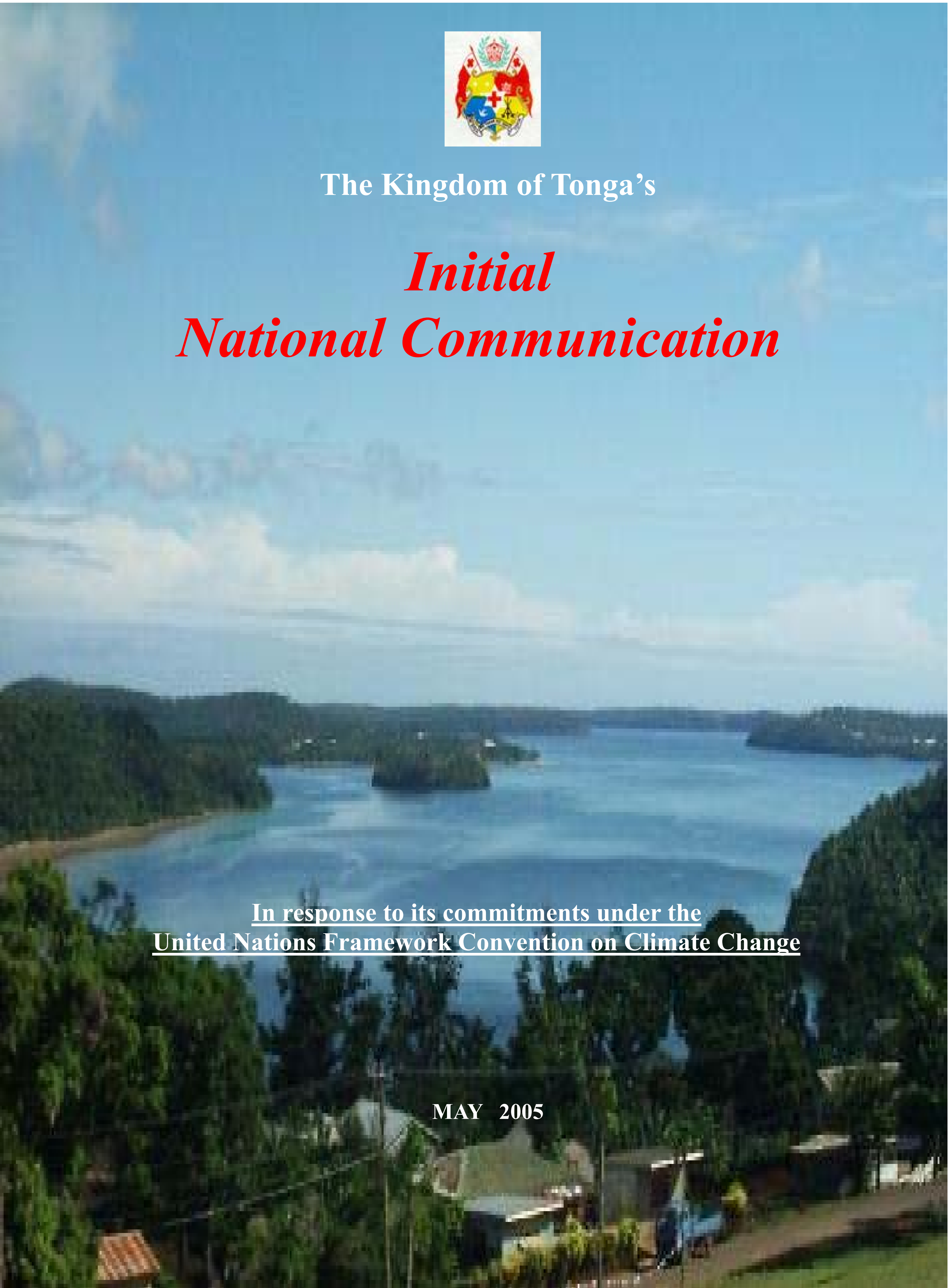

The Kingdom of Tonga's

Initial National Communication

In response to its commitments under the United Nations Framework Convention on Climate Change

MAY 2005

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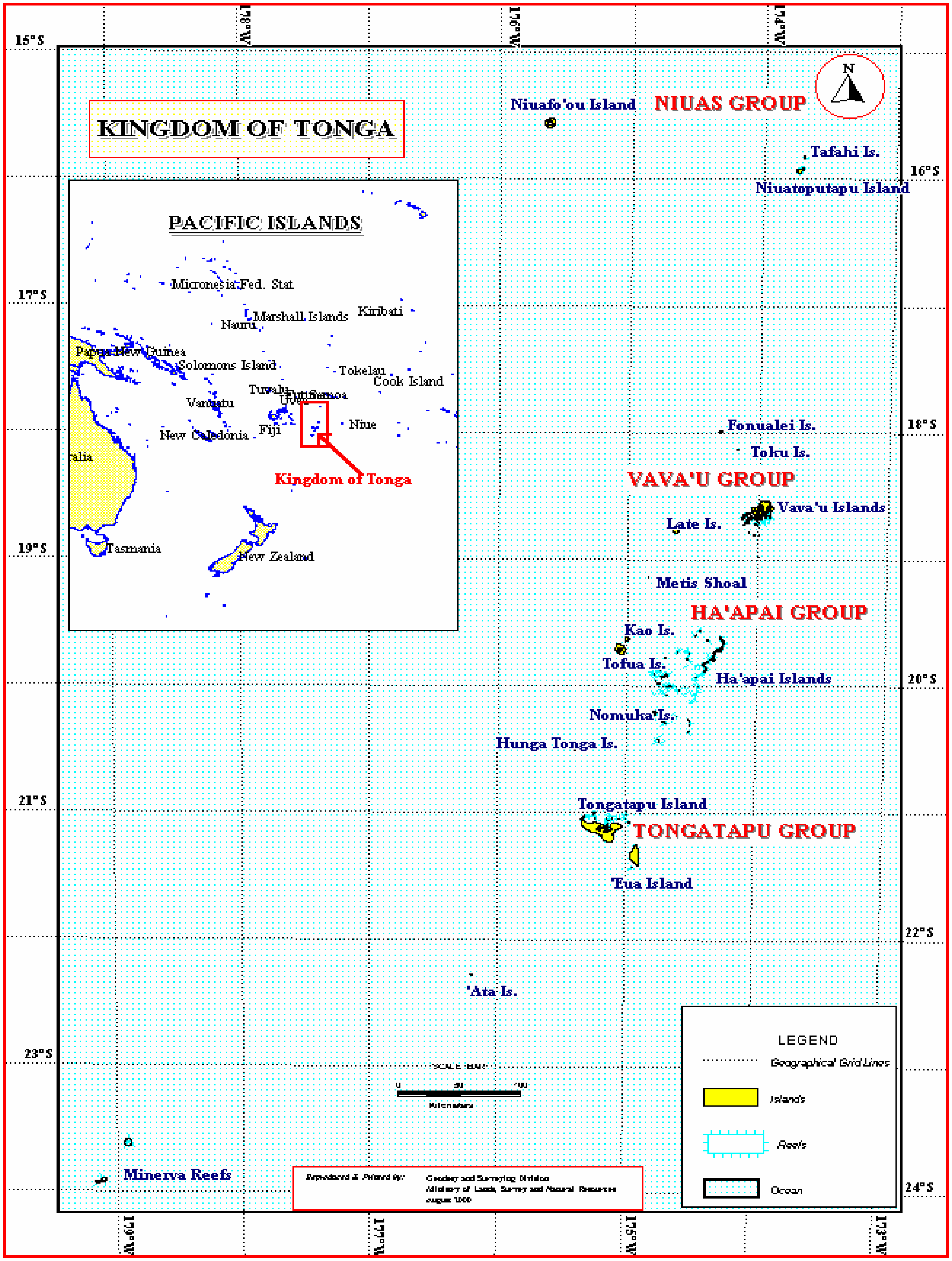

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FOREWORD

The climate of the earth is always changing and it has been altered as a result of natural causes. However, major changes in climate in the last century, and are projected over the next hundred years, are believed to be mainly resulted from human induced activities. They alter the composition of the global atmosphere, which in turn affects the biosphere and hydrosphere.

The Kingdom of Tonga is highly concerned about the serious and detrimental impacts of anthropogenic climate change, climate variability and sea level rise. It is evident that Tonga will be among the first to suffer from these impacts due to its physiographic, ecological and socioeconomic characteristics.

Tonga has been working together with the global community in addressing climate change issues and their devastating effects. It has acceded to the United Nations Framework Convention on Climate Change (UNFCCC) in July 20, 1998. As a non- Annex 1 Party to this convention, Tonga accepted the commitments to prepare and subsequently submit its First National Communication to the Conference of the Parties to the UNFCCC to comply with Article 12 of the Convention.

It is indeed my pleasure to submit this Initial National Communication to the Conference of the Parties to the UNFCCC.

The Kingdom of Tonga looks forward to, and remains committed to working together with the rest of the international community in the effort to find solutions to minimize the adverse effects of global climate change on the environment for present and future generations.

Department of Environment TONGA

....

Mr. Uilou Fatai Samani
Director of Environment
GOVERNMENT OF TONGA

ACKNOWLEDGEMENTS

The preparation of the Kingdom of Tonga's Initial National Communication was financed by the Global Environment Facility through one of its implementing agencies, the United Nations Development Programme. The support of both organizations is gratefully acknowledged.

The continuous support and encouragement from Mr. Uilou Fatai Samani, Director of Environment during the implementation of this Climate Change Enabling Activity Project (CCEAP) and preparation of this national communication report is fully acknowledged.

Sincere thanks are due to regional consultants, Mr. Solomone Fifita who assisted with conducting the Mitigation Analysis Workshop and Dr. Chalapan Kaluwin who provided valuable training and support with the National Greenhouse Gas Inventory, Vulnerability and Adaptation Assessment Workshops as well as assisting with the preparation, compilation and editing of this national communication report.

The National Coordinating Committee of this project, members of civil society, Non-Government Organisations, town and district officers have made significant contributions to the preparation of this national communication report. Such assistance is greatly appreciated.

Special thanks are extended to the Project Management Unit for compiling and editing the report and Technical Working Group for their concerted efforts and contributions from their respective areas of expertise.

The staff members of the Department of Environment have also provided valuable assistance and contributions to the preparation of the said report. Such assistance is also recognised.

Tonga Association of Non-Government Organisations (TANGO) has played a vital role in facilitating and expediting the completion of the aforesaid report. The continuous support and assistance of this organization is highly acknowledged.

Finally, thanks are extended to those who offered comments, reviewed documents or in any other way assisted with the preparation of this national communication report.

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ADB	Asian Development Bank
AMSAT	Australian Marine Science and Technology
C	carbon
CA	Competent Authority
CH_4	methane
CCEAP	Climate Change Enabling Activity Project
CO	carbon monoxide
CO_2	carbon dioxide
DOC	Degradable Organic Carbon
DoE	Department of Environment
EPU	Energy Planning Unit
ENSO	El Nino Southern Oscillation
FY	Financial Year
GDP	Gross Domestic Product
GEF	Global Environment Facility
Gg	Gigagrams
GHG	Greenhouse Gas
GHGI	Greenhouse Gas Inventory
GWh	Gigawatts per hour
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
ITCZ	Inter-Tropical Convergence Zone
Kl	kiloliter
Kt	kilotonne
LPG	Liquified Petroleum Gas
LULUCF	Land Use, Land Use Change and Forestry
MAGICC	Model for the Assessment of Greenhouse Gas Induced Climate Change
MCA	Ministry of Civil Aviation
MCF	Methane Correction Factor
MLCI	Ministry of Labour, Commerce and Industries

MLSNR	Ministry of Lands, Surveys and Natural Resources
MMP	Ministry of Marine & Ports
MoF	Ministry of Fisheries
MoH	Ministry of Health
MoW	Ministry of Works
MSW	Municipal Solid Waste
MWh	Megawatts per hour
N	nitrogen
NGOs	Non-Government Organisations
NMVOC	Non-methane Volatile Organic Compounds
NOx	nitrogen oxides
N_2O	nitrous oxide
NSCE	National Standing Committee for Energy
PICCAP	Pacific Islands Climate Change Assistance Programme
PMU	Project Management Unit
PREA	Pacific Region Energy Authority
SCENGEN	Global and Regional Scenario Generator
SHS	Solar Home Systems
SOPAC	South Pacific Applied Geoscience Commission
SPCZ	South Pacific Convergence Zone
SPREP	South Pacific Regional Environment Programme
TANGO	Tonga Association of Non-Government Organisations
TAR	Third Assessment Report
TEPB	Tonga Electric Power Board
TVB	Tonga Visitor's Bureau
TWB	Tonga Water Board
TWG	Technical Working Group
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

EXECUTIVE SUMMARY

BACKGROUND

The preparation of the Kingdom of Tonga's Initial National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) was financed by the Global Environment Facility through one of its implementing agencies, the United Nations Development Programme. The duration of this climate change enabling activities project is three years and is nationally executed by the Department of Environment. This national executive agency is assisted by the National Coordinating Committee in terms of coordinating project's work.

The process of preparing this first national communication necessitated the involvement and participation of national experts that make up the Technical Working Group of the project from various sectors and these were drawn from the government ministries/departments, non-government organization and statutory board. The Project Management Unit also assists the Technical Working Group with the implementation of project's activities as well as responsible for the overall management of the project.

The national communication is arranged as follows:

- National Circumstances
- National Inventory of Greenhouse Gases
- Mitigation Options
- Vulnerability Assessment
- Adaptation Options
- General Description of Steps Taken
- National Response to Climate Change

NATIONAL CIRCUMSTANCES

The Kingdom of Tonga lies between 15˚ and 23˚ 50" South Latitude and 173˚ to 177˚ West Longitude, and has a combined land/sea area of 720,000 km^2. It is an archipelago of 172 named islands with an area of 747 km^2 of which 36 islands are inhabited with an area of 670 km^2.

Tonga consists of four clusters of islands extended over north-south axis: Tongatapu and 'Eua in the south; Ha'apai in the middle; Vava'u in the north; and Niuafo'ou and Niuatoputapu in the far north. The capital Nuku'alofa is on Tongatapu, the largest island. Most islands in Tonga originate from coralline, comparatively flat and are often encircled by fringing reefs. Some atolls are raised by tectonic action. There are also some islands of volcanic origin, notably in the west of the Ha'apai Group.

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.

The climate of Tonga is tropical. It lies within the southeast trade wind zone of the South Pacific. Climatic parameters include rainfall, temperature, wind and sunshine hours. Tonga's annual rainfall can be defined by two seasons, the wet and dry seasons. Wet season is also known as the cyclone season and it is noticeable from November to April. Dry season runs from May to October. The wettest months are particularly January, February and March that may exceed 250mm of rainfall per month. During dry season, the amount of rainfall received per month is less than 250mm.

The mean annual rainfall for the major island groups of Tonga was calculated starting from year 1947-2001. Nuku'alofa received 1753mm, 1689mm(Lifuka) and 2185mm (Neiafu).The annual precipitation trends in Tonga were calculated also. Trends indicate a general decrease in annual rainfall in central and southern parts of Tonga particularly since 1970s.

The mean annual temperatures in Tonga vary from 26°C at Niuafoou and Niuatoputapu to 23°C on Tongatapu. During the hot wet season (November- April) the average temperature ranges from 25-26°C whereas at dry cool season (May- October) the average temperature ranges from 21-24°C. Historical climatic data records dated back to 1949 for Nuku'alofa, Ha'apai, Vava'u and Niuatoputapu. Trends suggest a marked increase of 0.4-0.8°C in annual mean temperature throughout the island groups since 1970s.

Tropical cyclones are often experienced mainly during the hot wet season. Between 1960 –2004 there have been 32 tropical cyclones impacted Tonga. On average, Tonga is affected by 1 tropical cyclone annually. Tropical cyclones damaged the island groups of Tonga have amounted to million of dollars.

The sea level trend suggested a general increase in sea level in order of 14mm/yr since records started in 1993-2001.

Tonga's 1996 population census was divided into five divisions (Tongatapu, Vava'u, Ha'apai, 'Eua and the Niuas). Its total population counted 97,784. Tongatapu was the most populous and has the highest population density. Its population totaled 66,979 which accounted for 69% of the total population, 15715 (16%) for Vava'u, 8138 (8% for Ha'apai, 4934 (5%) for 'Eua and 2018 (2%) for the Niuas.

Types of migration in Tonga include international, rural, in and out migration.

Tonga has a high level of educational achievement of 98.5 per cent literacy. The Government of Tonga provides Primary schools for every inhabited island. The Government also operates most schools while churches run some.

The government and churches also manage secondary schools in Tonga. Tonga School Certificate examination is administered in Form 5 whereas the Pacific Senior Secondary Certificate examination is administered in Form 6. The New Zealand Bursary examination is taken in Form 7. Strategic Development Plan seven reaffirms the Government's commitment to high quality universal education reaching Form 6 and the development of technical and vocational education and training.

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 30 1994 to June 2001.

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 industry are becoming important.

The agricultural sector serves as the 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 limited in extent, being primarily restricted to steep, remote and inaccessible areas, uninhabited islands, coastal areas, swamps and mangroves.

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. 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's energy sources are limited to indigenous sources particularly biomass, renewables (solar, wind, waves) and imported petroleum products. In 1992, indigenous biomass accounted for 56 per cent of total energy consumed while imported petroleum represented the remaining 44 per cent. By 2001, imported petroleum products captured 54 per cent of total energy with biomass accounted for 43 per cent. Renewable energy continued to rise from less than 1 per cent in 1990 reaching 2 per cent in 2003.

Transportation in Tonga is managed under three different bodies namely Ministry of Works, Ministry of Marine and Ports , and Ministry of Civil Aviation. Land transport is managed by the Ministry of Works, Sea transport is managed by the Ministry of Marine and Ports whereas Air transport is managed by the Ministry of Civil Aviation.

The two main sources of water in Tonga are from rainwater collected and stored in cisterns as well as freshwater lens found in highly 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 including Niuafo'ou and Tofua (Ha'apai island). According to 1996 census households in Tonga totaled 16,194. 84.6 per cent (13,705 households) had access to piped water supply, 58.3 per cent (9,444 households) had their own tanks, 2.4 per cent (393 households) had their own wells, 1.1 per cent (175 households) had other sources of water supply.

There are five leading causes of morbidity in Tonga from 1989-2003. These include acute respiratory infection, influenza, broncho pneumonia, diarrhea (infants) and pneumonia (adults). Year 2000 has the highest incidences of all diseases. Diseases of the respiratory and circulatory systems are the two root causes of death in 2002, Tonga.

There was an increase in number of cases reported in dengue fever, a vector borne disease (from 1983-1990). Food and Water borne diseases also reported in Tonga as caused by people's consumption of contaminated food and water.

NATIONAL INVENTORY OF GREENHOUSE GASES

Tonga's First National Inventory for Greenhouse Gases (GHG) has been calculated for the year 1994. Calculations of the national GHG emissions and sinks were done using the provisional GHG inventory software and the IPCC Revised Guidelines of 1996.

The national GHG inventory was determined on an individual sector basis for the Energy, Agriculture, Land Use, Land Use Change & Forestry and Waste Sectors. The CO_2 emissions from the International bunkers were reported separately as Memo Items and not included in the national totals.

The net carbon dioxide emissions for Tonga were 365.59Gg. The emissions were offset by absorption by sinks resulting in net 229.65Gg. Total non-carbon dioxide emissions included methane, 5.04Gg, nitrous oxide, 0.14Gg, nitrogen oxides, 0.49Gg, carbon monoxide, 3.82Gg and Non-methane Volatile Organic Compounds, 0.65Gg.

It was discovered during the inventory studies that there were significant data gaps and the IPCC values/factors were not totally applicable to Tonga's context. There is a need for national capacity building in order to establish and maintain appropriate systems for data collections, interpretation and analysis.

GREENHOUSE GAS MITIGATION OPTIONS

The anthropogenic emissions of GHG in Tonga originate from various sources in the Energy, Land Use, Land Use Change & Forestry, Agricultural and Waste Sectors.

The Mitigation Analysis identified and assessed the suitability of a wide range of options to abate these emissions. In the Energy Sector, these range from the utilisation of renewable sources of energy to the introduction of alternative fuels. The need for demand side management was also recognised.

Using of the nitrogen inhibitors to ensure that nitrogen gas rather than nitrous oxide and manipulating processes rates are options to mitigate nitrous oxide emissions. The application of ionophores (antibiotics) will directly reduce methane emissions from the Agricultural sector. Increased carbon removal and sequestration by agroforestry are sinks in the Land Use Change and Forestry Sector.

Waste minimisation and management programs are potential measures to reduce the Nitrous oxide and Methane emissions from the Waste Sector.

CLIMATE CHANGE VULNERABILITY AND ADAPTATION ASSESSMENT

There are a number of key climatic parameters that have been ascribed to climate change. These include increase in temperatures, sea level rise, and increase in the frequency of cyclones, more intense weather phenomena such as hurricanes and droughts as well as changing in rainfall patterns.

The initial vulnerability and adaptation studies carried out for the Kingdom of Tonga in the context of these effects involved the assessment of climate change impacts on Agriculture, Forestry, Coastal Areas, Fisheries, Human Health and Water Resources.

The overall conclusion of the assessment is that all sectors are likely to be significantly affected by climate change with major adverse environmental, economic and social consequences. Of particular concerns are the anticipated impacts on agricultural production, water supply and coastal resources.

The assessment also identifies measures for adapting to the adverse effects of climate change. These include public awareness programmes, introduction of salt and temperature tolerant crops, agricultural diversification, development of a national water management plan, land use planning and management, coastal management and protection, forestry management and also the enhancement of agroforestry.

GENERAL DESCRIPTION OF STEPS TAKEN

The Kingdom of Tonga as a small island developing state has limited potentials to address the myriad issues to be experienced as a result of the climate change phenomena. Not withstanding notable progress that had been achieved in areas such as policy framework, public awareness, systematic observation and research as well as capacity building.

NATIONAL RESPONSE TO CLIMATE CHANGE

Climate Change is recognised as a national issue that requires timely and committed initiatives by the government to develop capacity to address existing and potential impacts on the livelihoods of the people of Tonga and also its environment.

There are six objectives highlighted to;

a) Institutionalise and mainstream climate change preparedness;

b) Increase national capacity to prepare and adapt to climate change;

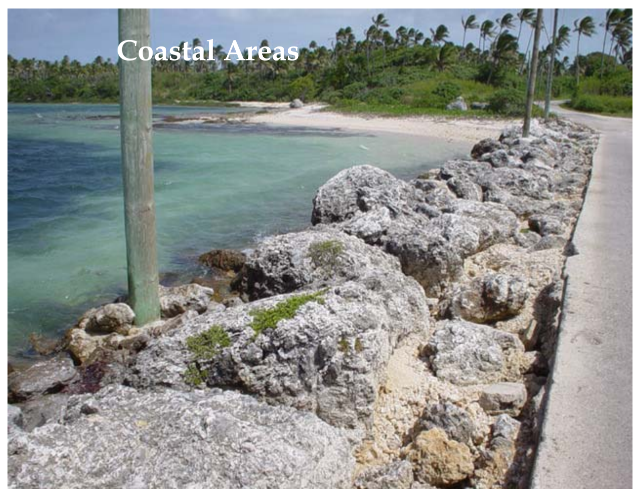
c) Minimise the national greenhouse gas emissions in the medium term;

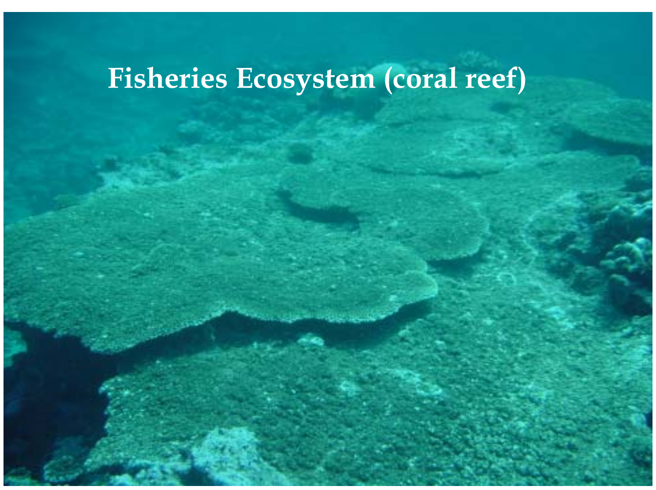
d) Increase public awareness and improve understanding of climate change, variability, sea level rise, extreme events and their preparedness;

e) Facilitate and mainstream adaptation options into all sectoral planning; and

f) Develop a national climate change framework and policy.

Chapter 1: NATIONAL CIRCUMSTANCES





1.1. INTRODUCTION

The Kingdom of Tonga is a small island developing country located in the Central South Pacific. It lies between 15° and 23° 30' South and 173° and 177° West. Tonga has a combined land and sea area of 720,000km². It is an archipelago of 172 named islands with an area of 747km² of which 36 islands are inhabited with an area of 670km². Tonga has a total population of 97,784 (Population Census, Department of Statistics, Tonga, 1996).

1.2. GEOGRAPHY

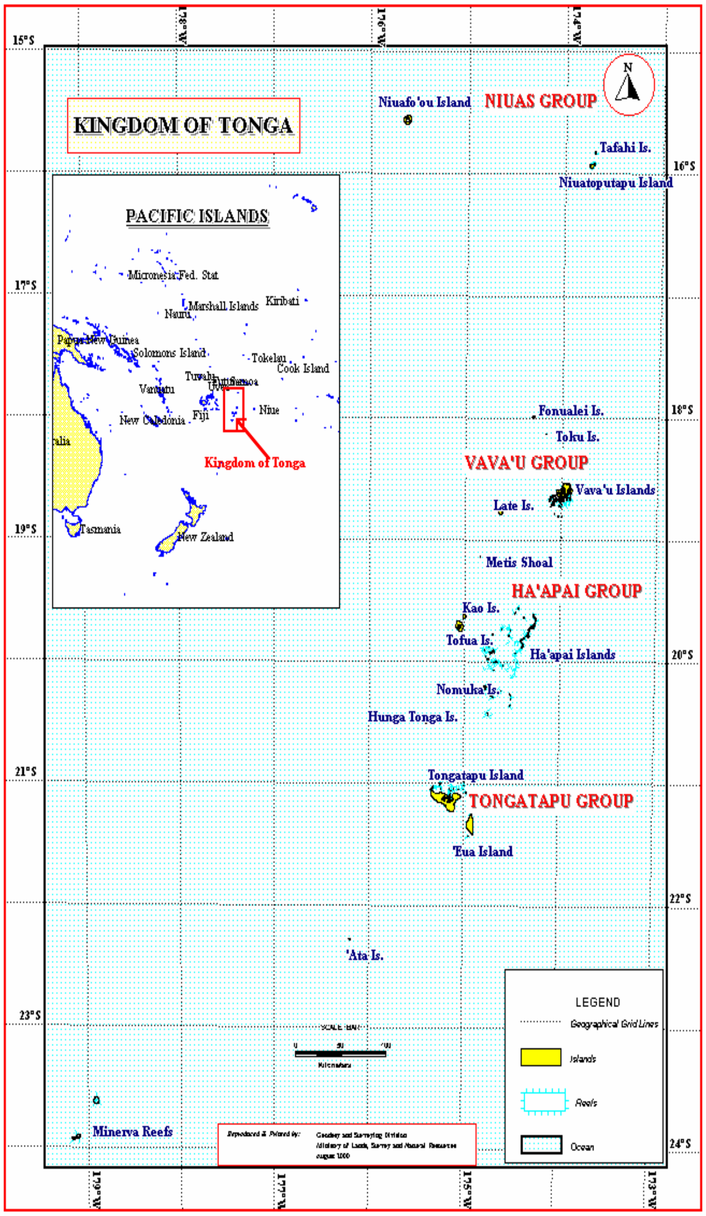


Figure 1.1: Location Map of the Kingdom of Tonga
Source: Geodesy & Surveying Section [Ministry of Lands, Survey & Natural Resources], TONGA.

Tonga consists of four clusters of islands extended over a north-south axis: Tongatapu and ‘Eua in the south, Ha'apai in the middle, Vava'u in the north and Niuafo'ou and Niua Toputapu in the far north.

Nuku'alofa, the capital is situated in Tongatapu, the largest island. Tonga's archipelago lies along the boundary of the Pacific and Indian-Australian tectonic plates. It comprises both volcanic and uplifted coral islands and reefs, which cap the peaks of two parallel submarine ridges stretching south of Fiji. Tongatapu and ‘Eua are limestone capped islands which with low islands form the Tongatapu group. The south of the Vava'u Group is generally composed of high volcanic and elevated limestone islands with reef communities or fringing reefs. Ha’apai has high volcanic and low limestone islands. The Niuas are high volcanic islands surrounded by fringing and barrier reefs.

1.3. CLIMATE

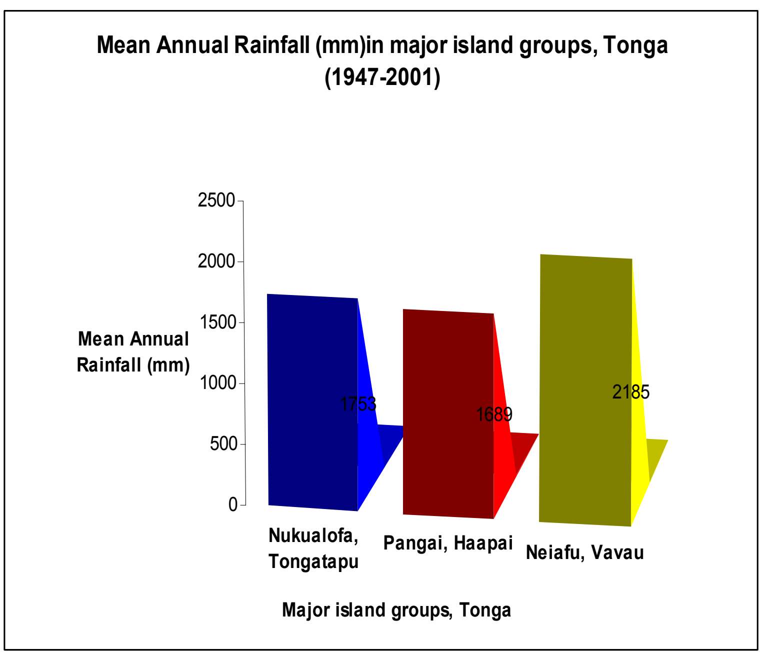
The climate of Tonga is tropical. Tonga lies within the south-east trade wind zone of the South Pacific. Wind speed over its surrounding oceans averages around 12 knots. Strong winds are not common except during tropical cyclone passages in summer (November – April) and gales from eastward migrating high-pressure systems during winter (May – October).

1.4. CLIMATIC PARAMETERS

1.4.1. Rainfall

The rainfall regime is very much associated with the semi-permanent SPCZ, the area of convergence between the equatorial easterly trades and the sub-tropical south-easterlies. Tonga's annual rainfall can be defined by two seasons, the Wet and Dry seasons. A pronounced wet season (also the cyclone season) is noticeable from November to April and a dry season runs from May to October. Wet season contributes to about two thirds of the total annual precipitation. The wettest months are particularly January, February and March that may exceed 250mm of rainfall per month. The humidity of the air may reach 75% at midday. By contrast, during the Dry season, the amount of rain received is less than 250mm per month and the humidity is lowered to 67% at midday. (Prescott,1997)

Rainfall is highly variable from year to year with abnormally low or high rainfall persisting for more than three months is extremely rare. Two predominant causes of rainfall variation in Tonga are ENSO and Tropical Cyclones. The ENSO causes prolong drought whereas Tropical cyclones can result in unusual wet years.



The mean annual rainfall for the major island groups, Tonga was calculated starting from year 1947 to 2001. Nuku'alofa, Tongatapu received 1753mm, 1689mm (Lifuka, Ha'apai), and 2185mm (Neiafu, Vava'u).

Figure 1.2: Mean Annual Rainfall in major island groups, Tonga (1947 – 2001)

Annual Precipitation Trends in Tonga

Figures 1.3 & 1.4 show the observed annual precipitation trend from spatially selected meteorological stations throughout Tonga that have at least 30 years of data.

Trends indicate a general decrease in annual rainfall in central and southern parts of Tonga particularly since 1970s. Interannual variation in Tonga's rainfall has been strongly associated with the ENSO and the positioning of the ITCZ and SPCZ respectively. *Salinger et al, 2000* suggested that this decrease in Tonga's rainfall coincides with an eastward shift of the SPCZ since 1970. Research suggests that these changes may also be closely correlated with the so-called Interdecadal Pacific Oscillation (IPO). It should be noted however, that changes observed in the 20th century are considered to be consistent with patterns related to anthropogenic GHG-induced climate change (Salinger *et al.*, 2000).

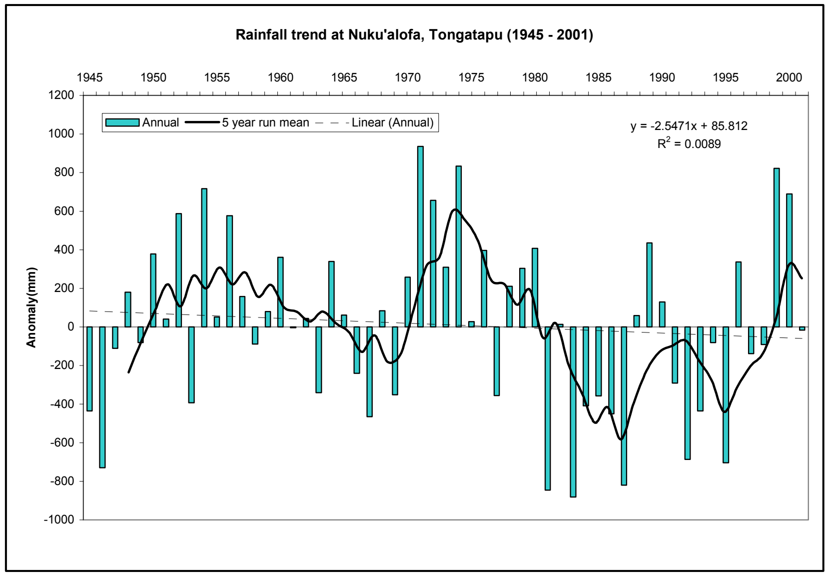


Figure 1.3: Annual rainfall anomalies and trends for Nuku'alofa, Tongatapu.

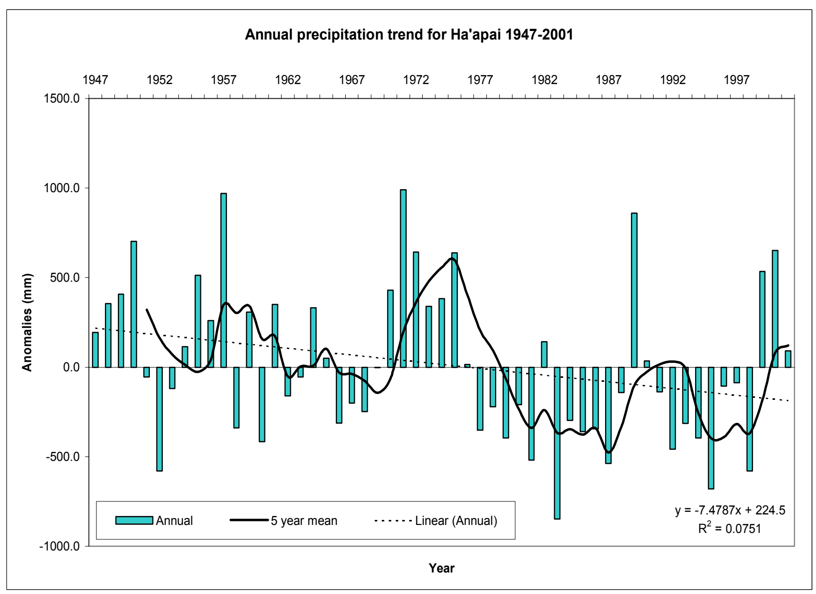


Figure 1.4: Annual rainfall trend for Lifuka, Ha'apai

1.4.2. TEMPERATURE

Temperature variations throughout the Kingdom show an increase in daily and seasonal variations with increasing latitude. Mean annual temperatures vary from 26˚C at Niuafo'ou and Niuatoputapu (~15s) to 23˚C on Tongatapu (~21s) with a diurnal and seasonal range of 6˚C and 2˚C and 6˚C and 5˚C respectively.

During the Hot Wet Season (November- April), the average temperature ranges from 25-26^{0}C whereas at Dry Cool Season (May – October), the average temperature ranges from 21-24^{0}C.

Observed Annual Temperature Trends in Tonga

Historical climatic data records date back to 1949 for Nuku'alofa, Ha'apai, Vava'u and Niuatoputapu. Trends suggest a marked increase of 0.4 to 0.8°C in annual mean temperature throughout the island group since the 1970s. Seasonal and extreme temperatures in addition, also stipulate a significant positive trend. While soil temperature data is extensively short for a full climatological assessment, it is worthwhile to note that soil profile temperatures show a slight increasing trend.

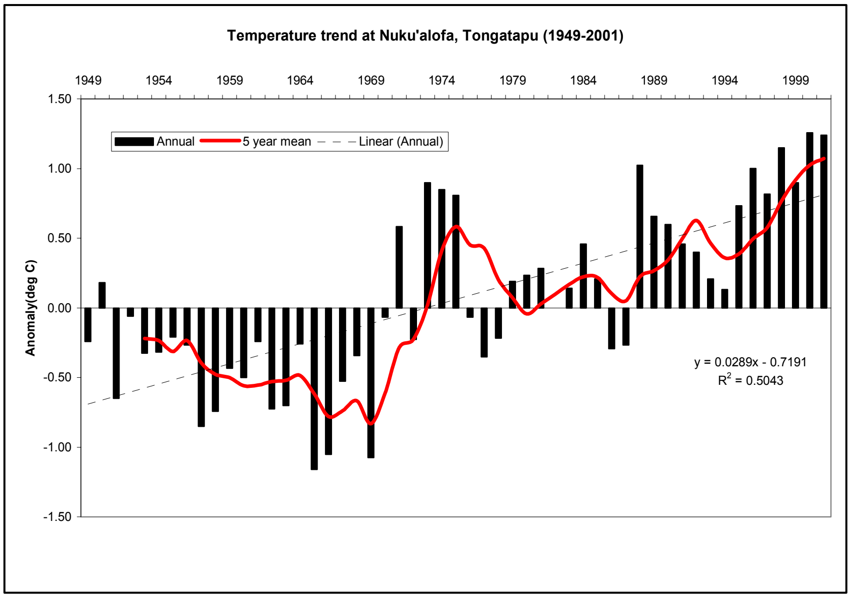


Figure 1.5: Mean annual temperature anomalies and trend for Nuku'alofa, Tongatapu.

Seasonal Temperature Trends

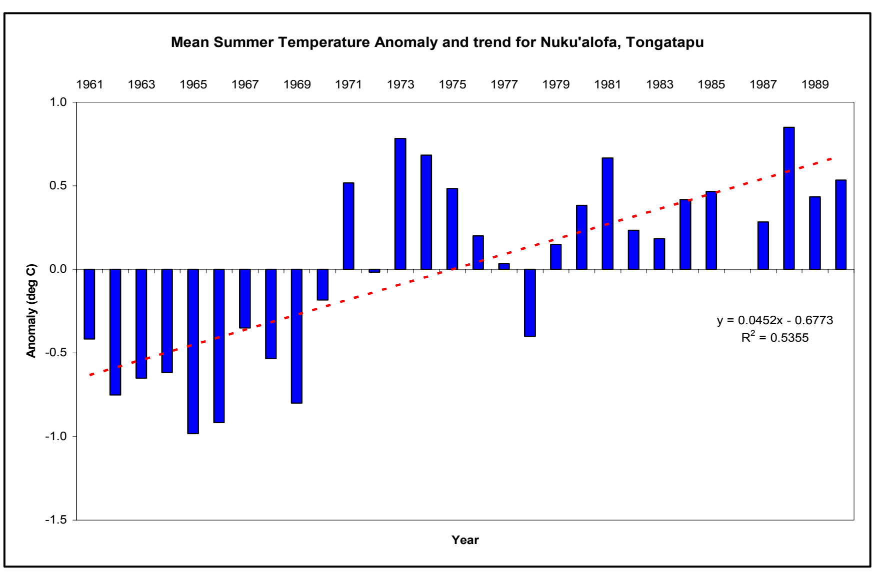


Figure 1.6: Mean summer temperature anomalies and trend for Nuku'alofa, Tongatapu.

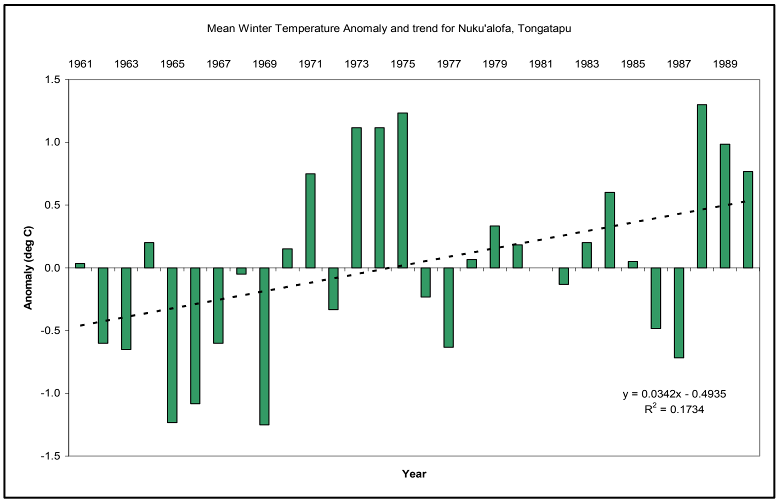


Figure 1.7: Mean winter temperature anomalies and trend for Nuku'alofa, Tongatapu.

Extreme Temperature Trends

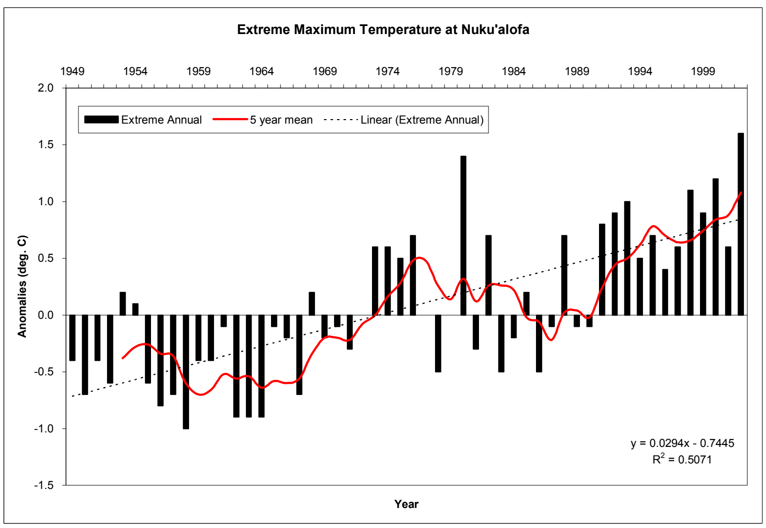


Figure 1.8: Extreme maximum temperature anomalies and trend for Nuku'alofa, Tongatapu.

Soil Temperatures

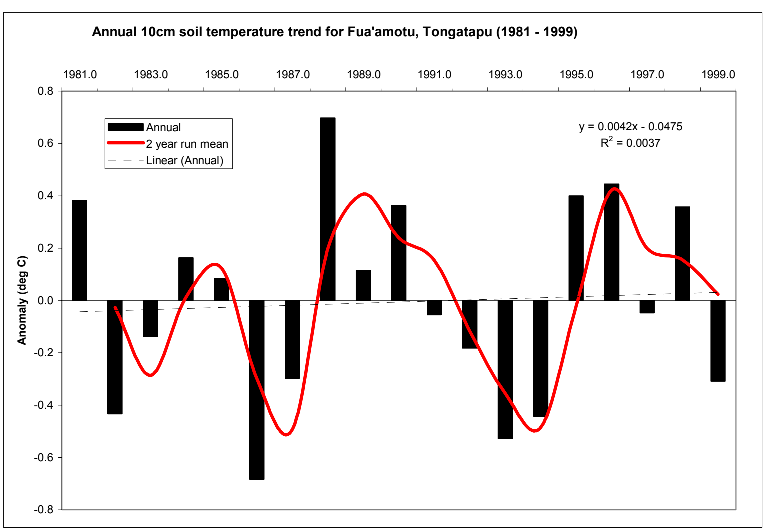
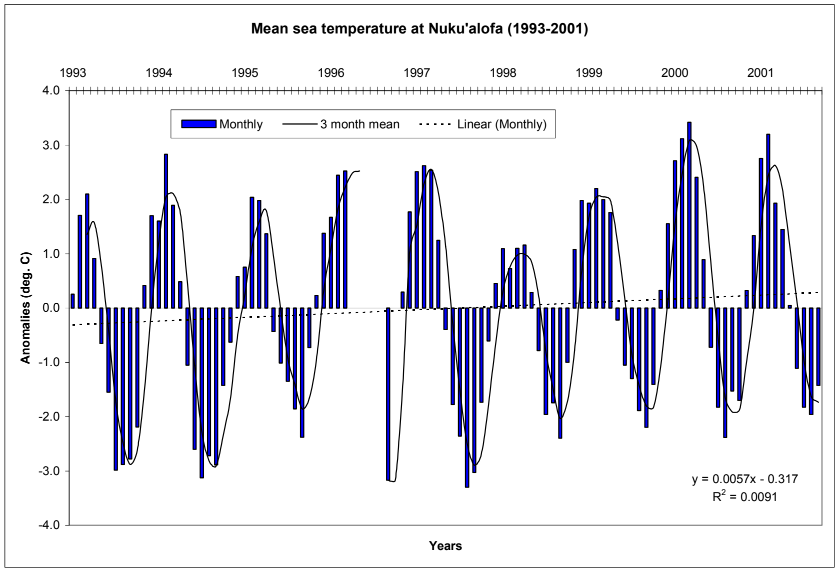


Figure 1.9: Annual 10cm soil temperature anomalies and trend for Fua'amotu, Tongatapu.

Sea Temperature

Sea temperature data from the Nuku'alofa tide gauge although relatively short indicates a slight increase in sea temperature. The current analysis based on 9 years of data suggests a positive inclination of 0.0057°C/yr (0.057°C/decade). This is comparable to the 0.037°C/decade average increase in the global ocean heat content of the uppermost 300m.

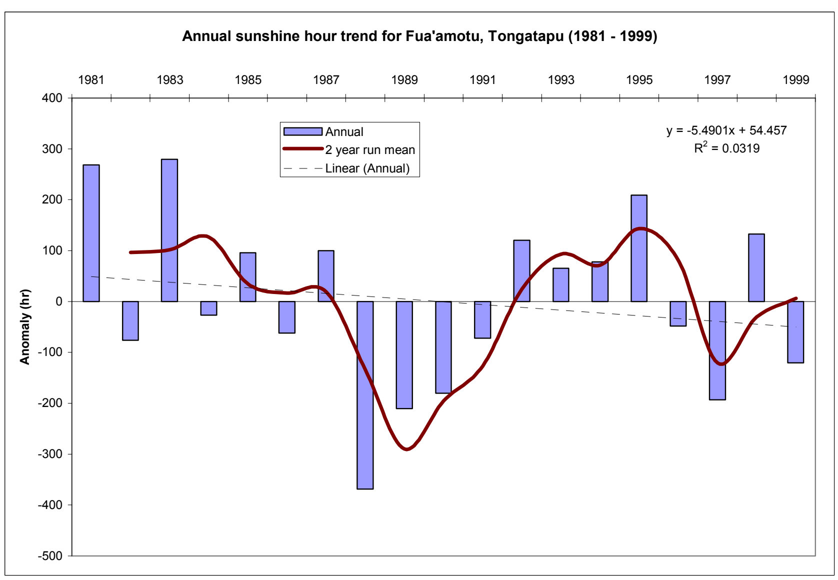
Figure 1.10: Annual mean sea temperature trend at Nuku'alofa



1.4.3. Sunshine Hours

Linear sunshine hour trend demonstrates an annual sunshine hour decline of 5.5 hours. This data is inconsistent with the rainfall pattern for Tongatapu. A longer data record is required to further clarify this discrepancy.

Figure 1.11: Annual hours of sunshine recorded at Fua'amotu.



1.5 TROPICAL CYCLONES

Tonga experienced tropical cyclones mainly during the hot wet season. Between 1960 - 2004, there have been 32 tropical cyclones impacted the Kingdom (Table 1.1). On average, Tonga is affected by 1 tropical cyclone annually.

Extensive damages were inflicted by these cyclones on school buildings, dwelling houses and other buildings, agricultural sector, water supply and electricity, telecommunications, fisheries, other government and public properties.

Tropical cyclone damages to the island groups of Tonga in the past have amounted to million of dollars. For instance, tropical cyclone Isaac, 1982 damaged the island groups of Haapai & Tongatapu. Total cost for the damage inflicted was T$18.7 million. Tropical Cyclone Ofa, 1990 severely hit the NiuaToputapu group. The estimated cost for the damage was T$3.2 million. Tropical Cyclone Cora, 1998 hit the Tongatapu, Haapai and Eua groups and damages costed T$19.6 million. Tropical cyclone Waka, 2002 severely damaged the islands of Niuafoou, NiuaToputapu and Vavau and the total estimated cost for the damage was T$104.2 million (Natural Disaster Management Report, MoW,2002).

Table 1.1: Tropical Cyclones that have impacted Tonga (1960 -2004)

Month/Year		Total Number of Cyclones	Strength of Cyclone/intensity	Name of Cyclones
1960s	Jan-60	4	Storm	Nil
	Mar-61		Severe	Nil
	Nov-64		Gale	Nil
	Feb-69		Gale	Nil
1970s	Apr-73	1	Storm	Juliette
1980s	Feb-81	8	Gale	Betsy
	Mar-82		Hurricane	Isaac
	Mar-84		Gale	Nil
	Jan-85		Storm	Drena
	Feb-86		Storm	Keli
	Apr-86		Gale	Martin
	Feb-89		Gale	Nil
	Apr-89		Storm	Kerry
1990s	Jan-Feb 90	13	Hurricane	Ofa
	Feb-90		Gale	Nil
	Nov-90		Hurricane	Sina
	Dec-90		Gale	Nil
	Dec-91		Storm	Val
	Dec-92		Storm	Joni
	Dec 92-Jan 93		Hurricane	Kina
	Dec 92-Jan 93		Storm	Nina
	Feb-93		Gale	Mick

	Mar-97		Hurricane	Hina
	Jun-97		Storm	Keli
	Jan-98		Hurricane	Ron
	Dec-98		Storm	Cora
2000s	Mar-00	6	Gale	Mona
	Mar-01		Hurricane	Paula
	Dec 01- Jan 02		Hurricane	Waka
	Jan-03		Hurricane	Ami
	Mar-03		Hurricane	Eseta
	Jan-04		Hurricane	Heta

Source: Tonga Meterological Office, 2004.

Key:

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

1.5.1. Frequency of Tropical Cyclonic Events

Historical records indicate an increased trend in tropical cyclone frequency both in the South West Pacific since the 1960s.

The Tonga data indicate little or no trend. Therefore, there is little evidence to confidently predict an increase in cyclone intensity and frequency. A longer data set is required.

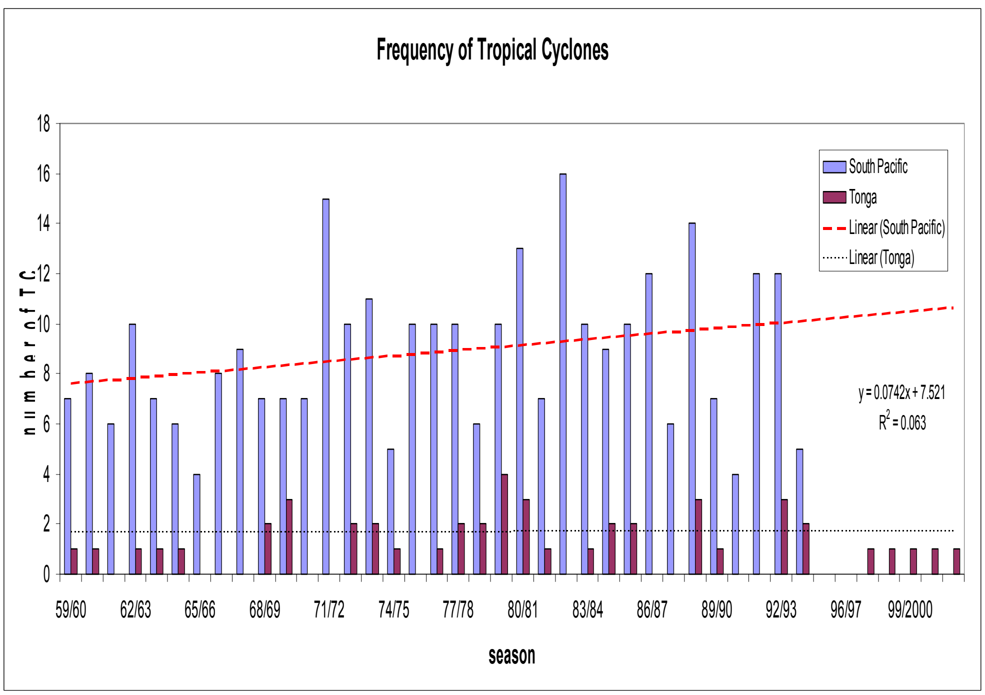


Figure 1.12: Tropical cyclonic events in Tonga and the South Pacific

1.6. SEA LEVEL

The sea level trend (Figure 1.13) 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 but the magnitude of the trend continues to vary widely from month to month. The result of August 2004 shows a trend of +11.6mm/yr (Tonga's Country Report for the South Pacific Sea level and Climate Monitoring Project, 2004).

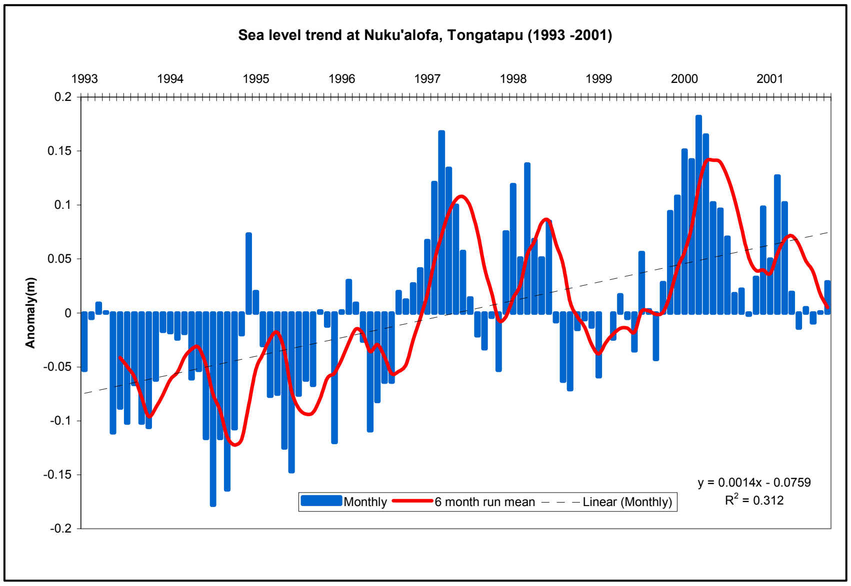


Figure 1.13: Sea level Trend for Nuku'alofa, Tongatapu

It should be noted however that data recorded is far too short to suggest a true representation of sea level rise in Tonga. IPCC suggests a minimum of 30 years of monitoring is a useful benchmark to develop trends. 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. The current figure is expected to decrease as more credible data will be collected. Despite this limitation, it is still constructive to consider that data obtained from tide gauge thus far signifies a positive sea level trend. The projected sea level rise accompanying climate changes due to the enhanced greenhouse effect are expected to adversely affect almost all the islands of Tonga.

1.7. POPULATION AND DEMOGRAPHY

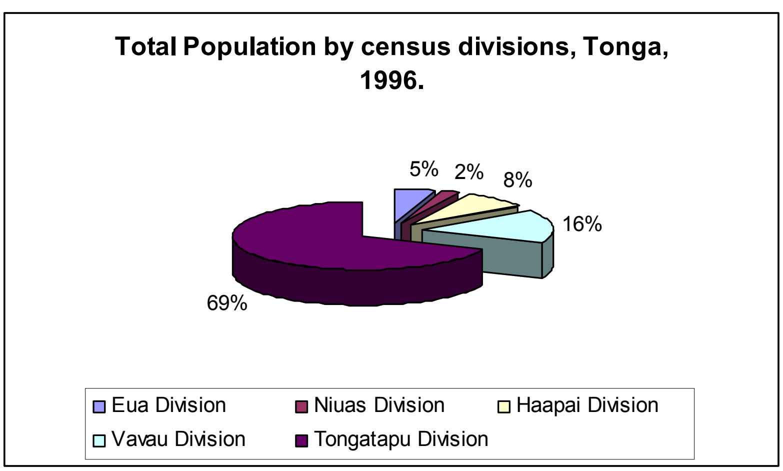


Figure 1.14: Total Population by Divisions, Tonga, 1996.

The 1996 population census of the Kingdom of Tonga was its fifth decennial census. Tonga was divided into five divisions (Tongatapu, Vava'u, Ha'apai, 'Eua and the Niuas divisions) for demographic purposes.

According to the 1996 census, Tonga's total population counted 97,784. Tongatapu was the most populous and has the highest population density. Its population totalled 66,979 which accounted for 69% of the total population), 15715 (16%) for Vava'u, 8138 (8%) for Haapai, 4934 (5%) for Eua and 2018 (2%) for the Niuas (Figure 1.14).

It was also recorded 98.2 percent of the total population were Tongans and Part Tongans whereas the other 1.8 percent was shared by other ethnic groups.

Out of the total population of 1996, 49,615 (51%) were males and 48,169 (49%) were females, a ratio of 103 males to every 100 females compared to 101 males to 100 females in the 1986 census.

Population has grown by 3.3% with an average annual growth rate of 0.3% over the ten-year period. (1986-1996).

The Infant Mortality Rate (IMR) has declined from 26 per 1,000 in 1986 to 19 per 1,000 births in 1996. Both males and females experienced the same level of mortality.

Life expectancy was 69.8 for males and 71.8 for females.

Total Fertility Rate (TFR) has declined from 5.2 per woman in Tonga in 1986 to 4.1 in 1996.

Crude birth rate was 30.3 and crude death rate was 7.5.

Table 1.2: A summary of vital rates obtained from the 1996 census

Total Fertility Rate	4.1 per woman
Life Expectancy (male)	69.8 years
Life Expectancy (female)	71.8
Infant Mortality Rate	19.0
Crude Birth Rate	30.3
Crude Death Rate	7.5
Net Migration Rate	19.8
Annual Growth Rate	3.3

Source: Population, Census, Department of Statistics Tonga 1996.

1.7.1. Population Historical Trend

The historical growth of the population of the Kingdom of Tonga has increased since the early 1960's (Table 1.3 & Figure 1.15)

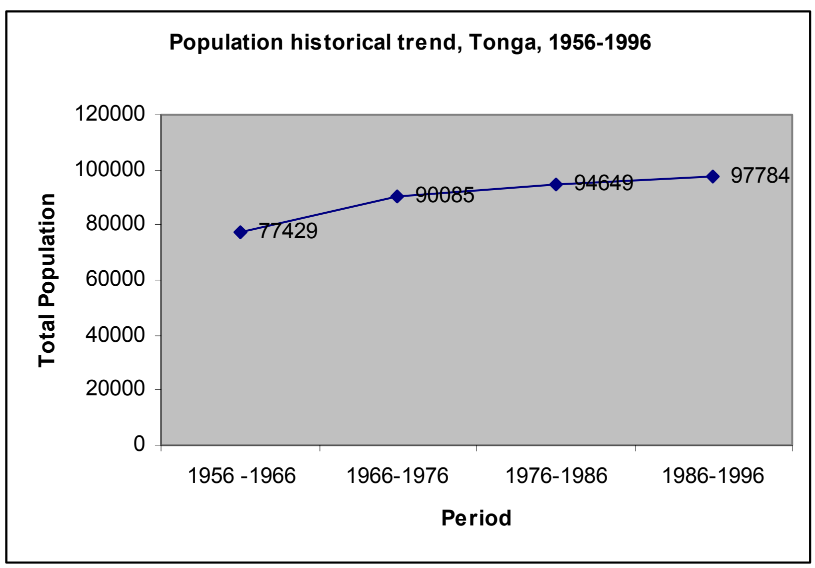


Figure 1.15: Historical population trend between 1956-1996.

Table 1.3: Population historical trend, Tonga, 1956-1996

Census Number	Period	Duration	Population	% Increase p.a.
1	1956 - 1966	10 yrs	77,429	3.60
2	1966 - 1976	10 yrs	90,085	1.60
3	1976 - 1986	10 yrs	94,649	0.49
4	1986 - 1996	10 yrs	97,784	0.3

Source: Department of Statistics, Tonga

1.7.2. Migration

International Migration

The low rate of annual growth in 1996 (0.3%) was due to the high level of international net migration. International migration plays an important role in the population growth and changes in the structure of the population of Tonga.

Migration by Divisions

The 1996 census data showed different kinds of mobility among the population of Tonga. Firstly, 20 per cent of the population had their place of birth different from their usual place of residence. The Niuas revealed the highest rate followed by Ha'apai (Table 1.4).

Secondly, for the in-migrants Tongatapu accounted for 71%, Vava'u for 11%, Ha'apai for 5%, 'Eua for 8% and 3% for the Niuas.

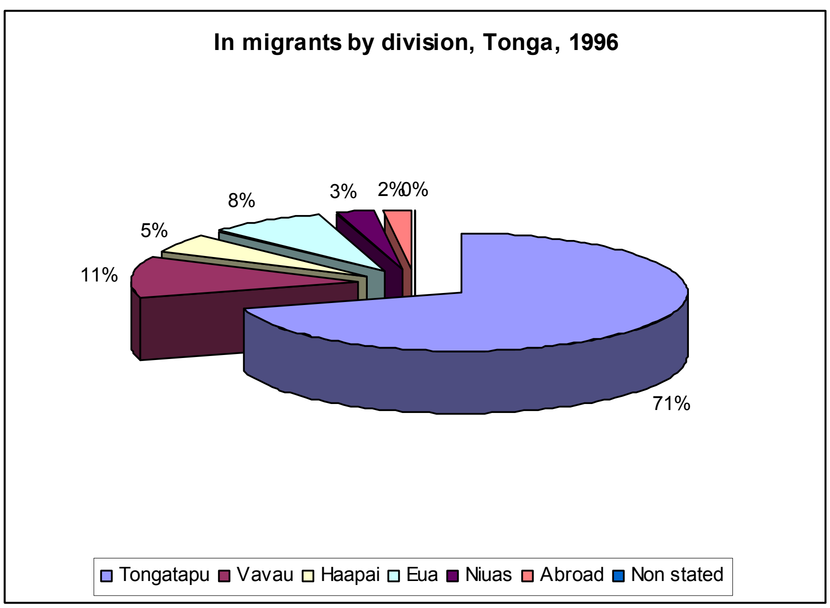
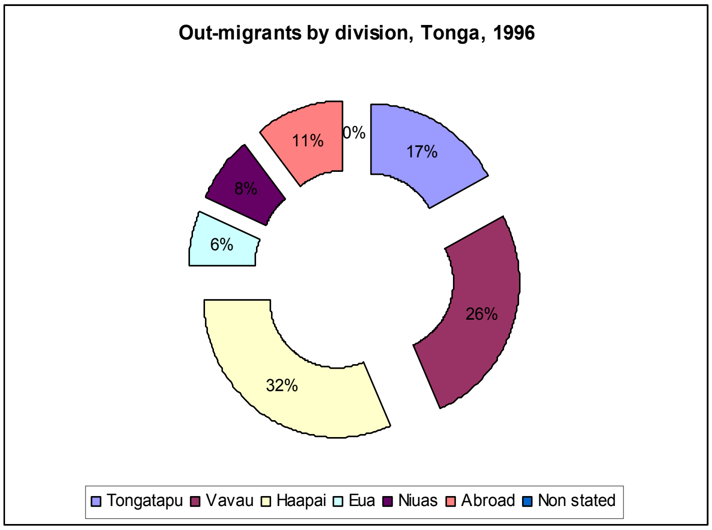


Figure 1.16: In-migrants by division, Tonga, 1996.



For the out-migrants, Tongatapu accounted for 17%, Vava'u, 26%, Ha'apai 32%, 'Eua 6%, and 8% for the Niuas.

Figure 1.17: Out-migrants by division, Tonga, 1996.

Thirdly, except for Tongatapu and 'Eua, other divisions lost more people than they gained. Tongatapu gained the most with net-migrants of +11,251 persons. (Table 1.4) Majority of these were from Vava'u and Ha'apai.

Table 1.4: Non-movers, In-migrants, Out-migrants, Net-migrants by Division, 1986-1996

Division	Non-migrants	In-migrants	Out-migrants	Net-migrants
Tongatapu	49,225	14,821	3,570	+11,251
Vavau	13,458	2,337	5,489	-3,152
Haapai	7,194	1,093	6,640	-5,547
Eua	3,126	1,711	1,350	+361
Niuas	1,626	581	1,672	-1,091
Abroad	408	423	2,245	-1,822
Not-stated	16	1	1	-
TOTAL	**75,053**	**20,967**	**20,967**	**0**

Source: Population Census, Department of Statistics, Tonga, 1996

Note: Non-movers are those reside at the place of birth as their place of usual residence.
In and out-migrants are those moved from their place of birth and lived at a different place.

Rural to Urban Migration

The 1996 census results indicated that 12% of the population born in Tonga and residing in Nuku'alofa at the time of the census were originally rural born.

Table 1.5 illustrates that 78% of the in-migrants into Nuku'alofa came from rural areas in Tongatapu, Vava'u and Ha'apai. The largest percentage (31%) came from Ha'apai. There was 26% in migrants from Vava'u and 21% from Tongatapu. Reasons for such migration were due to employment and educational purposes since Nuku'alofa is the center of employment and education in Tonga.

Table 1.5: Migration to Nuku'alofa, 1996

	In-migrants	% distribution	Out-migrants	Net-migrants
Tongatapu	2,462	21.09	1,437	1,025
Vavau	3,001	25.71	647	2,354
Haapai	3,654	31.31	353	3,301
Eua	739	6.33	381	358
Niuas	789	6.76	129	660
Abroad	1,026	8.79	118	908
Non-stated	1	0.01	1	-
TOTAL	**11,672**	**100.00**	**3,066**	**8,606**

Source: Population Census, Department of Statistics, Tonga, 1996.

Population Projection

The population projection was limited to 30 years, started from year 1996 to 2026. It is believed that projection beyond this point would be erroneous and misleading considering that there are various variables that cannot be accurately forecasted. However, it is projected that the population of Tonga will still be increase in fifty –hundred years ahead (2050 and 2100).

1.8. EDUCATION & TRAINING

Tonga has a high level of educational achievement of 98.5 per cent literacy. Only 1.5 percent was illiterate. In details, at the age of 6 years old and above, 72.8 per cent of Tongans and Part Tongans could read and write both in English and Tongan languages. 25.1 per cent could read and write in the Tongan language only and 0.6 per cent was literate in English language only (Table 1.6).

Table 1.6: Literacy of Tongans and Part-Tongans aged 6 years and above by language and by sex, 1996.

	Male numbers	%	Female numbers	%	Total numbers	%
Literate:	**39794**	**98.4**	**39224**	**98.7**	**49018**	**98.50%**
English and Tongan	29335	72.5	29076	73.1	58411	72.8
English only	225	0.6	249	0.6	474	0.6
Tongan only	10234	25.3	9899	24.9	20133	25.1
Illiterate	650	1.6	523	1.3	1173	1.5

Source: Population Census, Department of Statistics, Tonga, 1996.

Primary education is universal and retention of almost all students until the mid-secondary school level. The Government provides a primary school for every inhabited island with a primary school-age population. The Government also operates most schools, while churches or NGOs run some. These schools have received formal training in education. Approximately one third of the students in Class 6 (the final year of primary school) repeat the year in the hope of scoring well and be able to be offered a place in one of the more prestigious secondary schools. The emphasis is on an academic program from primary to upper secondary and tertiary level.

The Government manages eight secondary schools, teaching over 20 per cent of the secondary students. Eight non-government education authorities provide most secondary education, and seven of these receive government grants (T$100 per student). Teachers are well qualified by regional standards. The percentage of teachers in government schools holding degrees has been typically higher than that in non-government schools. There is considerable variation in student performance between schools, with those in government schools generally performing better.

The Pacific Senior Secondary Certificate examination is administered in Form 6. The number of candidates rose from 632 in 1990 to 1,041 in 1998, when 26% qualified for Form 7, 26% for teacher's college, and 43% for the civil service. The New Zealand Bursary/University Entrance/Scholarship Exam is taken at the end of Form 7. Percentage of successful examinees has been high but falling, especially in 1999. Girls outperform boys in secondary entrance examinations. This was evident at the top secondary school (Tonga High School), which achieved 60-70% of A and B grade in the New Zealand Bursary exams.

By 1999, more than half the local formal training of post-secondary students was undertaken in eight government institutions. Various non-formal training is provided by both government and non-government organizations. Overseas education and training has been crucial to human resources development. The Government's donor-assisted overseas scholarship programme has been supplemented by study funded privately and through the New Zealand Aotearoa and Australia Agency for International Development (AusAID) programmes.

The share of education in public current expenditure fell from 20% in FY1991 to 16% in FY2001, but still remains high by regional standards. Annual development expenditure has fluctuated according to the implementation of significant foreign assistance-funded projects.

The Ministry of Education has six programs split into primary education services, which received 46% of the education budget of T$12.2 million in FY2000, and secondary education received 24%, while post-secondary education received 21%.

Ninety per cent of the allocation for primary education resources absorbed by salaries and little left for schools operations and maintenance. Parents and communities however, make significant cash and in-kind contributions to primary education, equivalent to 39% of the total Primary Division budget in 1998.

Public expenditure on secondary education largely goes to the eight government schools. The non-government schools that educate about 80% of the secondary school population receive roughly 8% of the allocation.

The Strategic Development Plan Seven, 2001-2003 reaffirms the Government's commitment to high quality universal education reaching Form 6 and the development of technical and vocational education and training. The Ministry of Education's strategic plan included the goals of:

- organizational restructuring of the Ministry itself;
- appropriate amendment of the Education Act;

- establishing a National Qualification Board;
- developing formal preschool programs for early childhood education; and
- establishing a national university.

1.9. ECONOMY

Tonga's economy grew at the average annual rate of 1.8% during the period 1973-1995, with per capita growth at 1.2%. Remittances and government spending were engines for growth. Real GDP grew at the annual rate of 2.2% in the 7 year period from June 30 1994 to 30 June 2001; but growth rates ranged from minus 0.1% to 6.2%. The primary sector grew at just 0.4%; the secondary sector at 4.6%; and the tertiary sector at 3.5%. The government administration and community services sectors were the main contributor to growth. In 1996, full-time government workers accounted for 39% of the 13,318 Tonga employees who are regularly paid in cash.

The inflation rate between June 1985 and June 2001 varied around average of 6.4%. Inflation was below 3% in FY 1996 through 1998, but subsequently accelerated to over 6% in FY 2001 and 10% in early FY 2002 as a result of expansionary macroeconomic policies and substantial currency depreciation, drought and cyclone damage, and higher world prices.

The fiscal situation deteriorated in the period FY 1996-FY 1998 largely because of the impact of civil services wage rise and economic stagnation. In FY 2001 a 20% civil service wage rise and below budget non-tax revenue collection increased the current budget deficit to almost 0.5% of GDP. The overall budget deficit was 2.6% of GDP and was financed by the domestic banking system, causing a rise in public domestic debt outstanding to 55%. The original FY 2002 budget estimate was for an overall deficit of 2.3% of GDP, but over 4% is more likely. Unless expenditure is constrained, there will be further borrowing from the banking system that will place an already fragile foreign reserves position under additional pressure. A reduction in the wage bill is also needed to allow for more expenditure on operation and maintenance.

The formal financial system consists primarily of the National Reserve Bank of Tonga, three commercial banks, and the Tonga Development Bank. The policy objectives of NRBT are to keep the reserves at a level equivalent to at least three months of imports. NRBT made considerable progress in moving during the early 1990, but its weak income position has forced it to rely increasingly on direct instruments of control. The capacity of NRBT to conduct banking supervision is limited.

Money supply growth averaged 11.2% per annum during the 10yr period to June 2001 and was driven by domestic credit expansion, with net foreign assets stagnation. Domestic credit expansion in turn reflected growth in credit to the private sector, which accelerated markedly following the entry of two new commercial banks in 1993. Monetary policy was tightened in FY 1995, FY 1999, and early in FY2001. However, excess liquidity permitted a rapid domestic expansion of 31.4% towards the end of the latter year. Broad money increased 26.5% and gross official reserves declined to less than 2 months of import cover, placing pressure on the currency. The Government approved the imposition of a credit ceiling.

There was deepening of the financial sector in the 1990', and savings and lending rates were generally positive in real terms. The interest rate spread was just over 4%. However, the acceleration of inflation early in FY 2000 and in FY2001 turned real deposit rates negative.

The external accounts were characterized by large trade deficits throughout the 1990s, large net private transfer flows, and a generally negative current account balance. Remittances were the major source of foreign exchange. In mid-2001, the external debt was USD 63.6Million, or 44.7% of GDP. The debt service ratio was 12.1%.

The domestic currency, the pa'anga, is pegged to a currency basket consisting of the Australian, New Zealand, and US dollars and the Japanese yen. During the fiscal years 1991-2001, the pa'anga was devalued by 22% in nominal effective terms, and 10% in real effective terms. Most of the currency devaluation followed the private sector credit expansion of FY 1998 and the subsequent loss of foreign reserves.

Macroeconomic stability has been under threat on several occasions during 1990-2001. In FY2002, there was a need for short-term fiscal and monetary tightening. However, in the first quarter of the fiscal year 2002, the necessary tightening was not occurring. The outlook was for a slight slowdown in real GDP growth in FY 2002 to 2.9%, and a rise in the inflation rate to over 10%. The medium term period to FY2006, growth was projected to be in the 2.5% to 3% range.

1.10. AGRICULTURE

Agricultural production is still the predominant activity in the economy of Tonga and continues to dominate the value-added contribution to GDP. The contribution was more than 40% in the 1980s however, it fell below 40% from 1993/94 to the present. Depicted in Table 1.7 are the percentages each sector contributes to GDP. Table 1.7 shows that the contribution of agriculture to the GDP is falling from a peak of 34% achieved in 1994/95. The services sector on the other hand, has recorded increases in its contribution to the level of GDP indicating a gradual diversification from agricultural sector to the services sector. This gradual diversification from the heavy reliance on one sector will assist in diversifying and broadening the economic base in order to strengthen the economy against future exogenous shocks. Moreover, with services the problems associated with isolation, weather and economies of scale are mitigated.

The agricultural sector is important as a source of domestic food supply, employment, cash income, foreign exchange earnings, and raw materials for processing and handicrafts. A large percentage of economically active Tongans (58.4%) rely on primary production for their livelihood. Agriculture has consistently been the main foreign currency earner over the years. In the 1960's to 1970's, the main agricultural export crops had been copra and banana. With the defunct of the banana project and the decline of copra, vanilla became the main export crop. Squash became the main export crop in the early 1990's along with vanilla, and in the mid-1990's kava became an important export crop. In the last few years, nonu also became an important export crop. Export statistics of the 1990's showed that traditional root crops have consistently been exported in substantial volumes.

Table 1.7: Annual share of GDP (%) at constant prices, by industries.

	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99
Agriculture, Forestry, and Fisheries.	32.2	34.0	32.0	31.5	30.8	29.9
Mining and Quarrying.	0.3	0.5	0.4	0.4	0.4	0.4
Manufacturing	3.2	2.7	3.1	3.2	2.9	3.2
Electricity and Water	1.7	1.7	1.8	1.8	1.8	1.8
Construction	5.6	5.6	6.0	5.2	4.9	5.3
Commerce, Hotels, and Restaurants	11.7	10.8	10.5	10.1	10.8	11.0
Transport and Communications	6.1	6.0	6.3	6.5	6.7	6.9
Finance and Business Services	5.4	5.4	5.3	5.5	5.9	6.1
Government Administration and Community Services	14.6	14.6	15.6	16.5	16.5	16.2
Ownership of Dwellings	3.0	2.8	2.9	3.0	3.0	2.9
Entertainment, Recreation and Personal Services	4.0	3.8	4.0	4.2	4.2	4.2

Source: Department of Statistics, Tonga

Traditionally, all the household requirements from agriculture were provided by very complex, robust, and productive farming systems. These were multi-storeyed rotational fallow systems utilizing bush or grass fallow followed for several years by a series of root crops intercropped with coconuts and other tree species. They had proven very sustainable in the past, but with increasing population pressures and land pressures for urban development, the fallow periods have shortened and fertility declined (Halavatau, 1998) coupled with increasing pests and diseases (Halavatau, 2001).

Performance of the Agriculture Sector

The performance of the agriculture sector can be judged from the agricultural export, cash flows from domestic food markets and food imports.

Export

The contribution of agricultural export can be seen from the foreign currency earned from the export between 1994 -1999 (Table 1.8). It is quite clear from this Table that squash has dominated export for quite sometimes. However, export of staple crops and other traditional crops has contributed significantly to the export economy. Squash, vanilla, and recently kava are the main foreign currency earners.

Table 1.8: Agricultural exports for 1994 – 1999

T$ (000)						
	1994	**1995**	**1996**	**1997**	**1998**	**1999**
Export	16.29	16.68	11.94	11.23	7.56	16.61
Squash (net)	4.7	4.2	3.9	5.8	4.1	2.4
Squash (ton)	16545	8290	12789	11839	7238	18268

Source: Department of Statistics, Tonga, 1999.

Domestic Food Markets

The domestic marketing chain for local foods is quite well established in Tonga as a whole either as market centres or stalls on the roadsides. The supply of locally produced food in the domestic markets provides ready access to communities everyday. The supply is quite regular unless interrupted by natural disasters. The price of locally available agricultural produce is not regulated. This means that farmers can put up prices to outrageous levels whenever they want. This usually happens after a natural disaster or when produce is sold out of season. The prices are sometimes beyond the buying capacity of low to medium earners.

Food Imports

Food imports has been a concern in Tonga for many years and is currently over T$20 million per annum. (Statistics Department, 1999). In 1999 food import accounted for more than the total export. Meat accounts for most of the food imports followed by cereal products, dairy products, and sugar and confectionery. It appears that Tonga does not import according to food needs but rather more because of luxury demands.

The ratio of the value of agricultural exports to the value of food imports is probably the most useful indicator of Tongan agricultural performance over time. The ratio had further declined from 0.5 in 1986 to 0.27 in 1988 (Figure 1.18) but picked up after that and peaked at 0.86 in 1993 and thereafter declined to a low of 0.23 in 1998 before picking up in1999. The recovery of the ratio after 1987 can be explained by the introduction of squash pumpkin to the economy. After 1989, squash became the major exporter for Tonga with increasing contribution to the economy. The low ratio in 1998 was caused by the poor squash crop because of the drought and the very low contribution by vanilla to export economy in that year. Kava export was second to squash pumpkin in 1998 contributing over T$2 million. If the country imports foods in accordance to food needs, then the ratio will be higher, reflecting a better performance for agriculture.

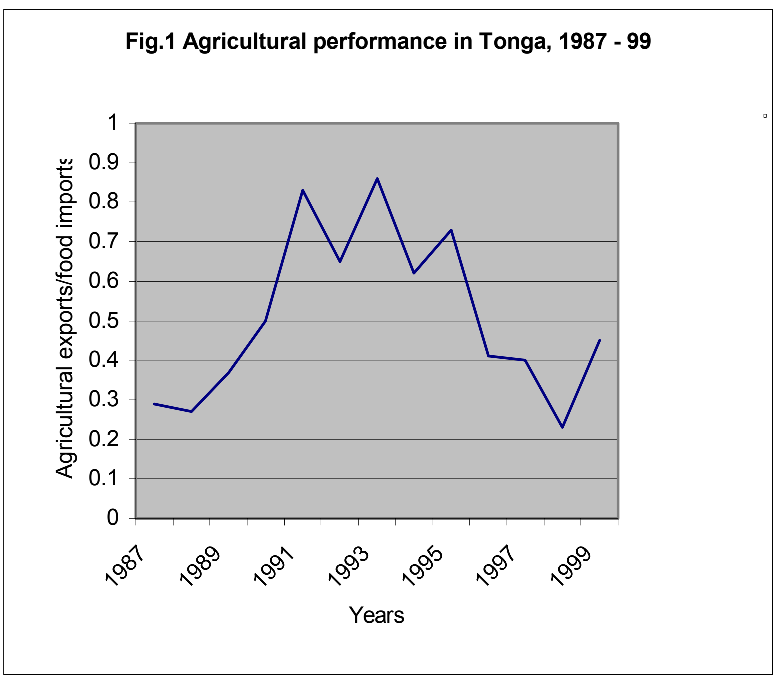


Figure 1.18: Agricultural performance, Tonga, 1987 -99

1.11. FORESTRY

There are few remaining natural forests in Tonga and limited in extent, being primarily restricted to steep, remote, inaccessible areas, uninhabited islands, coastal areas, swamps, and mangroves. Accessible natural forests often represent remnants of natural diversity that could yet be lost to agricultural development and encroachment. Further, considerable areas of regenerating forest have developed for which various land-use options exist. These could include allowing high forest to develop and service a range of needs (e.g. soil and water conservation, provision of plants for utilitarian and cultural purposes), integration into agro forestry systems, or conversion to intensive agricultural use. It is therefore important to employ comprehensive land-use planning.

About 70% of Tonga's populations of live on Tongatapu. On this densely inhabited island, little original forest remains and many native plant and wildlife species are either extinct or severely threatened. One of the many functions served by the remaining natural forest fragments in inhabited and nearby areas is to provide local people with firewood, edible plants, plants used for medicinal and cultural purposes, carving materials, and so forth (Thaman, 1975). Populations of high-value species have declined and consequently material is becoming harder to find. Increased fragmentation and disturbance promote the spread of adventive weeds and pests into natural forest, which threatens the integrity of these areas. The coastal forest strips in the islands of Tonga, which serve the essential function of preventing shoreline erosion and protecting inland agricultural and inhabited areas, have been dramatically reduced in extent. In the main island of Tongatapu, some consider the remaining forests to be unimportant because they are assumed to be secondary, small in extent, and more disturbed than the remaining primary forests on the islands of 'Eua, Kao, Tofua, and Late. However, these fragments are the main forest areas with which many of Tonga's people have regular contact. This contact is essential because of the importance of forest products in Tongan culture and underpins the support for protection of high-value forests elsewhere in the Kingdom of Tonga.

1.12. COASTAL & FISHERIES RESOURCES

The sea and its resources as well as the coastal areas (from 50 feet above high tide watermark) are Crown property and the rights to all resources (sand, dead coral, marine life) are vested in the Crown (Constitution of Tonga and The Continental Shelf Act, 1970). The sea and its coastal resources have provided for the livelihoods of Tongans. Coastal areas include areas of complex and specialized ecosystems such as mangroves, coral reefs and sea grasses, beaches and diverse species that occupy the coastal habitats.

Coastal Development is the driving force that has shaped the coastal areas. Development at the waterfront in Tonga has been limited to the construction of wharves, jetties adjoining major towns and villages, and housing developments in mangrove swamps. This was done with very little precautions to prevent siltation of the coastal environment during the activity. Several causeway constructions to link outlying islands to the main islands have been completed. These constructions have resulted in coral deaths on the lagoon side, and fishermen have complained about the decrease in fishing productivity in this area. (Tonga National Assessment Report, 2002).

The rapidly increasing rate of construction of houses and buildings has resulted in a rapidly increasing demand for beach sand. Sand is surface-mined from the beaches by the Ministry of Lands, Survey and Natural Resources and then sold to the public.

The environmental impact of current beach-mining activities is evident in Tonga, as many of the more popular beaches have been stripped of sand and are now no little more than beach rock. Offshore sand deposits have been found as suitable for cement aggregate but the cost involved in proper extraction operation is not affordable by the country's current economic status. In addition environmental impacts including siltation, sediment plumes and habitat disturbance make offshore extraction unsustainable at places. The Ministry of Works is investigating alternative sources of sand such as crushing screening quarried limestone or sawn coral blocks from quarries (Tonga National Assessment Report, 2002.)

Fisheries

The reefs and lagoons are the prime fishery for subsistence supplies. In addition to fishing, a wide range of shellfish and other marine life are harvested from the tidal flats at low tide for consumption or for production of shell handicrafts for sale to tourists.

There are three categories of Marine Fisheries Resources in Tonga (offshore, bottomfish, and inshore resources. They vary in magnitude and are subjected to different levels of exploitation. The offshore resources, primarily four species of Tuna, are only lightly utilised and form part of a large regional resource. Management and conservation actions such as minimum sizes, export controls and closed seasons are required immediately. Any increase in benefits from Tonga's inshore resources will probably be from increasing the quality of the product through, for example, improved processing or handling techniques, rather than increasing the volumes of landings. The Government of Tonga recognized the potential for the development of fisheries resources and as such the Ministry of Fisheries was established in early Year 1991.

Tonga faces many challenges with the management and conservation of its fisheries resources. Unlike other Pacific Island countries, there is no traditional marine tenure system in place. However, Fisheries Management Act 2002 has provision, which indicates that Minister of Fisheries can declare special coastal community based management areas. After the approval of the community management plan, they will be responsible for managing their coastal marine resources.

1.13. ENERGY

Energy plays a crucial role in sustainable development and this relationship is high on the national and international agenda. Limited access to adequate energy services, or shortage of such services, is a barrier to Tonga's social and economic development and the alleviation of poverty. A significant portion of the population does not have access to basic electricity for lighting, and very few use LPG or kerosene for cooking. It is important for Tonga's national planners and decision-makers to be aware that energy services drive economic and social development and represents an essential bottleneck if not sufficiently available.

Tonga's indigenous energy resources are limited. There is no hydroelectric or geothermal potential. Electricity generation is diesel-based. Wave energy has been investigated but is not being pursued as an alternative. Thus Tonga's immediate available resources are its depleting wood stock, abundant coconut residues, and solar energy. Depleting wood resources are caused mainly by pressure on land for agricultural purposes. The country is increasingly reliant on imported petroleum products to satisfy its commercial energy needs. Thus it is vulnerable to external events that affect the price and availability of petroleum products and export potential and foreign currency flows from remittances and aid.

The pattern of energy use in Tonga during the decade has changed dramatically, reflecting the rapid development of energy-intensive economic activities, thus intensifying Tonga's reliance on imported petroleum products. In 1992, indigenous biomass accounted for 56% of total energy consumed, while petroleum represented the remaining 44% (of which a third was consumed by power generation). By 2001, imported petroleum products captured 54% of the total energy requirement, with biomass, for households and agricultural processing, dropping to 43%. In terms of power generation, electricity grew from 3% in 1991 to roughly 5% by the year 2000, and close to 95% of the potential residential consumers is served. Renewable energy continued to rise from less than 1% in 1990 reaching 2% by 2003.

The main characteristic of the power subsector is the high demand growth over recent years. The consolidated energy generation for the four systems grew from 24.21 GWh in 1989/90, while sales amounted to 20.01 GWh. By 2001, sales reached approximately 28.8 GWh, a 44% increase during the 10-year period. Energy losses in power transmission declined by 4% (from 13% in 1990 to 9% in 2001). Consumers were estimated at 8,000 in 1992 and 13,000 active consumers in 2001 – a 62% growth, of which 76% are residential, 7% commercial and others accounts for the balance.

In 1992 the value of petroleum import was estimated at \$3m (equal to 30% of total imported goods), and \$17m by the year 2000. The recent rising of oil in the international market as well as a growing demand in the transportation sector accounted for the sharp increase in the value of fuel import. In terms of volume, an average growth rate of 12% was observed in 1990. During 1985 – 1990, imports of petroleum products increased at an average rate of 12% by volume. At least 80% of imported fuel was consumed by the transportation sector during the decade. Retail prices during the decade fluctuated in response to the external markets, when oil prices soared as high as US 45/barrel and plummeted to as low as US 5/barrel. In 1995 retail prices for gasoline was as low as TOP 59.88/litre, 64/lire for diesel, and 54.58/litre for kerosene. During the third quarter of 2001, retail prices per litre reached TOP 1.66 for diesel, 1.44 for gasoline, and 1.45 for kerosene.

The rising fuel demand also impacted on storage capacity. During the third quarter of 2001, oil storage capacity expanded by an additional 2,130 tonnes at Nuku'alofa and 70 tonnes at 'Eua.

The majority of households in rural areas cook primarily with fuelwood and coconut residues. The consumption of biomass has decreased against the growing consumption of petroleum. The purchase price of fuelwood continued to rise in Tongatapu, particularly within the Nuku'alofa area, due to observed supply limitations.

Solar energy is traditionally utilised for crop drying and food preservation. Photovoltaic (PV) technology has been used extensively to provide electricity to rural communities, primarily on outer islands that do not have grid supplier power. It is estimated that 582 PV lighting systems and a community freezer have been installed. By 2003, an additional 170 systems will have been installed at 7 islands at the Ha'apai group and 100 at Niuafo'ou. Solar thermal application for water heating is also well developed on Tongatapu and has expanded in the residential sector and within the tourism industry.

The direct impact of energy services on the environment became visible with traffic smokes in Nuku'alofa and dumped waste oil on the grounds throughout the island group.

As commercial energy increased its share of the country's total energy requirements, energy conservation among producers and consumers responsive to energy-saving measures assumed greater importance.

Minimal development occurred in the administrative sector although the privatisation of power generation was achieved in 1998 when Shoreline took over the power generation. The institutional framework is fragmented and the overall management of the sector received low priority that resulted in a lack of focus on important energy issues, which required attention of some central authority.

To date, the primary objective of providing leadership to the sector was to contribute to a balanced approach between energy resource development and supply, on the one hand, and energy conservation, on the other. To this end, it is necessary to redefine the objectives and functions of the central energy institutions to increase the allocation of human and financial resources.

1.14. TOURISM

The tourism industry continues to play its role as one of the major contributor to the kingdom's economy via foreign exchange earnings. Although the number of tourist arrivals has slightly declined since 1999 as illustrated in Table 1.9 and Figure 1.19, the foreign exchange earnings remained rather stable. Pre-1999, rising tourist numbers probably reflected the growing attraction to the new millennium celebration at the island where time begins. Although post-1999, may seem to have a downfall trend, in fact it is only the fluctuation in numbers per annul. An average 43,000 arrivals annually, dominantly by plane rather than by sea due to improved air services to Tonga, still serve the country's economy.

Table 1.9: The numbers of tourists to Tonga and Foreign Exchange Earnings 1996-2002.

Year	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
No. of tourists	40,153	36,244	45,814	50,419	48,460	43,977	36,585
Foreign Exchange Earnings (million$)	15.9	15.8	12.3	14.4	14.06	14.14	-

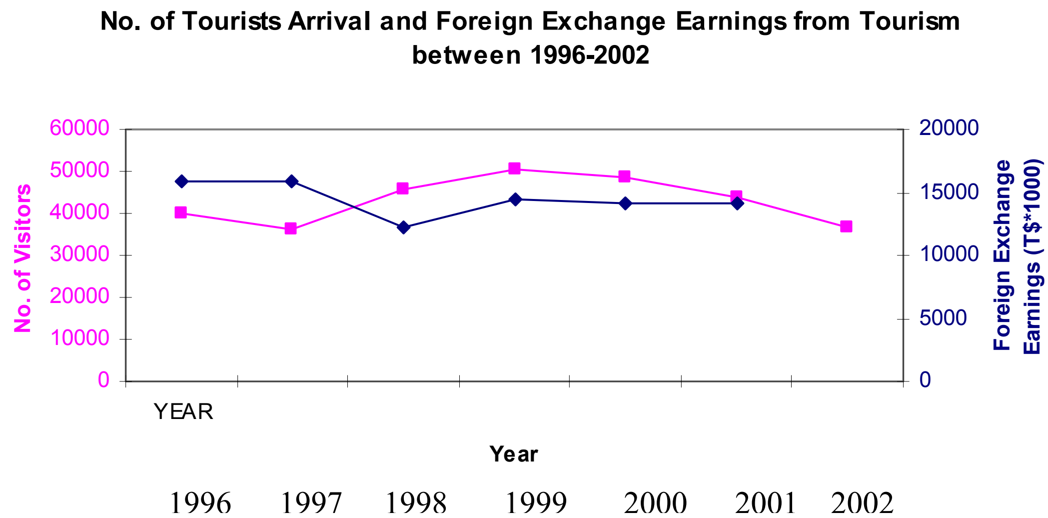


Figure 1.19: Graph representing the number of Tourist Arrivals and Foreign Exchange Earnings from Tourism 1996-2002.

With the descending figures of visitors in the last three years, the Tonga Visitor's Bureau (TVB) is taking the lead, undertaking actions in order to attract more visitors to increase the economical benefits from the tourism sector. TVB have also identified several strategies which include the need to develop new eco-tourism products; introducing minimum standards to improve tourism services and products; and coordinate the development of tourism as a major sector.

Some of the current emphases of the government now in order to exert a pull on tourists are developing national parks, beautifying natural sceneries, natural heritage sites and public areas. The country is also promoting marine-based activities which capture the attention of adventurous tourists such as deep sea diving, snorkeling and whale watching and also wildlife conservation. Developing more island resorts is also one of the country's interests.

Apart from contributing to the Kingdom's overall foreign exchange earnings, the tourism industry indirectly creates employment through out the informal sector from demand for handicrafts, fishing and farming products. Likewise in the formal sector, tourism also indirectly creates employment in accommodation facilities (*hotels, motels, guesthouse, etc.*), restaurants, travel agents and tour operators, and so forth. Tourism also widely distributes the economical benefits in the private sectors for other services such as transportation services, professional/technical services and goods/products from retailers/wholesalers.

Given the current status and future prospects in the tourism industry worldwide, it is presumed that very likely the number of visitors hence foreign exchange earnings will grow steadily in the next five years (Tonga Visitors Bureau, 2002). Nevertheless, as there is the need to promote culture-based activities and products such as traditional dances, carvings and handcrafts, it can indirectly deplete the natural resources utilized, thus sustainable resource management plan is crucial.

1.15. TRANSPORT

Transportation in Tonga is managed under three different bodies namely Ministry of Works (MOW) (for land), Ministry of Marine & Ports (MMP) (for sea), and the Ministry of Civil Aviation (MCA) (for air transport). However, there is no overall coordination of the transport sector and there is yet to be a transport policy for Tonga.

Land transport in Tonga has been very challenging as opposed to the limited land resource. As a result, the total length of road networks cannot be increased because of the existing land tenure system where the land has been sub-divided. As such, the objective of road transport at present is the issue of maintenance and thus, to move towards a more sustainable method for road maintenance and rehabilitation. In addition, the bulk of the existing road network was constructed from aid resources and these resources will not continue to assist this sector. Thus, it has been very critical for the government to move forward and manage its physical infrastructure in a more sustainable manner.

The Marine Transport Sector involves domestic and international services. Domestic inter-island transports operate between different groups of island, as well as international services being offered. The administrative structure of the marine transport sector has changed over the early 1990s through the division of responsibilities between the Minister of Marine & Ports and the Minister of Finance (Controller of Customs). Accordingly, functions have been reorganised between the MMP and the Ports Authority in 1998 according to the Ports Authority Act. Adequate safety standards and certification norms for Tongan vessels and crews have been established and are enforced by the MMP. However, there may be other acts and regulations in this sector that needs firmer enforcement to adequately assist the development of the sector. In addition, this will assist Tonga's support for international treaties/conventions in the sector.

The MCA is responsible for the regulation of air transport services in Tonga. This includes the operation and maintenance of six airports, including fire and security services, air traffic services, navigation and meteorological services. The MCA has been challenged for improvement in its administration of its Civil Aviation responsibilities including its role in the ascertaining Civil Aviation capacity is in line with international standards.

Over the past decade, Tonga had been fortunate to receive some infrastructure programmes that it had invested interest in, to reflect the national importance of the sector to the country. Part of these included road construction projects, development work on airports and wharves, and some administrative strengthening in the responsible Ministries. To reflect the importance of the Transport sector, government has made it one of its priority areas in its current and previous Strategic Development Plans, to focus on these areas with policy guidelines land strategic result areas (Tonga National Assessment Report, 2002)

1.16. WATER RESOURCES

Water, like land, is not only precious, but is a limited resource in Tonga. Tonga does not have surface water apart from a few salty lakes on the islands of Tofua, and Niuafo'ou. The main source of water is from rainwater collection or from a thin fresh water lens within highly porous limestone substrate. The volcanic island of 'Eua gets its water from caves high above sea level. A large number of small islands in Ha'apai and Vava'u rely entirely on rainwater tanks for their water.

According to the1996 Census, out of the total 16,194 households in Tonga, 84.6% (13,705 households) had access to piped water supply, 58.3% (9,444 households) had their own water tank; 2.4% (393 households) had their own well, and 1.1% (175 households) had other sources of water supply.

Table 1.10: Number of households by sources of water supply, Tonga, 1996.

Sources of water supply	Number of households	%
Piped	13705	84.6
Own water tank	9444	58.3
Own wells	393	2.4
Other sources	175	1.1

Source: Population Census, Department of Statistics, Tonga, 1996.

Water consumption per household per month, in the Greater Nuku'alofa area was estimated at 0.03 ML in 1998. These are only the households that have water meter. For the same year, in Nuku'alofa, it was estimated that 9.06 ML of water was for non-domestic uses; a total average of 87.67 ML was for domestic uses; and 70.45 ML was unaccounted for (Water Board Data Base). The non-domestic water uses were mainly from the Small Industries Centre and from the service industry such as hotels and motels, and service stations. Water for agricultural purposes was not recorded.

The growth of the capital towns such as Nuku'alofa, Neiafu and Pangai will undoubtedly have great impacts on water availability and quality. As the natural recharge of aquifers is controlled by climatic changes, recent monitoring carried out by the Mineral Resources Unit of the Ministry of Lands, Survey and Natural Resources shows a situation of increasing salt concentration (using the WHO Standard for Conductivity – 1,200µS). Sustainable development in Tonga without adequate freshwater supply for all its needs and services represents a very bleak outlook for future generations (Tonga National Assessment Report, 2002).

1.17 HUMAN HEALTH

The goal and vision of the Ministry of Health is to respond effectively to the health of the Tongan people providing appropriate range and level of high quality health services and being accountable for the outcome of these services.

In Tonga the Ministry's strategic goals include; healthy communities and population through improved services, health sector development, staff training and development, as well as service partnerships.

There are five major diseases causing morbidity in Tonga from 1989 -2003. These include Acute respiratory infection, influenza, Broncho pneumonia, diarrhea (infants) and pneumonia (adults). Year 2000 reflects the highest incidences of the five major diseases in Tonga (Table 1.11 & Figures 1.20-1.24)

In 2002, disease of the respiratory system and diseases of the circulatory system are the two leading medically certified causes of in-patient and outpatient deaths in Tonga (Ministry of Health, 2003). Epidemics are costly in terms of hospitalization cost, patients' care, vector control efforts, national economic productivity and human sufferings. In 1999 and 2000 the incidence of diarrhoeal diseases peaked at the period when drought conditions were believed to have encouraged inadequate sanitary conditions and practices in many communities.

Table 1.11: Five leading causes of morbidity, Tonga, 1989 -2003

Diseases	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Acute Respiratory Infection				151	1594	6539	2622	1503	1815	19571	21164	63048	25717	24082	24311
Influenza	12936	19127	9562	13865	6344	11491	16427	13778	19927	18105	19571	61282	21622	22395	21597
Broncho Pneumonia	548	836	569	882	346	1687	1562	1901	1924	1466	1930	2150	1975	1498	1056
Diarrhea (Infants)	389	522	552	681	697	1121	997	923	724	1567	1588	1893	1452	1396	1035
Pneumonia (Adults)	326	263	1016	1264	1040	1176	1317	1355	1204	1173	1286	1596	1459	1273	1285

Source: Ministry of Health, 2003.

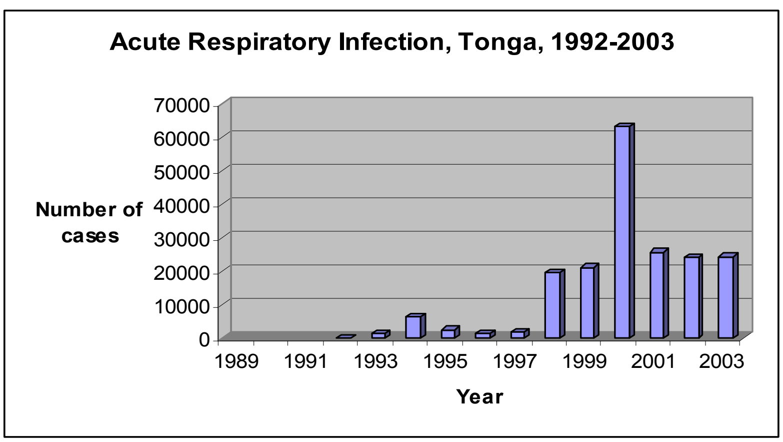


Figure 1.20: Acute Respiratory Infection, Tonga, 1992-2003.

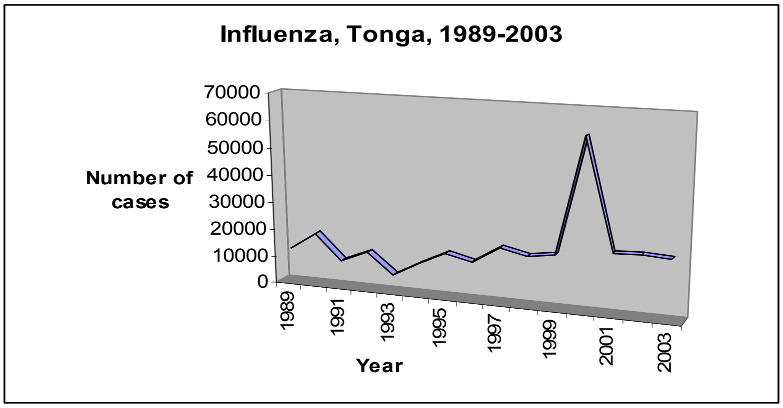


Figure 1.21: Influenza, Tonga, 1989-2003.

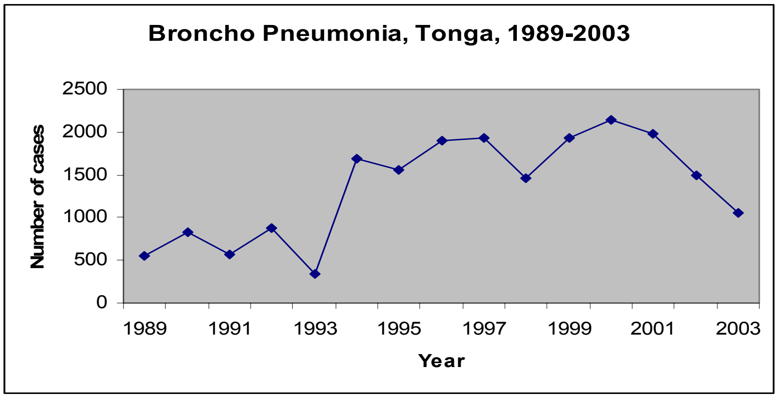


Figure 1. 22: Bronch Pneumonia, Tonga, 1989-2003.

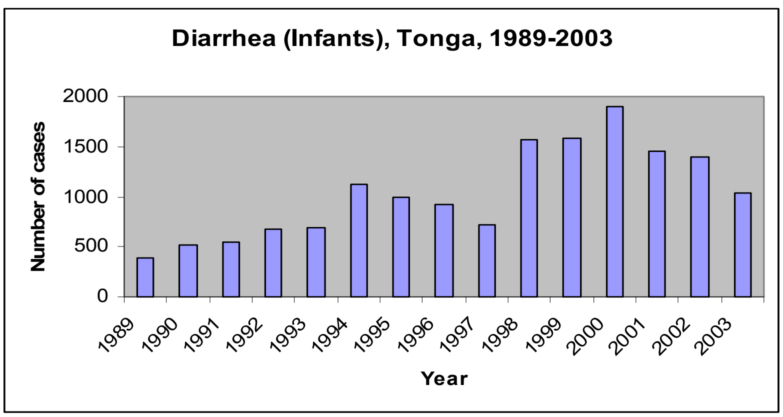


Figure 1.23: Diarrhoea (infants), Tonga, 1989-2003.

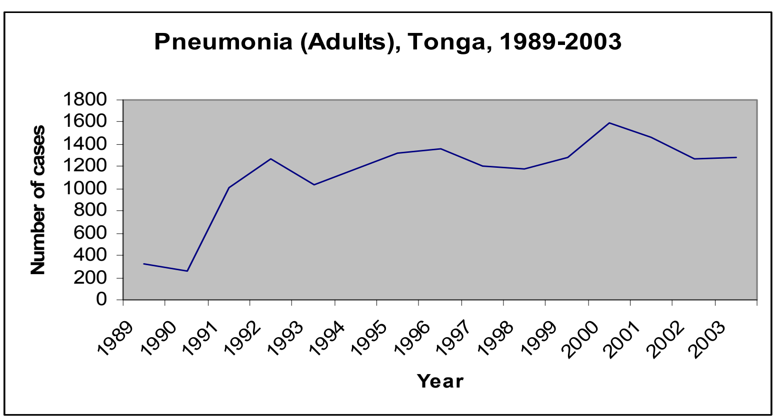


Figure 1.24: Pneumonia (adults), Tonga, 1989-2003.

VECTOR BORNE DISEASES

Dengue fever

Dengue fever affects infants, young children and adults, but rarely causes death (Benenson, 1995) Dengue viruses are transmitted to humans through bites of infective female *Aedes* mosquitoes. Once infected, a mosquito is capable of transmitting the virus to susceptible individuals for the rest of its life, during probing and blood feeding.

Research shows that climatic conditions contribute to dissemination of pathogens, which transmitted vector borne diseases such as dengue fever (Patz, 2000).

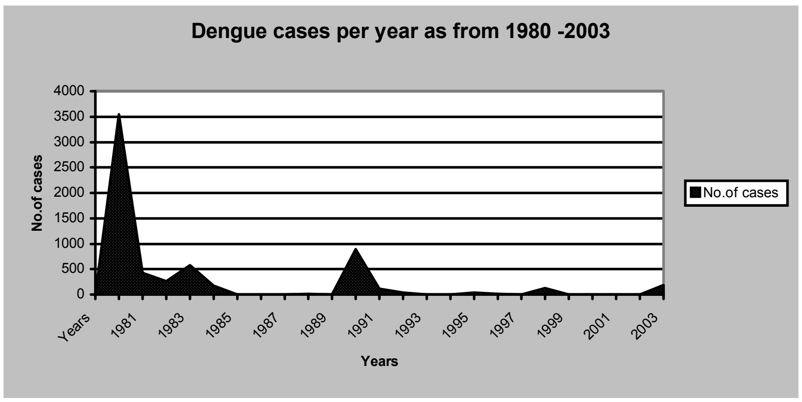


Figure 1.25: Dengue Fever, Tonga, 1980-2003

In reference to the reported cases in dengue fever, it is observed that in 1983, there was a slight increase in number of cases and again in 1990. It is assumed that climatic change after the cyclone Isaac has contributed much to this increase. However, data collected was incomplete but it's believed that favorable warmth condition harbors mosquito vectors, which transmit dengue fever.

Important determinants of vector borne disease transmission include; vector survival and reproduction, vector's biting rate, and pathogens incubation rate within the vector organism. Vectors pathogens and host each survive and reproduce within a range of optimal climatic conditions: temperature and precipitation are the most important, while sea level elevation, wind and daylight duration are also important. In reference to the Tonga Metrological Report, 2002, Salinger (2000) stated that interannual climate variability over the Pacific is dominated by the El Nino/ Southern Oscillation phenomenon, Tonga included.

FOOD AND WATER BORNE DISEASES

The Ministry of Health is aware that the cost of food borne illnesses to communities, including personal sufferings, loss of family income, community health care costs and loss of industrial productivity involve thousands of dollars annually. Therefore the WHO Regional Director, Dr. Omi stated, "This is the importance of government agencies working closely together with consumers, producers and processors to address food safety from production to consumption. Therefore, Health Department especially the Environmental Health Section urges to recognize the public health issue, to apply identified strategies and take necessary actions to achieve safe food for all and to minimize risk of climate change poses to human health.

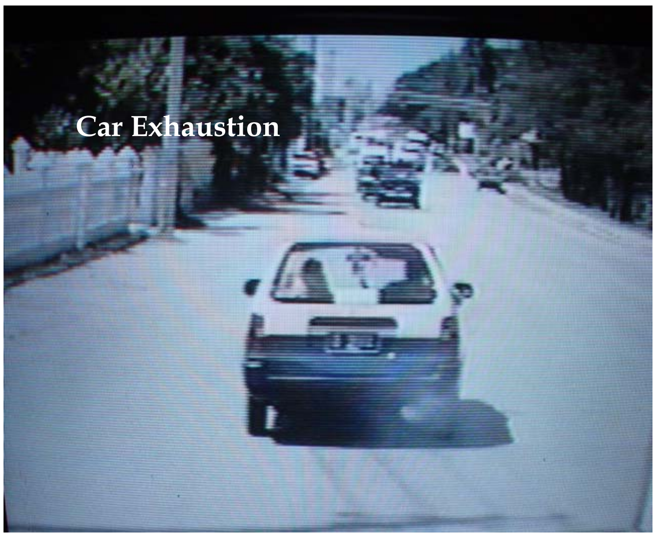
From the Ministry of Health report on infection diseases that food poisoning cases with gastroenteritis had increase over the period. That clearly indicates people's consumption of contaminated food and water.

OTHER INFECTIOUS DISEASES

Other infectious diseases occurrence in Tonga has been tabled in the previous paragraph, Benenson (1995) stated that infectious agents vary greatly in size, type and mode of transmission. There are viruses, bacteria, protozoa and multicellular parasites. These microbes that cause "anthroponoses" have adapted, via evolution, to human species as their primary host.

Human exposure to water borne infections occurs by contact with contaminated drinking water, recreational water, or food. This may result from human actions such as improper disposal of waste, or be due to weather events. Rainfall can influence the transport and dissemination of agents, while temperature affects their growth and survival (Gubler, 1998).

Chapter 2: NATIONAL GREENHOUSE GAS INVENTORY



2.1. INTRODUCTION

The Kingdom of Tonga acceded to the United Nations Framework Convention on Climate Change (UNFCCC) in July 20, 1998, which entered into force on 18 October of the same year. By becoming a non- Annex 1 Party to this Convention, Tonga undertook the inventory of its Net Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases (GHGs) not controlled by the Montreal Protocol to the extent of its potentialities permit and in accordance with Articles 4 and 12 of the UNFCCC.

The preparation of this initial Greenhouse Gas Inventory (GHGI) will set a foundation and baseline for the GHGs emitted from human induced activities in Tonga.

2.2. METHODOLOGIES

The reference year for the Kingdom of Tonga's inventory of greenhouse gas emissions and sinks was 1994.

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) were the major GHGs identified in the inventory. Tropospheric ozone precursors including nitrogen oxides (NO_x), carbon monoxide (CO), and Non-methane Volatile Organic Compounds (NMVOC) were also estimated.

The inventory used both the methodologies outlined in the IPCC Revised Guidelines of 1996 for the National GHG Inventories (volumes 1, 2, and 3) and the provisional GHGI software to calculate the national GHG emissions and sinks.

As required by the Revised 1996 IPCC Guidelines, all CO_2 emissions from the International bunkers be excluded from the national totals and be reported separately as Memo Items.

The national GHGI was undertaken on an individual sector basis for the Energy, Agriculture, Land Use, Land Use Change and Forestry (LULUCF) and Waste Sectors.

Copies of the completed IPCC worksheets and reporting tables from the sectors involved are produced and kept as a separate document which can be provided upon request.

2.2.1. Energy Sector

The inventory focused primarily on the energy supply, demand and GHG emissions for the year 1994.

The first step of the inventory was to identify the sources of emissions and sinks. Sources of emissions were determined as the numerous sources of energy fuels (indigenous & imported) accounting for the release of GHGs into the atmosphere by ways of burning and combustion being the largest emission sources. It was also noted by the inventory that these methods were not restrictive and that gases were also emitted during the storage and transportation of fuels.

Sources of sinks were determined as that contributing to the reduction and stabilisation of GHG emitted into the atmosphere. The main sources of sinks found were primarily biomass and corals. Biomass remains a significant emitter of CO_2; however its reporting has been reflected in the land use and agricultural activities due to limited reliable data in relation to its burning.

The methodology adopted for the inventory followed the Revised 1996 IPCC Guidelines, whereby the GHG emissions were determined by:

Source categories by fuel combustion in numerous economic activities (Sectoral Approach).

The GHG emissions from energy sources were determined by the volume of fuel imported, as Tonga is not a producer or an exporter of primary, secondary liquid and solid fuels. Details of consumption by source categories were available therefore the analysis omitted the results of GHGs released by the energy sources.

Emissions by source categories were determined by the secondary fuels combusted in the following: power generation, manufacturing & construction, transportation, commercial & institutional, residential, agriculture and forestry & fishing, mining & quarrying, water sewerage, and international bunkers.

Local specific data for the imported petroleum products were converted from its original units (kl) to an appropriate unit (kt) by a set of conversion factors to facilitate the application of the IPCC methodology.

Due to the unavailability of credible local data, default values provided by the IPCC Guidelines were adopted throughout the calculations.

The data for the inventory were collected from the following sources:

- MLSNR Energy Planning Unit, Annual Report 1994 & Energy National Data Base
- Department of Statistics
- Ministry of Civil Aviation Annual Report 1994
- Fua'amotu Airport Fuel Depot, Fuel Inventory Record 1994
- SOPAC Regional Energy Database

It should be noted that the sources of data were selected due to the merit and credibility of the source so that dispute over the finer details is avoided. It was also considered that it was essential to obtain data from universal sources where data is accessible to researchers.

The National Inventory for the GHG emissions from energy activities has been organised into the following sections:

CO_2 from fuel combustion by source categories (IPCC Tier 1 Sectoral Approach)

- Energy industry (power generation)
- Transport
- International bunkers (memo items only)
- Commercial / institutional sector
- Residential sector

Non-CO_2 from fuel combustion by source categories (IPCC Tier 1 Sectoral Approach)

- methane - CH_4
- nitrous oxide - N_2O
- nitrogen oxide - NO_X
- carbon monoxide - CO
- Non – methane Volatile Organic Compounds - NMVOC

2.2.2. Memo Items

As required by the IPCC methodology, all CO_2 emissions from the international bunkers be reported separately and not be included in the national totals.

The major fuel used by the international bunkers was jet kerosene.

CO_2 emissions from the international marine bunkers were not calculated.

The IPCC Tier 1 Approach was employed to calculate the CO_2 emissions from the international aviation bunkers for the year 1994.

2.2.3. Agricultural Sector

Tonga's economy is largely agricultural- based and it grows mostly root crops (yam, taro, sweet potato, cassava, and giant taro) principally for domestic consumption; squash pumpkin, vanilla, and kava for exports; fruit trees including banana, plantain, and papaya; and crops such as pandanus and paper mulberry for handicrafts. Livestock production is also an important industry that is growing. In addition, there is also a noticeable growth in the Forestry and Land Use sectors, which also impacts on the Agricultural Sector. All these agricultural-related activities generate greenhouse gases.

Emissions from the agricultural activities were inventoried to measure the quantities of CH_4 in enteric fermentation of domestic livestock, N_2O from the agricultural fields, leaching from the agricultural soils, and cultivation of histosols also CH_4 and CO from prescribed burning of savannas and burning of agricultural residues.

Local activity data for the sector were gathered from the government agencies including the Ministry of Agriculture and Forestry, Statistics Department, and others. Research articles, theses, and bibliography of special publications were also reviewed. Some of the professional staffs of Government were also consulted. Emission factors for enteric fermentation prescribed burning of savannas and field burning of agricultural residues in the case of CH_4 and for soil processes in the case of N_2O, were taken as default values from the IPCC Guidelines. For the calculation of CH_4 emitted from burning of crop residues, residue to crop ratios for root crops grown in Tonga were calculated according to locally available data.

2.2.4. Land Use, Land Use Change and Forestry

Only limited areas of indigenous forests remain in Tonga, predominantly found in very steep or otherwise inaccessible areas, in coastal littoral areas and swamps, or in mangrove swamps. The total forested area has been estimated as 4,000 hectares, the bulk of which is found in 'Eua. Due to limited availability of land, mangrove areas in Tongatapu and Vava'u have been subdivided and some already cleared and filled to make home sites. These have resulted in a reduction in volumes of fish caught from these areas and also inadequate sewerage system is a severe health hazard due to flooding of pit latrines and septic tanks.

A strong reforestation policy towards providing local timber needs and reducing overall loss of foreign exchange has resulted in over 300 hectares of exotic trees being planted in 'Eua. A plan to commercialize the plantation is currently being discussed.

Much of the country is under coconut growing in Panicum grassland and together with a large proportion of the native forests are anthropogenically impacted.

The priority calculations of emissions from land use change and forestry sector focus upon four activities, which are sources or sinks of carbon dioxide. These are:

- changes in forest and other woody biomass stocks
- forest and grassland conversion
- abandonment of managed lands
- carbon emissions from agriculturally impacted soils

Local activity data for this sector on plant species, forested areas, some biomass stocks, annual growth rates of trees, forests, and savannas were obtained from the government ministries, departments and others. Where country specific data were not available, data from the IPCC guidelines were used. Research articles and theses of special publications were also reviewed. Professional staffs of government and other institutes were also consulted.

Where national emission factors were not available, IPCC default factors were used. Some of the areas used were calculated based on the experience of the author and after consultation with professional staff specifically in the Forestry section. Some of the biomass growths used were based on determinations made by the author in the fields.

2.2.5. Waste Sector

Three main source categories of GHG emissions in the Waste Sector were considered: methane emissions from the anaerobic fermentation processes in the solid waste disposal sites, methane emissions from the treatment of wastewater and sludge, and indirect Nitrous Oxide emissions from Human Sewage. Carbon Dioxide emitted from further combustion of waste is not considered in this context because waste incineration is not a common practice at the solid waste disposal sites in Tonga

In solid waste disposal sites, methanogenic bacteria (anaerobic digesters) decompose organic matters hence releasing methane gas, which accounts for 5-20% of the global anthropogenic methane emission. The methane emission from wastewater and sludge, on the other hand, accounts for 8-11% of global methane emissions (IPCC 1995).

Nitrous oxide is released from human sewage and it only accounts for less than 1 per cent of the waste sector emissions.

2.2.5.1. Solid Waste

Solid waste disposal was only limited to one managed landfill located on the eastern site of Nuku'alofa that is 4 kilometres from the centre of town in the main island of Tongatapu.

Tongatapu, the major island is the only island in Tonga that has a centrally managed landfill for solid waste. Outer island groups including 'Eua and Vava'u have just established each a managed solid waste disposal sites during the last few years, and they are not included in this report due to very limited available data. Island groups of Niua and Ha'apai on the other hand disposed their wastes in an unmanaged shallow site within their own backyards or privately assigned areas.

Country specific data for solid waste discharged at the solid waste disposal sites were obtained from various relevant government agencies including the Ministry of Health, Department of Environment, Statistics Department, Ministry of Labour and Commerce, and other organizations.

The per capita waste generation rate was equated and based on the Years 1994, 1996 and 1999 studies on waste disposed at the landfills. It has been suggested that the generation rate was slightly high in 1994, as the study should have been conducted for longer period to get a satisfactory result. The waste disposal rate was also determined and based on waste discharged at the landfills.

Since the country specific data were unavailable to estimate the methane emissions from the solid waste disposal sites, the IPCC default values were utilised. The 1996 IPCC default values used for the estimation of methane emissions were Methane Correction Factor (MCF), Fraction of Degradable Organic Carbon (DOC) in Municipal Solid Waste (MSW), Fraction of DOC that actually degrades, Fraction of Carbon Released as Methane, and Conversion Ratios.

2.2.5.2. Domestic and Commercial Waste Water

There is no public sewerage system in Tonga. Wastewater generated residentially and commercially are managed on sites by variety of systems, including septic tanks, pour – flush toilets and pit latrines. Additionally, there are two areas using off-site wastewater treatment plants; Liahona treatment plant and Vaiola Hospital waste water treatment plant.

The 1996 IPCC methodology was employed to estimate the net CH_4 emissions from wastewater and sludge. Three parts were considered using local data and 1996 IPCC default values; total organic material; emission factors; and emission estimate.

2.2.5.3. Human Sewage

The nitrous oxide emissions from human sewage were calculated using local available data and basing on the protein consumption per capita and the total population of Tonga. The IPCC Default factors for Fraction of nitrogen in Protein and emission factor of N_2O were also used to estimate nitrous oxide emissions from human sewage.

2.3. RESULTS

Table 2.1: The Kingdom of Tonga's Initial National Greenhouse Gas Inventories of Anthropogenic Emissions by Sources and Removals by Sinks of All Greenhouse Gases not controlled by the Montreal Protocol Year 1994.

Greenhouse Gas Source & Sink Categories Total (Net) National Emissions (Gigagrams per year)	**CO_2 Emissions 365.59**	**CO_2 Removals -595.24**	**CH_4 5.04**	**N_2O 0.14**	**NO_x 0.49**	**CO 3.82**	**NMVOC 0.65**
1. ALL ENERGY	**79.98**		**0.01**		**0.49**	**3.49**	**0.65**
Fuel Combustion							
Energy and Transformation Industries	22.40				0.07	0.01	
Manufacturing Industries and Construction	2.39				0.01		
Transport	46.28		0.01		0.41	3.48	0.65
Commercial – Institutional	0.15						
Residential	3.60						
Agriculture, Forestry & Fishing	2.52						
Other	2.64						
2. AGRICULTURE			**2.35**	**0.04**		**0.33**	
Enteric Fermentation			2.33				
Leaching from Agricultural Soils				0.02			
Cultivation of Histosols				0.01			
Emissions from Agricultural Fields				0.01			
Prescribed burning of savannas			0.01			0.18	
Field Burning of Agricultural Residues			0.01			0.15	
3.LAND USE CHANGE & FORESTRY	**285.61**	**-595.24**					
Changes in Forest and Other woody Biomass		-77.57					
Forest and Grassland Conversion	280.11						
Abandonment of Managed Lands		-517.67					
Carbon Emissions from Agriculturally Impacted Soils	5.50						
4. WASTE			**2.68**	**0.10**			
Solid Waste Disposal on Land			0.80				
Liquid Industrial Waste Water and Sludge Domestic and Commercial Waste Water			 1.67 0.21				
Human Sewage				0.10			

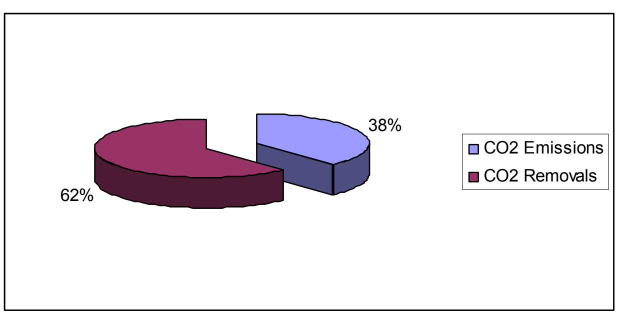


Figure 2.1: Net CO_2 Removals (%) from overall sectors-1994.

It is evident that Tonga is a net sink of CO_2 amounting for the net removals of (229.65) Gg of CO_2 (62 % CO_2 removals) in 1994 (**Figure 2.1**).

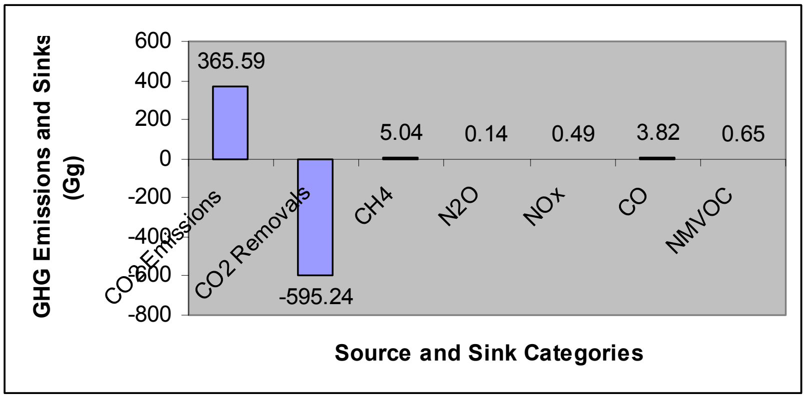


Figure 2.2: Total GHG Emissions and Removals (Gg) from overall Sectors, 1994.

Trace quantities of the total non-CO_2 Emissions from various sectors in the inventory were also estimated including CH_4 [5.04Gg], N_2O [0.14Gg], CO [3.82Gg] and NMVOC [0.65Gg] respectively (**Table 2.1 & Figure 2.2**).

CO_2 gas appears to have the largest emissions among the GHGs in the inventory. About 78.12% of CO_2 being emitted from the Land Use Change and Forestry Sector whereas 21.88% being released from the Energy Sector.

53.17% of CH_4 was emitted from the Waste Sector, 46.63% from the Agricultural Sector and 0.20% from the Energy Sector. Furthermore, 91.36% of CO was released from the Energy Sector and 8.64% from the Agricultural Sector.

71.43% of N_2O was emitted from the Waste Sector and 28.57% from the Agricultural Sector. NOx and NMVOC were released only from the Energy Sector.

2.3.1. Energy Sector

Energy Supply - 1994

Tonga's energy sources are limited to indigenous sources, particularly biomass, renewables (solar, wind, waves) and imported petroleum products. Biomass accounted for 26.8% and solar energy accounted for 0.1% while the imported fuel product provided the remaining 73.1% of the total energy supply (**Table 2.2**).

Table 2.2: Energy Sources in Tonga.

Energy Sources	Terajoules [TJ]	%
Indigenous Biomass	519.1	**26.8**
Renewables [solar]	1.8	**0.1**
Imported Petroleum	1415.8	**73.1**
Total	1936.7	100

Source: EPU, MLSNR, TONGA

2.3.1.1 Indigenous Energy Supply

Open fire cooking relies heavily on fuelwood and coconut husks particularly in the remote areas of Tonga. The total supply of indigenous biomass in 1994 was 519.1TJ (30kt).

Fuelwood and wood waste accounted for 94% whereas coconut residues accounted for 6% of the total indigenous biomass supply.

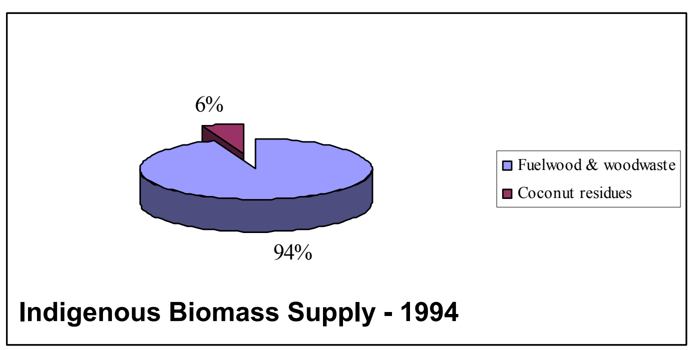


Figure 2.3: Indigenous Biomass Supply - 1994

It has been discovered that there is a continuous decline in biomass supply. This is attributed to increasing and prevalent application of LPG for cooking in rural and residential areas.

2.3.1.2. Renewable Energy Supply

Tonga has great potential in renewable energy sources and when harnessed will provide a significant amount of energy, which will contribute to reducing the volume and cost of fuel import. Previous studies have found that sources of energy from waves, wind and solar are viable as alternative sources of energy, however the lack of funds and limited capability has constrained the extensive application of renewable energy technology.

Historically, the application of solar energy for residential purposes was focused largely on crop and fish drying for subsistent consumption only. During the late 1980's demonstration projects, funded by the European Union, in the remote islands of Vava'u and Ha'apai has proven the viability of the technology for home power supply.

In 1994, about 200 Solar Home Systems (SHS) have been installed throughout the outer island groups of Tongatapu, Ha'apai, Vava'u and the Niua's. It is anticipated that in years to come more SHS will be installed to provide electricity for the remote island homes.

2.3.1.3. Imported Energy Supply

By volume, the total imported energy supply available in 1994 was 39147kl (31kt, Table 2.3). About 49% of the imported fuel was Diesel oil followed by Gasoline, 37%. Dual Purpose Kerosene, Liquefied Petroleum Gas (LPG), Lubricant & Solvents accounted for the balance.
(Figure 2.4)

Table 2.3: Imported Fuel Supply in Energy Sector–1994

Imported Fuel Type	kiloliters [kl]	kilotonnes [kt]
Diesel Oil	17871	15.12
Gasoline	15392	11.32
Dual Purpose Kerosene	3853	3.06
LPG	1662	0.94
Lubricants & Solvents	369	0.33
Total	**39147**	**30.77**

Source: EPU, MLSNR, TONGA

Energy Demand – 1994

In 1994, Tonga's total petroleum consumption was 38779kl [28kt, Table 2.4] of which 64% was combusted in the transportation sector, 23% in power production, and the remaining 13% was consumed by other sectors.

It was assumed that less than 1% of the imported petroleum products were lost via evaporation, spillage & leakages.

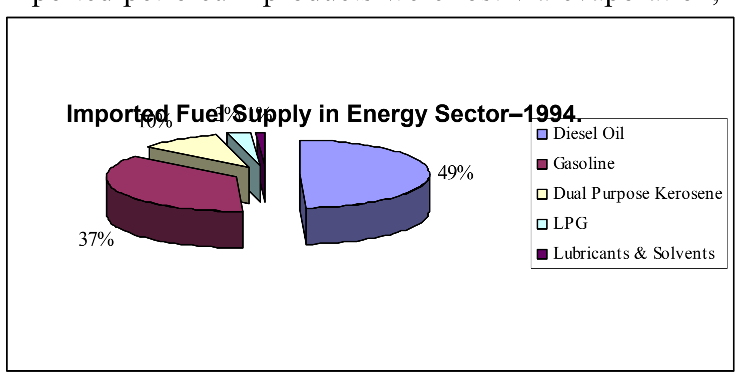


Figure 2.4: Imported Fuel Supply in Energy Sector – 1994.

Table 2.4: Fuel Consumption by Subsectors in Energy Sector – 1994

Subsector(s)	kiloliters (kl)	kilotonnes (kt)	%
Agriculture, Forestry & Fishing	1103	0.81	3
Manufacturing Industries & Construction	894	0.77	2
Energy & Transforming Industries (Power Generation)	8936	8.20	23
Transport & Communication	24868	16.46	64
Finances & Business	83	0.05	0
Residential	1912	1.19	5
Others (Mining, Quarrying & Water Sewerage)	983	0.83	3
Total	**38779**	**28.31**	**100**

Source: EPU, MLSNR, TONGA.

Transport

The fuel consumption for transportation, particularly for road transportation, remained the largest consumer of imported fuel product, amounting for more than two-thirds of the total volume imported. The importation of vehicles, international and domestic flights and inter-island communication have escalated in the recent years thus impacting directly on the fuel demand and consumption.

Power Generation

In 1994, electricity supply peaked at 25738 MWh. Electricity was generated largely for the purposes of lighting and refrigeration at home, air conditioning and entertainment at business and financial institutions. About 52% of power generated was consumed by the residential sector followed by the Finance & Business sector [29%], Street Lighting [5%], Construction & Manufacturing [4%] and the remaining 6% was the other sectors (**Table 2.5 & Figure 2.5**).

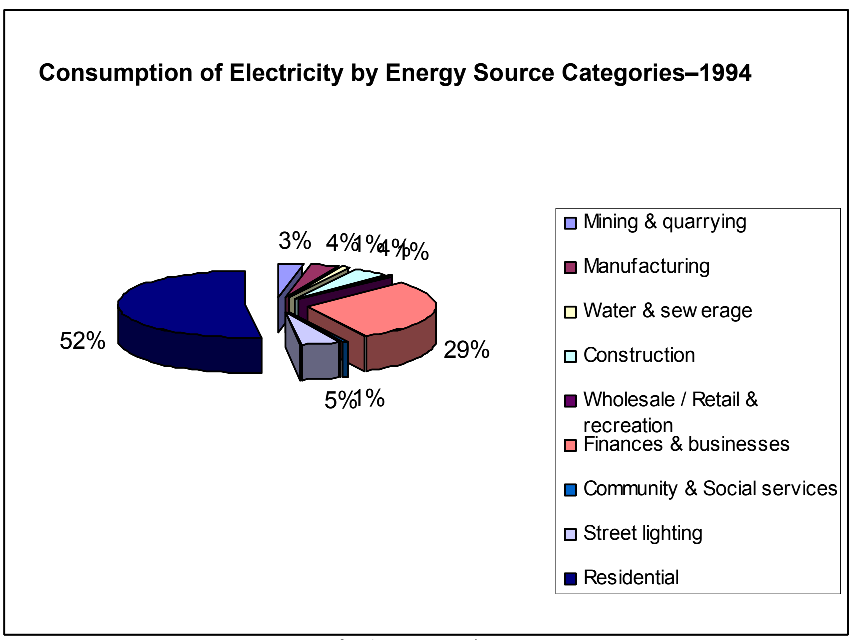


Figure 2.5: Consumption of Electricity by Energy Source Categories – 1994

Table 2.5: Consumption of Electricity by Energy Source Categories – 1994

Categories	1994
Mining & quarrying	800.6
Manufacturing	904.6
Water & sewerage	317.7
Construction	1130.7
Wholesale/ Retail & recreation	226.1
Finances & businesses	7541.9
Community & Social services	226.1
Street lighting	1222.3
Residential	13367.9
Total	**25738**

Unit: MWh Source: EPU, MLS&NR, TONGA

GHG Emissions

Sectoral Carbon Dioxide Emissions

Fuel combustion was second to the largest source of GHG emissions in Tonga. From the Energy Sector, CO_2 emissions during 1994 totaled 79.88Gg, which accounted for 21.88%of the national total CO_2 emissions (**Table 2.1**).

Within the Energy Sector, CO_2 emissions from the Transportation Sector totaled 46.28Gg that accounted for 58% of the total CO_2 emissions. A further 22.40 Gg of CO_2 emissions which represented 28% of total CO_2 emissions was produced by the Energy & Transformation Industries [Power generation] Sector. Trace quantities of CO_2 emissions were derived from Residentials [3.60Gg: 5%], Agriculture, Fishing & Forestry [2.52Gg: 3%], Manufacturing & Construction [2.39Gg: 3%], and the other sectors [2.64Gg:3%, **Figure 2.6 & Table 2.6**]

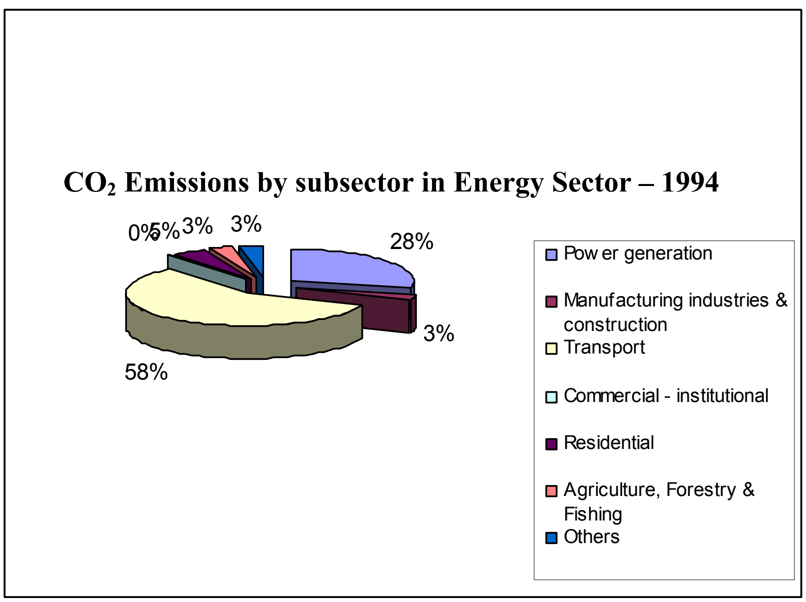


Figure 2.6: CO_2 Emissions by subsector in Energy Sector – 1994

Table 2.6: CO_2 Emission (Gg) by Source Categories, 1994

Subsector (s)	**CO_2 Emission (Gg)**
Power generation	22.4
Manufacturing industries & construction	2.39
Transport	46.28
Commercial - institutional	0.15
Residential	3.6
Agriculture, Forestry & Fishing	2.52
Others	2.64
International bunkers	8.84
Total	**79.98**

Source: EPU, MLSNR, TONGA

Table 2.7: Sectoral Non- Carbon dioxide Emissions by Source Categories, 1994

Greenhouse Gas Source Categories Gg	CH_4	N_2O	NO_x	CO	NMVOC	Total
Energy and Transformation Industries			0.07	0.01		**0.08**
Manufacturing Industries and Construction			0.01			**0.01**
Transport						
-domestic			0.02	0.01		**0.03**
-road	0.01		0.39	3.47	0.65	**4.52**
-national navigation						
Commercial – Institutional						**Nil**
Residential						**Nil**
Agriculture, Forestry & Fishing (mobile)						**Nil**
Total Emission	**0.01**	**0.00**	**0.49**	**3.49**	**0.65**	**4.64**

Source: EPU, MLSNR, TONGA

The non-CO_2 emissions from the Energy Sector totaled 4.64 Gg, which was 2% of the total GHG emissions for the reference year.

Within the Energy Sector, the non-CO_2 emissions for 1994 derived mainly from transport sector. The emissions totaled 4.55Gg that accounted for 98% of the total non- CO_2 emissions. Carbon monoxide was the largest emitter [3.49Gg] among the non-CO_2 gases. Comparatively, the non-CO_2 emissions from the Energy & Transformation Industries, Manufacturing Industries and Construction sectors were relatively minute and being equal to or less than 1.0Gg (**Table 2.7**)

2.3.2. Memo Items

CO_2 Emissions from International Bunkers

The emissions from International Aviation Bunkers were limited to emissions resulted from the combustion of jet kerosene from aircrafts that flew internationally in 1994. International aviation bunkering accounted for 8.84Gg of CO_2 emissions in the reference year (**Table 2.6**).

Releasing of CO2 from the International Marine Bunkers was not estimated.

Emissions of CO_2 from the International bunkering have been excluded from the national totals however, it was reported for informational purposes only.

2.3.3. Agricultural Sector

CH_4 Emissions

Methane is a common compound and its cycle is less well understood than the carbon cycle. Natural methane is released primarily by anaerobic decay of vegetation in wetlands, by digestive tracts of termites in the tropics, by the ocean, and by leakage from methane hydrate deposits. The main anthropogenic sources are leakages from the production of fossil fuels, human-promoted anaerobic decay in landfills, and the digestive processes of domestic animals. The main sources of absorption are thought to be tropospheric reactions with hydroxyl radicals, stratospheric reactions with hydroxyl radicals and chlorine, and decomposition by bacteria in soils.

The Tonga's anthropogenic methane emissions totaled 5.04 Gg. The methane emissions come from two major sources. They are waste management and agriculture. At an estimated 2.35 Gg (Table 2.8), methane emissions from agricultural activities represent 46.63% of total Tonga anthropogenic methane emissions (Table 2.1). Ninety nine percent of these emissions can be traced to enteric fermentation in livestock animals and the remainders to the prescribed burning of savannas (0.01 Gg) and field burning of agricultural residues (0.01 Gg).

Table 2.8: CH_4 Emissions by the Agricultural Sector - 1994

Activity	CH_4 Emissions (Gg)
Enteric Fermentation	**2.33**
Prescribed Burning of Savannas	**0.01**
Field Burning of Agricultural Residues	**0.01**
Total	**2.35**

N_2O Emissions

The sources and absorption of nitrous oxides are much more speculative than those for other greenhouse gases. The main natural sources are thought to be bacterial breakdown of nitrogen compounds in soils, particularly forest soils, fluxes from ocean upwelling, and stratospheric photo dissociation and reaction with electronically excited oxygen atoms. The primary human-made sources are enhancement of natural processes through the application of nitrogen fertilizers, combustion of fuels [in fossil-fueled power plants and from the catalytic converters in automobiles], certain industrial processes [nylon and nitric acid production], biomass burning, and cattle feedlots.

Estimated Tonga anthropogenic nitrous oxide emissions totaled 0.14 Gg in 1994. The nitrous oxide emissions come from two sources. They were waste management and agriculture. On a global scale agricultural practice contribute approximately 70.0% of anthropogenic nitrous oxide emissions. By contrast, in Tonga, agricultural activities were responsible for only 28.57% of the nitrous oxide emissions [Table 2.1]. Nitrogen fertilization accounted for all agricultural emissions of nitrous oxides [Table 2.9].

Table 2.9: N_2O Emissions by the Agricultural Sector.

Activity	N_2O Emissions (Gg)
Leaching from Agricultural soils	0.02
Cultivation of Histosols	0.01
Emissions from Agricultural Fields	0.01
Total	**0.04**

2.3.4. Land Use Change & Forestry Sector

CO_2 Emissions / Removals

Carbon is a common element on the Earth, and immense quantities can be found in the atmosphere, in soils, in carbonate rocks, and dissolved in ocean water. All life on Earth participates in the "C Cycle" by which CO_2 is extracted from the air by plants and decomposed into carbon and oxygen, with the carbon being immobilized into plant biomass and the oxygen released to the atmosphere. Plant biomass, in turn, decays and mineralizes carbon as CO_2 back into the atmosphere or stored organic carbon in soil or rock. There are vast exchanges of CO_2 between the ocean and the atmosphere, with the ocean absorbing carbon from the atmosphere and plant life in the ocean absorbing carbon from water, dying, and spreading organic carbon on the sea bottom, where it is eventually incorporated into carbonate rocks such as limestone/silicates.

The most important natural sources of CO_2 are released from oceans and land, including plant respiration, non-plant respiration and combustion of natural and human-made fires. Known anthropogenic sources include deforestation, combustion of fossil fuels,

The total emissions of carbon dioxide in Tonga were 365.59 Gg in 1994. Most CO_2 was emitted as results of Land Use Changes and Forestry activities, amounting to 285.61 Gg (Table 2.10).

Ninety-eight percents of the emissions (280.11 Gg) from Land Use Changes and Forestry Sector were from forest and grassland conversion of biomass and the other 2% (5.50Gg) were from carbon emissions from agriculturally impacted soils. Of the 280.11 Gg CO_2 released from forest and grassland conversions, 185.9 Gg (66.4%) were from immediate release from burning of biomass and 74.2 Gg (33.6%) were from delayed emissions from decay or biomass.

Land use change and forestry are important to greenhouse gas inventories in two ways:

- Humans can alter the biosphere through changes in land use and forest management practices and, in effect, alter the quantities of atmospheric and terrestrial carbon stocks, as well as the natural carbon flux among biomass, soils, and the atmosphere. This contribution is discussed above.

- Vegetation can "sequester" or remove carbon dioxide from the atmosphere and store it for potentially long periods in above- and ground below-ground biomass, as well as in soils. Soils, trees, crops, and other plants may make significant contributions to reducing net greenhouse gas emissions by serving as carbon "sinks".

The amount of carbon dioxide sequester by Land Use and Forestry activities totaled 595.24 Gg. 87% or 517.67 Gg of the sequestration were by uptake of above ground growth in the Abandonment of Managed Lands and 13% or 77.57 Gg were from removal by forest and other woody biomass. The amount of CO_2 uptake (595.24 Gg) is more than the total emission (285.61Gg) resulting in a net sink of 309.63Gg of CO_2 from Land Use Change and Forestry in Tonga, indicating that there may not be problems of greenhouse effects in Tonga.

Table 2.10: CO_2 Emissions and Removals and the Net Sink (Gg) for Land Use Change and Forestry Sector

Activity	Emissions	Removals (Gg)	Net Sinks
Changes in Forest and Other Woody Biomass		(77.57)	
Forests and Grassland Conversions	280.11		
Abandonment of Managed Lands		(517.67)	
Carbon Emissions from Agriculturally Impacted Soils	5.50		
Total	**285.61**	**(595.24)**	**(309.63)**

2.3.5. Waste Sector

From the Waste Sector, the anthropogenic emissions of CH_4 in 1994 were 2.68Gg that accounted for 53% of the national total CH_4 emissions. The emission of N_2O was 0.10Gg that accounted for 71.43% of the national total N_2O emissions (Table 2.1).

Within the Waste Sector, 2.68Gg accounted for 96% of the total CH_4 emissions whereas the remaining 4% accounted for the total N_2O emissions. CH_4 emissions from the Industrial Waste Water and Sludge totaled 1.67Gg, which accounted for 59% of the total CH_4 emissions. A further 0.80Gg (29%) and 0.21Gg (8%) of the total CH_4 emissions were derived from Solid Waste, Domestic & Commercial Waste Water (Table 2.11 & Figure 2.7).

Table 2.11: Summary of GHG emissions from Waste Sector

Waste Type	CH_4Emissions (Gg)	N_2O Emissions (Gg)	GHG Emissions (%)
Solid Waste	0.8	**-**	29
Domestic and Commercial Waster Water	0.21	**-**	8
Industrial Waste Water and Sludge Stream	1.67	-	59
Human Sewage	-	0.1	4
Total	**2.68**	**0.1**	**100**

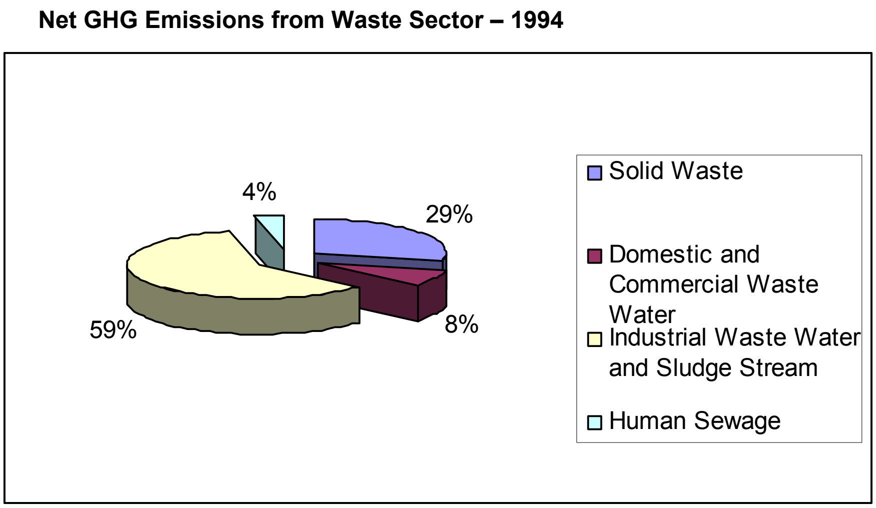


Figure 2.7: Net GHG Emissions from Waste Sector – 1994

Table 2.12 below shows that organic waste at the disposal site accounted for 29% of the total waste. This accounted for 0.80 Gg of methane gas emitted into the atmosphere.

Table 2.12: Waste Characterisation at the Solid Waste Disposal Site (Tukutonga)

Waste Type	Domestic and Commercial	Domestic only	Commercial only
Mixed domestic	22.6	34.2	10.1
Paper	29.7	12.2	47.3
Plastics	6	3.1	9.6
Glass	1.4	0.9	1.9
Metals	8.3	9.3	7.7
Organics	29.2	37.4	20
Textiles	0.7	1	0.5
Hazardous	0.3	0.4	0.2
Construction	1.2	0.7	0.62
Other	**0.8**	**0.8**	**0.6**

Source: DoE, Tonga.

From the Domestic and Commercial Waste Water, it is estimated that the water consumption by each individual in Tonga is approximately 80 litres per person per day, and only 75% of that finds its way to the sanitation system. It is therefore estimated that domestic wastewater flow is about 60 litres per day per person. For commercial and industries they consumed 20 % or 20 litres per day per person.

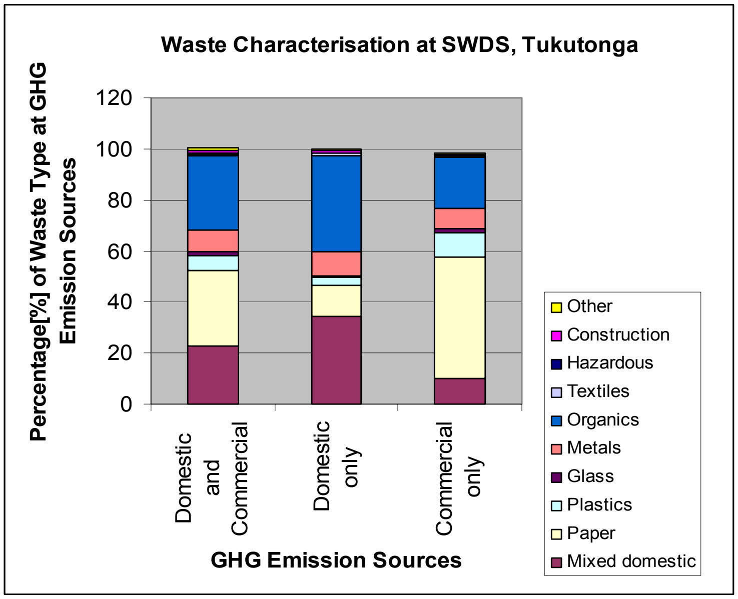


Figure 2.8: The GHG Emission Sources against the Percentage of Waste Type at the Solid Waste Disposal Site (SWDS), Tukutonga

A standard septic tank of a single family of 7 would take 7-10 years before sludge accumulation in septic tanks needs to be pumped out. The septic tank of a family of 8 took 8 years to fill up. Collected sludge is transported to empty beds in Tukutonga just beside the solid waste dumping side. Dried sludge is then used for gardening and in plantations as a source of fertilizer. The sludge and scum generation rate is approximately 40 liters per person per year.

2.4 UNCERTAINTIES

2.4.1 Energy Sector

The uncertainties and limitations of the emission estimates are due to the following:

- limited calculation factors for the biomass resources therefore the emissions from biomass could not be determined
- classification of the fuels by the various sources could not determine the demand at various sectors therefore guess estimations was made
- limited factors for calculating the carbon content for the fuels

The problems encountered during the inventory included the variation of units of measurements (for example litres, kg, and toe) for the fuels recorded so a conversion of the units to a common one (TJ and 1000 tonnes) was necessary to ensure that the result was consistent.

Although the data of imported fuels were readily available, details of imported & indigenous fuel consumption by sectors were hard to find, therefore a formula was adopted to estimate the consumption by sector, to determine the sectoral emissions.

In most instances, there were no conversion and emission factors available locally therefore IPCC default factors were utilised.

Several assumptions were necessary when data were not accurate and specific. The detail consumption by source categories for lubricants and solvents were unavailable, therefore it was assumed that all lubricants imported were consumed by the power generation, while all solvents were combusted in manufacturing activities.

2.4.2. Agricultural Sector

Potential sources of uncertainties relate to the activity data and conversion and emission factors. The 1994 animal census used for the enteric fermentation calculation was based on the number of animal during the survey period and not for the whole year. This imposed an unknown bias in calculation. The area of prescribed burning of savannas was estimated depending on data prior to 1994 and after 1994 and based on the expert judgement of the author. The author also calculated residue to crop ratios for root crops grown in Tonga. For the calculation of nitrous oxide emissions from agricultural soils, the quantity of nitrogen fertilisers used was the total imported and not necessarily the amount used. It should be emphasised that uncertainties because of the estimations used in the calculation minimised the error in the estimation of GHG emissions compared to leaving aspects of emissions because no data are available.

2.4.3. Land Use, Land Use Change and Forestry

Determining the area of forest that is anthropogenically impacted was difficult. People harvest various things including firewood, medicine, wood for handicrafts, etc from forests presenting difficulties in determining the area disturbed by man.

Where national emission and conversion factors were not available, IPCC default values were used. Because of the general nature of the IPCC default values significant uncertainty in the GHG emissions and removals could results. To minimize this, the author determined annual growth rates for forests and savanna grasslands and used in the calculations.

Because this inventory is the baseline for the country, it is important to include as much as possible all sources of emissions and uptakes. For this reason, the author based on expert judgement and available data estimated the area of abandonment of managed lands. Again, the error involved in the inclusion of these data is lesser than would have been if they were omitted from the calculations.

2.4.4. Waste Sector

One of the factors that contributes to the poor management of solid waste in Tonga is the lack of available data and basic information on waste composition and quantity being produced so that a holistic design can be developed to combat further environmental and health problems. Poor solid waste management will also lead to further emissions of greenhouse gases, notably methane and carbon dioxide.

Generally, there were no specific default values /factors in Tonga for the estimation of:

- methane emissions from the solid waste disposal sites and waste water and sludge.
- nitrous oxide emissions from human sewage and as such the IPCC default factors were subsequently used. This is a source of uncertainty because apparently, these values may not be applicable to Tonga.

2.5. RECOMMENDATIONS

There have been certain obstacles encountered during the preparation of the initial GHGI for the Kingdom of Tonga notably, the unavailability of local activity data, the absence of country specific default values / factors in most sectors. To alleviate such existing problems and to improve the accuracy of local data, it is highly recommended that;

- future efforts be based on training, research and data collections;
- continuous strengthening of local capacity for future GHGI compilations be undertaken;
- institutional focal points to coordinate the inventory preparation and data collection at the sectoral level where significant gaps remain evident be established;
- country specific data on emission factors in various sectors be obtained;
- financial assistance from respective GEF donors to effectively carrying out future updates of the inventory in the Kingdom be granted.

Chapter 3: MITIGATION OPTIONS


Solar Energy


Climate Change Training & Awareness


Inland Replantation


Composting of Organic Waste

Recycling


Coastal Revegetation

3.1. INTRODUCTION

In accordance with Article 2 of the UNFCCC, the ultimate objective of the Convention is to stabilize the concentrations of Greenhouse Gases (GHGs) at a level that would prevent dangerous anthropogenic interference with the global climate system.

Among the guiding principles to achieve this set goal is that Parties to the Convention should take precautionary measures to anticipate, prevent or minimize the causes of climate change.

The Kingdom of Tonga like most developed and developing country parties to the UNFCCC have now developed climate change mitigation strategies not designed primarily for the purposes of advancing sustainable economic and social development however, they also contribute towards the accomplishment of that goal of reducing GHG emissions in Tonga.

3.2. ENERGY SECTOR

Energy plays a crucial role in the Kingdom's sustainable development strategies and maintaining a fine balance between the energy, the environment and the economy is a national priority. The heavy reliance on imported fossil fuels and the underutilization of the Kingdom's renewable energy resources potential are major barriers to Tonga's social and economic development.

The Kingdom's power generation and transportation are wholly dependent on the imported fuels, a major drain on its meagre foreign earnings and subjecting the entire economy to the vulnerability of the international oil markets and its politics. At the same time, Tonga is still struggling to prove that commercialized renewable energy technologies such as solar photovoltaic, solar water heaters and wind power can be utilized on a financially sustainable basis and be a substitute of fossil fuel.

It is important for Tonga's sustainable development effort to be supported by a dynamic and vibrant energy sector that strives to provide reliable, cost-effective and environmentally friendly energy sources for all its citizens and residents.

Tonga's indigenous energy resources are limited. There is no hydroelectric or geothermal potential. Electricity generation is diesel-based. Wave and wind energy have been investigated and awaiting financial resources for pilot and demonstration projects. Thus Tonga's immediate available resources are its depleting wood stock, abundant coconut residues, and solar energy.

Depleting wood resources are caused mainly by pressure on land for agricultural purposes. The country is increasingly reliant on imported petroleum products to satisfy its commercial energy needs. Thus it is vulnerable to external events that affect the price and availability of petroleum products and export potential and foreign currency flows from remittances and aid.

The pattern of energy use in Tonga during the decade has changed dramatically, reflecting the rapid development of energy-intensive economic activities, thus intensifying Tonga's reliance on imported petroleum products. In 1991, indigenous supply of biomass accounted for 30% of total energy supply, while imported petroleum represented 69.7% and solar energy 0.02%. In the same year, the sectoral demand showed that transportation consumed 53.5% of the imported fuel supply, power generation at 20.9% and 3% at residential while the other sectors shared the remaining balance.

In 1999, the imported supply reached its highest at 46kt when the fishing and agricultural activities also reached its peak.

By 2000, the energy balance showed a growing demand for imported petroleum products for which petroleum captured 75.3% of the total energy supply while biomass declined by 6% and solar energy significantly expanded by 10% thus reaching 0.2% at the end of the decade.

The power sector experienced staggering growth during the decade where the consumption fluctuated between 22.5 – 29.6GWh. Close to 95% of the potential power residential consumers was served and the demand in the residential sector continued to dominate the power demand throughout the decade, followed by a growing commercial sector.

The main characteristic of the power subsector is the high demand growth over recent years. The consolidated energy generation for the four systems grew from 24.21 GWh in 1989/90, while sales amounted to 20.01 GWh. By 2001, sales reached approximately 28.8 GWh, a 44% increase during the 10-year period. Distribution and transmission losses declined by 4% (from 13% in 1990 to 9% in 2001). Consumers were estimated at 8,000 in 1992 and 13,000 active consumers in 2001 – a 62% growth, of which 76% are residential, 7% commercial and others accounts for the balance.

In terms of pricing, retail prices during the decade also fluctuated in response to the external markets when oil prices soared as high as US 45/barrel and plummeted to as low as US 5/barrel. In 1995 retail prices for gasoline was as low as TOP 59.88/litre, 64/litre for diesel and 54.54/litre for kerosene. During the third quarter of 2001 retail prices per litre reached TOP 1.66 for diesel, 1.44 for gasoline and 1.45 for kerosene.

The rising fuel demand also impacted on storage capacity. During the third quarter of 2001, oil storage capacity expanded by an additional 2,130 tonnes at Nuku'alofa and 70 tonnes at 'Eua.

The majority of households in rural areas cook primarily with fuelwood and coconut residues. The consumption of biomass has decreased against the growing consumption of petroleum and LPG reflecting a change in lifestyles, exposure to modern technologies

Solar energy is traditionally utilised for crop drying and food preservation. Photovoltaic (PV) technology has been used extensively to provide electricity to rural communities, primarily on outer islands that do not have grid supplier power. It is estimated that 582 PV lighting systems and a community freezer have been installed. An additional 170 systems have been installed at 6 islands at the Ha'apai group in 2002 and by 2003 an additional 100 at Niuafo'ou. Solar thermal application for water heating is also well developed on Tongatapu and has expanded in the residential sector and within the tourism industry.

In 1991, about 100 solar water-heating systems were recorded and by 2000 about 801 were recorded.

The direct impact of energy services on the environment became visible with traffic smokes in Nuku'alofa and dumped waste oil on the grounds throughout the island group.

As commercial energy increased its share of the country's total energy requirements, energy conservation among producers and consumers responsive to energy-saving measures assumed greater importance.

Minimal development occurred in policy and legislative areas although power generation was privatised in 1998. Distribution and transmission were also privatised.

To date, the primary objective of providing leadership to the sector was to contribute to a balanced approach between energy resource development and supply, on the one hand, and energy conservation, on the other. To this end, it is necessary to redefine the objectives and functions of the central energy institutions to increase the allocation of human and financial resources.

The institutional framework for the energy sector is fragmented. The Ministry of Lands, Survey and Natural Resources (MLSNR) has overall responsibility for energy related matters. An inter-ministerial body, the National Standing Committee for Energy (NSCE), was established in 1979 to report to Cabinet on energy matters and to formulate national energy policy, but the committee has not met since 1997. MLSNR provides the secretariat for the NSCE.

The Energy Planning Unit (EPU) was established within the MLSNR in 1983 to be the Secretariat to the NSCE and is currently involved mainly in the implementation of solar energy projects, public awareness campaigns on renewable energies and conservation, and other tasks related to the petroleum subsector. MLSNR also has a Geology Section, which co-ordinates petroleum exploration.

Several other Government bodies and the private sector are involved in energy and energy-related matters. The Tonga Electric Power Board (TEPB) is a wholly government owned entity initially vested with the sole authority to generate and distribute electricity in the country. However, generation was privatised when Shoreline was granted a permit to generate electricity in 1998.

The Competent Authority (CA) of the Ministry of Labour, Commerce and Industries (MLCI) negotiates wholesale and retail petroleum prices, while the Ministry of Finance assesses and collects duties on petroleum products.

The Ministry of Agriculture and Forestry is responsible for forest resource development, which includes the improvement of fuelwood supply through the distribution, in co-operation with MLSNR, of seedlings of fuelwood species.

In terms of energy project co-ordination, the Central Planning Department co-ordinates the government project cycles, including evaluation and presentation to Cabinets of energy projects submitted by line ministries. The Ministry of Foreign Affairs co-ordinates requests for external assistance for capital expenditure projects and technical assistance programs.

The private sector plays an active role. Private oil companies (British Petroleum, Shell and Tri-Star) are responsible for the import, storage, domestic distribution and retailing of petroleum fuels. The Ministry of Works (MOW) handles the procurement of petroleum from the oil companies for the government use. Small electrical importers and electrical contractors have maintained their essential roles in the energy market.

PREFERRED OPTIONS

The following energy sector interventions have been selected following the considerations of resource potentials, economic and social benefits and most importantly the contributions towards the reduction of greenhouse gas emissions in Tonga.

1. Demand Side Management

(i) Energy efficiency labeling

- Large programs are required to be set up.
- Programs will require reliable information and enforcement.

(ii) Energy efficiency standards

- Focus on lighting, refrigerators, freezers and air conditioners.
- Must be supported by labeling scheme.

(iii) Training & education programs

- Focus on lighting, refrigerators, freezers and air conditioners
- Program must aim at: correct installation and cleaning; controls to reduce operation while not in use; and choice of correct appliances.

(iv) Ground transport

- Fiscal actions: discourage large engined and low efficiency cars, impose high taxes on large engined vehicles, tax company cars, reduce duty on spares, and high fuel taxes.
- Encourage emission & standards testing.
- Educational programs on maintenance and driving techniques.
- Road improvements and maintenance.
- Traffic management improvement.

2. Supply Side Management

(i) Increase efficiency in existing systems, particularly power generation and distribution systems through technology shifts.

(ii) Biomass for domestic uses.

(iii)Increased utilization of renewable energy technologies such as photovoltaic, solar water heaters and wind generators to meet domestic demands for electricity and water heating.

3. Fuel Substitution

(i) Assess the viability of cleaner fossil fuel.

(ii) Assess the viability of using copra oil, fuel cells.

4. Forestry

(i) Develop sustainable supplies of fuelwood by extending forest area and extensive tree planting.

Tonga has a range of opportunities to mitigate its greenhouse gas emissions. It can achieve this by:

1. increasing the utilisation of renewable energy sources as a substitute for fossil fuels;
2. improving energy efficiency; and
3. absorbing gases back out of the atmosphere.

3.3. AGRICULTURAL SECTOR

Greenhouse Gas emissions are noticeably increasing in Tonga and the Land Use Change and Forestry and the Agricultural Sectors are major contributors. Agriculture and Forestry are so important to Tonga's economy that GHG mitigation options need to have maximum effects on reducing emissions with minimum financial impacts and environmental consequences.

The objective of this study is:

- To identify and evaluate technologies and practices that will reduce nitrous oxide, methane and carbon dioxide emissions in Tonga.

This sectoral reports review practices and technologies available locally and those from outside Tonga that have potentials to work in reducing GHG emissions if adopted in Tonga.

Potential Management Practices and Technologies for Reducing Nitrous Oxide Emissions from Agricultural Sector

Nitrous oxide emissions from agriculture are a result of the biological soil processes denitrification and nitrification. Denitrification is the stepwise reduction of soil nitrate to gaseous nitrogen compounds, with nitrous oxide being one of the intermediate products. Nitrification is the biological oxidation of soil ammonium to soil nitrate, with nitrous oxide being produced as a by-product.

Mitigation options should aim to reduce the nitrous oxide emission rate of these processes per unit of soil surface by:

- manipulating process rates; and
- ensuring that during denitrifiaction, N is emitted as N_2 rather than N_2O.

Manipulating Process Rates

At the process level, denitrification and nitrification are both affected by a range of soil variables, of which mineral N availability and soil aeration are considered the main factors. The proposed mitigation options focus on reducing the availability of mineral N for nitrification and/or denitrification, while some mitigation practices focus on soil drainage or irrigation management to improve aeration and avoid prolonged periods of wet soil conditions.

Ensuring N is Emitted as N_2 than than N_2O

The ratio at which N_2O and N_2 are produced during denitrification can range from less than 5% to more than 50% and largely depends on environmental conditions. It is generally considered that $N_2O:N_2$ ratio increases with higher NO_3^- concentration, and decreases with higher soil pH, organic C, soil water content and temperature.

Mitigation Options Relevant to Tonga

The N_2O emissions in Tonga from the Agricultural Sector are largely from application of nitrogen fertilisers to soils. The mitigation options are:

- ***Reduced Amount of N Recycled by the Grazing Animal***

  The amount of N recycled by grazing animal can be reduced if stock numbers is reduced. This is on the assumption that the excreta N production per animal remains the same or increases at a slower rate than the stock number decline. This is only feasible if productivity per animal is also increased.

- ***Increased Efficiency of N Recycled by the Grazing Animals***

  This can be achieved by dairy and beef cattle are kept in feed-pads and then the excreta collected and re-utilised as effluent in forage production. A better balance between energy and protein supply using grasses can reduce N excretion rates while not affecting animal performance.

- ***Increased Efficiency of N from Synthetic Fertilisers***

  This can be achieved by using nitrogen inhibitors or adjusting timing of N fertiliser application. Nitrification inhibitors can delay the nitrification process and thus N_2O emissions from nitrification, and also delay the formation of nitrate and thus reducing N_2O from denitrification. Several overseas studies have shown that the use of a nitrification inhibitor can reduce N_2O emissions from urea fertiliser by an average of 50%.

Nitrous oxide emissions following fertiliser application are highest in wet soils and shortly after (heavy) rainfall. Emissions appear to be high during the first 24 to 48 hours after rainfall that follows a relatively dry period. This is due to the enzyme responsible for reducing N_2O into harmless N_2 gas not surviving well in dry conditions. N_2O emissions from N fertilisers can be reduced by delaying the timing of application to avoid periods of (heavy) rainfall or wet soils.

Potential Management Practices and Technologies for Reducing Methane Emissions from Agricultural Sector

The methane emissions from agriculture in Tonga are mostly from enteric fermentation in livestock animals (2.33 Gg) and the remainders from prescribed burning of savannas (0.01 Gg) and field burning of agricultural residues (0.01 Gg). Enteric methane arises as a by-product of the fermentation of feed in the rumen. The rumen contains a large and diverse population of microorganisms and these breakdowns feed to produce volatile fatty acids, carbon dioxide and methane. The micro-organisms responsible for the production of methane are methanogens, which synthesise methane from hydrogen. The amount of methane produced in the rumen varies with factors such as diet type, level of feeding, size, age and species of animal. As percentage of the gross energy consumed, as much as 15% can be lost as methane. Reducing the amount of methane produced by ruminants is therefore, very important for reduction of emissions of GHGs and the conversion of dietary energy into animal products.

Mitigation Options Relevant to Tonga

- ***Ionophores***

  Ionophores are antibiotics that modulate the movement of cations such as sodium, potassium, and calcium across cell membranes. In ruminants they affect several pathways of fermentation. In New Zealand, the ionophore Monesin is used widely. When added to the diet, ionophores are claimed to affect methane production in 2 ways. Firstly, they increase feed conversion efficiency and this reduces methane output per unit of product. Second, because of their effect on rumen fermentation, they directly reduce the amount of methane produced per unit of food intake.

- ***Improved Forage/Feed Quality***

  Forages that increase the amount of milk or meat produced would decrease the amount of methane produced. Manipulating the nutrient composition of the diet of ruminants can directly reduce methane output. For example, a high proportion of concentrates (grass based feeds) in the diet tends to reduce the protozoal population in the rumen, reduce rumen pH, alter the acetate:proprionate ratio and decrease the amount of methane produced per unit of feed intake.

- ***Reducing Livestock Numbers***

  Reducing livestock numbers can help reduce methane production but may not be desirable because of financial consequences. It should be done with the aim of improving productivity per unit animal. This option should be considered where animal population is too large and not managed properly.

3.4. LAND USE CHANGE AND FORESTRY SECTOR

Potential Management Practices and Technologies for Reducing Carbon Dioxide Emissions from Land Use Change and Forestry Sector

Carbon dioxide emissions are currently not reported from the agriculture sector but are included within the energy sector and land use change and forestry sector national inventory calculations. Some agricultural activities like grazing management and agroforestry practices have implications for soil carbon sequestration.

Mitigation options should be aimed at reducing carbon dioxide emissions or by taking carbon dioxide out of the atmosphere and storing it in terrestial, oceanic, or freshwater aquatic ecosystems. A sink is defined as a process or an activity that removes a greenhouse gas from the atmosphere.

Mitigation Options Relevant to Tonga

- ***Bioenergy***

  Biofuel options appear to have a great potential for using agricultural land to mitigate greenhouse gas emissions. They have the double benefit of a perennial crop capable of sequestering C and the production fuel to directly replace fossil fuel use. These can be achieved through agroforestry systems in which woody trees are grown together with traditional crops in different arrangement. Alley cropping in leguminous multipurpose trees (MPTS), MPTS grown in grid patterns or along boundaries has shown that coppices not only supply firewood for the households but also green mulches for soil improvement. Timber trees can also be grown along boundaries for the same purposes.

  Recent advances in technology for cellulose conversion increases the potential to increase the efficiency of ethanol production from biomass and produce fuel that can compete directly with petrol.

- ***Increased C Sequestration by Agroecosystems***

  Carbon sequestration in ecosystems occurs when C entering the system through gross primary production (photosynthesis) is greater than the C leaving the system through plant and heterotrophic respiration, lateral transfers, leaching and harvest. The predominantly grass fallow vegetation (Panicum) in Tonga is also pasture for livestock. The grass leaves are highly ephemeral (lifespan of about 30 days) so that the high rates of photosynthesis C flux are not reflected in a sustained large biomass but constitute a substantial flow of C to soils. How much of this C becomes stored in the ecosystem then depends on decomposition processes. Where grass is grazed, the flow of C to the soil is reduced but for Tonga this is not a significant area.

The above discussions raised the importance of soil carbon sequestration. Currently, the remaining forests and most of the bush fallow (predominantly Panicum grass) return substantial C to soils. The question is "*How can we manage this soil C to ensure that soil productivity is maintained while loss of C by emissions is minimised?*" Minimum tillage systems (including direct drilling) and soil conservation practices will accomplish this but it would have to be accompanied with national policies.

- ***Roles of Land Use Changes***

  Land use affects C stocks. Expanding forest areas and allowing agricultural land to revert to a more natural state will cause C stocks to increase. The current C removal is due to uptake by forests. It is therefore important that any marginal land and degraded lands should be reverted to forests. A national policy should be put in place to back up this activity.

- ***Carbon Sequestration in the Oceans***

  Government should look at enhancing the net oceanic uptake from atmosphere by may be fertilisation of phytoplankton with nutrients, and the possibility of capturing CO_2 and injecting to ocean depths.

  Coral reefs and seaweeds in the ocean can also utilize CO2. It is therefore important to ensure corals and seaweeds are properly maintained or grown not only for commercial purposes but also as potential Carbon dioxide sinks.

3.5. WASTE SECTOR

Few potential mitigative options are adopted to minimize the GHG emissions from the Waste Sector in the Kingdom.

Solid Waste

- ***Minimisation Program***

  The total methane (CH4) emission from solid waste disposal sites was estimated to be 0.8 Gigagrams (Gg) in 1994. The volume could be lowered if an appropriate waste minimisation program was developed to combat further GHG emission of methane gas.

Two studies on waste characterisation and quantification during the period of 1994 and 1999 revealed that degradable organic wastes accounted for approximately 65% of total landfill waste arrival. If that 65% could be managed and minimised, further emissions from the solid waste disposal site will be significantly reduced.

- ***Home composting of domestic degradable organic wastes***

The IPCC 1996 guidelines suggest that waste in rural areas is typically scattered over the land rather than being deposited at solid waste disposal sites and hence it tends to decay aerobically generating extremely low, if any, CH_4 emissions. This principle of rural home composting could be applied to urban areas where most of their organic wastes are dumped at solid waste disposal sites. If the whole idea of home composting programs were to be preached to the urban population who use the solid waste disposal site, it is no doubt that further emissions of CH_4 could be minimised.

- ***Recycling program***

One of the major problems encountered when dealing with waste arrival at the solid waste disposal site in Tonga is the inclusion of waste that has the potential to be recycled rather than dumped at the landfill. Most of the organic food waste can be used for domestic animals' foods; aluminium cans and plastics can be recycled or reused for other purposes, and the list goes on. Those minor issues can make a big different as far as CH_4 emissions are concerned. It is therefore suggested that appropriate recycling activities be developed in Tonga.

- ***Waste sorting***

One of the difficulties identified at the landfill site in Tonga is the failure to sort wastes at the solid waste disposal site. Organic and inorganic wastes should be separated and placed in specifically designated areas within the landfill.

- ***Awareness Program***

Community involvement in any development has been proven to be more sustainable and successful. Community consultation should be a core component as far as the waste minimisation process is concerned. Awareness programs include community workshops and training, radio and television talk shows, and creating youth and school education materials.

Wastewater and Sludge

Domestic, commercial, and industrial wastewater and sludge account for 1.88Gg of CH_4 gas emitted into the atmosphere during the base year 1994 in Tonga.

- ***Composting toilets***

One way this volume could be minimised is by using a **composting toilet.** Composting toilets involve simple self-sufficient recycling methods of waste management. It is an on-site method of sewage management that can offer significant protection of water quality and human sanitation, and reduce emissions of CH_4. Composting toilets rely mainly on aerobic decomposition, which relies on the presence of oxygen. Aerobic processes release very little odour and methane gas in contrast to anaerobic processes (in the absence of oxygen).

Anaerobic decomposition occurs most often in treatment plants and at solid waste disposal sites. In 1995, Dr Crennan implemented a trial project in Tonga, which was very successful in rural areas. It could also be used in urban areas to combat further CH_4 emissions from wasterwater and sludge.

3.6. CONCLUSION

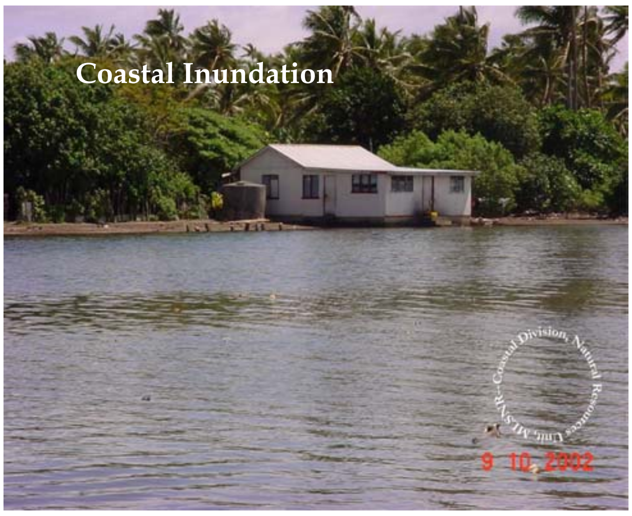
Range of opportunities to abate the emissions of GHGs from the Energy Sector will be successful if they can operate within the technical, financial, institutional frameworks and the capabilities available locally. Tonga needs external financial resources and technical expertise and assistance.

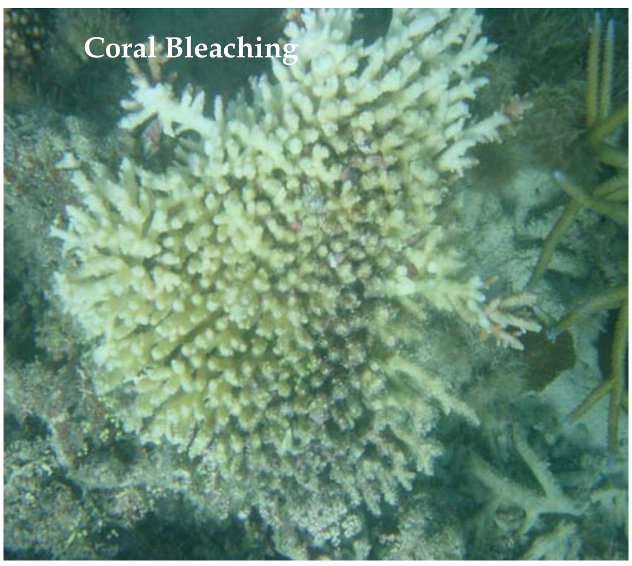
Clearly, the mitigation programme encounters the challenges of economic development and in the event a programme is implemented, the long-term sustainable development aspirations must never be lost from sight.

From the LULUCF & Agricultural Sectors, it is clear from this review that options available for reducing GHG emissions are not simple and single solutions do not exist. Experimental evidences for many of the options are limited but the potentials for them to work are very high. Many options are available and in general, each one has small impact, but if implemented collectively they could help reduce GHG emissions. This report discussed the three gases separately, in agriculture and forestry (including land use change) they cannot be viewed in isolation from each other, as technologies, which influence the emissions of any single gas often, have ramifications for the other gases.

Consequently, if mitigation processes will be thoroughly considered and promptly taken into actions, that would reduce the GHG emissions by more than 30 percent from the Waste Sector.

Chapter 4: VULNERABILITY ASSESSMENT





4.1. INTRODUCTION

The Kingdom of Tonga like many small island developing countries is highly vulnerable to the adverse effects of climate variability, sea level and climate changes. Tonga's vulnerability is principally due to its physiographic, socioeconomic and ecological characteristics. The effects of climate variability are manifested by tropical cyclones, storm surges, drought, inundation and flooding. International scientists have reported that anthropogenic climate change will exacerbate the aforesaid effects. (IPCC, WG1, 2001)

This vulnerability assessment is conducted to examine the degree of the current and future risks induced by climate and sea level changes on the vulnerable sectors in Tonga.

4.2. METHODOLOGIES

Methodologies used in this vulnerability assessment by sectors concerned were based on the IPCC Technical Guidelines for assessing of climate change impacts and adaptation (Carter et al. 1994) and also the IPCC Common Methodology on sea level rise. These steps were followed accordingly:

- Key vulnerable sectors in Tonga were identified;
- Observed and historical climatic trends in Tonga were prepared;
- Present conditions in sectors concerned were examined;
- Future climate and sea level scenarios were developed;
- Climate and sea level scenarios that developed were used to examine their future effects on sectors identified.

In addition, there were also other practical methodologies used in assessing the potential impacts of climate and sea level changes.

4.3. KEY VULNERABLE SECTORS

The following were identified as important vulnerable sectors for Tonga.

- Water Resources
  - » *Water Resources in Rural Areas and Outer Islands*
  - » *Water Resources in Urban Areas*
- Forestry and Agriculture
- Coastal Areas
- Fisheries
- Human Health

4.3.1. Informational Sources:

Data and information utilized in these sectoral assessments were gathered from the following sources:

(a) Water Resources;

- Literature review of national, regional an international reports on the water resources, Tonga
- Personal view and judgement of the author
- Tonga Meteorological Office
- Ministry of Lands, Survey & Natural Resources
- Tonga Water Board

(b) Forestry and Agriculture:

- Ministry of Agriculture and Forestry
- Research articles, theses of special publications
- Consultations with professional staff of government

(c) Coastal Areas:

- Reports and data collected at the Mineral Resource Unit within the Ministry of Lands, Survey & Natural Resources
- Interviews with coastal landowners and experts from government

(d) Fisheries:

- Ministry of Fisheries
- Department of Environment
- Tonga Meteorological Office
- Anecdotal information from fishers and village people from rural island communities

(e) Human Health:

- Reports at the Ministry of Health
- Expert judgement of the author

4.3.2. Other practical methodologies were used in sectoral assessment

Water Resources

A computer programme called WATBAL9F based on a water balance simulation was run to estimate the recharge to groundwater using monthly rainfall data from the Tonga Metrological Services (TMS) and potential evaporation data estimates from Thompson 1986.

Forestry and Agricultural Sectors

A computer programme called "Plant Gro" was used to assess potential impacts of climate and sea level changes on these sectors. The programme predicts the yield of a crop by matching a crop file to a climate file and a soil file. The PlantGro has several crop files. A climate file was created using the average weather data collected in Nuku'alofa for over 50 years. Two soil files were created: (i) for a soil formed from andesitic volcanic ash (Vaini soils); and (ii) for soil formed on coralline sands (Nuku'alofa soils). The yield predictions were for: (i) a situation of no climate change; (ii) a situation with increase in temperature; (iii) a situation with reduction in rainfall; and (iv) a situation with rise in sea level. The sea level rises were represented by the increase in salinity in the soil files. Three levels of soil salinity were used to depict the sea water inundation conditions (8ds/cm for volcanic ash soils and 12 ds/cm for the coralline soils), an intermediate condition (4ds/cm for volcanic ash soils and 6ds/cm for the coralline soils), and a condition with low salinity (2ds/cm for volcanic ash soils and 3ds/cm for coralline soils).

4.4. OBSERVED & HISTORICAL CLIMATIC TRENDS, TONGA.

The historical and observed climatic trends for Tonga include temperature, precipitation, ENSO, sea level rise and tropical cyclone. These data and information were used in this vulnerability assessment and discussions.

4.4. 1. *Temperature Trend*

Historical temperature trends for Nuku'alofa, Vava'u, Ha'apai and Niuatoputapu were dated back to 1949. Trends suggest a marked increase of 0.4^0C to 0.8^0C in annual mean temperature throughout the island groups since 1970s (**Figure 4.1**).

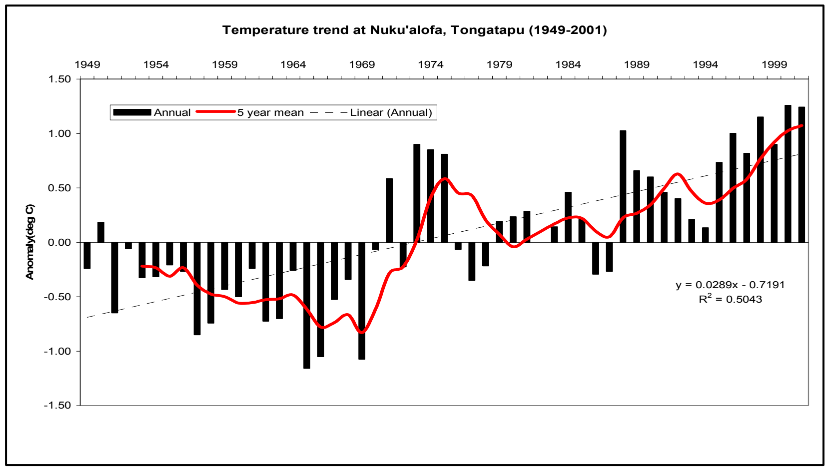


Figure 4.1: Annual Mean Temperature Trend for Nuku'alofa, Tongatapu.

4.4.2. *Precipitation Trend*

The annual precipitation trends were obtained from spatially selected meteorological stations throughout Tonga, which had at least 30 years of data. Trends indicate a general decrease in annual rainfall in the central and southern parts of Tonga particularly since 1970s (**Figure 4.2**).

There has been as well an indication of a decrease in seasonal precipitation throughout the Kingdom (**Figure 4.3**).

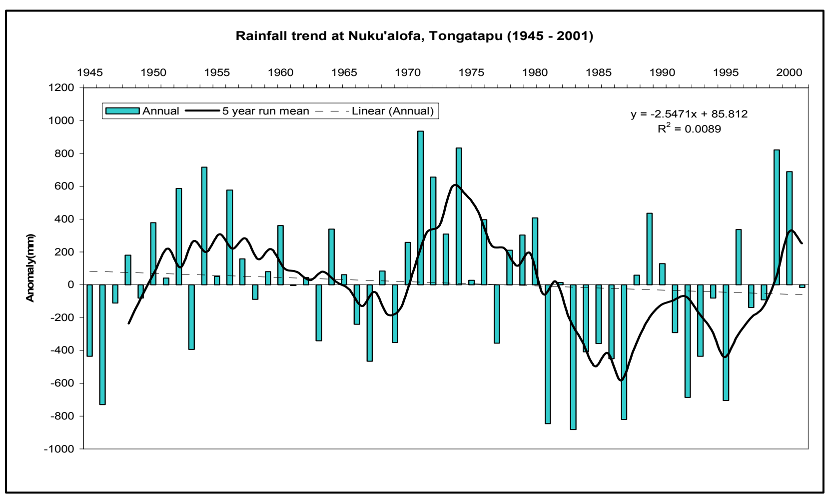


Figure 4.2: Rainfall Trend, Nuku'alofa, Tongatapu (1945-2001)

Inter-annual variation in Tonga's rainfall has been strongly associated with ENSO and the positioning of the ITCZ and SPCZ respectively. *Salinger et al* suggested that this decrease in Tonga's rainfall coincides with an eastward shift of the SPCZ since 1970. Research suggests that these changes may also be closely correlated with the so-called IPO (Salinger and Mullen, 1999). It should be noted however that changes observed in the 20th century are considered to be consistent with patterns related to anthropogenic climate change (Salinger et al., 1995; Hay, 2000).

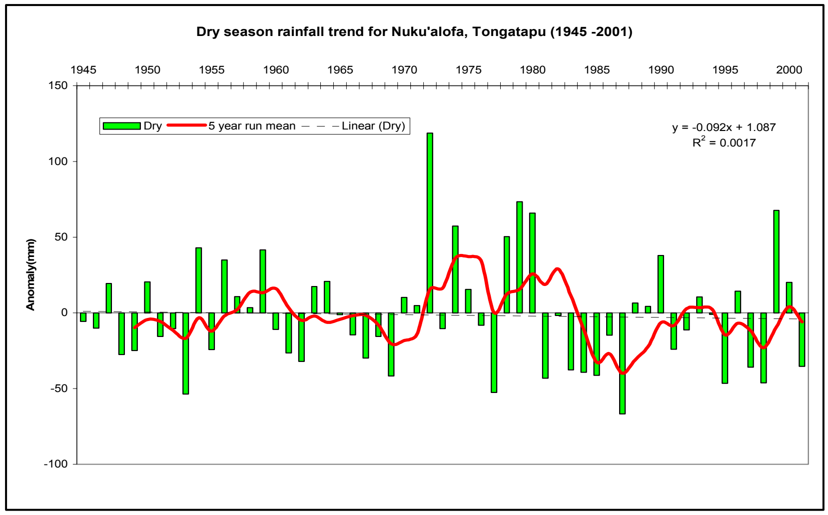


Figure 4.3: Seasonal Precipitation Trend

4.4.3.El Nino Southern Oscillation [ENSO]

Beyond the long-term trends in climate, interannual climate variability over the Pacific with the inclusion of Tonga is dominated by the ENSO phenomenon (Salinger et al., 1995).

Southern Oscillation Index (SOI) is the indicator used to monitor the motions of the ENSO phenomena. SOI is essentially the difference in mean sea level pressure between Tahiti and Darwin (MSLP Tahiti –MSLP Darwin). Persistent positive values indicate La Nina conditions (wet in the western pacific) while negative values indicate El Nino conditions (wet in the eastern pacific).

Figure 4.4 shows a good correlation between the SOI and Nuku'alofa rainfall. As the SOI increases, rainfall patterns follow a La Nina type pattern. The converse (El Nino type rainfall pattern) is also true for observed negative SOIs.

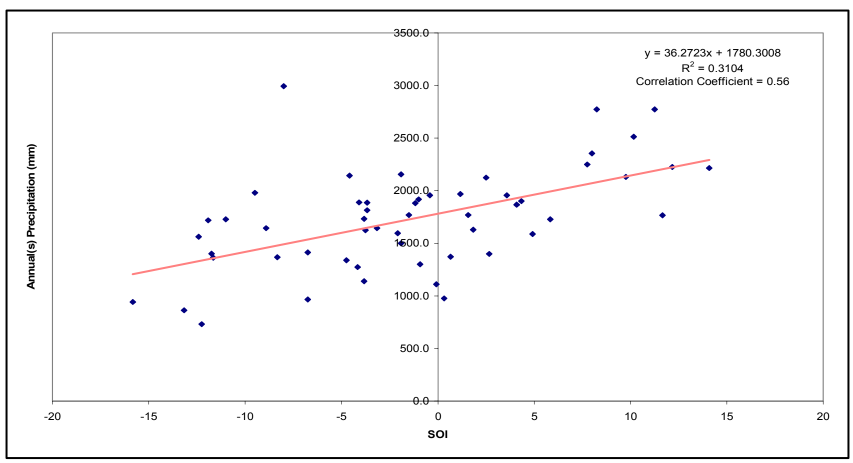


Figure 4.4: Correlation between SOI and observed annual rainfall for Nuku'alofa

4.4.4. *Sea Level Trend*

The sea level trend (**Figure 4.5**) 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 but the magnitude of the trend continues to vary widely from month to month. The result of August 2004 shows a trend of +11.6mm/yr (South Pacific Sea level and Climate Monitoring Project).

It should be noted however that data recorded is far too short to suggest a true representation of sea level rise in Tonga. A longer-term data record is desirable to ensure noise from ENSO cycles and various local atmospheric, oceanographic and geodetic processes are limited before better estimate can be made. The current figure is expected to decrease as more credible data will be collected. Despite this limitation, it is still constructive to consider that data obtained from tide gauge thus far signifies a positive sea level trend. The projected sea level rise accompanying climate changes due to the enhanced greenhouse effect are expected to adversely affect almost all the islands of Tonga.

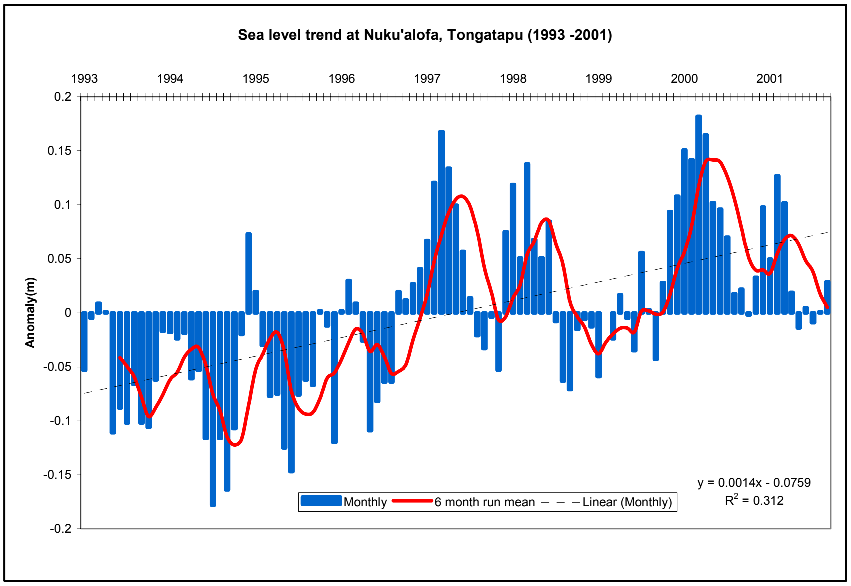


Figure 4.5: Sea level Trend for Nuku'alofa, Tongatapu.

4.4.5. *Tropical Cyclonic Events and Trends in Tonga and the South Pacific*

Historical records indicate an increased trend in tropical cyclone frequency in the South West Pacific since the 1960. This trend could be attributed to improved recording of such events through the introduction of advanced technologies e.g. geostationary and polar orbiting satellites and changes to tropical cyclone definition. There is also a direct relationship between increased cyclonic activity and El Nino events, however data that have been obtained in Tonga thus far indicate little to no trend (**Figure 4.6**). There is little evidence to confidentially predict an increase in cyclonic activity as this stage and as such a longer data set is required.

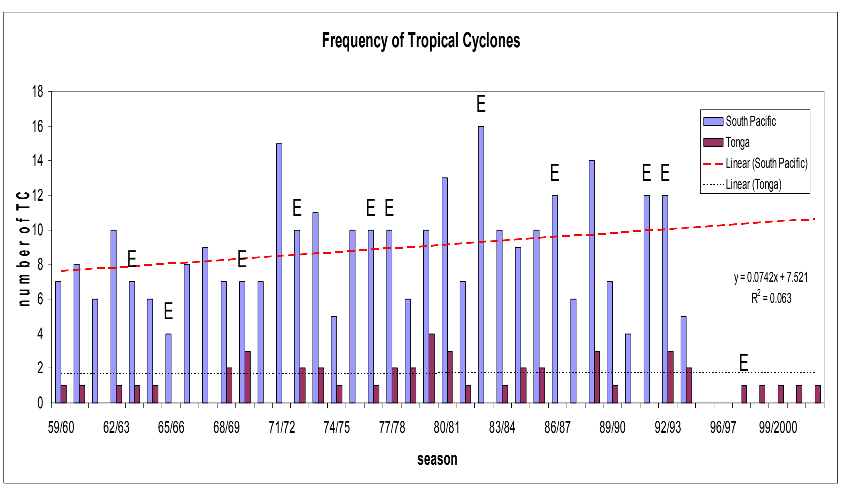


Figure 4.6: Tropical Cyclonic events in Tonga and the South Pacific

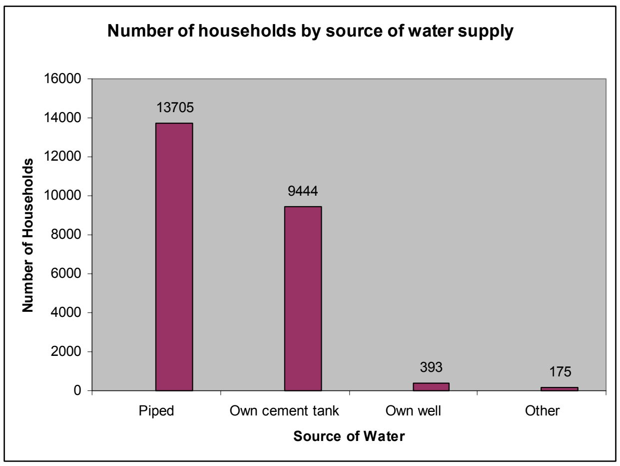
Note: E indicates cyclone seasons where El Nino conditions were prevalent

4.5. PRESENT CONDITIONS IN SECTORS IDENTIFIED

4.5.1. Water Resources

Two main sources of water in Tonga are from rainwater collected and stored in cisterns as well as fresh water lens found in highly porous limestone substrate. Additionally, many households in Tonga have access to more than one source of water supply. For instance, households may both have access to piped water and also rainwater collected in cement tank, however, in some isolated islands, rainwater is the only source of water (Statistics Department, 1999).

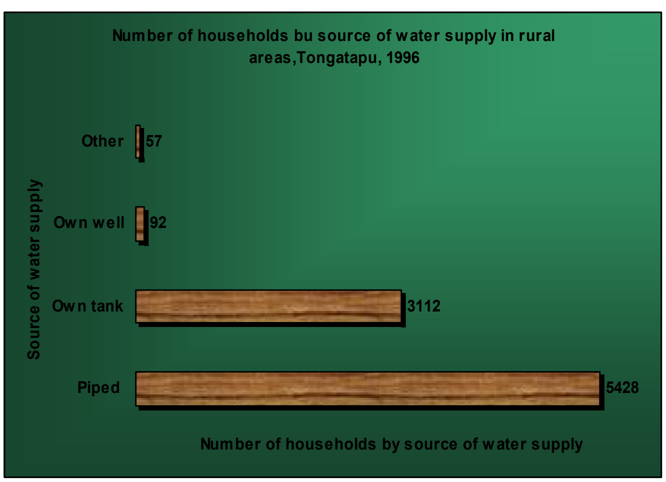
Further, surface water resources are not present in Tonga with the exception of 'Eua (coral island) and a number of volcanic islands including Niuafo'ou and Tofua (Ha'apai Island).



In accordance with 1996 Census, out of the total 16,194 households, 13705 or 84.6% in Tonga had accessed to piped water supply, 9,444 households (58.3%) had their own cement water tanks; 393 households (2.4.%) had their own well and 175 households (1.1.%) had other sources of water supply.

Figure 4.7: Number of Households by Source of Water Supply, 1996, Tonga.

4.5.1.1. Water Resources in Rural Areas and Outer Islands



Out of 10,796 households in Tongatapu, 5428 or 50.3% of households used piped water as source of water supply, 3112 households (28.8%) had their own cement water tanks; 92 households (0.8 %) had their own wells and 57 households (0.6%) had other sources of water supply.

Figure 4.8: Number of Households by source of water supply in rural areas, Tongatapu, 1996.

Out of the 2728 households in Vava'u, 1051 households or 38.5% had access to piped water supply, 1321 households (48.4%) had their own cement water tanks, 21 households (0.8%) had their own wells, and 39 households (1.4%) had other sources of water supply.

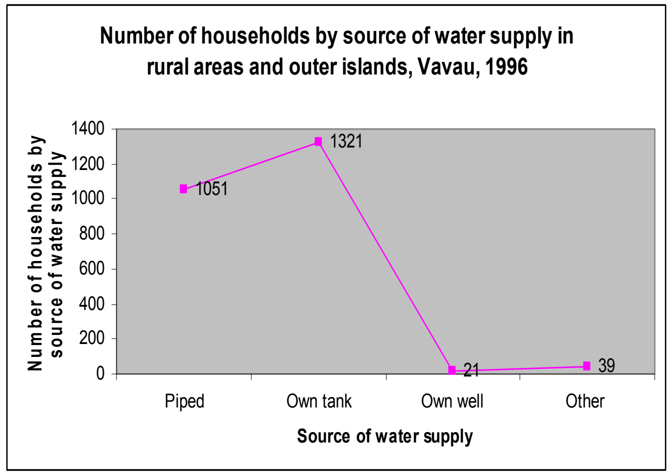


Figure 4.9: Number of households by source of water supply in rural areas and outer islands, Vava'u, 1996.

Out of the 1469 households in Ha'apai, 324 households or 22.1% had access to piped water supply, 906 households (61.7%) had their own cement water tanks, 93 households (6.3%) had their own wells and 2 households (0.1%) had other sources of water supply.

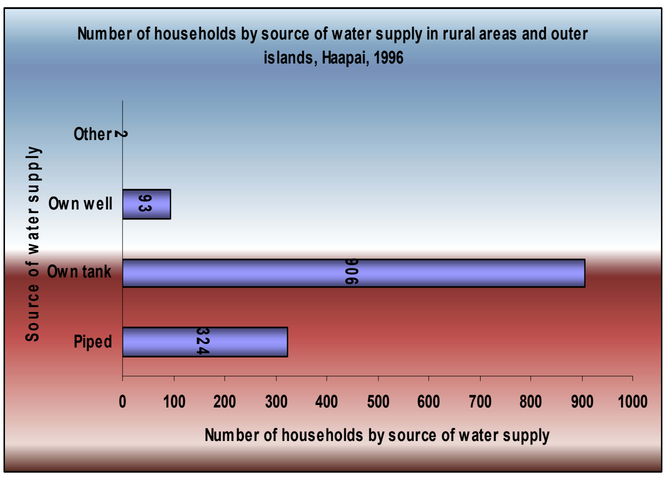


Figure 4.10: Number of households by source of water supply in rural areas and outer islands, Ha'apai, 1996.

Salinity Analysis

Salinity of freshwater lens measured at water table provides an approximate guide to the nature and quality of freshwater lens. When salinity is below the limit for drinking water (2500uS/cm), it shows that freshwater lens is of reasonable thickness and when salinity reaches/exceeds the aforementioned limit, then it means freshwater lens is generally thin.

In this assessment, several rural villages in Tongatapu, Ha'apai and Vava'u were selected (**Figures 4.11-4.13**). Salinity data of freshwater lens as collected from the quarterly monitoring programs in these villages were assessed and subsequently used to observe and depict possible impacts of climate change (change in rainfall pattern and recharge rate) on groundwater quality in these villages.

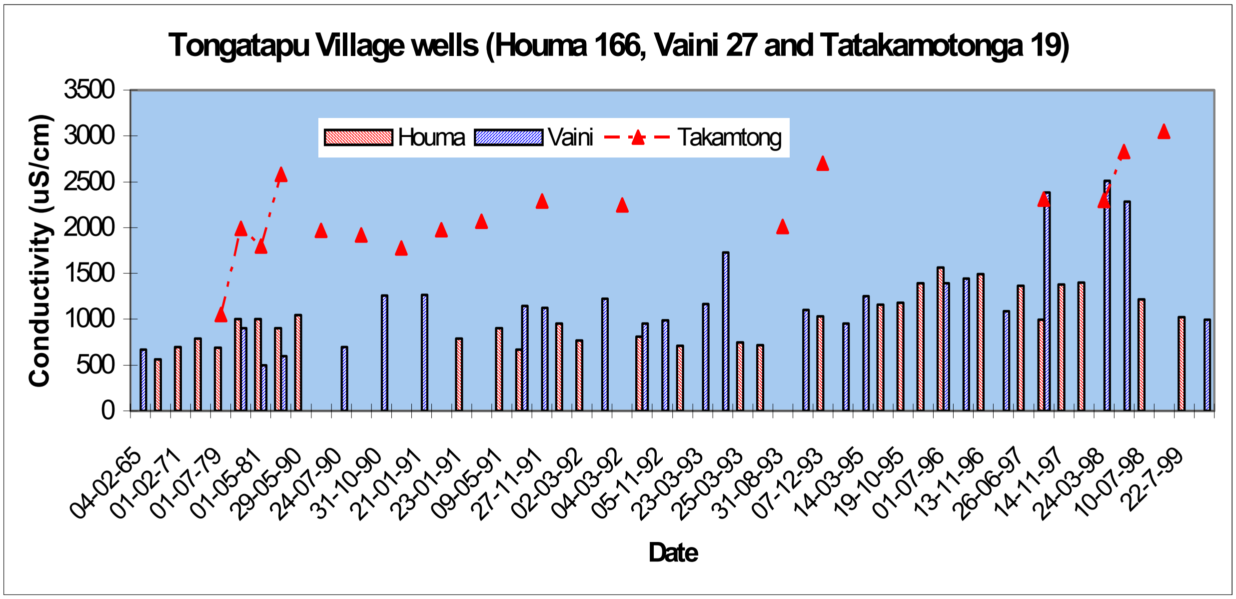


Figure 4.11: Graph of Electrical conductivity against date where monitoring programs were undertaken on wells in selected villages (Houma, Vaini and Tatakamotonga) on Tongatapu.

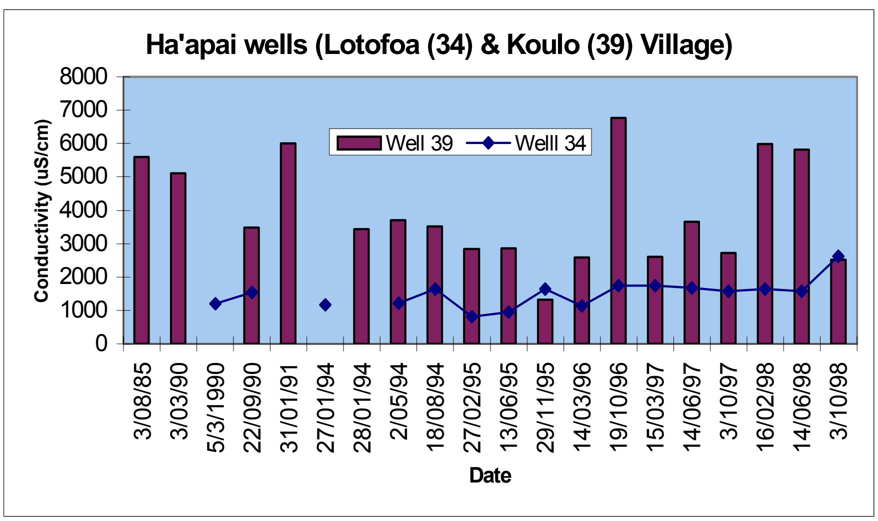


Figure 4.12: Graph of Electrical conductivity against date when monitoring programs were conducted on wells in selected villages (Lotofoa, Koulo), Ha'apai.

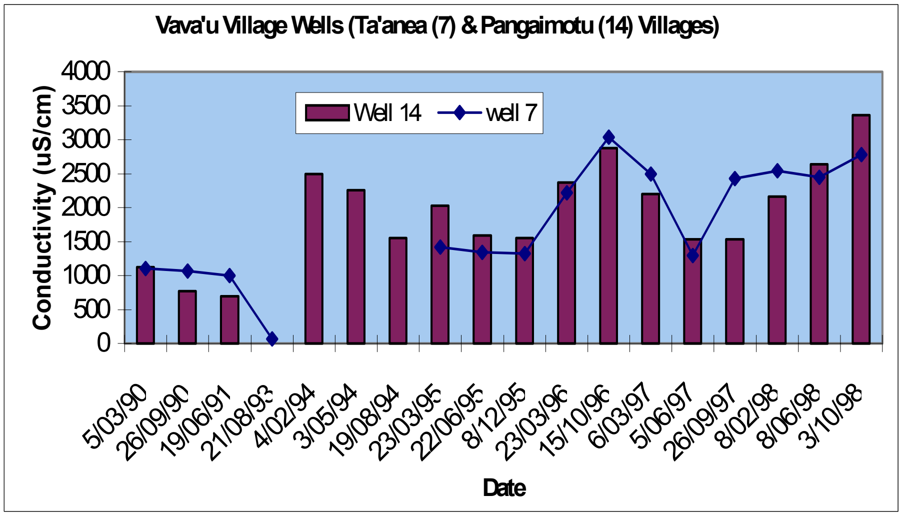


Figure 4.13: Graph of conductivity against date where monitoring programs were conducted on wells in selected villages (Ta'anea, Pangaimotu), Vava'u.

From the above graphs (**Figures 4.11-4.13**), trend of electrical conductivity (salinity) has increased particularly during the periods of 1997 to 1998. This increase relates to the impact of a drought experienced in Tonga and the rest of the Pacific islands particularly in 1998.

Sea level rise, salt-water intrusion into the aquifer and over pumping rates on these village wells have also contributed to such increase.

Recharge Analysis

Table 4.1 summaries the results from running WATBAL for Tongatapu (Nuku'alofa), Ha'apai (Lifuka), Vava'u, Niuatoputapu and Niuafo'ou respectively. The period of analysis was from 1947 to 2001 (55 years). The result indicates that Ha'apai has the lowest recharge among all the island groups in Tonga.

Table 4.1: Summary of the 55 years average results for recharge on respective islands

Island	Mean Annual Rainfall (MAR) (mm)	% Recharge (of rainfall)	Recharge amount (mm)
Nuku'alofa, Tongatapu	1749	30	524.7
Ha'apai	**1696**	**27**	**457.9**
Vava'u	2199	40	879.6
Niuafo'ou	2446	44	1076.24
Niuatoputapu	2289	42	961.38

Source: Metrological Services, MAC, Tonga.

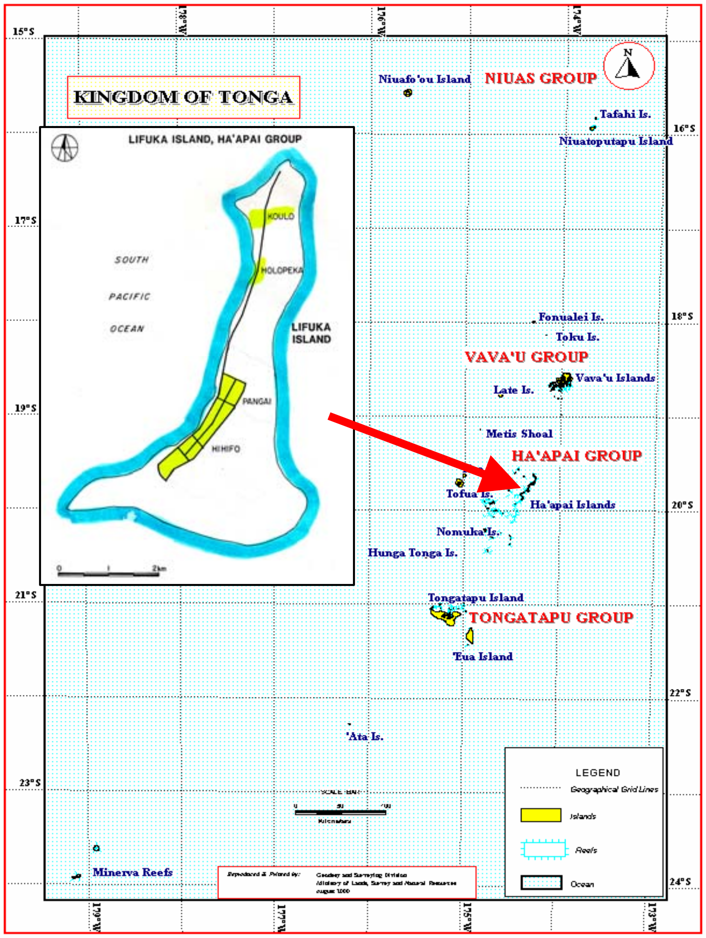


Figure 4.14: Location map of Lifuka, Ha'apai Island.

Figure 4.15 shows the annual average recharge plotted against year and Figure 4.16 shows graphical comparison of average recharge along with annual rainfall plotted against year for the 55 years period 1947-2001 in the Island of Lifuka, Ha'apai.

Figure 4.15 also indicates that recharge fluctuates widely on an annual basis. It can also be seen that in some years (1952 and 1983), negative recharge is experienced. Negative recharge implies a net loss of freshwater from a freshwater lens. This happens when evapotranspiration exceeds recharge from rainfall. The lowest recharge occurred in 1983 (-35 mm) while the highest occurred in 1957 (1297 mm).

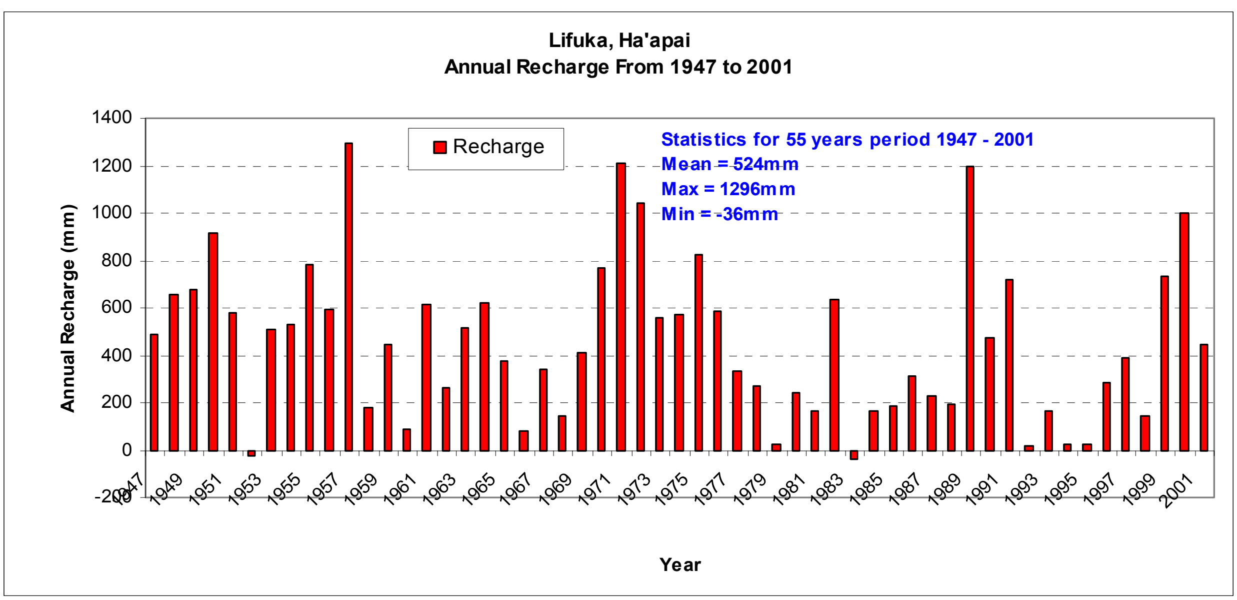


Figure 4.15: Annual recharge at Lifuka, Ha'apai, 1947-2001

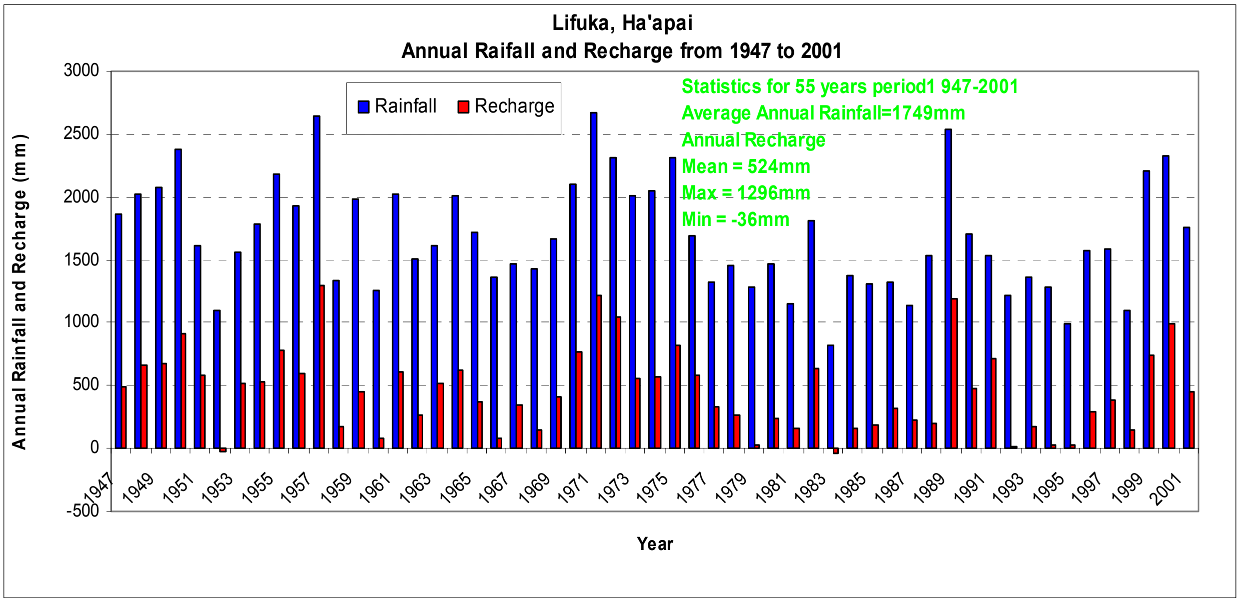


Figure 4.16: Annual Rainfall and Recharge at Lifuka, Ha'apai, 1947-2001

A graphical comparison of the annual recharge and annual rainfall patterns from 1947 to 2001 in Lifuka, Ha'apai is shown in Figure 4.16. It clearly shows that recharge depends on the amount of rainfall. Decrease in rainfall particularly in the central and southern parts of Tonga in the 1970s was reported (Fa'anunu, 2002). In the event of prolonged drought (1998/1999) the shallow/thin freshwater lens of Lifuka was affected.

Impacts of Extreme Events

Impacts of extreme droughts were already experienced in the Ha'apai islands. A recent drought in 1998/1999 had a large impact on rainwater resources. Thousands of Pa'anga was spent by the government on shipping water to small islands of Ha'apai which depends on rainwater as a primary source of potable water supply.

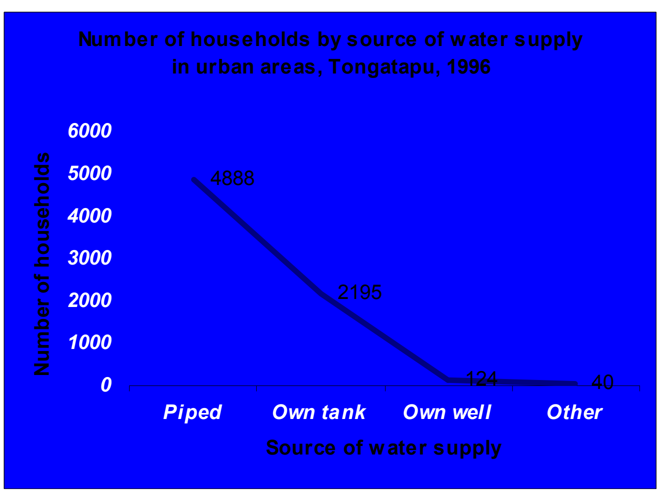


Figure 4.17: Number of Households by source of water supply in urban areas, Tongatapu, 1996.

4.5.1.2. Water Resources in Urban Areas

Urban areas in Tonga include Nuku'alofa (Tongatapu), Neiafu (Vava'u) and Pangai (Ha'apai).

Out of the 10,796 households in Tongatapu, 4,888 households in Nuku'alofa (45.3%) had access to piped water supply, 2,195 households (20.3%) had their own cement water tanks, 124 households (1.1%) had their own wells and 40 households (0.4%) had other sources of water supply.

Out of 2,728 households in Vava'u, 851 households in Neiafu district (31.2%) had access to piped water supply, 618 households (22.7%) had their own cement water tanks, 6 households (0.2%) had their own wells and 17 households (0.6%) had other sources of water supply.

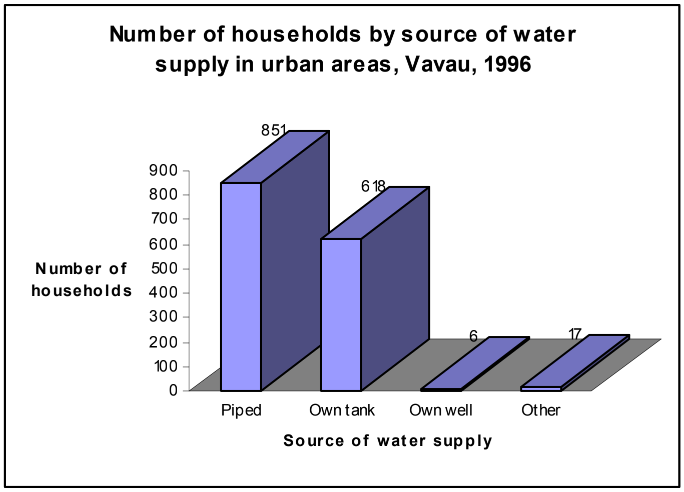


Figure 4.18: Number of Households by source of water supply in urban areas, Vava'u, 1996

Out of the 1,469 households in Ha'apai, 342 households in Pangai district (23.3%) had access to piped water supply, 449 households (30.6%) had their own cement water tanks, 52 households (3.5%) had their own wells, and 4 households (0.3%) had other sources of water supply.

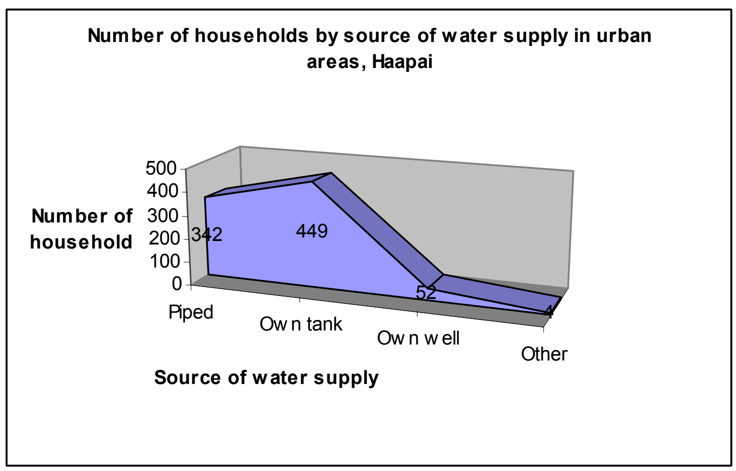


Figure 4.19: Number of Households by source of water supply in urban areas, Ha'apai, 1996

This vulnerability assessment on water resources in urban areas was based on Nuku'alofa (Tongatapu), the capital, where one third of the country's total population resides and is also the center of economic and infrastructural development for the whole country, government and non-government agencies, industrial and commercial buildings are situated.

The three major impacts of climate change on Water Resources will be a reduction in annual mean rainfall, increase temperature and rising mean sea level. These would in turn negatively affect the water quantity and quality.

Water Quantity and Water Quality

Currently, there are 39 drill and hand dug wells operating at Mataki'eua (**Figure 4.20**).

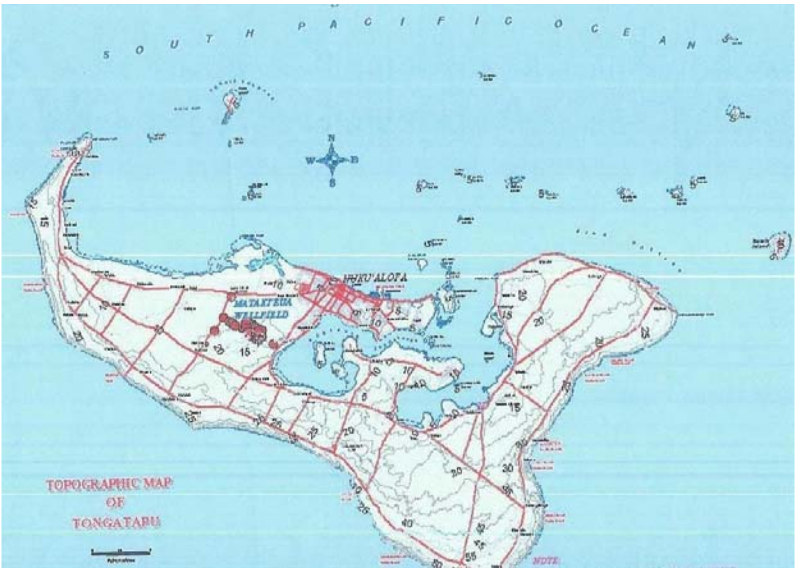


Figure 4.20: Topographic Map of Tongatapu with Matakieua Wellfield

Matakieua wellfield is where water is generated and distributed to all Nuku'alofa areas. Freshwater lens in Matakieua varies between 5-20 meters. Production of the wellfield has steadily increased from 5 Ml/day in 1991 to an average of 9 Ml/day in 2001. The calculated average consumption for 2003 is around 155 l/person/day.

The current total pumping capacities of the Mataki'eua Wellfield are approximately 9100 m^3/day, respectively. Freshwater produced has an average electrical conductivity (EC) of about 1100 µS/cm. Monitoring of salinity monitoring boreholes indicates that the current pumping rates are not having a significant impact on the freshwater lens volumes.

Total extraction rate from the Mataki'eua/Tongamai wellfield is approximately 9.8Ml/day, which represents about 19% of Tongatapu's current estimated sustainable yield of 51Ml/day. The present total combine extraction on the whole island is estimated to be 14.4 Ml/day or about 28% of the current sustainable yield.

Thickness of the freshwater lenses varies depending on locations (**Figure 4.21**).

Figure 4.23 illustrates variation in thickness of freshwater lenses depends largely on the underground water recharge and rainfall. Thickness of freshwater lenses has increased in one salinity-monitoring bore at Mataki'eua (MB7) from about 9–11m in the period 1997, 1999 to 14m in mid 2000 and than about 18m from late 2000 to early

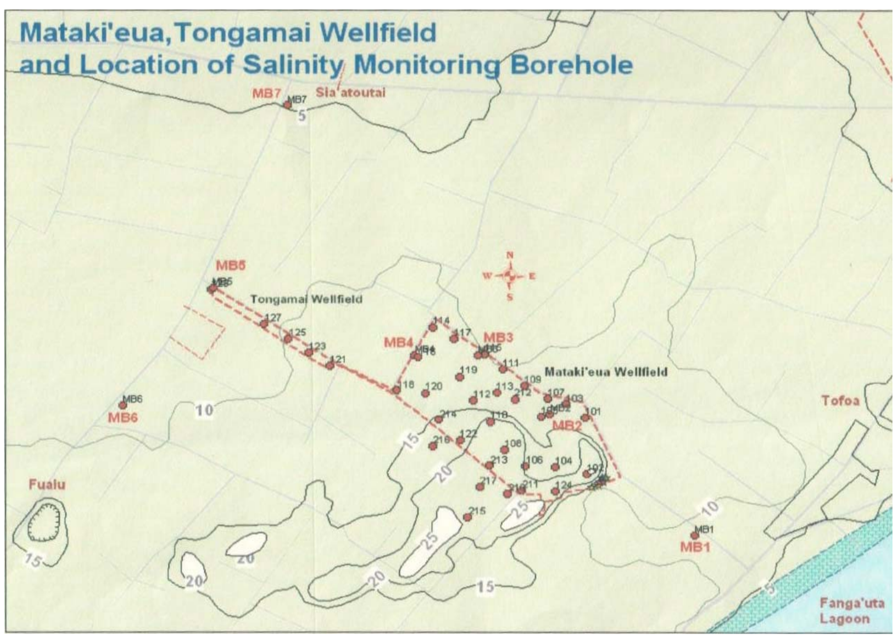


Figure 4.21: Location of Matakieua & Tongamai Wellfield and Salinity Monitoring Borehole (MB1–MB7)

2002 (**Figure 4.23**). Rainfall recorded during these periods has also shown an increase above the average normal rainfall. There was an increase in freshwater thickness at other boreholes (MB1-MB6) but not much.

Rainfall

The islands of Tonga are influenced by rainfall of both convectional and cyclonic origin. Rainfalls due to orographic influences on low-lying islands are slight owing to the relatively low topography. Orography does affect rainfall patterns on the high islands.

Table 4.2: Annual rainfall statistics for period 1947-1990

Location	Records	Mean	Std Dev	Cv	Max	Min
Nuku'alofa, Tongatapu	1947-2001	1753	448	.26	2655	838
Pangai, Ha'apai	1947-2001	1689	437	.26	2664	826
Neiafu, Vava'u	1947-2001	2185	487	.22	3286	1183

Source: Metrological Services, MAC, Tonga.

Neiafu (Vava'u) has higher rainfall than Nuku'alofa (Tongatapu) and Pangai (Ha'apai).

A measure of the variability of rainfall is the coefficient of variation (Cv). Pangai, Ha'apai and Nuku'alofa, Tongatapu show higher annual Cv than Neiafu, Vava'u (**Table 4.2**). This concludes that the northern islands in Tonga have higher and less variable annual rainfall than those in the centre (Ha'apai) and south (Tongatapu). Figure 4.22 shows the Impact of ENSO on underground water resources in Tongatapu.

The impacts of present climate variability on groundwater resources in Tongatapu are particularly noticeable. Prolonged drought leads to a decrease in the annual and monthly rainfall. During the El Nino year of 1983 the rainfall recorded at Nuku'alofa was 838 mm, while the opposite occurs in the La Nina year of 1999 with an annual rainfall of 2540 mm (**Figure 4.22**). There was no annual recharge for 1983, in contrast the recharge rate elevated to 1105 mm or 40% of annual rainfall in 1999. It has also been recorded that the monthly and annual rainfall escalated to 2540 mm in 1999, 2408 mm in 2000 and 1702 mm in 2001.

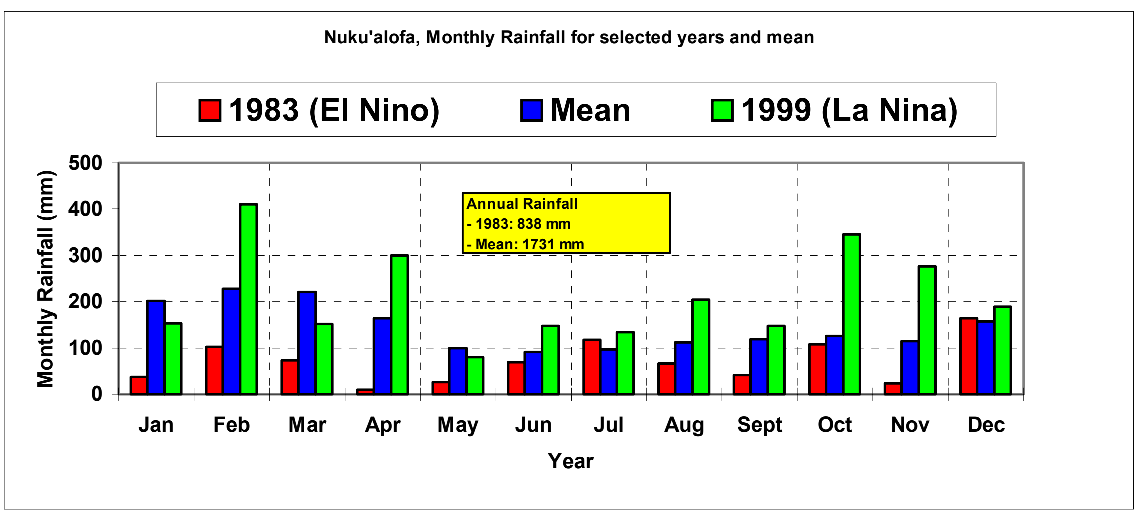


Figure 4.22: Impact of rainfall on salinity profile of underground water resources in Tongatapu.

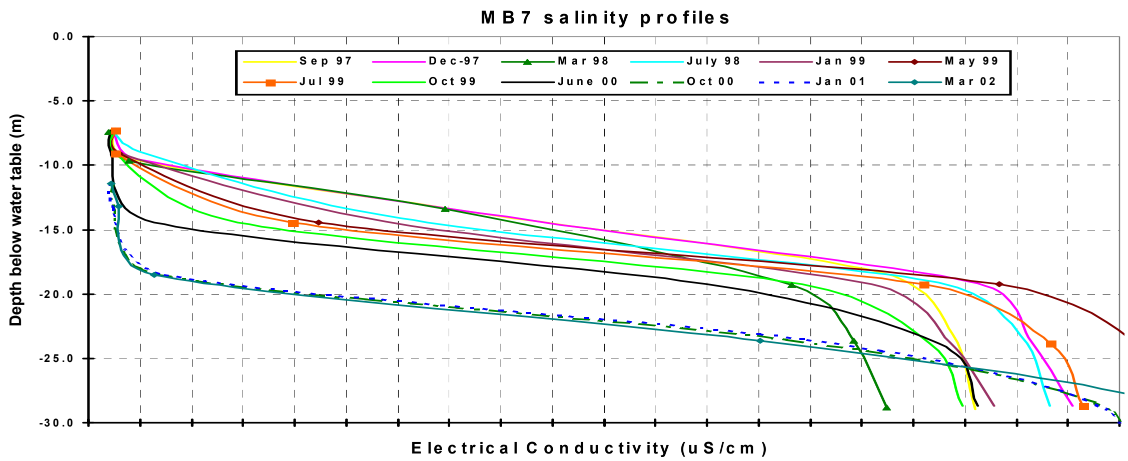


Figure 4.23: Salinity Profiles

Groundwater studies in Tongatapu

A number of groundwater investigations and studies were conducted prior to those recently undertaken by the Hydrogeology Unit within the Ministry of Lands, Survey and Natural Resources and the Tonga Water Board.

The most relevant of the previous studies are:

- Pfeiffer and Stach (1971, 1972);
- Waterhouse (1976);
- Hunt (1978)
- Lao (1978),
- Kafri (1989),
- Hasan (1989), and
- Falkland (1992)

Previous recharge estimates

Recharge estimates have been provided in a number of previous studies. Table 4.3 summarizes the recharge estimate and methods used for the analysis.

Table 4.3. Result of previous groundwater studies for Tongatapu

Name	Method	Recharge in (mm)	% of rainfall	Volume in m≥
Peiffer & Strach (1972)	Previous experience and knowledge	175mm	10	1.25 x 10^5 m^3/day
Lao (1978)	Water Balance Approach	450	25	3.1 x 10^5 m^3/day
Hunt (1978, 1979)	Sharp Interface Mathematical model	-	25 - 30	-
Kafri (1989)	Chloride ion concentration	Same as Lao	25	-
Hasan (1989)	Water Balance Approach	355	20%	-
Falkland (1992)	Water Balance Approach	528	30%	-

Source: Tonga Water Supply Master Plan, 1992

Previous estimates of recharge vary between 10 and 30% of rainfall depending on the methodology used.

Effects of Extreme Events

Extreme events such as storm surges, high seas and gale force winds combined with projected mean sea level rises, will probably increase the incidence of wave overtopping or inundation of low lying areas.

There are already examples of these occurrences on Tongatapu especially during El Niño episodes. Storm surges during 1982 and 1998, particularly in the hurricane season (November – April), caused inundation of some land in the low lying areas of the northern part of Tongatapu, especially the western part of Nuku'alofa (Sopu, Halavave and part of Kolomotu'a on the lagoon side). Recent regular inundation of low-lying parts of the northern part of Tongatapu occurs during El Niño episodes as a result of elevated sea levels.

Overtopping by waves or inundation by high sea levels has caused seawater intrusion into freshwater lenses hence reducing the availability of potable freshwater.

4.5.2. Forestry and Agriculture

Potential impacts of climate change on agriculture in Tonga are highly uncertain. This study is probably the first attempt to study impacts of climatic change on agriculture and forestry. Different impact methodologies also yield widely varying results of the direct impacts of climate change on crop yields and agricultural production even when examining the same region and the same climate scenarios. Tongatapu was chosen for this impact studies.

The robust conclusion that does emerge from impact studies elsewhere is that climate change has the potential to change significantly the productivity of agriculture at most locations. Some currently highly productive areas may become much less productive.

Agricultural production is still the predominant contributor to Tonga's GDP. The contribution was more than 40% in the 1980's but it however fell below 40% from 1993/94 to the present.

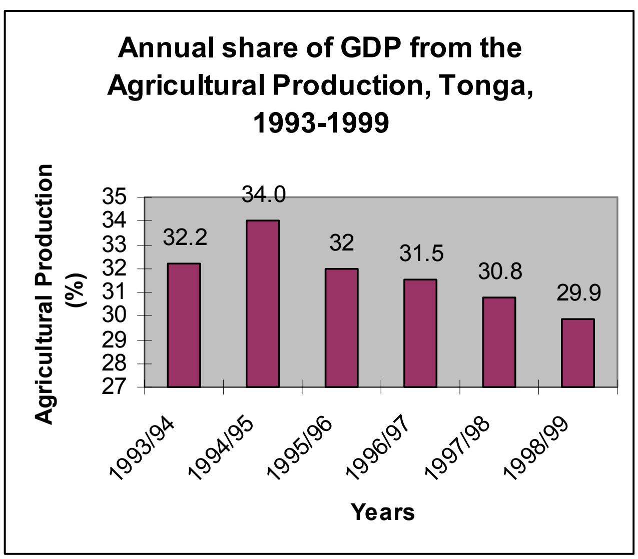


Figure 4.24: Annual share to GDP from the Agricultural Production, Tonga.

The contribution of agriculture to GDP falls from a peak of 34% in 1994/95. The services sector on the other hand, has recorded increases in its contribution to the level of GDP indicating a gradual diversification from agricultural sector to the services sector. This gradual diversification from the heavy reliance on one sector will assist in diversifying and broadening the economic base in order to strengthen the economy against future exogenous shocks. Moreover, with services the problems associated with isolation, weather and economies of scale are mitigated.

Impacts of Tropical Cyclones

Tropical Cyclone Cora, December 1998 severely damaged Tongatapu, Vava'u, Ha'apai & Eua and minor damages to the Niuas. Extensive damages to agriculture and major sources of food supply in Tonga were reported. Of the affected island groups, Tongatapu suffered the most. Vava'u and Ha'apai relied on Tongatapu for food supply. Damages to agriculture due to this cyclone intensified this problem of food shortage.

Tropical Cyclone Waka that hit Vava'u in December 2001- January 2002 caused damages which totaled T$104,156,075. Damages inflicted by TC Waka on the agricultural sector (cash and food crops) was T$20,000,000.

Tropical Cyclone Heta that severely hit Niua Toputapu (far north of Tonga), January 2004 was about T$945,000. The Agricultural sector was the worst affected accounting for 40% of the total cost of damages inflicted by TC Heta (Ministry of Works and Disaster Relief Activities Report, 2004).

Impact of Prolonged Droughts, 1998

Vava'u and Ha'apai relied on Tongatapu for supply of food. Prolonged drought linked to the 1998-1999 El Nino prior Tropical Cyclone Cora, 1998 has negatively affected the food production in Tongatapu. As a consequence food shortages were experienced in Vava'u & Ha'apai.

4.5.3. Coastal Areas

Coastal areas are lands adjacent to the sea alternatively covered and left dry by the ordinary flow and ebb of the tides and all lands adjoining thereunto lying within 15.24 meters of the high water mark of the ordinary tides. These areas cover both the terrestrial and aquatic components of the coast. They are characterized by the rich diversity of their ecosystems and abundance of their resources not only for sustaining the livelihood of Tongans but they have been the central point for inhabitation, business, agriculture, communication and coastal development.

The main environmental components of the coast which are most likely under the threat of climate change and sea level rise include the coral reefs, mangroves and beaches.

Plate 4.1: Viewing SE at Nuku'alofa from its reef-front

Coral Reefs

Coral reefs play a vital role in coastal stability, provide protection of the shoreline from erosion, trap sediments for land accretion and also provide breeding and nursery grounds for marine species.

Plate 4.2: Dead corals around the northern reefs of Tongatapu due to increased temperature

Coral reefs in Tonga are extensive and found in all the islands and can provide economic and environmental benefits. In addition, they are sources of fish and marine ecosystems and also an excellent sink for greenhouse gases including carbon dioxide and methane. Whilst this is an important area for economic initiatives, not much has been researched into the coral ecosystems to link it with the impacts of climate change, variability and sea level rise as well as extreme events. Further, in recognizing the potential for such a resource for the country, it is imperative that research is conducted to examine the different types of coral communities, their health and link it to climate change, variability, extreme events and sea level rise impacts and facilitating adaptation measures.

Plate 4.3: Mangroves at Fanga'uta Lagoon.

Mangroves

Mangrove areas of Tonga are very small in global terms. Much of the mangroves are found in Tongatapu. It was used to be approximately 1000ha about 30 years ago but this has been reduced by clearance and conversion to other uses such as traditional wood construction, fuelwood, herbal medicines, dyes, gathering of crabs and fish. Mangroves also act as sink for greenhouse gas (CO_2) and protection against strong winds, cyclones, storm surges and extreme events. Cutting and removing of mangrove trees reduce resilience to sea level rise and storm surges.

Under the Tonga Environmental Management Plan, mangrove areas in Tongatapu have been designated for sustainable use of mangrove resources. The emphasis of the Management Plan is to allow mangrove areas to recover and grow. This includes planting trees to ensure replacement of any trees lost or previously damaged.

Beaches

More than 10 beaches are located generally outwards to the east, south and west coastline. Most of the popular sandy beach areas have been stripped, exposing beach rocks as the result of high demand for construction material, exceeding the potential for sand regeneration. Storm berms have greatly been minimized in thickness and totally removed at places, lacking trees and shrubs.

Plate 4.4: One of the banned from mining beaches on Tongatapu.

The main environmental issues experienced in low-lying areas particularly along the north shores of Tongatapu are inundation and coastal erosion.

Tidal Inundation

Some very low lying coastal villages including villages of Kanokupolu, Popua, Tukutonga and also the small islands of Nukunukumotu with topographic elevation below 2m above sea level are currently affected by sea level rise. These areas are tidally inundated and the worst times are during spring tides.

Plate 4.5: (left) Westward view of Kanokupolu village during a spring tide event, October 2002

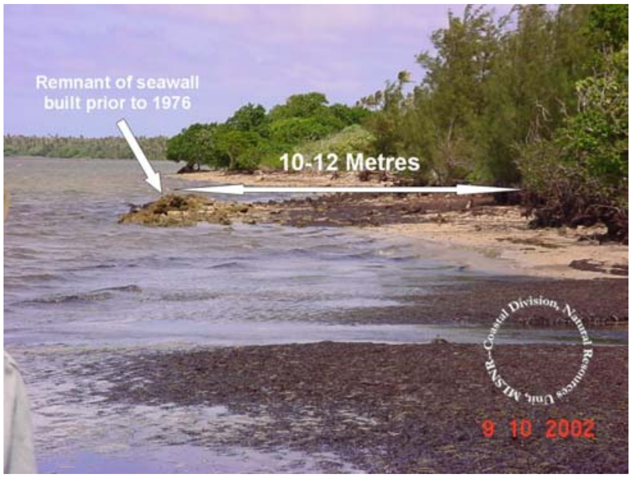
Plate 4.6: (above) Abandoned house and flooded pig fence at Kanokupolu. Water height is approximately 1-2ft deep

Plate 4.7: (left) One of the Kanokupolu residentials.

Coastal villages between Ha'atafu and Kolovai (western side of Tongatapu) are very low down to less than 5m above sea level. Kanokupolu village (immediately south of Ha'atafu village), which is less than 2m above sea level, is the most vulnerable village (**Plates 4.5-7**). Currently, the affected coastline runs about 2.2km along the eastern coast from south of Ha'atafu to Kolovai penetrating landward to an average of 100m from the shoreline.

Kanokupolu is also being flooded with a tidal lagoon (**Plates 4.5-7**). This lagoon floods both tax and town allotments. Houses have been evacuated as well.

Agricultural crops such as taro, watermelon and other plantations claimed by locals were previously common in the flooded areas but no longer there. Since 1968, the inundated area at Kanokupolu village was calculated using sets of aerial photographs over the area (Tappin, 2002).



Landward migration of the shoreline is also presumed from fieldwork observations, indicated by fallen trees and exposed tree roots on the shoreline. Remains of possibly an old protection seawall built before 1976 stands 10 - 12meters seaward from the present shoreline also indicate recession of the land (**Plate 4.8**).

Plate 4.8: Remnant of a seawall at Kanokupolu at 10-12m seaward from the current shoreline.

Coastal villages between Kolonga and Nukuleka (eastern side of Tongatapu) are also low lying where most of which are below 1m above the high water mark. The seawall that runs immediately adjacent along the main road is slowly degrading by the notably rise in sea level. During spring tides, the water reaches adjacent residents on the opposite side of the main road temporarily flooding lower areas.

Plate 4.9: The seawalls at Manuka, where it has been breached by recent tidal waves, exposing coastal tree roots and ultimately brought it down at places. (Picture taken in early 2003)

Coastal villages within the eastern side of the Nuku'alofa area mainly Sopu, Popua, Tukutonga, Nukunukumotu and Manima islands (island less than 100m of walking distance). Inundations in these areas have enormous impacts on the population that permanently resides here. About half of Nukunukumotu island has been inundated compared to 20-30 years ago. Tidal flooding inundates town allotments and more than half of the registered 18 tax allotments.

Coastal villages within the Fanga'uta and Fangakakau areas have been greatly affected by the rising sea level, again flooding of previously dry land. Land reclamation is common to recover registered town allotments, which are presently within the tidal zones. This currently creates public conflicts; land reclamation by higher earners is blamed for the flooding of areas owned by the lower earners.

Coastal Sand Beaches

Rising sea level is dominant and is indirectly eroding beaches such as Fua'amotu beach which evidently show pronounce depletion in sand.

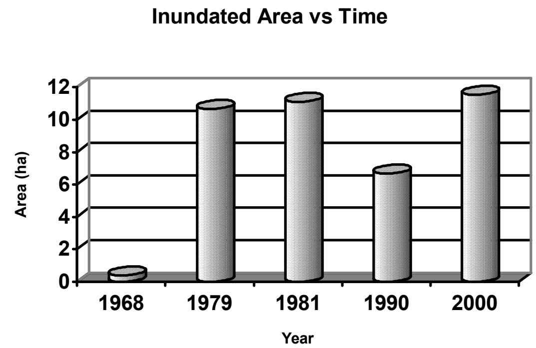


Figure 4.25: Graph of Inundated Area at Kanokuplou Village from 1968 to 2000.

Plate 4.10: During spring tides, water reaches across the main road at Manuka Village and inundates these areas which are <0m below the high water mark.

Coastal Erosion

Coastal Erosion is noticeable in almost every coastline around the Tonga islands including both beach and lagoon coastlines. Tidal inundations are commonly associated with coastal erosions as seen in the above stated villages and that is when erosions are most severe. For example in Nukunukumotu more than half of the island is currently within the subtidal zone compared to 25 years ago; at Kanokupolu several town and tax allotments have been subtidalised.

Coral Bleaching

Tongatapu Island is surrounded by fringing reefs along the western, southern and eastern coastline as well as sub-barrier reefs towards the north. Coral bleaching is becoming common and has recently increased probably due to a variety of factors such as sea level changes, increasing temperature. Bleaching event in Tongatapu and the Ha'apai group (2000) is the result of a warming band of oceanic water extending from Fiji to Easter Island. The bleaching (**Plates 4.2 & 4.11**) is mainly restricted to places shallower than 30 meters and is not widespread at 40meters as widely evident on the reef slopes and in

Plate 4.11: Bleached corals indicated by white colours, due to increased water temperature. This is common around northern reefs of Tongatapu.

the lagoon adjacent to Haatafu beach,Tongatapu. Corals were found to exhibit varying degrees of bleaching due to varying physiologically or genetically adapting abilities of various species.

Plate 4.12: A residential at Kanokupolu which has been divided from the main village by a lake. This has caused the abandonment of this still usable house.

Loss of Land

Inundation of low-lying areas has resulted in the loss of many tax and town allotments as evident in Kanokupolu village and Nukunukumotu Island. Accelerated coastal erosion due to high tides, storm surges and waves also play a major role in these losses. The loss of these land areas has great impacts on individual landowners, the community and the country as a whole due to the limitation of land availability.

Loss of Residential

Loss of allotments means looking for other means of residential and a place for gardening (**Plates 4.6 & 4.12**).

Housing / Infrastructures

Within the present affected areas, abandonment of houses is common due to inundation of the surrounding areas (**Plates 4.6 & 4.12**). Eventhough the houses are still usable, living just above water is unfavourable by average people.

Over half of the population within Tongatapu resides in low lying areas that are over 20% of the total Tongatapu land area, Nukunuku district, Fangakakau and Fangauta area. These areas consist of numerous housing and various infrastructures vulnerable to sea level rise.

Long-term climate change, variability and sea level changes continue to impact on the properties and infrastructures of Tonga.

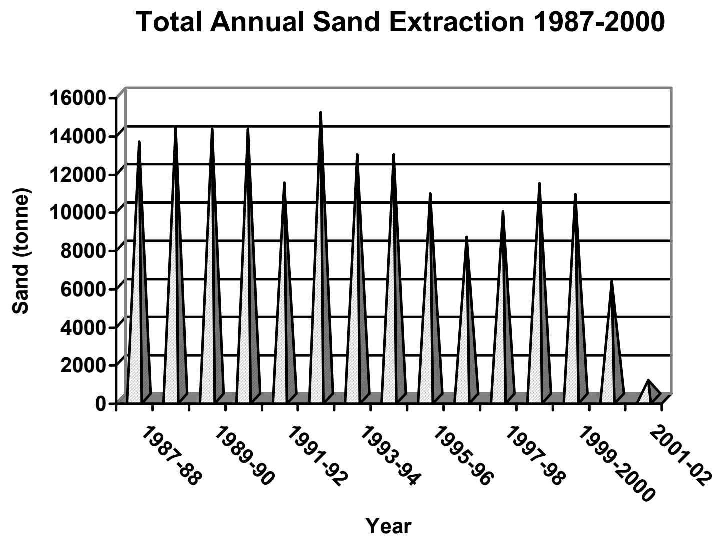


Figure 4.26: Total Annual Sand Extracted from Tongatapu Beaches since 1987. Note the drop in tonnes since 1993, may be associated with increasing number of private companies extracting their own sand directly from the beaches, thus the actual total extracted amount should still be around 14,000 tonnes annually or otherwise may have influenced by depleting reserves.

Construction Aggregates

Sand is one of the most critical commodities for construction purposes in Tonga. The pressures on sand continue to amplify with ever-growing entails for improving housing public amenities and for economic potential. Table 4.4 shows the recorded amount of sand removed from beaches since 1987 to 2002.

Table 4.4: Amount of Sand Mined from Beaches 1987-2001

Year	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95
Amount *(tonne)*	13445	14200	14135	14135	11310	15000	12800	12804
Year	***1995-96***	***1996-97***	***1997-98***	***1998-99***	***1999-2000***	***2000-2001***	***2001-2002***	***2002-03***
Amount *(tonne)*	10740	8470	9815	11283	10725	6165	981	

Source: Geology Unit, MLSNR. Note: The data do not account for illegal removed sand and sand for cultural purposes such as funeral burial and amount extracted by private companies.

With recent banning of beach sand extraction by the Ministry of Lands, Survey and Natural Resources (MLSNR), tax allotments on low-lying areas of Manuka and Navutoka villages (within 100-300m adjacent from shoreline), have been mined for sand as an alternative. Still the stress on beach sand remains high, from the high market price of inland sand. In addition, strong current, storm surge, waves, winds and climate variability are responsible for movements of sands in and around the islands of Tonga. The influence of climatic factors on sands needs to be researched urgently.

Tourism

Removal of sand from beaches as the result of increasing demand for development, constructions, demotes tourism industry in Tongatapu. Over half of these beaches today have lost its potentials to contribute to the economic welfare of the Kingdom.

Plates 4.13 & 4.14 *(left, east view & right, viewing west). Sand cover of the 'Ahononou Beach used to be 3m above the exposed beachrock on the seaward side. HWM use to 30-40m from vegetation line (current HWM).*

Plates 4.15 & 4.16. *(right,, north view & left, south view). One of the attractive sand covered beaches in the Hihifo Area; Fahina Beach has been completely mined out leaving only the beach and basement rocks.*

Live Coral Exporters

The bleaching of many reef areas however is more likely associated with recent license approvals for 5 exporters to extract live corals and related fishes. With this large number of exporters (hence higher demand), relative to the resources available, have significant impacts on Tongatapu's reef environment.

The reefs on the eastern side of the north shores adjacent to villages of Navutoka to Kolonga, have been seriously affected.

4.5.4. Fisheries

Some of the critical habitats of the coastal areas (coral reefs and mangroves) are important fisheries ecosystems. These habitats are seriously affected by the impacts of climate change, which in turn negatively affected the Fisheries sector in Tonga.

Living marine fisheries resources are the single, largest renewable resource available to many Pacific Islands countries yet they have emerged slowly as growth elements in the region's economies. In many ways Tonga's Fisheries sector is a sleeping giant with the potential to carry the economy into the twenty-first century, but to awaken the giant will require careful thought and planning, and a singleness of purpose which has not previously been evident in the Government's attitude toward the Fisheries sector.

In Tonga, the economic contribution of Fisheries Sector has been estimated at approximately around T$14 million in 2003, which is from export of registered companies only. This was an earning from export of 573mt of Tuna (fresh and frozen), 156mt of bottom fish (snapper and grouper), 398mt of aquarium rocks and more than 340,000 numbers of fish and giant clams and pieces of soft/hard coral, 6.7mt of dried shark fins, 223mt of seaweed and other miscellaneous fishery products. Apart from the economic value of exporting marine resource commodities, there are significant amount of marine resources that are consumed and utilized locally by the people of Tonga in immeasurable amount.

Fishing and activities related to fishing are at the heart of Tonga's rural economy. Even people who are wholly engaged in farming benefit from subsistence fishing through reciprocity obligations and traditional non-market transfers. These transfers occur both directly (through distribution of the catch) and indirectly as fishermen sell a portion of their catch and use the proceeds for reciprocity obligations. The World Bank (1996) estimates the value of subsistence fishing in Tonga at around T$2.5 million. This equates to a per-household income of T$221 for rural Tongan families.

Direct assessment of the impacts of climate variability, climate and sea level changes on fisheries resources in Tonga is very scarce or almost absent at present time. However, the importance of the potential impacts of this matter has been realized recently in the Fisheries sector. This concern was mainly due to decline in catch rate in many fisheries (**Table 4.5**) that resulted from fluctuation in abundance and distribution of targeted marine species affected by variation in oceanographic condition driven by climate change and climate variability.

Table 4.5: Total catch of fish species, 1999-2004

Year	alb	bigeye	yelfin	marlin	s/fish	others	Total catch (species)
1999	801	112	163			126	1202
2000	862	120	175			134	1291
2001	1268	191	259	45	15	130	1919
2002	1042	192	222	46	14	201	1647
2003	660	80	227	40	14	287	1308
2004	80	27	80	9	31	39	266

Source: MOF, Tonga.

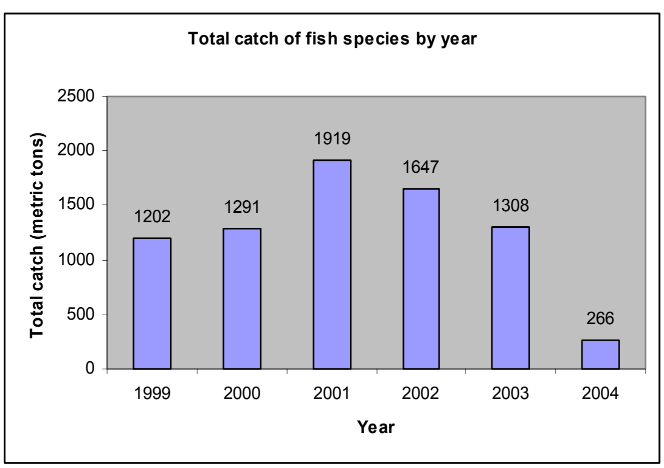


Figure 4.27: Total catch of fish species, Years 1999-2004

The warmer weather brought about by the El Nino (1998-99) affected the activities in the fishing industry and resulted in a T$2.8 million (18.7%) decline in exports of fish and other marine products during the year compared with the T$3.3 million (28.0%) increase in 2001/02 (NRBT Annual Report 2002/03)

The fishing industry did not improve much during the year, 2003/04. The low fish catch rate was also believed as a result of the El Nino condition (NRBY Annual Report 2003/04).

Currently, there are no computer models developed yet specifically for the assessment of climate and sea level change impacts on marine fisheries resources in Tonga apart from indirect prediction of loss of coral reef affected by increase in runoff from increasing precipitations or coral bleaching due to increase in sea surface temperature. Only tuna resources (shared stock and regionally manage) have slowly and seriously taken into consideration the impacts of climate change as an issue in managing the regional marine resources. Consequently, regional approach in using of computer models for assessment of climate change impacts have been developed taking into account climate variability but still in developing stage. Therefore, the prediction of climate change impacts on tuna resources is becoming a major issue on regional basis and it will increase our understanding of the local context in adapting to vulnerable area.

Tuna Resource

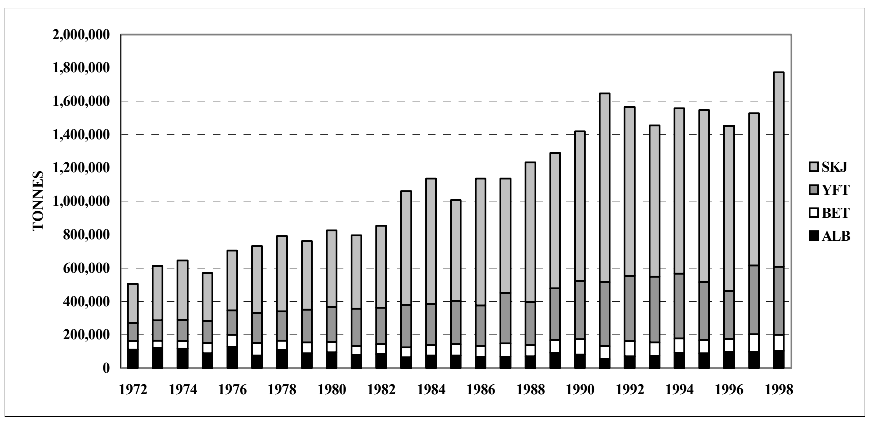


Figure 4.28: Total catch of fish species, 1972-1998

Long-term climate variability and climate change, oceanography and marine ecosystems leads to fluctuations in the abundance of exploited fish populations. This variability occurs at multiple time scale and in recent years there has been increased emphasis on detecting decadal changes, often referred to as 'regime shift'. Regime shift is an abrupt change from a quantifiable ecosystem state while going on to state that the determination of ecosystem state remains an unresolved, and imprecise, oceanographic problem (IPO, SPCZ, and ITCZ). Here we explore various functional approximations for observed long-term variability in Tuna recruitment and environmental properties in the Western and Central Pacific Ocean (WCPO). It is apparent that there is long-term variability in recruitment that may be periodic and therefore predictable, but while the link to basin-scale climate indices is clear, the link to proximate environmental forcing is not immediately obvious. However, the observed variability does appear to synchronise among species and with large-scale ecosystem changes documented for the North Pacific. An ecosystem indicator called Fisher Information is calculated for both North and Pacific and WCPO data and proves capable of detecting regime shift in both environments.

The impact of ocean climate on Tuna in the WCPO has been under investigation for sometimes. El Nino Southern Ocillation (ENSO) events are the dominant sources of inter-annual variability in the WCPO and its tuna fisheries, with very high recruitment and catch of tropical tunas (skipjack, yellow fin and big eye) following the El Nino phase (e.g. 1983, 1997) and low recruitment and catch following La Nina (e.g. 1999-2001); the pattern is reversed for the more temperate albacore. These are climate variabilities experienced in the Tonga region as well.

4.5.5. Human Health

This is the first attempt to undertake this vulnerability assessment on the Human Health sector, Tonga.

Under this assessment, it was discovered that diarrhoeal diseases in both infants and adults have high percentages (2.54%) comparing to other food borne disease such as food poisoning (0.02%, fish poisoning (0.07%), typhoid fever (0.04%) and bacillary dysentery (0.02%) (MoH Annual Report, 2003)

There was a high percentage of diarrheal diseases in both adults and infants in Tonga, 2002. This was mainly caused by drinking of contaminated water. (Annual Report, MoH, 2003). During wet season in Tonga the incidence of dengue fever, a vector waterborne disease, has more prevalent. Rainfall has provided favourable conditions for the multiplication of mosquitoes.

In 1981-1982, 1998-1999, the occurrence of El Nino Southern Oscillation was followed by an outbreak in dengue fever syndromes. The average mortality rate for dengue fever in Tonga is approximately 1person per year. Conversely in the year 2003, 4 cases (age group 1-15 years old) were recorded to be dying from dengue fever.

During the El Nino period that was accompanied by a prolonged drought, there was the inadequacy and lack of clean water supply and as such skin infectious diseases were reported. A drier atmospheric condition also poses threats to human health such as increased incidence of asthma and other ailments of the respiratory system (Ministry of Health Annual report, 2003).

The existence of cyclonic activity has resulted in deaths, injuries and increase incidence of various infectious diseases and psychological stress and disorders.

There was one death reported when Tropical Cyclone ‘Ofa passed through Niua Toputapu, 1990 (Tonga Meteorological Office, Tonga). One of the implications of cyclonic activity is the increase in incidence rate of influenza. Baseline data collected reveal that the five leading causes of morbidity during the year are acute respiratory infection (48%) and influenza (43%) including both infants and adult diarrheal diseases (Ministry of Health Report, 2003).

4.6 CLIMATE and SEA LEVEL SCENARIOS DEVELOPMENT

Climate scenarios are often simplified representation of future climate based on internally consistent set of climatological relationships that had been constructed for explicit use in investigating the future potential consequences of climate and sea level changes on sectors concerned. These steps were followed accordingly:

1. Historical and observed climate data were obtained from six meteorological stations in Tonga; Nuku’alofa, Nuku’alofa tide gauge, Fua’amotu Aerodrome [Tongatapu], Salote Pilolevu Aerodrome [Ha’apai], Lupepau’u Aerodrome [Vava’u], and Mata’aho Aerodrome

[Niuatoputapu]. These stations were deliberately selected according to the availability of credible local data and spatial representation.

2. These climatic data were compared with various scenarios projected by the IPCC General Circulation Model [GCM].
3. The IPCC SRES/TAR and MAGICC/SCENGEN Simple Climate Models were sources used to generate possible future climate and sea level scenarios.
4. Climate change studies as undertaken in Tonga generally based their analysis on records with a baseline of thirty years using the periods 1961-1990. Time intervals for the scenarios generation were 2050 and 2100 years respectively.

The global average surface temperature is projected to increase by 1.4^{0}C to 5.8^{0}C by the Year 2100

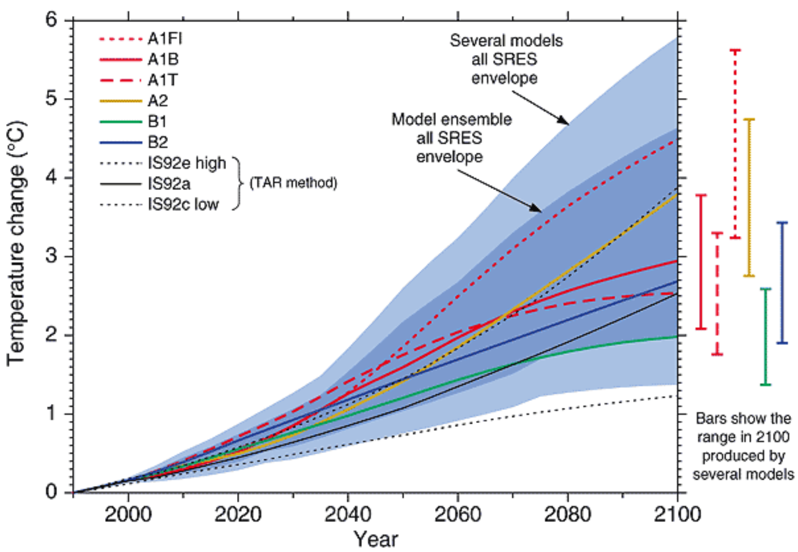


Figure 4.29: SRES Temperature change scenarios

The global mean sea level is projected to rise by 9 to 88cm by the Year 2100

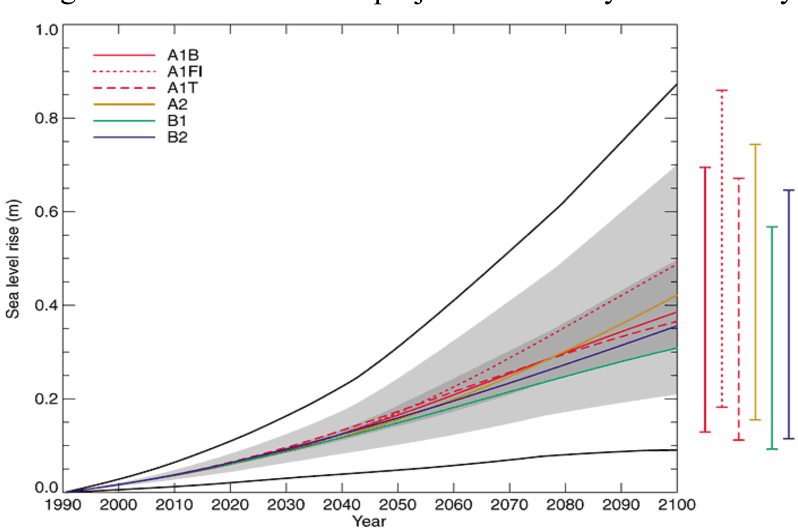


Figure 4.30: SRES Sea level scenario

PRECIPITATION (Δ%)			
		SCENARIOS	
GCM	Emission Scenarios	2050	2100
HADCM2	SRESA1	-10.5	-15.8
	SRESA2	-10.6	-21.4
	SRESB1	-7.9	-12.4
	SRESB2	-8.7	-14.1
	IS92a	-9.8	-18.0
ECHAM4	SRESA1	3.6	5.4
	SRESA2	3.6	7.4
	SRESB1	2.7	4.3
	SRESB2	3.0	4.8
	IS92a	3.4	6.2
CSIRO2-EQ	SRESA1	5.2	7.7
	SRESA2	5.2	10.5
	SRESB1	3.9	6.1
	SRESB2	4.3	6.9
	IS92a	4.8	8.8
GFDL-TR	SRESA1	4.0	6.0
	SRESA2	4.0	8.2
	SRESB1	3.0	4.8
	SRESB2	3.3	5.4
	IS92a	3.8	6.9
CGCM1-TR	SRESA1	-13.1	-19.7
	SRESA2	-13.2	-26.6
	SRESB1	-9.8	-15.5
	SRESB2	-10.9	-17.5
	IS92a	-12.2	-22.4

It is evident from the Figure 4.30 that GCMs are not yet able to provide reliable and true indication of how rainfall patterns might change in the Pacific region including Tonga. Three of the five GCMs (ECHAM4, CSIRO2-EQ-GFDL-TR) used to model rainfall using the preliminary SRES scenarios suggest an increase in rainfall in the next 100 years while the other models (HADCM2, CGM1-TR) suggest the opposite.

Figure 4.31: Precipitation Scenarios generated by SCENGEN for Tonga (5"x5" grid over Tonga)

4.7 FUTURE IMPACTS OF CLIMATE CHANGE AND SEA LEVEL RISE ON SECTORS IDENTIFIED

Table 4.6: Anticipated Climate Change and Sea Level Rise Impacts on Water Resources in Rural Areas and Outer Islands

Impacts/ Climate Change Factor	Implications	Areas affected
Decreased Rainfall *Periods of low rainfall are likely to be accompanied by prolonged dry periods. *Decreased rainfall will reduce recharge to groundwater. SRESB2 climate scenario used in this assessment projected a decrease of average rainfall by approximately 10.9% in year 2050, which means that average annual recharge would reduce from about 457mm to about 317mm, a reduction of about 30 % indicating a greater proportional reduction in recharge then the reduction in	*Prolonged dry periods will decrease water supply for uses in rural areas and outer islands *Reduction in recharge to groundwater means reduction in potable water supply for uses in rural areas and outer islands. *Lack in the availability of potable	Lifuka, Ha'apai

rainfall. By the year 2100, the scenario shows a decreasing rainfall by about 17.5%, which will reduce the average annual recharge to about 149mm, a reduction of 32% from current condition.	freshwater for uses in rural areas and outer islands.	
Increased Rainfall *Increase the incidence of flooding *Temporary increase in water supply *Increase surface runoff & sedimentations/ siltations	*Pollution to groundwater providing poor water quality *Pollution of nearby coastal areas & lagoons due to sediments, debris etc being washed off to these areas *Temporary increase in recharge to groundwater & rainwater collected in cisterns	
Increased Temperature *The effects of projected temperature increase on water resources are mainly on evapotranspiration of water. Evapotranspiration can also be influenced by other factors such as solar radiation and wind speed. Increase in evapotranspiration would decrease the recharge to groundwater. The reverse would apply when there is a decrease in evapotranspiration would tend to increase groundwater recharge. A simple analysis was made for Ha'apai by increasing the estimated monthly potential evapotranspiration estimates and using the recharge model WATBAL to analyse the impact on average annual recharge to groundwater It was reported that the impacts of potential evaporation increases changes on recharge are not highly significant. For instance, if mean annual evapotranspiration were increased by 20% (from 1,461 mm to 1,753 mm), the recharge would potentially reduce from 524 mm to only 406 mm, a net reduction of about 22%.	*Increased temperature will increase water consumption hence reducing the quantity of groundwater supply. *Increase water loss means low recharge rate hence reduction in groundwater quantity.	
Sea Level Rise As mentioned before, sea level rise will not directly have an impact on the groundwater lens thickness and volume but just raise the water lens proportional to the rising of sea level. However, if land is lost due to the rising in sea level, then water lens will shrink and reduce from its original size. Rising sea level can also cause inundation of low-lying areas, which can increase salinity of thin water lens of these areas.	*Salt-water intrusion will reduce the quantity and quality of potable freshwater. *Land loss will reduce the size of the freshwater lens hence reducing the availability of potable freshwater.	
Socio-economic factor **Population growth** Increases in population will have a direct impact on water resources in two main ways. Firstly, there will be the increasingly demand for fresh water and secondly, there will be an increased threat of contamination to groundwater resources. The population of Lifuka is estimated to be 2850	*Increase in population growth will increase demand for water consumption. *Pollution of groundwater makes it unsafe and unhygienic for	

(Furness and Helu, 1993) and it is expected to be increased by the year 2050 and 2100 respectively, so the need for a properly managed of water supply system cannot be understated. It is estimated that the present demand for water is 100 liters/capita/day and will be expected to increase by year 2050 and 2100 respectively.	drinking purposes.	

Table 4.7: Anticipated Climate Change and Sea Level Rise Impacts on Water Resources in Urban Areas

Impacts/ Climate Change Factor	Implications	Areas affected
Decreased Rainfall * The projected rainfall scenario adopted for this analysis was then incorporated into the 55-year rainfall data and run through the recharge model to analyse the impact on annual recharge to groundwater. The impact of 10.9% and 17.5% reduction in rainfall is very significant. By the year 2050, if the mean annual recharge be reduced by 10.9% (from 524mm to 377mm), the net recharge will be reduced by 28%. By contrast, in year 2100 17.5% reduction will reduce recharge from 524 mm to 295 mm a net reduction of approximately 44%.	*Reduction in recharge to groundwater means reduction in potable water supply for use in urban areas	Water Resources for survival. Health sector and comminity Slows down economic development (Economy)
Increased Rainfall *Increase the incidence of flooding *Temporary increase in water supply *Increase surface runoff & sedimentations/siltations	*disrupt sanitation system * enhance breeding places for insect vectors such as mosquito * Increase severity and frequency of diarrhoeal diseases when sanitation sytem are disrupted	Health sector and community
Sea level Rise *The projected sea level rise of 0.32 m (2050) and 0.88 m (2100) in Table 4.2.2 does not have a significant effect on the magnitude (thickness and volume) of island freshwater lenses except if land is lost by inundation in a much larger scale than what has been projected. If the effective recharge zone is not lost or reduced, then a rise in mean sea level (MSL) will be reflected by a matching rise in mean groundwater level. The thickness and hence volume of the freshwater lens will not change significantly if all other factors (mainly recharge patterns) remain the same. The recent inundation of land at Kanokupolu and overtopping of land with seawater through storm surges during Hurricane Isaac in 1982 is the last good example. If rising sea level causes land to be inundated, then there will be a consequent loss in potential area for fresh groundwater occurrence.	*Inundation and land loss will reduce the size of freshwater lens hence reducing the water quantity and quality of water resources in urban areas *overcrowding and deterioration in living conditions *disruption of sewage, sanitation and water supply infrastructure through flooding *increase proximity of freshwater lens to the land surface and pollutants	Agriculture and reduce effective recharge area Water resources Water Resources Community and Health sector Water Resources

Increase Temperature *The results in Table 4.2.3 show that the impacts of potential evaporation increases changes on recharge are not highly significant. For instance, if mean annual evapotranspiration were increased by 20% (from 1,461 mm to 1,753 mm), the recharge would potentially reduce from 524 mm to only 406 mm, a net reduction of about 22%. As with rainfall, the effects are non-linear. The effects of decreased evaporation were not studied quantitatively at this stage but similar percentage changes to recharge could be expected to the results of increased evapotranspiration.	*enhance breeding of mosquito and other insect vectors which will help for the transmission of water related infections *Heat stress and other direct implications will cause death *increase water demand for cooling etc	Health sector and community Health sector and community Water Resources
Socio-economic factor (Population growth) An increase in populations are likely to place a severe strain on the resource base of urban areas of Tonga given that all urban area is already close to its carrying capacity. These changes will be of particular concern in urban areas of Tonga. Increases in population on already densely populated urban areas will have a direct impact on water resources in two main ways. Firstly, there will be the additional need for freshwater and secondly, there is an increased threat of contamination of groundwater resources due to additional human settlements and occupation of effective recharge area.	*increased threat of contamination of groundwater resources due to additional human settlements and occupation of effective recharge area.	Health sector and Economic Development Water Resources
Economic growth and changes in housing and infrastructure * Increases in the cash economy and improvements in housing may lead to increases in water consuming appliances such as washing machines and possibly dishwashers. * intensification of industrial and commercial development and related infrastructure in Nuku'alofa and other urban areas, with possible spreading of such development to East, South and West. Depending on the type of industries and commercial activities there may be a significant increase in water demand from these sectors. * Clearing of vegetation, particularly coconut trees from existing land for future housing and other infrastructure development will tend to increase recharge to groundwater, as evapotranspiration will tend to decrease. Conversely, interception by roofs for rainwater storage would tend to lower recharge. Any additional recharge would increase the potential yield of existing freshwater lenses underlying future housing areas.	* Increase in water demand Decrease quality of drinking water (salination) *Increase in water demand Decrease quality of drinking water (salination) *Increase in recharge to groundwater as evapotranspiration tend to decrease * Lower recharge if interception by rainwater storage increase	Water resources and Economic Development. Water resources and Economic Development. Increase sustainable yield of Water Resources Slow down economic development

Table 4.8: Anticipated Climate Change and Sea Level Rise Impacts on Forestry and Agricultural Sectors

Impacts	Implications	Areas affected
Decreased Rainfall Periods of low rainfall are likely to be associated with prolonged dry periods	*Loss of soil moisture *Dry periods/drought will cause heat stress on plants, crops *weakened crops prone to pests *Reduced crop yield *Threat to food security	*Throughout agricultural sector/farming systems in Tonga
Increased Rainfall *flooding of agricultural land areas especially on low lying areas *reduced sunshine hours/amount of sunlight for plants photosynthesis *increase of pests life cycle *loss of soil nutrients *excessive soil erosion	*increase of agricultural pests *damage to crops *reduce crops yield *threat to food security	
Sea Level Rise Tonga being a small island state is at great risk from projected impacts of climate changes, particularly sea-level rise. *Increasing soil salinity as caused by sea level rise. *Rise in sea level will lead to land loss. By the year 2100, it is estimated that with a 1m sea level rise, 10.3 km² of land in Tongatapu island would be lost (Mimura and Prescott, 1997). This figure will increase to 37.3 km² (14% of the land area) with storm surges superimposed on the 1m sea level rise.	*Reduction of crop yield *Threat to food security E.g. Increasing soil salinity of volcanic ash soils to 4ds/cm can kill crops like cassava, pawpaw, and yams. When soil salinity in volcanic ash soils is increase to 8ds/cm, only coconut, taro, and tannia were found to be salt tolerant. The impacts of climatic change on crop productivity are more marked on coralline soils. Under inundation condition, the productivity of most crops except coconuts, tannia, and taro are negatively affected. Root crops like cassava and yams are killed by salinity of 6ds/cm.	* The vulnerable areas likely to be affected by climatic changes are coastal areas. These are areas that will be affected by the sea level rise scenario. By the year 2100,it is estimated that 10 km² will be lost if there will be a 1m sea level rise and in 1 every four years storm surges will inundate and flood up to 37 km² of land. In a normal sea level rise phenomenon, most of the affected areas will be coralline soils but when storm surges are superimposed then substantial areas of volcanic ash soils will also be affected, taking the affected areas to about 15% of land area of Tongatapu. Most of the economic infrastructures, residences and some farmlands are located in the vulnerable areas. The capital town of Nuku'alofa sits in the vulnerable areas and large residential areas in the Central and Western districts. The low coral islands, inhabited and uninhabited are also included in the vulnerable areas.
Increased Temperature *Loss of soil moisture *Increasing life cycles will increase agricultural pests	*Increased temperature will reduce productivity of cool crops such as Irish potato and other cool European vegetables like cabbages, tomato, etc.	It is estimated that over 50% of the population of Tonga live in these vulnerable areas. Many of the tourism scenic sites are also located in these vulnerable sites.

Tropical Cyclonic Activity *Destruction to crops	*Reduction in crop productivity *Threat to food security	

Table 4.9: Anticipated Climate Change and Sea Level Rise Impacts on Coastal Area

Impacts on Coral Reefs, Mangroves & Beaches	Implications	Areas affected
Increased Temperature and Reduced Light Intensity Coral Reefs are very sensitive to changes in temperature and light intensity. Temperature increase and reduction in light intensity will result in *increased coralbleaching and mortality *death of reef species	*destruction of habitats of some marine species *reduction in diversity of marine species in coral reefs *threat to the survival of eco-tourism and fisheries sectors *Land loss particularly coastal areas due to grater exposure of the shoreline to wave action	Areas currently below 2m above mean sea level, will surely be affected by 2050. As indicated by the vulnerability study in 1992, (Mimura, Hori & Prescott) 3.9% of the total land area of Tongatapu Island, that is 10.3km^2 where 2.2km^2 are residential areas, is below 2m above mean sea level. Even though sea level may only rise by 5.0-32.0cm, but a gradual rise of 4mm/yr can have great influences on the coastal processes, hence great-unforeseen influences on coastal erosion.
Tropical Cyclonic Activity *increased coral reef destruction	*same as increased temperature & reduced light intensity	Coastal erosion is one of the major contributors to inundation in most places, at the same time, inundation can accelerate coastal erosion, thus where inundation occurs, coastal erosion is most severe as evident at Kanokupolu. The potency of coastal erosions are often overlooked until extreme damages has already passed, thus erosional processes need to be considered. Therefore, the predicted inundated area by 2050 might well be even higher than stated above.
Sea Level Rise *Inundation of mangroves *Increased instability of the coasts through shoreline erosion *Beach erosion and beach loss, loss of coastal vegetation due to erosion and inundation	*reduce acreage of mangroves *reduce resilience to storm surge and sea level rise *coastal land loss *increased exposure of coastal vegetation to salination and sea salt spray *destruction to marine species habitat leading to decline in marine species diversity	

Table 4.10: Anticipated Climate Change and Sea Level Rise Impacts on Fisheries Sector

Impacts	Implications	Areas affected
Increased Temperature *coral bleaching and mortality *inundation of mangroves	*reduction in the extent of coral reefs and increased mortality among marine species	Throughout the island groups, Tonga

	*reduction in the acreage of mangroves & increased mortality among marine species	
Sea level rise *coral bleaching & mortality *inundation of mangroves	*reduction in fish catch rate *loss of income and livelihood of local fishermen *declination in export of fish and other marine resources *negatively influenced Tonga's economy	Throughout the island groups, Tonga

Table 4.11: Anticipated Climate Change Impacts on Human Health

Impacts	Implications	Areas affected
Increased Temperature *heat stress *enhance breeding of mosquitoes hence increase the incidence of dengue fever	*Heat stress and other direct implications will cause death. *Dengue fever will lead to death	*Throughout Tonga
Decreased Rainfall *reduce water availability and water quality	*Exacerbate problems of sanitation and hygiene *Increase incidence of diarrhoel diseases *increase incidence of asthma & other diseases due to drier atmospheric conditions *reduced food productivity may lead to food shortage & possibly malnutrition	*Throughout Tonga
Increased rainfall *Increase rainfall may enhance breeding places for insect vectors such as mosquito.	*Increase the incidence of water and food borne diseases *Increase transmission of vector borne diseases e.g. dengue fever *Increase the incidence of diarrhoel diseases	*Throughout Tonga
Tropical Cyclonic Activity *fatal death and injuries *loss in food production *damage to water supply systems *overcrowding	*in extreme events cause injuries and death *reduce food productivity may lead to food shortage and possibly malnutrition *contamination of existing water supply leading to water borne diseases *destruction of properties will enhance overcrowded *incidence of respiratory diseases may increase *increase rate of influenza	*Throughout Tonga
Sea level rise *loss of properties/poor housing *reduce volume of potable freshwater resources.	*overcrowded may lead to an increase of respiratory diseases. *leads to dehydration; diarrhoel diseases	

4.8 CONCLUSION

Findings from various sectoral assessments clearly indicate the detrimental effects (environmental and socio-economic effects) of climate change and sea level rise in Tonga.

Immediate and appropriate actions by the government and people of Tonga are highly recommended to minimize the disastrous effects of climate change and sea level rise.

Chapter 5: ADAPTATION OPTIONS

5.1. INTRODUCTION

The magnitude of the potential impacts of climate change, sea level rise and climate variability in Tonga and the Pacific are serious that actions must be taken now even when all the facts/ information are not available yet in-order to manage and mitigate these risks.

There are many strategies that can be undertaken to reduce and mitigate the risk of climate change, sea level rise and climate variability, a number of adaptation strategies have "no–regrets"(win-win) implication for social and economic development and justified even in the absence of climate change, sea level rise and climate variability issues.

Development of new methodologies coupled with standardize techniques has assisted the Tonga Government assess the impacts of regional, global and national environmental changes, including climate change, sea level rise and variability to facilitate and implement adaptation measures/policies and the benefits that they can provide are discussed here and include:

Using the vulnerability and adaptation assessments reports, the following sectors; Coastal areas, Fisheries Resources, Agriculture and Forestry, Water Resources and Health were considered priority for Tongan Government and discussed here with the view of developing Tonga Adaptation strategy.

5.2 COASTAL AREAS

It is appropriate to state that all exposure units described here are vulnerable or will have difficulties adapting to climate change, variability and sea level rise. It will also be safe to mention that the public are aware of climatic changes and vaguely what to do in order to adapt, however the fiscal side will always be in the way of things.

Low-lying areas, both in reef and lagoon adjacent communities are facing coastal inundation with rising water table, tidal flooding and coastal erosion. Where the only secure adaptation measure is reclamation using crushed limestone, which has financial implications. Some communities with resources may move to higher grounds to adapt in the face of the climate and environmental changes. Others have migrated to other islands as an adaptation option, which often have other health related, social and environmental challenges.

The following are some of the important adaptation options that were identified in the coastal areas and discussed:

5.2.1. Coastal Protection Systems.

This area covers the following:

Foreshore Protection Infrastructure against Rising Sea Level and Extreme Events

A long lasting and effective foreshore protection seawall similar to the present Nuku'alofa foreshore protection would minimize and probably eliminate the flooding of other low-lying areas with important infrastructures or properties that are exposed to med-high energy waves. Villages or areas with immediate needs of protection are shorelines of Kanokupolu-Ha'akili-'Ahau, Nukuleka-Talafo'ou-Navutoka-Manuka, East of Sopu and Siesia at Nukunukumotu Island and Atata Island.

The Nukuleka-Talafo'ou-Navutoka-Manuka areas already had protection seawalls in placed since the early 1980's by the Tonga Government via the Ministry of Works, and it now need to be redesigned and reconstructed. The present almost vertical, ~1-2m thick and ~1m high seawall needs to be thickened and heightened to match the current stronger Nuku'alofa Protection Foreshore.

Although this proposed measure may be regarded as *very expensive* but one huge spending can equal several ineffective attempts.

Plate 5.1. *The Coastal Protection Wall at Nuku'alofa Waterfront*

Land Reclamation against Rising Sea Level

The most common counter measure undertaken by people living in low lying zones less than 1m above sea level against inundation is reclaiming of land. Land reclamation is more common along lagoonal adjacent areas, where the depth to be reclaimed is shallower and cheaper to reclaim or probably truer in many cases, landowners with deeper pockets. The lagoonal adjacent areas are however not prone to waves so much as adjacent reef coastlines are. Nevertheless are facing tidal inundation and thus need serious reclamation. Crushed limestone aggregates are probably the best recommended infilling or reclamation material. It has proven more effective than other identified available materials with no damaging side effects.

Where reclamation along reef coastlines are more risky, still The Ministry of Works are now conducting adaptation measures at the adjacent shorelines of Kanokupolu. Mounts of coral rubbles to sub-impermeable mud-clay sediments are being dredged ~120m adjacent from the current shoreline, and piled along the shoreline, for purpose of reclaiming the original shorelines of the 1950's. In doing so, will close up the open channel ways, and eliminate further flooding occurrences. The reef flat sediments should also be included as infilling materials within the inland depression from the resultant drainage system of the lagoon. This artificial shoreline will prograde up to 30 metres seaward at places and also to elevate these areas 1.5-2.0 metres above sea level. The resultant deeper flanking reef flat is assumed it will minimize wave energy on the shoreline. Re-vegetating the area will also contribute to the stability of this measure.

Siesia settlement on Nukunukumotu Island needs similar measures as for the Kanokupolu area as it faces the same flooding problems. The town officer of Siesia claimed to have reported this issue on several occasions since the 1980's but has not been considered due to unknown reasons.

Island resorts such as 'Atata, Pangaimotu, Makaha'a, etc. have been reported on coastal erosions, but there yet to be any measures appropriate or taken to at the same time sustain the original natural attractiveness of these islands. Thus there is still need for further studies of these sights before strategies can be recommended.

Coastal Replantation & Revegetation

One of the on-going counter-measures against coastal erosion is re-vegetation. This is mainly planting various coastal plant species along coastlines with important infrastructures such as roads and house, etc. This measure is undertaken by most communities particularly those that are settling within affected zones. Some communities work independently and others are given a hand by foreign aids via the Department of Environment or NGO's such as TANGO.

Revegetation often fails when plants don't grow at places from increasing salinity and also humans and animals (pigs in most cases) interactions. People claim that they only cut down planted trees where they're dead. Isolating these critical areas with dead trees can however still serve a purpose and not just good firewood.

Eliminate Onshore Sand-Mining

Sand Aggregates for construction purposes is forever increasing in demand since the restriction on onshore sand mining to just one beach during the first half of 2002. This also minimised the amount of sand permitted to any buyer to just 5 tonnes, but had no effect on the amount of sand permitted for funeral burial purposes, which is 5 tonnes of free sand.

The restriction on beach sand mining however does not eliminate illegal mining, which is ever increasing with an average of 80 tonnes per week. With all these issues on onshore sand-mining, there is yet to be any solid actions taken by the government. There have been several written reports and proposals submitted to the Central Planning Department, Nuku'alofa to find funding for a dredger and machineries in order to carry out offshore sand-mining but no positive outcomes yet received.

Fencing Domestic Animals

Domestic animals have also been identified as one of the contributors to accelerated coastal erosion. Traces of several activities indicate the damaging behaviour of horses, cows, goats, dogs and predominantly pigs. Domesticated pig's activities have been far the most uncontrolled amongst other domesticated animals. Their daily search of food within the sub-tidal zones leads to coastal deterioration. Fencing wandering animals can minimize coastal flooding via trampling tracks, which can initialize channel ways, etc.

Easy as this measure may appear, the idea stands against the cultural belief of many locals. To let domesticated pigs wander is believed by many owners to add weight to their pigs. To act against the people's cultural beliefs is as difficult as to break a rock with your bare hands.

5.2.2. Review and Assess Coastal Protection Systems Employed in the Country

The vulnerability and adaptation assessment throughout the country and on the various sectors have identified numerous coastal protection system employed in the country. These are soft and hard coastal protection systems used with success and failures. In terms of mitigation and adaptation to these climate change, sea level rise, climate variability and extreme events, the need to review and assess the coastal protection used is important for coastal management planning and environmental sustainability.

5.2.3. Integrated Coral Management Plan

The number of live coral exporters should be controlled to minimize the chances of overexploiting this critical natural protective resource and feeding place of not only marine life in the sea but also terrestrial beings.

The Ministry of Lands, Survey and Natural Resources, should be assigned the task to monitor coral extraction activities. Coral extractions should be inspected by the assigned ministry on a regular basis and supervised, that it is carried out in a sustainable manner.

5.2.4. Policy Development- Laws and Enforcements

In order to achieve a sustainable modern coastal environment, the above stated measures need to be enforced and laws should be revised and amended to somehow penalise the offender immediately when caught in the act.

A good example in lack of enforcement is in the field of illegal beach sand-mining. Several people have been charged with illegal mining, though a few people get away with it.

This is probably the main weakness in enforcement because it is almost against the culture to charge or penalize a person that is with higher status in the society and well known in the community.

5.3 FISHERIES

Several management strategies for minimizing the adverse effects of climate change on marine resources have been proposed. These measures, many of which already are being implemented including conservation, restoration, and enhancement of habitats such as mangroves and coral reefs as well as some species such as giant clam and trochus. In addition, establishment and management of marine reserves and protected areas for identified critical species and implementation of bilateral and multilateral agreements and protocols for exploitation and management of shared stocks such tuna are also part of the endeavor to take adaptation strategies for climate change. Aquaculture also may be considered as another means of reducing stress on wild stocks. However, great precaution must be taken to ensure that this measure does not exacerbate existing problems of habitat loss and competition for nutrients.

Although good progress has been made in understanding the vulnerability and adaptation potential of small island states to climate change, the foregoing discussion highlights critical information gaps and uncertainties that still exist. Purely from smaller rural islands perspective in the Tonga group, there is still very little knowledge or awareness about climate change and sea level rise and the potential impacts on their livelihood. Rural village people do recognized various changes in nature but there are not aware or know what is climate change and its link to various changes that occurred. The agendas set out below therefore is designed not only to fill existing gaps but also to help identify opportunities for minimizing the adverse effects of climate change (including avoidance of mal-adaptation), as an important component of adaptation planning in Tonga.

Public Awareness

The general public/community by enlarge should be well informed about the concept of climate change and its potential impacts on marine resources and the livelihood of the people. This can be done in many ways which will develop a broader understanding to the people of what is happening to our climate and its impacts on the environment and marine resources. In simple ways, develop practical ways for people to slowly adapt in practicing environment friendly practices in everyday life. Reach out to community people and educate them to understand why we need to preserve marine habitats and species that are more vulnerable to climate change. Inform the public about the time scale of climate change, understand sign of changes and what to do in order to adapt to those changes.

Monitoring Changes

In order to monitor and identify changes cause by climate change on marine fisheries resources, there is a great need to keep tract of the pattern of various climatic variables in relation to changes in the environment and abundance, growth, reproduction, mortality, distribution, diversity and behaviour of marine species and habitats. This type of assessment require personnel that are well equipped with appropriate skills and experiences for this type of work and be able to carry out analysis and interpretation of results. This is an area where there is a great need here in Tonga, the training of appropriate personnel to fully understand the whole concept of climate change and all interacting factors in population biology or stock assessment with oceanographic skills and translate the information into understandable grass root level.

Proper and accurate monitoring processes always require appropriate instruments and equipment, which are always lack in small island state like Tonga. Powerful and fast Internet connection is required in order to access to various source of good information provided by various agencies through the Internet. A lot of satellite images of various oceanographic variables required for assessing and predicting the pattern of climate change and its potential impacts on marine resources can be obtained directly from various resources through Internet.

There are other specific instruments/equipment that may need to carry out the monitoring which will be identified or modified as the monitoring process is in progress. Equipment such as salinity & DO meter, nutrients analysis instruments, current meter, etc. are some of those that will be needed for assessment and monitoring process.

Computer skills in creating database for data collection and analysis with modeling potential is a relevant training area for those that have some understanding of climate change concept and marine biological science. This is enable personnel to maintain the continuity of data collection, analysis and interpretation and make appropriate prediction of potential impacts of climate change on marine resources taking into consideration all climatic and non-climatic relating factors and variables to reduce the uncertainty of forecast.

Legislation and Regulation

Develop a legal framework and in-cooporate all climate change phenomenon to build sound sustainable development policy for marine sector and its inter-acting stakeholders.

5.4. AGRICULTURE

The impact considerations as discussed in the vulnerability assessment and community discussions have helped us to focus on developing adaptive strategies for this sector and are discussed:

5.4.1. Adaptation Potential for the Agricultural sector

Public Awareness

It is important to train and educate farming communities and the public in climatic change and its potential impacts on our life. Improved training and general education of populations dependent on agriculture should also be conducted. Agronomic experts can provide guidance on possible strategies and technologies that may be effective. Farmers must evaluate and compare these options to find those appropriate to their needs and the circumstances of their farm.

Transfer of Technology and Knowledge

Technological options with promise for adapting to climate change are:

- ***Introduction of Salt Tolerant Species**:* Increased soil salinity will be the most important agricultural problem in the vulnerable areas. Salt tolerant varieties of current crops should be sourced; otherwise new salt tolerant crops should be introduced.
- ***Introduction of Heat and Tolerant Crops:*** The current sources of vegetables for Tongans are mostly European cool vegetables like cabbages, tomatoes, potatoes, etc. With the expected temperature increases as part of the climate change phenomenon, there is a need to introduce heat and tolerant vegetable crops both for domestic consumption and export potentials.
- ***Improved Pest and Disease Management:*** The predicted climate change phenomenon will create a new pest and disease regime, and therefore the need to develop improved pest and disease management program.
- ***Crop Research**:* There is a need also to invest on agricultural research aiming at developing crop management strategies for the proposed climate change.
- ***Restoration of Degraded Lands:*** Sea level rise will result in land degradation implies that there should also be a degraded land restoration policy to restore lands for purposes including agriculture.
- ***Farm Relocation:*** Sea level will flood and inundate some of the farmlands. These farms should be relocated to places fit for farming.
- ***Agricultural Diversification**:* Government should be ready with an agricultural diversification plan for vulnerable areas. These should include potential non-agricultural developments better fitted to the predicted conditions of the vulnerable areas.

5.5. FORESTRY SECTOR

Under the forestry sector these are some important options:

Public Awareness

The farming communities and the public should be educated in the role of trees and the impacts of felling trees in the farms and at the coastal areas and its contribution to climate change. Public awareness should also include promotion of land use policy and legislation.

Land Use Policy

The existing land use policies should be reviewed with the intention of developing and enforcing a more appropriate policy. The policy should accommodate appropriate aspects of the climate change.

Legislation and Regulation

The existing forestry legislation and regulations should be reviewed and if any aspects found inappropriate should be amended. The climate change phenomenon should be considered in developing appropriate legislation.

Reforestation

A reforestation program should be developed to replant the coconuts and trees felled by farmers in their pursuit for cash benefits.

Promotion of Agroforestry

Many of the current farming systems problems are related to roles of trees. It is therefore essential to revert farming systems to traditional agroforestry systems but with modifications addressing environmental shortfalls of the systems.

5.6. HUMAN HEALTH

The following options have been identified as potential that can facilitate adequate adaptation to climate change and sea level rise in the heath sector:

- Research is needed including developing innovative approaches to analysis weather and climate in relation to human health, and improving understanding of how to incorporate outputs from Global climate models into human studies.
- Emphasize the importance of reduction of greenhouse effects by means of conducting awareness programs and training workshops.
- A standardize health impact assessment procedures, tools and methods are being developed however a qualified person required to do this task.
- Adaptation policies required to complement mitigating policies – Efficient implementation of adaptation strategies could significantly reduce adverse health impacts.

- Limited knowledge on climate impacts on health, a national awareness programs should be addressed.
- Monitoring climate impacts on human health – require data gathering coupled with analytical consideration.
- Insufficient staff to undertake research on such field – Recruitment of new qualified staff, or otherwise, one Public health Inspector be trained on research**:**
    - » Research on climatic impacts on human health;
    - » Establish and strengthen data collecting system and recording system in the Ministry;
    - » Develop awareness programs for communities, schools, and churches;
    - » Advocate for clean healthy environment and waste disposal plus eradication of breeding habitats for vector pathogens.

Future challenges for the Environmental Health Section of the Ministry of Health are as follows:

- Strengthen policies, national plans of action and government agency partnership;
- Implementation of multisectoral climatic awareness and assessment procedures by competent authorities;
- Promote national training & local workshops on potential impacts and minimization of potential effects.

5.7. WATER RESOURCES

There are number of adaptation options and strategies that can be considered to cope with possible future impacts of climate change and sea lever rise on water resources. The options considered here deal with water issues in the country and linked to economic efficiency and environmental benefits, cultural and social suitability and practicability considerations.

Adaptation options identified and discussed are cover water resources in the outer islands and large islands of Tonga and include:

5.7. 1. Demand Management Measures

In the short term, demand management measures are generally more cost effective than alternative source development. By reducing the demand for water or by ensuring more effective use of existing sources, there will be less pressure on limited water resources.

Leakage Control

Leak detection control work is a necessary ongoing activity as part of the water supply system management. It will reduce the amount of unnecessary water loss.

Consumer Education and Awareness

There is an ongoing and increasing need for effective community education and awareness about water resource issues. This is not specifically related to possible impacts of climate change on water resources. The issue of climate change can be addressed along with the many other factors that impact on sustainable water resources management.

The need for water conservation is above all a community issue. Only with the support and participation of the community at large, especially women and children, will the small islands be able to reduce wastage and move towards sustainable development of their freshwater resources. Appropriate community information and education in this regard are most important and can be provided through public meetings, school presentations, TV program and radio broadcasts. It is essential that governments and water agencies recognise the need for community participation in water resources conservation, planning and management in order to preserve freshwater resources for future generations on small islands.

Price Policy

Urban centers like Nuku'alofa where public water is supplied to the consumer, a pricing policy has been developed as an effective way of managing demand to include low-income earners and others.

Water Conservation Plumbing Measures

A number of practical measures can be employed to conserve water usage. These include spring-loaded taps and low flow shower roses. Seawater could be used in flush toilets instead of freshwater in order to save limited freshwater resources.

5.7.2. Alternative Water Supply Methods

In the short, medium and long term, there are a number of adaptation options aimed at developing additional or supplementary freshwater resources, or maximising the use of currently available resources. These are described in some detail below.

Expansion of Rainwater Collection Schemes

These measures obviously add additional construction costs but as a long-term strategy they provide a means of 'drought proofing' to cater for future droughts especially on islands relying on rainwater as a major source of water supply.

Groundwater Protection Measures

Several measures are available to protect groundwater from contamination whether from seawater intrusion or biological and/or chemical pollution.

i) Land Use Planning and Water Reserves

Effective land use planning and management is most important for the protection of water resources from contamination. This is particularly important on coral islands with highly permeable soils and shallow water tables where groundwater is very susceptible to pollution. Water reserves or 'groundwater protection zones' should be established and land use regulated where potential freshwater resources exist for future use. This will require negotiation between government and private landowners and agreement on appropriate administrative, legal and financial conditions.

ii) Non-polluting Sanitation Systems

Composting toilets can act to protect fresh groundwater, and have been the subject of trials in recent years on a number of Pacific islands. These trials were conducted to assess the physical, biological and cultural acceptability of this relatively simple technology. The advantages of appropriately designed composting toilets are: simple construction; protection of groundwater (under the village areas); water conservation (as no flushing water is required); and production of a useful agricultural fertilizer.

iii) Dry Sanitation Systems

Dry sanitation systems can be used which does not use water for flushing, transport or treatment, which saves considerable quantities of water. Dry sanitation also avoids the considerable water loss through leaking toilet cisterns.

iv) Coastal management and protection

Measures to protect coastal areas on small islands are an important component in the long-term sustainable management of islands, including the water resources. If island margins are eroded the area available for freshwater lens occurrence may be diminished.

Desalination

Desalination is a relatively expensive and complex method of obtaining freshwater for small islands. The cost of producing desalinated water is almost invariably higher than ‘conventional’ options (e.g. pumping of groundwater) due to the high-energy costs and other operating costs. In extreme cases where other water resources are exhausted it may be a necessary source of freshwater.

For operational reasons, desalination technology has not been successful in some small islands and the desalination plants have been removed or lie idle. Common problems have been insufficient filtering of feed water, intermittent power supplies and insufficiently trained operator.

At present, desalination should be considered only when more conventional water sources are non-existent, fully utilised or more expensive to develop. Trained operators and a dependable source of supply for chemicals and replacement parts are essential for reliable operation.

Importation of Water

Importation of water from other country is one of the last options mainly due to very high cost involving therefore it is not recommended to the outer islands.

Emigration

If all other adaptation measures were exhausted, emigration of people most at risk to larger and higher countries could be undertaken as a last resort.

5.8. CONCLUSION

Since Tonga is one of the vulnerable countries to climate change and sea level rise, there is an urgent need to put the aforesaid adaptation strategies into actions or else Tonga will continue to suffer in silence from the ongoing and increasingly disastrous and unbearable impacts of climate change and sea level rise.

Chapter 6: GENERAL DESCRIPTION OF STEPS TAKEN

Greenhouse Gas Abatement Training

Greenhouse Gas Inventory Training

School Visitation

School Visitation

Community Training

Community Training

6.1. INTRODUCTION

The UNFCCC Article 12.1(b) requires that Parties to the Convention provide a general description of steps in the implementation thereof the Kingdom of Tonga has undertaken a number of activities in fulfillment of its obligations under the Convention.

6.2. POLICY FRAMEWORK

Currently, there is no climate change policy but it is now driven under the CCEAP to get the Government of Tonga's approval in developing one. This has to be mainstreamed into sectoral and the National Strategic Development Plan.

6.3. SYSTEMATIC OBSERVATION AND RESEARCH

The Meteorological Office is headquartered at Nuku'alofa, the capital and it is the center of Tonga's climate observation system. Its functions include the systematic collection of meteorological data for the island, providing weather related information for the aviation, shipping purposes and also providing weather forecasts to the general public. It is also the official source of information on cyclonic events during the hurricane season. In this regard, it is a critical component of the national emergency management system. In addition, the meteorological office also collects data on a number of climatic parameters such as rainfall, temperature, atmospheric pressure and wind speed and direction. Climatic records dated back since 1945. Recently the work of the office had been assisted by the installation of a tidal gauge, which monitors, *inter alia*, air temperature, tidal data, wind speed and wind direction.

With respect to the monitoring of water resources, the Ministry of Lands, Survey and Natural Resources, Ministry of Health and Tonga Water Board are responsible. The Ministry of Lands, Survey & Natural Resources is also involved in monitoring of beach profiles whilst the Department of Environment also undertakes work on coral reef monitoring in collaboration with other relevant government ministries.

6.4. CAPACITY BUILDING

In order for Tonga to effectively address climate change issues, it must develop the necessary institutional capacity. In addition, national capacity is built and enhanced through direct involvement in various climate change related training and education. Further, conducting of different sorts of climate change awareness programs, producing and distributing of climate change materials will assist not only with sharing and disseminating of information but also raising the awareness of the general public about climate change and its detrimental effects in Tonga.

Training and Education

Under this programme of climate change enabling activities, a number of nationals have received trainings in:

- Inventory of Greenhouse Gases
- Greenhouse Gas Mitigation/abatement
- Vulnerability and Adaptation Assessment
- Preparation of National Communication
- Design website for climate change in Tonga

← Inventory of Greenhouse Gases Training

Greenhouse Gas abatement Training →

← Vulnerability and Adaptation Assessment Training

Preparation of National Communication Training→

Nationals also participated in other climate change related trainings and education including:

- Sea level monitoring training conducted in cooperation with the University of Flinders, AUSTRALIA and University of the South Pacific, FIJI. Officers from the MLS&NR, DoE and Meteorological at MCA took part in this training.
- Monitoring training in water quality, coral reef identification and coverage, seagrass identification, identification and sampling techniques carried out in various locations in Tongatapu & Vavau. Officers from TVB, DoE, MoW, MoH, TWB and MoF participated in this in-country training.

For educational purposes:

- The Environment Resource Information Center (ERIC) at the Department of Environment, which contains information on climate change, was established.
- Climate change issues were introduced into the local school curriculum and also used as one of the major topic in student's research project, which is a part of the school's internal assessment.

Useful expertise has been acquired through the preparation of Tonga's Initial National Communication, the inventory of greenhouse gases, the analysis of mitigation options, the development of adaptation policy, the assessment of vulnerability and adaptation options, the designing of a climate change website and the involvement in regional and international climate change related training.

Technical capacity at the national level has been also enhanced in various areas. Climate and Sea level Monitoring Project funded by the Australian Government has provided computers and other equipment for government agencies that are directly involved with climate change activities such as monitoring of sea level. Tide gauge and Global Positioning System were installed & funded by this project.

The implementation of this climate change enabling activity project has resulted in the designation of the Department of Environment as the Operational and Political Focal Point for all climate change activities. This has also led to the establishment of the project's National Coordinating Committee, Technical Working Group and the Management Unit.

Communication and Awareness

Various mechanisms whereby climate change information is disseminated and shared throughout Tonga are highlighted hereunder. These will raise awareness of the public regarding climate change, its causes, its adverse impacts, and potential measures to mitigate and adequately adapt to these negative effects.

Since 2002, a number of climate change awareness programs have been conducted throughout the Kingdom of Tonga. These programs include radio and television programs, school visitation, community workshops and consultations, establishment of Tonga's climate change website, production of climate change awareness materials and also presentation to project stakeholders and National Coordinating Committee of the climate change enabling activity project.

Radio Programs

The Department of Environment airs fortnightly radio programs including climate change programs and other environmental programs that relate to climate change.

Apart from this two weeks radio programs, the project also conducted its own radio programs.

Television Programs

National consultants, members of the Technical Working Group and also senior staff members of the Department of Environment have also taken part in panel discussions of climate change issues on television.

A climate change documentary was developed and televised as well.

←Tupou High School (Vaololoa Branch), Tongatapu

Ha'apai High School, Ha'apai→

School Visitation

Twenty secondary schools and colleges in Tongatapu, Vava'u and Ha'apai were visited. Climate change awareness was also conducted for teachers in Primary, Secondary schools and Teachers Training College in these three island groups.

Saineha High School, Vava'u→

←Principals and teachers, Government Primary Schools, Vava'u

Community workshops and consultation

Workshops and consultations were carried out throughout the island kingdom including Tongatapu, Vava'u & Ha'apai. Town and district officers also members from these towns and districts were participated. Seven districts in Tongatapu, six districts in Vava'u and three districts in Ha'apai joined these workshops.

← Workshop in Ha'apai, officially opened by the Governor of Ha'apai

Workshop in Vava'u, officially opened by the Governor of Vava'u →

← Workshop held for the Eastern district, Tongatapu

Workshop held for the Western District, Tongatapu→

Establishment of the climate change website (http://www.tonfon.to/tccp)

In March 2003, Tonga's climate change website was established.

Climate change awareness materials

Materials including factsheets, posters, brochures (both English & Tongan languages), video films (documentary and panels on television) were distributed to project stakeholders (government, NGOs, statutory board), schools, colleges throughout Tonga.

Presentation to project stakeholders & the National Coordinating Committee of the climate change enabling activity project

Various findings of the project were presented to the stakeholders and National Coordinating Committee comprising the Heads of government ministries and departments, NGOs and statutory board. This has further built stakeholders awareness, interest and involvement. A great deal of support has been obtained from these stakeholders.

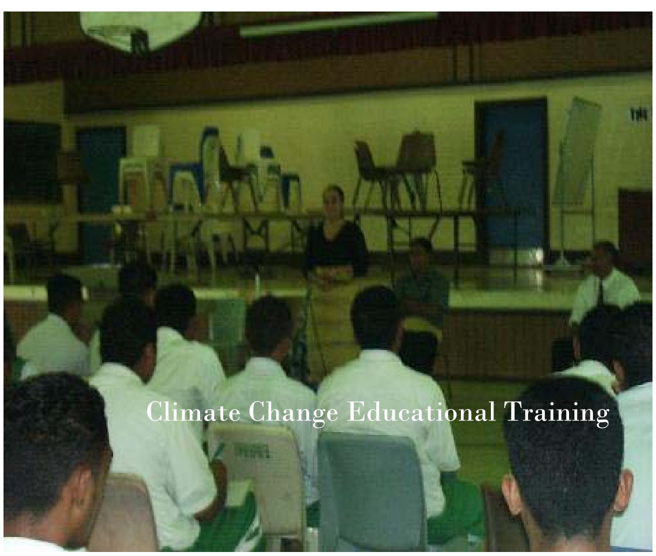
Chapter 7: NATIONAL RESPONSE TO CLIMATE CHANGE


Training and Awareness


Training and Awareness


Promote Climate Change Awareness


Community Training and Awareness


Climate Change Educational Training


Community Training and Awareness

Mission Statement:

Climate change is realized as a national issue that requires timely and committed initiatives by government to develop capacity to address the existing and potential adverse effects on the livelihood of Tongans and so as the environment.

Objectives:

1. Institutionalise and mainstream climate change preparedness;
2. Increase national capacity to prepare and adequately adapt to climate change adverse impacts;
3. Reduce the national greenhouse gas emissions;
4. Increase public awareness and knowledge of climate change and their preparedness;
5. Facilitate and mainstream adaptation options in all sectoral planning; and
6. Develop a national climate change framework and policy

Implementation Strategies

Objectives and Strategies	**Responsible Agency**	**Components**	**Resources Required**	**Time Frame**
Institutionalise and Mainstream Climate Change Preparedness				
GHG abatement and vulnerability and adaptation to be mainstreamed into sectoral and national development strategic plan and in all government proposed project plans & programs	DoE, CPD	*Consider GHG abatement, vulnerability to climate change and sea level rise, adaptation in all government planning. *Consider GHG abatement, vulnerability to climate change, sea level rise, adaptation in all government project proposal *Consider GHG abatement, vulnerability to climate change, sea level rise, adaptation in government sectoral planning	None	Immediate
Amend existing legislation on development in vulnerable areas to climate change impacts	DoE, MLSNR	*Prepare paper identifying issues to be addressed *Request Crown Law Office to draft necessary amendments	None	Immediate
Increase national capacity to prepare and adequately adapt to climate change adverse impacts				

Special training of staff in government sectors, NGOs, statutory board	DoE, TWG & PMU of project	*Training needs assessments *Identify training needs in region *Identify individuals participate in training *seek funds	Funds for staff training, workshop & travel costs	Short term
Reduce national GHG emissions				
Promote usage of renewable energy resources	DoE, EPU, MLSNR	*Prepare project proposal *Training & educate nationals	Funds for training & workshops	Long term
Ban importation of fuel inefficient vehicles, engines and appliances	DoE, Customs Dept.	*Develop criteria to gauge inefficiency *Prepare necessary legislation	Funds for research & work undertaken	Medium term
Raise awareness on applicances efficiency and labeling	DoE, EPU	*Develop appropriate awareness materials	Funds for preparing awareness materials	Short term
Increase public awareness and knowledge of climate change and preparedness				
Training for preparedness, government agencies, NGOs, community, schools.	DoE, *Disaster Management*, MoW	*Conduct training *Prepare training materials	Funds for training & workshops, travel costs	Medium term
Facilitate and mainstream adaptation measures into all sectoral planning	All parties	*develop policy paper *initiate pilot projects to gain experiences *develop tools and methodologies *conduct research	Funds to undertake adaptation/ mitigation pilot project (Kanokupolu site)	Short term
Develop a national climate change framework and policy	All parties	*Review and assess reports *develop a national climate change policy paper for Cabinet approval	Funds to undertake consultative workshops/ trainings to all project relevant stakeholders	Short term

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ANNEX 1: INSTITUTIONAL FRAMEWORK AND CLIMATE CHANGE IMPLEMENTATION COMMITTEE

The preparation of Tonga's Initial National Communication involved the following institutional framework and committees.

National Executive Agency

The Department of Environment was responsible for executing the Climate Change Enabling Activity Project. It also works closely with the National Coordinating Committee in terms of coordinating project work.

National Coordinating Committee

This committee was established to function as the advisory body of the project. It also serves as the venue to ensure the coordination and discussion of climate change related issues at the policy level. Respective members were from the following institutions and agencies:

Director of Environment (Chairman)	[Department of Environment]
Secretary for Lands, Survey &Natural Resources	[Ministry of Lands, Survey & Natural Resources]
Director of Agriculture and Forestry	[Ministry of Agriculture & Forestry]
Secretary for Labour, Commerce & Industries	[Ministry of Labour, Commerce & Industries]
Secretary for Fisheries	[Ministry of Fisheries]
Director of Health	[Ministry of Health]
Director of Education	[Ministry of Education]
Secretary for Foreign Affairs	[Ministry of Foreign Affairs]
Secretary for Civil Aviation	[Ministry of Civil Aviation]
Director of Works	[Ministry of Works]
Secretary for Marine & Ports	[Ministry of Marine & Ports]
Director of Planning	[Department of Planning]
President of TANGO	[TANGO]
Project Manager	[Department of Environment]

Technical Working Group

This group was established to ascertain that the project is properly implemented at the technical level. Members were from the following institutions and agencies;

Dr. Siosiua Halavatau	[Ministry of Agriculture & Forestry]
Dr. Vailala Matoto	[Ministry of Fisheries]
Mr Tevita Malolo	[Ministry of Lands, Survey & Natural Resources]
Ms 'Apisake Makasini Soakai	[Ministry of Lands, Survey & Natural Resources]
	[Ministry of Fisheries]
Mr 'Asipeli Palaki	[Department of Environment]
Mr 'Ofa Fa'anunu	[Ministry of Civil Aviation]
Mr. Tevita Fatai	[Ministry of Lands, Survey & Natural Resources]
Mr Taniela Kula	[Ministry of Lands, Survey & Natural Resources]
Ms Fetongi Tukutau	[Ministry of Health]
Mr Kutusi Fielea	[Tonga Water Board]
Ms Fatai Pale	[TANGO]
Ms Lu'isa Tupou Veihola Tu'i'afitu	[Department of Environment]

Project Management Unit

This unit was responsible for the overall management of the project.

Ms Lu'isa Tupou Veihola Tu'i'afitu	[Project Manager, Department of Environment]
Mr Taniela 'Ahomalanga Faletau	[Senior Project Officer, Department of Environment]
Ms 'Anasisivaloa Peaua	[Administrative Assistant, Department of Environment]