village coastal protection tree replanting project (2005)

□ Cat 1 □ Cat 2 □ Cat 3 □ Cat 4 □ Cat 5

9. Do you thinks there are ways we can build a coastal defence structures to prevent similar events in the future?

□ No □ Yes

10. Can you please give me an approximation of how much has already been spent by the Government of Tonga on sea wall construction in Tongatapu (1977 – 2006)?

□ T$0 – 2 million Paánga

□ T$2 – 4 million Paánga

□ T$4 – 6 million Paánga

□ Over T$6 million Paánga

11. Who pays for the costs of the construction of the foreshore coastal protection structures are established in the northern coastline of Tongatapu since 1986?

□ Government of Tonga

□ Government of Australia

□ Government of Germany

□ Government of Japan

12. Is there any new coastal protection structure development projects that are being implemented here in Tongatapu at the present time?

□ Yes □ No.

Whereabout?...

APPENDIX V

Results of Tongatapu local people survey

Survey of the local people of Tongatapu local village coastal landowner respondents' feedback results summary December 15, 2005 – February 10, 2006

Question 1. How long have you been staying in these coastal town/villages?

Length of Residency (Year)	Number of Respondents
0 – 25 years	1
25 – 50 years	10
50 – 75 years	25
Over 75 years	2

Question 2. How far is the location of your house from the coastline?

Distance from the coastline (m)	Number of Respondents
0 – 10m	28
10 – 25m	6
25-50m	2
50-75m	1
Over 100m	1

Question 3. What major storm events can you remember? (Tropical Cyclone).

Major storm event (Year)	Number of respondents remembered	Number of respondents cannot remembered
Isaac (1982)	35	3
Hina (1997)	32	6
Cora (1998)	30	8

Question 4. What happened to the coastal sea level, storm surge wave strength/height/and width at the coast of Tongatapu during Tropical cyclone Isaac (1982), Hina (1997), and Cora (1998)?

(A). Approximated Coastal Sea Level (m)

1. Tropical Cyclone Isaac (1982)

Approximated average coastal sea level (m)*	Number of Respondents
0 – 1.5m	1
1.5 – 2m	2
2.5 – 3m	1
Over 3m	34

2. Tropical Cyclone Hina (1997)

Approximated average coastal sea level (m)*	Number of Respondents
0 – 1.5m	8
1.5 – 2m	28
2.5 – 3m	1
Over 3m	1

3. Tropical Cyclone Cora (1998)

Approximated average coastal sea level (m)*	Number of Respondents
0 – 1.5m	5
1.5 – 2m	30
2.5 – 3m	2
Over 3m	1

*Above chart datum.

(B).Coastal storm surge wave strength/height/ and width (m)

(i). Respondents were asked to rank the coastal storm surge wave strength (m) in the coast of Tongatapu during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998) from lowest to highest rank (e.g. Category 1 – 5) according to a suggested ranking categories was created for this survey.)* Tropical Cyclone coastal storm surge wave strength is measured in terms of the approximated distance in meters of it inland encroachment to the low-lying coastal areas of Tongatapu from lowest to highest rank categories:

1 = lowest rank, 5 = highest rank

1 – Less stronger (0 – 50m)
2 – Stronger (50 – 100m)
3 – Very stronger (100 – 150m)
4 – More stronger (200 – 300m)
5 – Extremely stronger (>300m)

Major storm events (Year)	Coastal storm surge wave strength (Categories 1 – 5)	Number of Respondents
1. Isaac (1982)	Category 5	33
2. Hina (1997)	Category 1	1
3. Cora (1998)	Category 3	4

(ii). Can you please give me an approximation of the height of the coastal waves (m) in meters in the coast of Tongatapu during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998)?

1. Tropical Cyclone Isaac (1982)

Approximated coastal wave height (m)	**Number of Respondents**
0 – 1.5m	1
1.5 – 2m	1
2.5 – 3m	7
Over 3m	29

2. Tropical Cyclone Hina (1997)

Approximated coastal wave height (m)	Number of Respondents
0 – 1.5m	8
1.5 – 2m	27
2.5 – 3m	2
Over 3m	1

3. Tropical Cyclone Cora (1998)

Approximated coastal wave height (m)	Number of Respondents
0 – 1.5m	1
1.5 – 2m	2
2.5 – 3m	34
Over 3m	1

(iii). Can you please give me an approximation of the average coastal storm surge wave width (m) in meters at the coast of Tongatapu during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998)?

1. Tropical Cyclone Isaac (1982)

Approximated coastal storm surge wave width (m)	Number of Respondents
0 – 150m	1
150 – 200m	2
250 – 300m	4
Over 300m	31

2. Tropical Cyclone Hina (1997)

Approximated coastal storm surge wave width (m)	Number of Respondents
0 – 150m	7
150 – 200m	28
250 – 300m	2
Over 300m	1

3. Tropical Cyclone Cora (1998)

Approximated coastal storm surge wave width (m)	Number of Respondents
0 – 150m	1
150 – 200m	3
250 – 300m	33
Over 300m	1

(C). Approximated number of houses were affected or either damaged during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998) at the following major divisions of Tongatapu; Greater Nuku'alofa, East Coast Tongatapu, North East Coast Tongatapu, and North West Coast Tongatapu?

1. Tropical Cyclone Isaac (1982)

Coastal Division	Number of damaged houses	Number of Respondents
1. East Coast Tongatapu	0 – 750 houses	2
2. North East Coast Tongatapu	750 – 800 houses	3
3. Greater Nuku'alofa	850 – 900 houses	7
4. North West Coast Tongatapu	Over 900 houses	26

2. Tropical Cyclone Hina (1997)

Coastal Division	Number of damaged houses	Number of Respondents
1. North West Coast Tongatapu	0 – 750 houses	1
2. North East Coast Tongatapu	750 – 800 houses	2
3. Greater Nuku'alofa	850 – 900 houses	16
4. East Coast Tongatapu	Over 900 houses	19

3. Tropical Cyclone Cora (1998)

Coastal Division	Number of damaged houses	Number of Respondents
1. East Coast Tongatapu	0 – 750 houses	1
2. North West Coast Tongatapu	750 – 800 houses	2
3. North East Coast Tongatapu	850 – 900 houses	12
4. Greater Nuku'alofa	Over 900 houses	23

(D). Can you please give me an approximation of the total costs of the physical damage to the old Nuku'alofa sea wall foreshore protection structures caused by Tropical Cyclone Isaac (1982) in monetary values (T$million Paánga)?

Approximated costs (T$million Paánga)	Number of Respondents
T$1 – 2 million	1
T$2 – 3 million	1
T$3 – 4 million	3
T$4 – 5 million	4
Over T$5 million	29

(E). Can you please give me an approximation amongst those four major coastal divisions of Tongatapu; Greater Nuku'alofa, East Coast Tongatapu, North East Coast Tongatapu, and North West Coast Tongatapu which one of them was the most severely affected divisions by beach erosion and saltwater intrusion during Tropical Cyclone Isaac (1982), Hina (1997), and Cora (1998)?

Major Storm Event (Year)	Tongatapu Major Coastal Divisions/Number of Respondents			
	Greater Nuku'alofa	East Coast Tongatapu	North East Coast Tongatapu	North West Coast Tongatapu
Isaac (1982)	12	2	7	17
Hina (1997)	14	21	2	1
Cora (1998)	5	9	23	1

Question 5. Do you know exactly what year that Tropical Cyclone Isaac, Hina, and Cora were visited Tongatapu?

Major storm event (Year)	Number of respondents remembered	Number of respondents cannot remembered
Isaac (1982)	35	3
Hina (1997)	32	6
Cora (1998)	30	8

Question 6. Can you please give me an approximation of how many people would be at risk in the coastal villages of Tongatapu if a series of Tropical cyclone events like Isaac, Hina, and and Cora will be revisited Tongatapu coastal zone sector today?

1. Tropical Cyclone Isaac (1982)

Approximated number of people will be at risk	Number of Respondents
<25 000 (peoples)	1
25 000 – 40 000 (peoples)	1
45 000 – 50 000 (peoples)	2
55 000 – 60 000 (peoples)	6
Over 60 000 (peoples)	28

2. Tropical Cyclone Hina (1997)

Approximated number of people will be at risk	Number of Respondents
<25 000 (peoples)	2
25 000 – 40 000 (peoples)	3
45 000 – 50 000 (peoples)	31
55 000 – 60 000 (peoples)	1
Over 60 000 (peoples)	1

3. Tropical Cyclone Cora (1998)

Approximated number of people will be at risk	Number of Respondents
<25 000 (peoples)	11
25 000 – 40 000 (peoples)	23
45 000 – 50 000 (peoples)	2
55 000 – 60 000 (peoples)	1

Over 60 000 (peoples)	1

Question 7. Can you please give me an approximation of how effective and strong (life expectancy in years) the construction of the past/present existing sea walls/foreshore protection systems at the waterfront of Nuku'alofa in the protection of the low-lying coastal towns/villages of Northern coast Tongatapu?

1. Old Nuku'alofa Coastal Sea Wall Foreshore Protection Structure (1977 - 1982)

Sea wall life time (Year)	**No of Respondents**
0 – 10 years	32
15 – 20 years	4
25 – 30 years	1
Over 30 years	1

2. Modern-Day Nuku'alofa Coastal Sea Wall Foreshore Protection (1986 -)

Sea wall life time (Year)	**No of Respondents**
0 – 10 years	1
15 – 20 years	1
25 – 30 years	1
Over 30 years	35

Question 8. Can you please give me an approximation of how effective is the past/present existing coastal reforestations development project has been implemented in Tongatapu in the protection of the coastal gardens, and people properties from seawater spraying and soil erosion by ranking them in order of effectiveness start from 1 = lowest rank to 5 = highest rank? *Tongatapu local past/present coastal reforestation development projects effectiveness are measured in terms of its wind/wave protection strength by taking into consideration the duration of its growing period (years).

Local coastal forestry wind/wave protection strength categories (Years):

1 = lowest rank, 5 = highest rank

1 – Less protective	0 – 5 years
2 – Protective	5 – 10 years
3. – Very protective	15 – 20 years
4. – Highly protective	20 – 25 years
5. – Extremely protective	Over 25 years

Coastal Protection Forestry Replanting Project (Year)	**Coastal forest wind/wave protection strength Categories (1 – 5)**	**Number of Respondents**
1. Houma village (1993)	Cat 1	1
	Cat 2	2
	Cat 3	25

	Cat 4	7
	Cat 5	3
2. Fangaúta lagoon (1999)	Cat 1	5
	Cat 2	20
	Cat 3	8
	Cat 4	3
	Cat 5	2
3. Nukuálofa waterfront (1986)	Cat 1	1
	Cat 2	3
	Cat 3	4
	Cat 4	28
	Cat 5	2
4. Kanokupolu village (2005)	Cat 1	27
	Cat 2	5
	Cat 3	3
	Cat 4	2
	Cat 5	1

9. Do you thinks there are ways we can build a coastal defence structures to prevent similar events in the future?

Respondents Answer (Yes/No)	Number of Respondents
Yes	36
No	2

10. Can you please give me an approximation of how much has already been spent by the Government of Tonga on sea wall construction in Tongatapu (1977 – 2006)?

Approximated costs (T$ million Pa'anga) (1977 – 2006)	Number of Respondents
T$0 – 2 million Pa'anga	1
T$2 – 4 million Pa'anga	1
T$4 – 6 million Pa'anga	7
Over T$6 million Paánga	29

11. Who pays for the costs of the construction of the foreshore coastal protection structures are established in the northern coastline of Tongatapu since 1986?

Funding Source	Number of Respondents
Government of Japan	24
Government of Germany	13
Government of Tonga	1

12. Is there any new coastal protection structure development projects that are being implemented here in Tongatapu at the present time?

Respondents Answer (Yes/No)	Number of Respondents
Yes	36
No	No

Where about?

Kanokupolu village is located at the North West Coast of Tongatapu Island.

APPENDIX VI

Map of Tongatapu coastal zone