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Feb 2005
THE APPLICATION OF REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEMS TO CHANGE DETECTION FOR INTEGRATED COASTAL MANAGEMENT

The Sigatoka Coral Coast in Fiji

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS IN THE SCHOOL OF GEOGRAPHY AT THE UNIVERSITY OF THE SOUTH PACIFIC

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SUVA, FIJI

FEBRUARY 2007
Declaration

I declare that this thesis is my own work, except for those sections explicitly acknowledged, and the main content of the thesis has not been previously submitted for a degree at any other university.

Signed __________________________

Mrs. Lanieta Veileqe Tokalauvere (S97001290)

The research in this thesis was performed under our supervision and to our knowledge is the work of Mrs. Lanieta Veileqe Tokalauvere.

Names:  Dr. James Terry  and   Dr. Gienko Gennady

Dates:  _________________________  _________________________
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Abstract

The coastal zone of the South Pacific Islands represents varied and highly productive ecosystems such as mangroves, coral reefs and sea grasses. It is necessary to protect these coastal ecosystems to ensure sustainable development because they are found to be mostly degraded and polluted. This requires information on habitats, landforms, coastal processes, water quality and natural hazards on a repetitive basis. Reliable and timely information is required in order to monitor and manage the remaining mangrove resources, coastline changes and rural development areas. The area chosen for this research was the Sigatoka Coral Coast in Fiji. The main aim of this thesis is to investigate how changes in the past can be documented and analysed utilising Remote Sensing data and GIS tools. The GIS technique corrects and analyses the aerial photographs of 1967, 1978, 1986 and 1994. The aerial photographs were available with good spatial resolution once scanned and rectified. IKONOS satellite image was also used providing reference for correcting aerial photos. These aerial photographs were rectified using ERDAS Imagine software and data for analysis, mangroves, coastline and rural development areas were drawn and analysed in the Map Info Environment. Change detection maps were created through overlay of layers in different time periods, and visualising through multi-temporal images. The results showed that coastlines have moved inland 0.54 m/yr to 2.18 m/yr during the studied period from 1967 to 1994. The mangrove analysis showed 1.3% regrowth in some areas like Naevuevu and 11.6% regrowth in other areas like Korotogo from 1986 to 1994. On the other hand there was a 1.4% decrease in mangrove in Naevuevu from 1967 to 1978 and 10.7% removal of mangroves along the Sigatoka River from 1967 to 1994. The rural development analysis showed an increase in the number of houses in the studied areas from 1967 to 1994 and at the same time more deforestation.
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List of Abbreviations

1. AIACC- Assessments of Impacts and Adaptations to Climate Change
2. BAMS- Beach Analysis and Management System
3. CPD- Coastal Programs Division
4. CRC- Coastal Resource Centre
5. CZMP- Coastal Zone Management Program
6. DPI- Dots Per Inch
7. ENSO- El Niño Southern Oscillation
8. ETM+- Enhanced Thematic Mapper Plus
9. EU- European Union
10. FAB- Fijian Affairs Board
11. FMG- Fiji Map Grid
12. GCP- Ground Control Points
13. GIS- Geographical Information Systems
14. GPS- Global Positioning Systems
15. IAS- Institute of Applied Sciences
16. ICM- Integrated Coastal Management
17. ICZM- Integrated Coastal Zone Management
18. IGCI- International Global Change Institute
19. LANDSAT- Land Satellite Images
20. LIDAR- Light Detection and Ranging Technologies
21. NLTB- Native Land Trust Board
22. NAVSTAR- Navigation Satellite Timing And Ranging system
23. NDVI- Normalized Difference Vegetation Index
24. NGOs- Non Governmental Organisations
25. OCRM- Ocean and Coastal Resource Management
26. PACE-SD- Pacific Centre for Environment and Sustainable Development
27. PNW- Pacific Northwest
28. PWD- Public Works Department
29. RS- Remote Sensing
30. SHOALS- Scanning Hydrographic Operational Airborne LIDAR Survey
31. SOPAC- South Pacific Applied Geoscience Commission
32. SPREP- South Pacific Regional Environmental Programme
33. TIFF-Tagg Image File Format
34. TM- Thematic Mapper
35. UNCED- United Nations Conference on Environment and Development
36. UNEP- United Nations Environment Program
37. UoW- University of Waikato
38. US- United States
39. USP- University of the South Pacific
40. UTM- Universal Transverse Mercator
Chapter 1 Introduction

1.1 Introduction

One of the major issues today in many countries, including island nations in the South Pacific region, is the degradation of coastal zones. Issues of concern are the accelerated depletion of resources, declining condition of marine and coastal areas and impoverishment of coastal communities. Efforts are being taken to address these pervasive coastal zone issues by the participation of governments in international and regional conventions and agreements. Examples are the United Nations Conference on Environment and Development (UNCED) Agenda 21, The United Nations Law of the Sea, the Convention on the Conservation of Biological Diversity, the United Nations Environment Programme (UNEP)’s Regional Seas Conventions, the Washington Agreement on the Protection of the Marine Environment from Land Based Activities, the Agreement on the Conservation and Management of Straddling Fish Stocks and High Migratory Fish Stocks, the Convention on Climate Change, and the Ramsar Convention, a convention on wetlands signed in Ramsar, Iran in 1971. These conventions have focused on integrated marine and coastal management as a solution to declining conditions of marine and coastal resources and the environment. The Coastal Resource Centre (CRC) of the University of Rhode Island in the United States (US) took part in the implementation of programs that help in the solving of degradation problems and also in conserving the coastal zone (Ngoile 1998).

This thesis identified coastal changes that have happened in the past in Fiji by analysing remote sensing data through GIS overlay. Pacific Island countries are greatly dependent on the natural environment for subsistence, economic growth and employment; however, coastal areas have been under stress in recent decades. Some of the reasons behind this problem are rapid population growth, natural factors such as cyclones or big tidal waves and human influence such as mineral extraction from beaches or effects of hotels and resorts on coastal erosion. Due to these factors, many Pacific Island countries are looking for a way of sustainable coastal development.
This chapter introduces the major issues that will be discussed throughout this thesis, describes the reasons for undertaking this research and for choosing the area of study and explains reasons why this method was used for this research.

1.2 Aim

The major aim/purpose of this thesis is to investigate how changes in mangroves, coastlines and rural development areas in the past can be documented and analysed utilising remote sensing data and GIS tools.

1.3 Objectives

This thesis describes the analysis of Remote Sensing (RS) image data by a Geographical Information Systems (GIS) tool for Integrated Coastal Management (ICM). The thesis looks at general issues occurring within the coastal zones and specifically describes programs such as ICM as strategies for solving these issues. Under ICM, RS image data are analysed by the GIS tool to obtain historical information of coastal changes that are of value to coastal managers, decision-makers and resource users. The study focuses on the Sigatoka Coral Coast on the Southwest coast of Viti Levu Island in Fiji. The Sigatoka Coral Coast was chosen because it was found to exhibit a number of coastal management issues. These issues are listed and discussed later in the thesis. The specific objectives are to:

1. First, analyse whether RS data might be applicable for change detection. This thesis lists the different RS data available with their resolution and analyses which one is appropriate for this research.
3. Once the RS data suitable for change detection is found then analyse techniques for change detection purposes. The thesis outlines and analyses different techniques that are normally used for change detection purposes.
4. Test the proposed technologies on case study areas. This thesis shows the use of GIS tool and the selected RS image data on the study area, the Sigatoka Coral Coast in Fiji.
5. Recommend some of the best ways to use RS data and GIS software to detect changes for the better management of coastal zones. The last chapter recommends the best RS image data and GIS software for this type of research. This information was gathered from secondary sources and interviews with GIS specialists.

*The reasons for choosing these objectives are as follows:*

1. Objective 1 was chosen to know which other RS image data are available and chose the best image data for this research.
2. Objective 2 was done in order to gather which RS images are available for the studied periods, from 1960 to 1990.
3. Objective 3 was chosen in order to get a clear idea of the change detection techniques available including the RS and GIS tools.
4. Objective 4 was done to assess the suitability of using RS and GIS for this type of research and serves as guidance to others who want to use this change detection technique for similar types of research.
5. Objective 5 recommends the best suitable image for this type of research depending on its availability and quality. This would help other researchers thinking of doing the same kind of research to look into these other images and make good choices.
Figure 1: The location of Fiji within the South Pacific Ocean (Source: Resort Vanuatu)
1.4 The Study Area

The location of Fiji is marked with a red oval shape on Figure 1, within the South Pacific. The area of study is the Sigatoka Coral Coast in the Fiji Islands (Figure 2). This area is located on the Southwestern side of Viti Levu, one of the two major islands in Fiji. The Sigatoka studied area consists of six *tikinas*. *Tikina* is a Fijian name for district. The six districts are known as *Cuvu, Sigatoka, Conua, Koroinasau, Korolevu-iwai* and *Komave*, shown in Figure 3.
Figure 3: The six tikinas (districts) within the Sigatoka Coral Coast

This area was chosen because it was found to have faced a number of coastal management issues that are of major concern in Fiji today. These include overexploitation of marine and coastal resources including harvesting of live rock, poor coastal water quality, poor solid waste management, unsustainable development and lack of assessment and information on these coastal problems (IAS 2002).

1.5 Integrated Coastal Management

The ICM working group in Fiji describes ICM as a process that involves integration or the working together between sectors at both local and national levels and also between different levels of government (Thaman 2003). At the local level this involved the working together of the local communities along the study area with the local
government agencies, NGOs and the private sector (mainly tourism). At the national level the ICM National Committee was established with representatives from government departments like the Ministry of Tourism, The Fijian Affairs Board (FAB) and Fisheries Department and Non-Governmental Organizations (NGOs) (Thaman 2003).

This thesis defines coastal areas as: “Areas from the coastline (vegetation line/mark on the aerial photographs) up to the main road (Queens Road) and extension to the mangrove areas”. Included within this coastal area are:

1. Mangrove areas
2. Villages/rural settlements/hotels
3. Coastline (vegetation mark/line)

1.6 Remote Sensing (RS) and Geographical Information Systems (GIS)

Aerial photography image data and GIS tools were used together. The GIS technique is a tool that is commonly used now in most countries and also in the Pacific Islands. It was seen as an easy to use technique; it is also an inexpensive method. The shoreline positions were derived from the aerial photographs and topographic sheets. In the USA Pacific Northwest, three islands coastlines were digitised and assessed. The Oregon coast, historical aerial photographs from 1978, 1986, 1991, 1998 and 2001 and topographic sheets from 1927, 1953 and 1955 were used to analyse shoreline positions. The aerial photographs were scanned at 600 dpi and imported into Map Info where these aerial photographs are rectified and registered. The identified errors ranged from $<\pm 5$ m to $\pm 15$ m. The 1927, 1953 and 1955 topographic sheets were used for the Tillamook Country and 1928 topographic sheet for Port Oxford. These topographic sheets have scales of 1: 20 000 (1927), 1: 10 000 (1928 and 1953) and 1: 5000 (1955). All these shorelines were put together and the results show variability in the shoreline positions in those years (Allan et al. 2003).
In Fiji change detection analysis was used by the Nasinu Town Council to map and visualise the squatter settlements growth over the township over the years. The aerial photographs of 1973, 1986 and 1998 were the main data for this analysis. These aerial photographs were scanned at 600 dpi and rectified then combined to three layer image in ERDAS imagine analysis software. Then it was imported to Map Info to digitise areas of change. The result of the three layer image which is called the multi-temporal image revealed that few squatter settlements were built within 1973 and more were built in 1986 and 1994.

It was also used in Tongatapu in Tonga to find the coastline and vegetation cover changes. There were three different images used for this analysis. They were 1968 black and white aerial photographs, 1990 coloured aerial photographs and the 2000 IKONOS image. All these three images were rectified to 1m resolution so they can be compared, using ERDAS imagine analysis software. The results showed that 1968 showed very little vegetation clearing and the coastline remain intact. In 1990, the clearings increased and open water stands near the village and the coastline still remain intact. By 2000, the IKONOS image showed further clearings and the last mangrove area towards the sea has been removed and the sea water erodes the area closed to the village (Forstreuter 2001).

Aerial photographs were also used for the Tagaqe coastline analysis. in the Sigatoka Coral Coast in Fiji for coastline changes (Pitman et al. 2001). The aerial photographs were scanned at 600 dpi and were rectified in ERDAS imagine analysis software and shorelines were digitised using the Map Info program. The result showed changes in shorelines. These studies so far have proved that GIS is one of the tools that is useful for environmental assessment.

1.7 Organization of the Thesis

Chapter 1 provides an introduction to the various aspects of ICM and application of RS/GIS to ICM generally and some descriptions of the study area, as well as a description of research objectives and an overview of methodology employed. Chapter 2
provides an overview of major ideas in this research and also major resources and activities within a typical coastal zone, then focuses on ICM in the study area and use of RS and GIS tools for assessing coastal changes. Chapter 3 presents information on the physical characteristics, socio-economic and administrative information on the study area, the Sigatoka Coral Coast. Chapter 4 explains the RS and GIS tools used and outlines steps taken for data preparation and specifically the use of change detection maps. Chapter 5 shows results from using RS and GIS for ICM in the study area and discussion of the results gathered from the study. Chapter 6 provides a conclusion and summary of major findings and appropriate recommendations on the application of RS and GIS to coastal zone management issues.
Chapter 2 Integrated Coastal Management in Fiji with reference to the Sigatoka Coral Coast.

2.1 Definition of the Coastal Zone

Figures 4 (1) and 4 (2) show areas that are referred to as coastal zone areas. Figure 4 (1) displays the sea, beach and the land area. This photo is taken along the Sand dunes (Figures 11 and 14) of the Sigatoka Coral Coast. The Sigatoka Sand dune is located west of the mouth Sigatoka River the second largest river in Fiji. Figure 4 (2) shows four different habitats. They are coastal forests, sand beaches, mudflats and estuary. This photo shows the river that runs beside Yadua village (Figure 6) along the Sigatoka Coral Coast, Fiji. Figure 6 shows the map of villages and resorts along the Sigatoka Coral Coast.

In this chapter a range of coastal zone definitions are given that were adopted for other similar studies. The physical and cultural features and the processes and issues that normally occur along the coastal zone are discussed in another section. The need for ICM and change detection maps, a tool used in ICM, which is the product of using RS data and GIS software are also discussed in this chapter. The last section of this chapter
lists the change detection techniques available and RS data available from the periods 1960-1990, the period of observation for this research.

There is no common or unique definition of the coastal zone; different definitions exist to serve different purposes (European Environment Agency Report 2000). On the marine side the coastal zone can be defined as the region lying between land and the shelf break, although sometimes it is more broadly defined to include the continental slope and rise. On the landward side it can be defined as a narrow strip of land between 60-100 m from the coastline. On the other hand it can be referred to as all ecosystems that are influenced by coasts. The coastal habitats consist of watersheds, shorelines, wetlands, estuaries, mangrove forests, rocky shores, mudflats, sea grass beds and coral reefs (Veitayaki 2006).

Loosely defined, the coastal zone includes both the area of land subject to marine influences and the area of the sea subject to land influences (United Nations Education Programme 2001). The coastal zone can also mean the area that contains land and ocean components (Kay and Alder 1999). Within coastal zones, terrestrial environments influence the marine environment and *vice versa* (Carter 1988). Figures 4 and 5 display features that are components of the coastal zone in the study area, the Sigatoka Coral Coast.

The extent of the coastal zone often depends on the needs of particular research or management programs. For example, if beach management is the principal objective, then a narrow spatial definition of the coastal zone may suffice. In comparison, reducing pollution in coastal watersheds requires a broader definition (Suman 2002). Klemas (1994) defined the coastal zone as a significant area of great environmental and human importance. In the European Union’s definition the coastal zone extends to over 90 000 km² and includes an estimated 200 million people living on its 50 km wide zone (Sciberras 2002). Egypt’s coastal zone is defined as the land-sea interface extending at least 30 km inland into desert areas and extending seawards into territorial waters (Egyptian Environmental Affairs Agency 2000). The definitions outlined above do not
define the boundaries of the coastal zone for this study; therefore the definition for this study is outlined below.

In this study the coastal zone is defined as the beach area considered from the coastline (vegetation line on aerial photographs) up to the main highway, the Queens Highway, extension to the mangrove areas; this includes mangrove areas, rural settlements and hotels (Figure 5 (1-3)).
Figure 5: The defined coastal zone on the 1967 mosaic image with the Queens highway. Figure 5 (1) shows the Fijian Resort to the Sigatoka River, with all the study mangrove sites, Figure 5 (2) shows the Sigatoka River up to Tambua sands and Figure 5 (3) shows the Hideaway Resort to the Beach House.
Figure 6: The map showing the Queens highway with villages and resorts along the study area
2.2 Why is the Coastal Area Important?

Coastal areas encompass some of planet’s most productive and diverse ecosystems and productive habitats important for human settlements, development and local subsistence. Some examples of diverse ecosystems and resources are estuaries, lagoons with their mangroves and wetlands, coastal inshore and offshore areas, floodplains, tidal flats, beaches, fisheries, marshes and coral reefs. Naturally, it is the home of thousands of species living in a complex and highly productive environment where the health of these ecosystems is dependent on each other (Archer and Jarman 1992).

The coastal zone also supports a majority of the human population. It is the zone in which most of the infrastructure and human activities directly connected with the sea are located. Most people prefer to live in this area because of the location and resources available in it. The location offers beaches for relaxing, picnicking and playing games and deep blue sea for swimming and diving. Big trees growing along the beach offer shade and cool air (Cicin-Sain and Knecht 1985). However, there is competition for land, sea resources and space and high potential for conflicts, as globally, the coasts constitute 10% of the area and supports 60% of the population. People strive for economic activities and high prices are experienced, as there are more demands (Cicin-Sain 1992).

This is the transition zone where government agency authority changes abruptly, where storms hit, where waterfront development locates, where boats make their landfalls, and where some of the richest aquatic habitat is found. It is the destination and recipient of all materials added into the environment (El-Sabh et al. 1998). It is the location of unique and fragile but productive ecosystems that support coastal communities. Most human activities are taking place in these coastal areas.
Figure 7 shows the photo of Yadua village along the Sigatoka Coral Coast. The Yadua villagers make use of the resources available such as marine species fishes for food, coastal forests like mangroves. Mangroves are used for “masi” making; “masi” are traditional Fijian clothes for ceremonies. It is also evidence in the photo that some mangroves replanting have been taking place in Yadua. Mangroves are used for firewood, medicine and protection against big tidal waves and strong winds (Veitayaki 2005).

2.3 Threats to Coastal Areas and Importance of Coastal Management

The high numbers of people concentrated in coastal zones have led to high concentration of human activities in small areas least able to assimilate those activities and where adverse effects are most apparent (Zenkovich 1967). The coastal zones are highly sensitive to development for urbanization and infrastructure, tourism activities, fishing and agricultural activities that not only harm the environment but also lead to rapid degradation of coastal habitats and resources (Brown et al. 2002). Some coastal processes and coastal change that take place in a typical coastal zone are discussed below. These coastal changes are not only the result of human activities but also of natural processes (Chua Thia-Eng 1993).
2.3.1 Geo-physical Processes

Long-term natural processes can be a threat to humans and other living things in coastal areas. These natural processes continued to change the coastlines physically, chemically and biologically at scales from microscopic grains of sand to global changes in sea level. Some examples of these natural processes are big waves that erode substrate, creating sand and moving it from one area to another (Sherwood and Howorth 1996). Tidal waves also bring sand onto the beach then carry it back to the surf. Rivers carry sediment to the coast and build deltas into the open water. Storms come with heavy rain and strong winds causing deep erosion of the coast in one area and leaving thick overwash deposits in another (Blong 1994). Tectonic activities cause extensive uplift. Sea level changes affect most low-lying areas in the Pacific, for instance, during El Niño Southern Oscillation (ENSO) periods. ENSO events are a period of fluctuations in weather patterns in the tropical Pacific caused by westerly winds, which also affect other areas around the globe (Williams et al. 1995). ENSO-related events devastate coasts, burn forests, destroy harvest and dwellings and lead to loss of human lives (Diez 2005). Continual change in coasts is caused by these natural processes and also by human activities, e.g. coral harvesting, sand extraction, building seawalls, removal of mangroves for reclamation of land.

Erosion is a major process in coastal zones. It is defined as long-term loss of shore material as a result of waves, wind currents, sea level changes and also human activities such as sand extraction and removal of mangroves. Erosion is associated with a shoreward recession of the shoreline and the loss of land area. The problem of coastal erosion may extend its influence hundreds of kilometres alongshore in the case of large deltaic areas, and may affect residents of nearby communities and resorts located in the area (Sherwood and Howorth 1996).
Figure 8: Erosion in Tagaqe. Figure 8 shows coastal erosion along the beach of Tagaqe village in the Sigatoka Coral Coast. Strong winds and big tidal waves contributed to some uprooted trees and movement of sand and gravel from upper to lower beach areas. (Photo: Lavenia Tawake)

2.3.2 Ecological Problems in Coastal Zones

High rates of population growth and industrial and tourism activities have particularly affected coastal zones and these developments tend to generate ecological problems. Ecological problems such as nutrient overenrichment, particularly by nitrogen, in coastal and estuarine waters are common in most coastal zones worldwide. Symptoms of these problems include enhanced algal growth, geographic expansion and increasing frequencies of harmful algal blooms, oxygen depletion, fish kills and the disappearance of seagrasses (Ojeda 2002). An example of this algal growth is common along the streams, rivers and seas of the study site, the Sigatoka Coral Coast in Fiji. This algal growth is a sign of human and piggeries wastes being dumped from villages and hotels located next to these streams, rivers and seas (IAS 2002).

In addition, oil and chemical spills have caused a lot of damage to the environment and are considered among the most serious problems affecting coastal areas. Numerous and
frequent spills cause extreme damage to the environment. Land spills are also a related issue and a threat to the environment (Wessex Institute 2005). Other causes are strong organic pollution from surroundings wastewaters (Ojeda 2002). For example this problem occurs along the Walu Bay waters along Lami Area in Fiji. Oil and chemical spills from ships and industries located in this area have damaged the marine environment in this area (Veitayaki 2006).

Some of the root causes of these ecological problems are lack of interest in environment coupled with greed, inadequate knowledge about the environment, poverty, inadequate governance, inadequate economic evaluation of environmental resources and insufficient regional dialogue (Ozhan 2002).

2.3.3 Social and Economic Problems

Social problems associated with coastal zones include land property conflicts, poverty, health problems, political conflicts, and conflicts amongst the communities themselves. These problems result from overpopulation and limited resources for every person; conflicts arise amongst the resource users (Ojeda 2002).

Economic problems also involve tourism activities. Most of the tourism industries are located on coastal areas that offer features of value to many tourists. These features include sandy beaches, shady places and the deep blue sea for diving and sightseeing. Many citizens move and settle there to look for employment. The increase in population has brought conflicts amongst these people because all depend on the limited resources available for them. Pollution caused by the tourism industry and the people settling in these coastal areas is also important (Oikonomides and Dermissi 2003).

2.3.4 Pollution

Coastal environments are being degraded by pollution. Litter is one of the major problems that spoils the natural beauty of the environment in coastal areas. Litter has
potential for bad impacts on wildlife and human health. The bad effects of litter could burden the local communities by driving away tourists from their destinations; in some cases communities suffer loss in tourist revenue.

Nitrate contamination from agricultural fertilizers and animal excrement is a major source of pollution in streams, rivers and the sea; it is both unpleasant and unhealthy to humans. Aquaculture has generated a lot of employment opportunities in South Australia, Pacific islands, and Asian countries and also in Africa but may not be properly regulated, creating waste disposal and pollution problems (Sciberras 2002).

As a result of urban expansion, groundwater is being polluted, traffic is increasing led to air and noise pollution. The surrounding seas are used as a dumping place for waste discharge of all kinds, degrading coastal and marine habitats and have negative consequences on tourism, fishing and agriculture (Sciberras 2002).

2.4 Definition of Integrated Coastal Management (ICM)

“Integrated Coastal Management: a continuous and dynamic management process by which rational decisions are made for the sustainable use, development, and protection of coastal and marine areas and resources” (Cician-Sain and Knecht 1998: 39).

ICM related activities include the following:

First, is the attempt to organise human activities in a better way - to change culture and practice. This is the working together of the ICM groups with the communities living in a particular coastal area to show and train them ways to better manage their limited resources (Post and Lundin 1996). For instance this is the process that is taking place now in Sigatoka Coral Coast in Fiji. The ICM working groups and Stakeholders are carrying out workshops and trainings amongst the communities to make them aware of
the resources they have and to teach them ways to effectively use them and not to degrade them (Thaman 2003).

Second, ICM was implemented as an alternative approach to the fragmented and sector-based management approach currently used. It can be viewed that many resources and activities that take place in coastal lands and waters—fisheries, tourism, agriculture and aquaculture, residential and commercial real estate development, marine transportation, recreation, and so forth—all represent specialized activities. ICM appreciates these interrelationships that occur amongst coastal and ocean users and the environment they affect and is designed to overcome this sectoral management approach (Bower et al. 1994). ICM would not support such specialized sectoral management but would instead supplement, harmonize, and oversee it. Thus, for example, fishery managers would continue to concern themselves with fishery allocations and the like, but an integrated coastal management approach would take primary responsibility for the effects of land-based sources of pollution on fishery nursing areas as well as with the links (both positive and negative) between fisheries and other uses (Cicin-Sain and Knecht 1998).

### 2.4.1 Importance of Integrated Coastal Management

There are valid reasons for initiation of ICM. One is due to the complexity of coastal areas and systems, which require a multidisciplinary approach. Secondly, coastal resources do not belong to any particular group; all the people living in a particular coastal area own them. In many cases self-maximizing gains by individuals ultimately destroy the resource so ICM needs to address such issues (Lakshmi and Rajagopalan 2000). Thirdly many times poor decisions by coastal resource users lead to problems, failures and expense. Conflicts always arise in those situations and they are expensive and time consuming. It is important that all people must be involved in the development and protection of coastal environment and resources (Fazi et al. 2001).
Figure 9: Excessive erosion. Figure 9 illustrate the need for an ICM approach. This photo shows Vatukarasa village (Figure 6) along the Sigatoka Coral Coast. It shows accretion along the beach, the movement of sand from high to low areas. This movement of sand is caused by strong winds and waves from the sea. Mangroves can be planted as part of the conservation work that protects the beaches and villages from strong winds and big tidal waves. (Photos: Author)

2.4.2 Goals of Integrated Coastal Management

Some of the key goals of ICM are listed below:

- Achieve sustainable development in coastal areas
- Reduce vulnerability of coastal areas and people
- Promote linkages and harmonization amongst all stakeholders and coastal activities
- Coordinate activities of all agencies and at all levels
- Resolve competition and conflicts
- Facilitate transparent and efficient decision making in support of national, regional and international goals such as sustainable development
- Mobilize stakeholders’ support.
- Improve human activities and lessen impact in coastal areas

(GESAMP 1996)

The escalating pressure from trends like rising population and problems found are seen as an ongoing process in the coastal zones (Veitayaki 2006). This has seen the
implementation of integrated coastal management, CZM and ICZM as few examples. Although problems may be beyond the direct solutions science can offer, it is important that the best possible knowledge base be developed in order that changes in the coasts and seas in response to trends of society can be predicted. Effort needs to be put into improving communication among scientists, managers, policy-makers and others who deal with the consequences of coastal change and exploitation of the coastal zone and adjacent seas. While many coastal zone issues appear to be a localized response to a local activity, there are clearly global consequences. The ICM activities dealing with management of marine and coastal resources make use of RS and GIS as one of the tools for coastal management (Clark 1996).

2.4.3 Constraints to ICM

While trying to promote and implement ICM in many countries there were still some problems to overcome. Some of the issues are discussed below. One is the government structures and systems. The government structures and systems of different places will either promote or a barrier to the implementation of ICM. Another is the poor understanding of the integrated nature of the coastal environments. Most stakeholders, coastal and resource users, decision-makers, coastal managers have poor knowledge of the integrated nature or the interrelationships of the coastal environments. In addition is the time used for the implementation of ICM in a particular place. In many cases the ICM approach is quite expensive and time consuming. This is because ICM involves training of both coastal managers and coastal and resource users, meetings and workshops that involve more time. These people should fully understand ICM goals, aims and objectives before training others and implementing it. Additionally, the lack of authority and political decisions puts pressure on the approval of ICM approach. Many governments take up a lot of time and meetings in order to make decisions whether to approve the implementation of ICM. Most governments lack information regarding the ICM approach and that drags the making of the final decision.
2.4.4 Integrated Coastal Management in Fiji

In the case of Fiji the first national workshop was held in Fiji in April 2002. This workshop discussed and supported some new coastal management tasks. These included a demonstration of ways where ICM can be implemented effectively to address Fiji's pressing national coastal management issues through the development of an action strategy for a key coastal region. The site chosen for this initiation of this ICM project was the Coral Coast (located along the Southwest coast of Viti Levu) site. A national group was also established to advise and learn from Fiji's Coral Coast demonstration site focusing on inter-sectoral coastal issues and constituency at the national and provincial level for the development and adoption of a national policy framework for ICM. Additionally, through training, mentoring and in-country staff support, the project builds the capacity required within the Fijian Affairs Board, selected provincial and government entities, districts and the Institute for Applied Science of the University of the South Pacific (Thaman 2002).

There are some positive outcomes on the initiation of ICM approach in Fiji. One is the achievement in cases where integration is practised like in the Denarau Island. Another is the Environmental Impact Assessments coordinated by the Department of Environment of Fiji. In addition is the implementation of the Department of Forestry’s Code of Conduct for Logging Practices. There are limitations to the logging of Fiji’s forests by Loggers. The Locally Managed Marine Areas (LMMA) project has been successful in many marine areas of Fiji. The Institute of Applied Sciences (IAS) of the University of the South Pacific (USP) coordinates this project. It involves working together with local communities by establishing marine protected areas in their fishing boundaries. It has protected their marine resources to cater for the present generation and also for the future generation.

On the other hand, there are also some negative outcomes of this ICM approach. ICM is not legally instituted. So many local communities and stakeholders do not recognize it.
There are still problems associated with the implementation of this approach like differences amongst stakeholders and ICM groups (Thaman 2002).

**2.5 Remote Sensing (RS) and Geographical Information Systems (GIS)**

The use of Remote Sensing (RS) and Geographical Information Systems (GIS) for assessing coastal changes has proved to be an easy way of assessing coastal changes.

**2.5.1 Remote Sensing (RS)**

It was in the United States that the term “Remote Sensing” was first used, in the 1960s, it encompassed photogrammetry, photo-interpretation and photo-geology. It was widely used when the Landsat-1, the first earth observation satellite was launched in 1972 (Nakamura 1999). RS allows the physical characteristics of objects of interest to be identified, measured and analysed without direct contact (Rees 2001). The term remote sensing also includes all interpretation and measuring of objects from a distance (Bonham-Carter 1994). In its simple definition, RS imagery is a term, which includes all types of photographs that are captured remotely, that is from an aircraft or satellite. Two common types of remote sensing images are aerial photos and satellite images.

**1) Aerial Photographs**

Aerial photographs are a series of photographic images of the ground taken at regular intervals from an airborne craft such as an airplane. Most aerial photographs are of $9 \times 9$ cm prints and the enlargements size are approximately $16 \times 20$ cm for more detail. Aerial photographs are available both in digital and paper form (Korte 2001). The aerial photos in paper form have to be scanned in order to be available in digital form. Once scanned aerial photographs are available in digital format and are easily stored and copied onto Compact Discs (CDs) as image files. These digital images are easy to process in computers, geo-reference to GIS maps and also overlay with GIS layers.
These GIS layers are easily stitched together to form one big layer and are easily distributed as a multimedia data image files (Rees 2001).

2) Satellite Images

Satellite images are another type of RS image that are either used together with aerial photos or can be used alone in any research. They are taken from satellites that orbit the earth at a higher altitude than the airplanes. Some examples of satellite images are Landsat 1, 2, 3, 4, 5 and Landsat 7, Orview images, IKONOS images and many others. They are available in different resolutions and sizes and are sometimes quite expensive to purchase (Nakamura 1999).

2.5.2 Global Positioning Systems (GPS)

GPS is a network of 24 radio-transmitting satellites (NAVSTAR) developed by the US Department of Defense to provide accurate geographical position fixing. GPS developed as a global navigation system for military and civilian use, and orbits the earth continually at a height of 17 500 km (Alasdair 2000). The availability of GPS technology allows convenient, inexpensive and accurate measurement of absolute location (Campbell 2002). GPS in Fiji allowed plantation boundaries to be mapped at 1:10,000 scale for the first time. In the past, the survey only prepared sketch maps with incorrect boundaries. Mapping with differential GPS allowed a precision of greater or less than five metres, which is sufficient for, forest maps at 1:10,000 scale.

2.5.3 Geographical Information Systems (GIS)

GIS involves the use of software like ERDAS, Map Info and Arc View, to store, visualise and analyse data (Chou Yue-Hong 1997). GIS enables the capture, modeling, storage, retrieval, sharing, manipulation and presentation of geographically referenced data (Worboys and Duckham 2004). GIS is more advanced and image data are readily available. This in terms of the availability of new software and programs with low cost images to purchase and high resolution images to download from internet that does
mapping and other GIS related work. For instance the use of Arc GIS program and free downloading of Google Earth images with 60 cm resolution and purchasing of aerial photographs at low cost. However, in the Pacific for long-term assessment, the best images that can be used are the aerial photographs. The use of aerial photographs have proved to be successful in Suva for assessing urbanization in Nasinu Town area and in Tongatapu, Tonga for assessing coastal changes, like the coastline and vegetation cover change (Forstreuter 2003).

2.5.4 Change Detection Maps

Change detection is useful in many applications such as land use changes, habitat fragmentation, and rate of deforestation, coastal change, urban sprawl and other cumulative changes examined through spatial and temporal analysis techniques available in GIS and RS along with digital image processing techniques. Change detection maps are maps created using Remote Sensing data such as aerial photographs and satellite images to show changes that occur over different time periods. The preparation of change detection maps requires the superposition of two maps acquired at different dates where areas of change are noted and are recorded in the third map. The third map shows only the change, which then can be examined by area to reveal the extent and placement of changes. Such changes can be in the form of features in that particular area, such as land cover, land use or coastline position (Campbell 2002).

2.5.5 Uses of Change Detection Maps

Change detection maps can support Integrated Coastal Management. Many users have used change detection maps to show areas of change in mangrove, land use and coastline position. Quantitative change can be measured, e.g. vegetation loss and regrowth in hectares (Ramachandra and Kumar 2004).

Change detection maps also show type of land cover change, for instance from pine forest to agriculture. This information gives a greater understanding of a particular area
to coastal managers and decision makers. In Halong Bay, Vietnam, important information was gathered in order to monitor and manage the remaining mangrove resources (Quyen et al. 2004). Different sets of Landsat satellite imagery were investigated over time. Moisture detection was applied to differentiate the mangroves from the general vegetation in the area. The result showed that 21% of mangrove were lost through aquaculture in which tidal wetland was reclaimed. This impacted the coastline and changed the landscape of the bay (Quyen et al. 2004).

Nagamani and Ramachandra (2003) used change detection maps to understand natural resources and their utilization, conservation and management. Change detection in land use helps in the economic development of an area without further degrading the environment.

Other uses of change detection maps reflect coastal management issues. Such management issues are of water pollution leading to water borne diseases, lack of fertility and productivity of both wetlands and dryland soils. In Kuttand, India, change detection maps showed natural hazards affecting use and development of coastal resources (Mathew 2003). This information provides end users with the necessary information on long-term shoreline behaviour of coastal areas (Azab and Noor 2003).

2.5.6 Change Detection Techniques

Listed below are some techniques used for coastal change detection.

- LIDAR survey technique
- Airborne Laser Altimetry
- Beach Profile
- Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS)

Researchers have used a variety of methods and techniques to assess coastal changes. One is the use of a more expensive technology is photogrammetric survey using Interferometric Synthetic Aperture Radar and Light Detection and Ranging
Technologies (LIDAR). This type of technology is not used much in the Pacific Island countries (Graham et al. 2003).

Another is the use of beach profiling (Pandian et al. 2004) to assess coastline or shoreline changes monthly or yearly, which is appropriate for short-term assessment. Beach profiling was done in Tagaqe, Fiji to assess the coastline changes (Pitman et al. 2001).

Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) (Wozencraft and Lillycrop 2003), and Airborne Laser Altimetry (Robertson et al. 2004) were other technologies used in most countries for assessing coastal changes. The SHOALS not only provide a measure of shoreline position but also an indication of sediment processes. The Airborne Laser Altimetry was used to prove the feasibility of using LIDAR surveys in updating existing historical shoreline data sets by comparing contour shorelines and the high water line at studied locations (Robertson et al. 2004).

Topographical map sheets and vertical aerial photography were used for shoreline analysis. Results showed that average erosion rates amounts to 0-21 m/yr and total beach loss for the region equals approximately 4.5 km (Fletcher et al. 2004). In the Great Lakes Basin GIS tools were used to quantify changes and aerial photographs were used as reference for historical analysis. The change in shoreline ranged from 0.16 m/yr to as high as 0.84 m/yr (Zuzek et al. 2003).

The use of integrated models developed to assess coastal vulnerability and climate change in the Pacific Island countries, under the AIACC project, (Assessments of Impacts and Adaptations to Climate Change) (AIACC 2004).

Bathymetric survey can be used for surveying reef areas. This method is also expensive due to the purchasing of the equipment and the amount of manpower used to do the survey. This has been done once by SOPAC, a bathymetric survey was carried out in
some pacific islands like the Cook Islands and Samoa and it is available on their website, (http://www.sopac.org/tiki/tiki-sopac_reportsindex.php?ss=type&vv=BM).
Chapter 3 Field Setting: The Study Area

3.1 The Sigatoka Coral Coast

This chapter describes the study area for this research, which is the Sigatoka Coral Coast. It depicts the common characteristics the Sigatoka Coral Coast has from physical features to cultural features. It also explains the current work being carried out through the implementation of the ICM project coordinated by the Institute of Applied Sciences at the University of the South Pacific.

The Sigatoka Coral Coast encompasses the coastal areas of the province of Nadroga-Navosa from the village of Namatakula through to the Fijian Hotel at Rukurukulevu village. Figure 10 shows the study area on the Sigatoka Coral Coast for this research.

Figure 10: The area from the Fijian resort to Namatakula
The main focus was on Naevuevu, Yadua, Korotogo, Malevu, Namada, Tagaqe, Vatulalai, Votua and Navola, Korolevu, Komave and Namatakula villages located along the coastal area of Sigatoka.

The Cuvu district is the first district covered for this research. It is located as the first district from the left on Figure 3 in Chapter 1. It is the countryside’s surrounding of the Fijian Resort and has mainly dry grassy hills. The Sigatoka Sand dunes were declared as Fiji’s first National Park (Figures 11 and 18) and has a landscape of wind swept beaches and rolling sand dunes. The aerial view of the Sigatoka Sand dunes encompasses five km of coastline with sand dunes rising to more than 20 m.

Figure 11: Aerial view of the Sigatoka sand dunes in 1967.

Figure 11 shows only a small part of the studied area. The villages located on it are Sila, Naevuevu, Yadua and Volivoli. One of the mangrove sites that were studied for this
research is located near Yadua. Far up on the left hand side of this aerial photo is Naevuevu mangrove that was also studied for this research.

3.2 Characteristics of the Sigatoka Coral Coast

The Coral Coast has the longest chain of fringing reefs in Fiji. This is shown in Figure 12. Approximately 33 km² of fishing area is included. Several communities have been assisted by IAS to develop marine management plans on their fishing areas which covers approximately nine km² (the fishing area shaded in blue colour). Fishing areas in this study is defined as their qoliqoli boundary which is owned by each district. One of the major aims of marine management plans was to assist these communities to set up marine protected areas to cater for them and the future generation.

Figure 12: The qoliqoli area of the Sigatoka Coral Coast. The fishing boundaries look to be inaccurate at the western edge of the map, which draws the area around the Fijian Resort. However, this cannot be edited as we were only given the right by the Native Lands Commission of Fiji to use but not to make any changes on it.
Sigatoka Town is populated with both Fijians and Indians. It is 70 km from Nadi and is situated on the banks of the Sigatoka River. Its population in 1996 was 7,862 increasing by 5.1 percent since 1986 (Bureau of Statistics 1998). Roads either side of Sigatoka lead up the Sigatoka River Valley into fertile agriculture land with picturesque rural scenery.

The tarsealing of the main road (Queens Highway) (Figure 13) in the early 1970s made travel to Nadi and Suva much more convenient. Sigatoka town expanded considerably at about this time with new shops and movie theatres, but except for some tourist shops, has returned to its sleepy nature since then. A new sports stadium and modern bridge across the Sigatoka River are recent developments (Personal Observation).

![Figure 13: The Queens highway](image)

Figure 13: The Queens highway. Figure 13 shows the current tarsealed Queens Highway, viewing it from Yadua village going towards Sigatoka town. *(Photo: Author)*

At the mouth of the Sigatoka River, large and constant surf is popular with surfers. The Sigatoka Sand Dunes was designated as Fiji’s first national park in 1978 and has been proposed as a World Heritage Site. The Fiji Museum has recovered exceptional items from within the dunes and it is still possible to find ancient pottery, weapons and even old bones in some places (Wood et al. 1998).
3.2.1 Agriculture

Agriculture is an important industry with vegetable farming in the Sigatoka Valley and sugar cane near the coast. Vegetables are sold to the municipal markets, to hotels, and in the larger cities. The sugar cane is transported by light rail to Cuvu, where the local sugar company offices are, and then to Lautoka for milling. Industry is almost non-existent; there is a small juice-making facility in Sigatoka town and a coconut furniture-making facility near Naevuevu village. The land along the Coral Coast is mostly hilly with only small areas of agriculture potential. People in the villages have small plantations mainly of root and tree crops that meet their subsistence needs, Figure 14.

Figure 14: Agriculture along the Sigatoka river (Photo: Author)

3.2.2 Climate

Temperature is relatively consistent due to the ocean ranging from a low of 18°C during the coolest months (July and August) to a high of 32°C during the warmest months (January and February). Rainfall is highly variable and mainly orographic often falling in heavy, brief local showers. In addition, Fiji experiences a distinct wet season (November to April) and a dry season. Annual rainfall for the area is between 2000 and 3000 mm. The predominant winds are the trade winds from the east to southeast, which
are generally light to moderate in strength. Tropical cyclones that occur from November to April can cause high winds and widespread damage (Pitman et al. 2001).

Storm surge, which is a temporary rise in the level of the sea caused either by very low atmospheric pressure or the piling up of water against a coast by strong winds (both associated with cyclones), occurs occasionally on the Coral Coast. The most recent surge was in early 2001, resulting in flooding of coastal areas. It is recommended to design infrastructure for protection against inundation at a level of 3.3 m above mean sea level to protect against a 1 in 50 year event (Reidel and Byrne 1989).

3.3 Natural Habitats

3.3.1 Coral Reefs

The well-developed fringing reefs of the Coral Coast extend almost unbroken for 63 km and have a seaward extension of 500 to 1000 m. The only major gap is at the mouth of the Sigatoka River. Where creeks descend from the hills the reef is broken by passages of 100 to 300 m across (Cumming et al. 2002). The fringing reef has a shallow tidally submerged platform, which is interspersed with moats and channels. Beyond the platform is a consolidated reef crest. The shallow lagoon reef-flat permits snorkeling at high tide.

Figure 15: The fringing reefs adjacent to Namada village (Photos: Author)
3.3.2 Beaches and Dunes

White carbonate sand beaches are found behind the fringing coral reefs. The unconsolidated sediments are a mix of terrigenous, calcareous and other shallow water marine sediments. Active sand transport mainly occurs due to longshore drift (Pitman et al. 2001). At the mouth of the Sigatoka River, terrigenous sands have built up into high dunes (Figure 16).

![Figure 16: The Sigatoka sand dunes, at the mouth of the Sigatoka river along the Sigatoka Coral Coast (Photo: Lavenia Tawake)](image)

3.3.3 Lagoons and Coastal Waters

Along the Coral Coast the lagoon is fairly narrow. The 200 m isobath is around 1 km offshore. The average depth of the lagoon is around 20 m making it suitable for swimming, snorkeling, and fishing. Bathymetric surveys conducted by SOPAC indicate that the reef passages can attain depths of around 200 m that drop to around 800 m offshore. Water temperature is always above 20°C with the summer maximum around 30°C. Tides are semi-diurnal with neap tides having a mean range of 0.9 m and spring tides 1.3 m (Ryland 1981). The photos showing the lagoons and coastal waters are shown in Figure 17.
Figure 17: The lagoons and coastal waters around the Fijian resort in Cuvu district  
(Photos: Author)

Few studies have been carried out along this stretch of coast. Studies by USP conducted in the lagoon offshore from the Outrigger Resort (Figure 6 in chapter 2) indicate that nutrient levels often are higher than acceptable limits and faecal coliform levels at times may exceed acceptable levels after heavy rains, especially at the mouths of creeks and in nearshore waters (Mosley et al. 2005).

3.3.4 Rivers

Streams and rivers dissect the coast in many sections. The major river that runs across the Sigatoka area is the Sigatoka River (Figure 18 (1 and 2)). The Sigatoka River is the longest and the second largest river in Fiji in a fertile valley known as the “salad bowl of Fiji”. It has drainage of 1700 km$^2$ and is approximately 90 km long (Field 2003).
Figure 18 (1): The Sigatoka river, viewed from Sigatoka town (Photos: Author)

Figure 18 (2): The coloured 4 m IKONOS satellite image showing the Sigatoka river
3.3.5 Coastal Forests

The coastal forest is located to the East of Sigatoka. A logging concession area, Navutulevu, is active in the Coral Coast area. In 1997, 3,608 m³ of timber was harvested. Figures 19 (1 and 2) show the photos and map of the types of forest grown along the study site. The classification of forests is divided into three, protection (areas above 30 degrees slope restricted for logging), preserved (areas for reserve for nature parks, of national, cultural and environmental significance and endangered species) and multiple use (either for commercial or non commercial use). Denser multiple use forest is found in Korolevu-i-wai and Komave districts while more non-forest areas are in Cuvu, Sigatoka and Conua. Koroinasau district has a fair mixture of multiple use scattered, dense and medium forest and also non-forest areas. Protection forests components are slope classes and erosion erodability. It’s restricted as a way of promoting sustainable forest management (Personal Interview 2007).

Coastal forests (Figure 19) are very useful to the local communities and also to the tourists. The local communities utilise coastal forests for source of firewood, construction material, medicine, garlands and food. The tourists used coastal forests and mountains behind coastal plains as for hiking or visit waterfalls. Naturally, coastal forests itself provide ecological functions such as shade, protection from wind, sand and salt spray, erosion and flood control, and soil improvement. Some of the common important species that are found in these forests are coconut, hibiscus and pandanus (Thaman 1991).
Figure 19: Types of coastal forests along the Sigatoka Coral Coast. Figure 19 (1) and (2) show the coastal forests of the Sigatoka Coral Coast. (MUF-Multiple use forest, PTF-Protection Forest). (Photos: Author)
3.3.6 Mangroves

Mangroves occur adjacent to a few villages along the coast to the east of Sigatoka. Vatuolalai, Tagaqe, Vatukara, and Korotogo have mangrove areas and mangroves were also present adjacent to Namatakula, Komave, Navola, and Malevu in the past. Mangroves are more commonly found to the west of Sigatoka and occur in the villages of Yadua, Naevuevu, and Rukurukulevu.

There are four major mangrove areas that were chosen within this study area. The minor ones include Vatuolalai, Namada and many more which are also shown on aerial photos but were not analysed. The reason for choosing the selected mangrove areas is due to the quality of the aerial photographs. These areas are found to be clearly shown and can be easily digitised. The L29 and M29 sheet index of the 1:50 000 scale topographic maps were used as guidance while choosing and digitising these mangrove areas. One of the selected mangrove areas is in Korotogo, where the replanting of mangroves is an ongoing process. It was also done in Yadua (Figure 6). The replanting of mangroves took place as a result of erosion of beaches and collapsing of seawalls. This is shown in Figure 20

![Figure 20: Replanting of mangroves in (1) Korotogo and (2) Yadua. The two photos both show mangrove seedlings planted along Korotogo and Yadua beach areas. One of](image)

(1) (2)
the main reasons for this replanting is to protect the villages from big tidal waves since they are vulnerable to coastal hazards. *(Photos: Author)*

The major mangrove areas selected are:

**Figure 21: The four mangrove sites.** (1), the Korotogo mangrove, (2) is the Alasa mangrove, beside the Sigatoka River approximately 80 m on the left hand side of the Sigatoka Bridge, (3) is the Naevuevu mangrove, along the Naevuevu river and (4) is the Yadua/Yalasuna near the Sigatoka Sand dunes. *(Photos: Author)*
3.4 Urban and Rural Population

In the early years during the 1990s, the Sigatoka Coral Coast consisted of four coastal tikinas. They are Conua, Cuvu, Komave and Korolevu i Wai. Within these tikinas there are 18 coastal villages and an additional four settlements. The largest village is Vatukarasa with 450 people and the smallest is Sila with 73 people. The populations for the villages are shown in Table 1. The predominant residents of these villages are indigenous Fijians. There is also a tikina of 8 villages close to Sigatoka town, about two kilometers from the river mouth. Settlements at Korotogo, Votua, Cuvu, and Korolevu have built up mainly to house people working in the tourism industry. The Indo-Fijian population along the coast is concentrated in the sugar cane growing area from Korotogo to Cuvu and the town of Sigatoka (population in 1996 was 7862). In most of the
villages, many households still use pit toilets. Only in Vucilevu and Votua did most households have septic tanks in 1996 (Bureau of Statistics 1998).

**Table 1: The Population of the Sigatoka Coral Coast**

<table>
<thead>
<tr>
<th>District</th>
<th>Village</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conua Tikina</td>
<td>Korotogo</td>
<td>380 (2002)</td>
</tr>
<tr>
<td></td>
<td>Malevu</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td>Vatukarasa</td>
<td>450</td>
</tr>
<tr>
<td>Cuvu Tikina</td>
<td>Yadua</td>
<td>336 (1995)</td>
</tr>
<tr>
<td></td>
<td>Rukurukulevu</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Sila</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Tore</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>Naevuevu</td>
<td>222</td>
</tr>
<tr>
<td></td>
<td>Cuvu</td>
<td>338</td>
</tr>
<tr>
<td></td>
<td>Hanahana</td>
<td>89</td>
</tr>
<tr>
<td>Komave Tikina</td>
<td>Komave</td>
<td>200 (2002)</td>
</tr>
<tr>
<td></td>
<td>Navola</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Vucilevu</td>
<td>158</td>
</tr>
<tr>
<td></td>
<td>Namatakula</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Vatuolalai</td>
<td>154</td>
</tr>
<tr>
<td></td>
<td>Tagaqe</td>
<td>260</td>
</tr>
<tr>
<td></td>
<td>Namada</td>
<td>300</td>
</tr>
</tbody>
</table>

(Source: Bureau of Statistics)

**3.5 Economic Sector**

**Table 2: The Economic Activities in Rank Order of Importance**

<table>
<thead>
<tr>
<th>Economic Activities</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tourism Sector</td>
<td>1</td>
</tr>
<tr>
<td>Fishing</td>
<td>2</td>
</tr>
<tr>
<td>Coral Harvesting</td>
<td>3</td>
</tr>
<tr>
<td>Sand Mining</td>
<td>4</td>
</tr>
<tr>
<td>Mineral Extraction</td>
<td>5</td>
</tr>
</tbody>
</table>

(Source: Author)
3.5.1 Tourism

The sand dunes are a unique feature of the study site and are one of the major tourist attractions. The Sigatoka Sand Dunes are the location of one of Fiji's earliest recorded prehistoric sites. Evidence of the past is clearly visible throughout the dune system as pottery scatters, stone tools, human remains and other archaeological relics continue to be uncovered by natural processes. It covers an area of 650 hectares and is located directly west of the mouth of the Sigatoka River. A photo showing the Sigatoka Sand Dunes is shown in Figure 23.

![The Sigatoka Sand Dunes](image)

Figure 23: The Sigatoka sand dunes (Photos: Belene Blanco)

The Coral Coast is one of the major tourist destinations in the country. Tourism in the area began with the opening of the Korolevu Beach Hotel in 1959 and experienced significant growth in the 1970s after the sealing of the Queens Highway. Along the Coral Coast there are seven major hotels/resorts and a number of smaller guesthouses and backpacker accommodations. The map and photos of the tourist resorts along the Coral Coast are shown in Figures 26 (1) and (2). Dispersed between tourist developments are villages. These villages own the land on which the resorts and hotels are located. The local people are employed at the hotels, often provide entertainment and some host tourists in their villages. In many villages, at least one member of each household will be employed in the tourism industry. Thus tourism is the main income
earner and economic activity on the Coral Coast for the local indigenous people. It provides financial benefits and leads to an improved standard of living. The resorts often provide assistance to villages when needed such as community development in helping fund community projects (Personal Observation). Table 2 (pg 45) shows the tourism as the number one income earner compared to other economic activities in villages along the Sigatoka Coral Coast. This table was ranked through interviews conducted with the villagers along the Sigatoka Coral Coast.

The beach at Korotogo is of coarse sand and offers little privacy from the coastal road. Moreover, the lagoon is shallow with dead coral making it unsuitable for swimming or snorkeling. The wild beach along the Coral Coast is a good spot for wind surfing especially in the afternoon. The reef passages along the Coral Coast can cause dangerous currents. The beachfront at the Hideaway Resort is good for swimming and there is good snorkeling and surfing in the offshore passage, although currents can be dangerous. The beach at the Naviti Resort looks picturesque although at high tide there is little beach to enjoy (Rawlinson et al. 1994). Two photos of these beaches are shown in Figure 24 (1) and 24 (2) and the map showing the location of these resorts is in Figure 26 (1).

![Figure 24 (1): Beach at Outrigger Reef resort in Korotogo village](image1)
![Figure 24 (2): Beach at Namatakula village](image2)

(Photos: Lavenia Tawake)
The Sigatoka sand dune area, (Figure 23), is a major tourist attraction. Another tourist attraction is the Tavuni Hill Fort (Figure 25), a fortified site on the east side of the Sigatoka River. The Kula Bird Park is located in a valley inland from the Outrigger Reef Resort. The Kalevu Cultural Facility built near the Fijian Resort, an attempt by the Fijian resort landowners to further benefit from tourism, has had a mixed history of success. A major government ecotourism effort, the “Waikatakata”, including waterfalls and hot springs inland from Vatuolalai has failed due to land disputes. There are also a few small restaurants along the coast and a village dive operation (Thaman 2003).

Figure 25: Tavuni Hill Fort above Sigatoka town (Photo: Author)
Figure 26 (1): The resorts/hotels located along the Sigatoka Coral Coast
The Fijian Resort  Entrance at the Fijian Resort  The Sigatoka Town
The Sigatoka market  The Crows Nest  Vatukarasa village
Namada village  The Tambua Sands  The Hideaway Resort
Tagaqe village  The Naviti Resort  Vilisites Restaurant
3.5.2 Fishing

The fringing reefs are important sources of subsistence fish and shellfish for coastal villages. Fishing is also one of the main income earners. A survey of the subsistence and artisanal fisheries in Namatakula village in 1993 estimated the frequency of fishing in the village, 28 people fished 3-7 times/week, 22 people 1-2 times/week, 4 more than once a month, and 7 less than once a month. Fishing trips lasted up to four hours. The habitats most fished in were the outer reef edge, inner lagoon, estuary and the edge of mangrove areas. Methods most commonly used were spear, guns, handlines, collecting and gill nets. Target species included emperors, octopus, rockcod, trochus, siganids, carangids, prawns, mangrove jack, crescent perch, and parrotfish (Rawlinson et al. 1994). The only villages that issue licences for commercial fishing are Komave (1), Vatukarasa (1) and Korotogo (3). Namatakula and Namada sell their excess fish on the roadside to passing pedestrians and to hotel workers.
3.5.3 Coral Harvesting

Coral (Figure 27) harvesting has been carried out in three villages along the Coral Coast. In Komave it is limited and only individuals sell the coral to Walt Smith International. Walt Smith International is a private company based in Lautoka specializing in live rock trade. Their main live rock collectors are Namada, Vatukarasa, Vitogo in Lautoka and Matacaucau village in Tailevu. In Namada coral harvesting was extensive, starting back in 1998 and was a main income source with households earning around $200 per week. However, in 2004 they stopped harvesting in their fishing areas. In Vatukarasa harvesting is also extensive. Both villages sell the coral to Walt Smith International. Although coral harvesting is seen as one of the main income source in Namada, a current thesis study on the effects of coral harvesting by Walt Smith found that coral harvesting reduces fish abundance, removes habitats, changes benthos communities and also changes the topography of the reef (Movono 2007).

Figure 27: Coral growing on taboo areas in Namada (taboo areas are areas that the villagers are not allowed to fish for a certain period). (Photo: Author)
3.5.4 Sand Mining

Sand mining is the removal of sand for building purposes and construction of footpaths and roads. This activity is practised in Vatukarasa and Namatakula villages. Figure 28 show sand mining at Vatukarasa.

![Figure 28: Sand mining in Vatukarasa (Photos: Lavenia Tawake)](image)

3.5.5 Land Use

The logging and planting of hardwood continues today in the forested inland areas of Tikina Korolevu i Wai. In the 1970s, a sawmill was in operation inland from Tagaqe (Rawlinson et al. 1994). Figure 29 shows the Nadroga land classified according to slope. This classification determines the type of crops that is most suitable for this particular soil. For instance flat to gently rolling land is suitable for planting agricultural crops. This is evident in areas around Sigatoka Town and along the Sigatoka River and the studied coastal zone. There is little rolling land for cattle farming and other activities around Cuvu, Conua and Korolevu-I-Wai districts. More evidence of moderately and steep to very steep soils are found on the coastal and highlands of Komave, Korolevu-I-Wai, Koroinasau and Conua districts. It appears that most of the Sigatoka Coral Coast highlands are covered with steeper sloping lands compared to more flat to gently rolling
land on the study coastal zone. This can be considered as one of the major coastal zone issues. In order to protect these steep highland areas from erosion towards lowland areas (study coastal zone), trees like pine, coconuts and mahogany need to be planted to keep the steep lands together and reduce soil erosion. However, most reported cases of erosion along the study coastal zone are found along the beach areas. They are caused by big tidal waves and rivers and heavy rain.

A, B, C- flat to gently rolling land, D, E- rolling land, F- moderately steep, G, H- steep to very steep land.

(Source: Department of Land Resources Planning and Development 2001)

Figure 29: The slope types of the Sigatoka Coral Coast. Figure 29 shows the slope types of the Sigatoka Coral Coast that were surveyed in the 1980s and put into a map by the Land Resources Planning Unit of Fiji in the 1990s. This slope types map was based on soil classification. The map shows that some steep lands are found on the defined coastal zone. However, this research found that the defined coastal zone in this research is characterized mostly by flat lands.
3.5.6 Mineral Extraction

Limited sand and gravel extraction along the beach is carried out within a number of villages including Namatakula, Komave, Vatuolalai, and Vatukarasa. This is mainly used to construct houses and seawalls. In the past extensive gravel extraction occurred at Tagaqe Village and presumably others to upgrade the Queens Highway in the 1950s, 1960s and 1970s (Pitman et al. 2001).

3.6 Causes of Coastal Degradation

Many of the environmental and social problems that exist are partly due to the lack of appropriate and effective legislation and policy. Examples are the lack of legislation requiring an EIA for some development projects and the lack of a national policy to control and monitor coral harvesting. There is also a lack of regional planning.

The Institute of Applied Science of USP under the integrated coastal management project in the study area has assisted local stakeholders to create an action plan to assist the communities in the management of their resources. One of the major issues addressed is resource degradation. Discussed below are some of the causes to this resource degradation.

3.6.1 Reef Damage

Coral harvesting for the aquarium trade occurs in these villages in the study area. Live rock (reef rock covered with coralline algae and associated fauna and flora) is removed from the reef as blocks 15-35 cm in diameter usually by iron bars. Collectors gather from areas predetermined by the village chiefs. Impacts of coral harvesting include damage to non-target species, decline of coral population, potential reduction of reef topography and conflicts with tourism operators (IAS 2002).
Other causes of coral degradation are siltation from upland erosion, flooding and freshwater input. Upland erosion is caused by removal of forest area resulting in land left bare. Fish abundance is reported to be declining in some villages and some intertidal species are becoming rare (IAS 2002). The use of traditional fish poisons may also be a factor.

The overgrowth of algae, especially *Sargassum* species, is mentioned to be a problem in all villages except Votua, Vatuolalai and Korotogo. The excessive growth of algae smothers coral and is thought to be due to elevated nutrients in the waters, siltation, higher ocean temperatures and less herbivororous predators (IAS 2002).

### 3.6.2 Deterioration of Coastal Water Quality

Deteriorating coastal water quality seems to be a major concern in the study area and is often blamed on the resorts and hotels disposing of their solid and sewage waste into the ocean. However, the continued dependence of most of the villages on pit toilets and septic tanks out of which sewage waste may leach during heavy rains and the location of pig-pens close to the ocean in many of the villages probably also contributes to pollution in the coastal waters (Thaman 2003).

The disposal of rubbish in villages and on the coast is a big problem. Rubbish is mainly plastic bags, tin cans, and other non-biodegradable solid waste. As there is no formal rubbish collection villagers often dispose of rubbish along the coastline assuming that the ocean will remove it. Votua and Vatuolalai villages along the study area raised issues such as the disposal of rubbish from nearby hotels and sewage disposal from the Votua Housing via a small stream as a major cause of pollution in their coastal waters.

### 3.6.3 Coastal Erosion

Coastal erosion is one of the more serious concerns for the villages along the Coral Coast at present. All villages except Namada and Korotogo villages, both of which have the highway between the village and the shore indicated that coastal erosion was a major
problem, especially during cyclones. Storm surges damage existing seawalls, wash away houses, and cause extensive erosion of shoreline (Figure 30-Erosion in Tagaqe) (Terry and Thaman 2004).

![Figure 30: Coastal erosion in Tagaqe village](Photo: Lavenia Tawake)

3.6.4 Logging, Soil Erosion, Flooding and Siltation

Pine Logging is carried out upriver of Komave, Navola and Votua villages and on the slopes above Tagaqe and Namada and is thought to be a major cause of soil erosion. Soil erosion is the removal of soil from upper land to lower land due to uprooting of trees whose roots hold the soil together.

River flooding during heavy rains is another major concern along the Coral Coast. In two villages, Votualalai and Korotogo, the construction of the Queens Highway has contributed to the flooding in the village. In Korotogo the road is higher than the village and inappropriately constructed culverts lead to flooding in the village during heavy rain. Siltation is the deposition of silt and is an ongoing process along the beaches in Namatakula, Komave, Navola, Tagaqe, Vatukarasa and Korotogo especially during heavy rain (Pitman et al. 2001).
3.6.5 Social Changes and Conflicts

Apart from the negative impacts tourism may have on the environment, tourism also has some negative social impacts on local communities on the Coral Coast including changes in cultural attitudes and reliance on hotel employment rather than pursuing further education (Thaman 2002).

In addition, the absence of cross-sectoral planning often leads to conflict among coastal resource uses. A common conflict is between land-based activities and harvesting of coastal resources. Erosion, sedimentation and flooding caused by poorly managed agriculture and logging threaten the long-term productivity of coastal ecosystems and affect tourism activities such as hiking and freshwater swimming (ESCAP 1998). Another conflict exists between tourism and coral harvesting activities in certain areas as a result of degradation of coral reefs. Solutions need a coordinated effort of several government departments including Native Land Trust Board, Forestry, Fisheries, Environment, and Tourism (Thaman 2002).

Conflict over the management of marine resources also occurs between local people within one tikina as a result of some members choosing to exploit the reefs for economic gain and others wanting to stop the activity and use the resources in a sustainable way. Resort owners, particularly in the past, often laid claim to the marine environment fronting their land and would often not allow nearby villagers to cross the beach or use the lagoon. Recently, the local communities are now claiming that they have accessibility rights to lagoon and reef areas and those tourist operators should pay them to use these areas for recreation. This has led to conflict in some instances (Thaman 2002).
3.7 Recent Coastal Management Initiatives

The Coral Coast has many examples of promising initiatives by government agencies, NGOs, village communities, hotels, and other organizations, which make up the ICM committee. This ICM committee engaged in meetings and workshops and draw up action plans for the local communities. The Coral Coast is leading the way in Fiji in mangrove replanting to improve fisheries and address coastal erosion. The efforts are currently been led by a Japanese environmental group called the Organization for Industrial, Spiritual, and Cultural Advancement (OISCA) working together with a local group and carried out by village groups, schools or visiting Japanese volunteers. In the past the South Pacific Action Committee for Human Ecology & Environment (SPACHEE) and USP also carried out mangrove replanting in the study area and at other sites outside of the Coral Coast (Thaman 2002).

Korolevu i Wai and Cuvu districts have both established Environment Committees and a number of village level marine resource management activities are also being carried out or are pending including bans on coral harvesting, restrictions on fishing, monitoring of beche de mer fishing, and discussions on setting up a Marine Protected Areas (MPA) An MPA in Fijian is called a “tabu” area. This is an area where no one is allowed to fish for certain period of time (Thaman 2002).

In the past USP, Ministry of Tourism, Department of Environment, Fijian Affairs Board (FAB), World Wide Fund for Nature (WWF) in Lomawai district west of Coral Coast and Foundation for the Peoples of the South Pacific (FSP) in Cuvu district have conducted workshops on coastal and marine issues along the Coral Coast. Villages indicated that awareness programs on conservation of their coastal resources are greatly needed (Thaman 2002).

The FSP is carrying out a community based reef conservation programme in Cuvu Tikina. The initiative involves local communities and the Shangri-La Fijian Resort in promoting sound marine resource management, introducing active coral planting
methods for habitat enhancement, and in developing sustainable income generating incentives (Terry 2004). The recent coastal zone conservation and management projects in the Coral Coast study area are being used as a basis for a National Policy Paper (NPP) for ICM (Thaman 2002).
Chapter 4 Methods and Techniques of the Research

This chapter explains the methods and techniques used for this research. The major technique employed in this research is the use of remote sensing (RS) data, which are the aerial photographs with the help of geographical information systems (GIS) tools to analyse these aerial photographs.

4.1 Remote Sensing (RS) and Geographic Information System (GIS)

Within RS and GIS there are tools that allow spatial analysis and subsequently change detection, the main technique that was chosen for this research. The main reasons for choosing the change detection technique using RS data and GIS tools are listed below:

They are:

1. Readily available, the GIS software needed for this research are already on hand, they are Map Info, Arc View (viewing the IKONOS satellite image) and the image processing software, ERDAS.
2. Cheaper to purchase, for instance, the aerial photographs are available at affordable prices.
3. Easy to use the tools available in the GIS software like Map Info and image processing software, ERDAS.

4.1.1 Remote Sensing (RS)

This research lists all the RS data that are available with some of their descriptive information. It then chooses the one that is most suitable for this type of research analysis.
4.1.2 Data Available

- 1967 – 1994 Aerial Photographs (1-2 m resolution)
- 1975 – present Landsat (15-60 m resolution)
- 2002 – present Ikonos (1-4 m resolution)
- 1986 Paper topographic maps 1:50,000 (15-25 m resolution)
- 1980 PWD Digitised map 1:10,000 (3-5 m resolution)

From the data available above aerial photographs were chosen as the best and most appropriate image data to be used for this change detection analysis. Aerial photographs were used because these are the only data available right from 1967 onwards and the latest is in the year 1994 in the case for Fiji. These aerial photographs are available and once scanned with appropriate resolution it will have the best resolution from 1-2 m resolution.

Other satellite images available like Landsat were only available from 1975 onwards. For example there are 8 satellite images available in the Pacific as shown in Table 3. The resolution for Landsat images ranges from 15 m to 60 m, which is not applicable to this type of analysis. The availability of satellite images in the Pacific is very limited. Most of these Pacific islands do lack the technology and finance to purchase them. For example the IKONOS image was only available in the year 2002 while Landsat image was available from 1970s.


**Table 3: Satellite Images Available in the Pacific**

<table>
<thead>
<tr>
<th>Satellite Images</th>
<th>Resolutions</th>
<th>Costs of Satellite Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CartoSat 1</td>
<td>Spatial resolutions- 2.5 m panchromatic, no multi-spectral</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. $US 1,800 per scene of 27.5 km by 27.5 km. Area of interest, which will cost $US 2.75 per square km.</td>
<td></td>
</tr>
<tr>
<td>2. SPOT 5</td>
<td>2.5 m or 5 m panchromatic and 10 m multi-spectral</td>
<td>$US 6.750 per scene -2.5m panchromatic ($US 1.88 per square km)</td>
</tr>
<tr>
<td></td>
<td>-$US 3.375 per scene (60 km x 60 km) -5 m panchromatic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-$US 3.375 per scene (60 km x 60 km) -10 m panchromatic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-$US 3.375 per scene (60 km x 60 km) -10 m multi-spectral data</td>
<td></td>
</tr>
<tr>
<td>3. EROS-A1</td>
<td>1.8 m panchromatic, no multi-spectral</td>
<td>-$US 12 per square km for new collection</td>
</tr>
<tr>
<td></td>
<td>- $US 5 for archive data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-minimum purchase area is 25 square km for archive data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-100 square km for new collection</td>
<td></td>
</tr>
<tr>
<td>4. IKONOS</td>
<td>1 m panchromatic, 4 m multi-spectral</td>
<td>-$US 13.50 per square km for multi-spectral image new collection</td>
</tr>
<tr>
<td></td>
<td>- minimum purchase is 100 square km.</td>
<td></td>
</tr>
<tr>
<td>5. Orb View-3</td>
<td>1 m panchromatic, 4 m multi-spectral</td>
<td>-$US 14 per square km -4 m multi-spectral and 1 m panchromatic image data</td>
</tr>
<tr>
<td>6. QuickBird</td>
<td>60 cm panchromatic, 2.5 m multi-spectral</td>
<td>- US $16 per square kilometer ($41.44 per square miles)- 60 cm panchromatic (archive data)</td>
</tr>
<tr>
<td></td>
<td>- Min Order: (25 sq. kms)= (9.6 square miles)</td>
<td></td>
</tr>
<tr>
<td>7. Landsat 7</td>
<td>15 m panchromatic, 30 m multi-spectral</td>
<td>-free download</td>
</tr>
</tbody>
</table>

*(Source: SOPAC)*
4.1.3 Aerial Photographs (AP)

Aerial Photographs are the main image data used for this research.

Table 4: Aerial Photographs of 1967 to 1994

<table>
<thead>
<tr>
<th>Years</th>
<th>Number of aerial photographs in each year</th>
<th>Scale for each Aerial Photographs</th>
<th>Time Difference (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>12</td>
<td>1:24 000</td>
<td>11yrs (1967-1978)</td>
</tr>
<tr>
<td>1978</td>
<td>12</td>
<td>1:26 000</td>
<td>8yrs (1978-1986)</td>
</tr>
<tr>
<td>1986</td>
<td>6</td>
<td>1:54 000</td>
<td>8yrs (1986-1994)</td>
</tr>
<tr>
<td>1994</td>
<td>5</td>
<td>1:50 000</td>
<td>27yrs (1967-1994)</td>
</tr>
</tbody>
</table>

NB. The time difference in the last column shows the number of years between the analysis time periods.

The other data that are used together with the aerial photographs are:

1) The IKONOS satellite image
2) The Public Works Department’s (PWD) Road Layer and the new GPS surveyed roads.
3) The Topographic map of Sigatoka Coral Coast
4) The Multi-Temporal Images from Aerial Photographs

These data can also be called the GIS backdrops and are explained in detail below.

4.1.4 IKONOS Satellite Image Data

The IKONOS image (Figure 31) for the Sigatoka Coral Coast was purchased in the year 2002 through a European Union (EU) project. Its spatial resolution is 4 m for the multi-spectral channels and 1 m for the panchromatic channel. This was geo-referenced using the ERDAS software. Geo-referencing the IKONOS satellite image produced the satellite image backdrops (4 m resolution) but they could not be used for rectifying the aerial photographs with 1 m resolution.
Figure 31: The rectified 4 m IKONOS satellite image with the tikina boundaries and villages understudy for this research
The geo-referencing of this IKONOS image allows assigning of coordinates of points on this image. This geo-referencing is called “polynomial rectification second-degree method” under ERDAS Image analysis tools. This polynomial rectification of second degree was used for the rectification of IKONOS satellite image because it requires only limited number of ground control points compared to the aerial photographs which requires rubbersheeting method, more ground control points. Arc View was used for viewing the IKONOS satellite image at earlier stages of this study but then later shifted to Map Info due to data compatibility and licensing issues.

4.1.5 Vector Data Layers

The two vector layers (Figure 32) used for this research are the PWD road and the new GPS surveyed road layer of the Sigatoka Coral Coast. The GPS survey was done to create more ground control points to rectify the aerial photographs. This is because the PWD road layer only shows the major roads. The two layers were recorded at different times and undergo differential global positioning system correction (DGPS). DGPS allows them to have better than ±5 m accuracy. Both layers are similar as they have a scale of 1: 10 000 compared to other data sources. This PWD road layer and the new GPS surveyed layer are used as reference layers for the geo-referencing of the IKONOS satellite image and aerial photographs. They are more accurate compared to other data sources. Other data sources like topographic maps have a scale of 1: 50,000, which are not as accurate as these vector layers. This is referring to the L29 and M29 topographic map sheets of the Fiji Map and other layers.
Figure 32: The vector layers. The Public Works Department and the Global Positioning Systems (GPS) surveyed roads with its coordinate systems in longitudes and...
latitudes, degrees, minutes and seconds. The first map shows Sigatoka Coral Coast within the Fiji map and the second map shows only the Sigatoka Coral Coast with its coordinates

4.1.6 The Topographic Maps

The topographic maps of Sigatoka Coral Coast that covers the study area were also used in this research as guidance while doing the GPS survey and also while doing the rectification process. The L29 and M29 sheets indexes according to the Fiji Map Index were used. These topographic maps have a scale of 1:50 000 and a resolution of 50 m. Figure 34 shows the L29 topographic map sheet that was used while rectifying the aerial photographs. L29 topographic map is shown as an example of a topographic map. M29 was also used but not displayed.

4.1.7 The Multi-Temporal Images

Multi-temporal image is an image created by putting together three black and white aerial photographs image from different time periods or in other words the combination of the three image layers to one three-layer image file. A model in Figure 33 shows this process. Different layers can be combined to a synthetic image to highlight changes in mangroves and development areas in different years. The corresponding ERDAS module Layer Stack requires that all image layers not only have the same projection but also the same pixel resolution. Layer Stack is the tool used while using ERDAS software to put together these three black and white aerial images to create the multi-temporal image. The pixel values for this rectification is 2 m. Pixel resolution means the number of pixels that can determine the shape or size of an object. All the three images were already in the same scale and pixel values of 2 before it undergoes the layer stacking process.

The multi-temporal image was used to visualize changes in vegetation in different colours. The three colours, the red, green and blue, created from this multi-temporal
image signify changes in three different time periods whether there is removal or replanting of forest or vegetation. Red, Green and Blue (RGB) are the three main colours in the multi-temporal images. Other colours created are either a mixture of red and green, red and blue and blue and green and they also show changes in mangroves and development areas between years. GIS users call these mixtures of colours additive colours (Forstreuter 2000).

Figure 33: A model showing creation of multi-temporal images
4.2 Geographical Information Systems (GIS)

GIS software that were used for this research are Map Info and ERDAS Imagine Analysis. Map Info allows digitising and overlays of data for this research. Digitising is the drawing of line or polygon feature using the drawing tools in Map Info and ERDAS. Overlay is putting data layers on top of each other in different time periods to show areas of change. ERDAS is image analysis software that was also used for this research to geo-reference and correct both the IKONOS satellite image and the aerial photographs. The ERDAS tool allows the resampling, mosaicing, cutting and creation of multi-temporal images. These terms are discussed later in the chapter. Using ERDAS Imagine analysis software the aerial photographs of 1967, 1978, 1986 and 1994 were corrected.

Rectification is the process of correcting of images such as air photos, whereby an image is converted from image coordinates to real-world coordinates. Geo-referencing is the process of assigning coordinates to points on the image.

4.3 Global Positioning System (GPS)

A GPS survey was employed in this research in order to survey the new logging roads along the Sigatoka Coral Coast. The Public Works Department (PWD, Fiji) road layers only cover the major roads but not all the minor ones and the new logging roads. This GPS survey surveyed the new logging roads that help in the rectification of the satellite images and the aerial photographs. The end product of surveying and rectifying is change detection maps that show coastal changes in coastline and mangroves. The scientific information provided by these change detection maps helps coastal managers and decision makers in resolving some coastal management issues.

The GPS units were set up to log position data as a five-second interval that was changed on the second day to a one-second interval. The GPS units were capable of operating when placed on the dashboard of the vehicle with the unit facing forward but
when satellite coverage was poor, the units have to be held out of the window or by a member of the survey team standing outside the vehicle.

### 4.4 Change Detection Maps

Change detection maps are the third maps created by putting together two coastlines of 1986 and 1994, 1967 with 1978, 1994 with 1967 and 1967 with 1986 to show changes. The same was done with mangrove and rural development. The main purpose of change detection maps in this research is to show the changes in coastline, mangroves and rural development areas in different time periods. The different time periods are 1967, 1978, 1986 and 1994.

There are two requirements for RS images to be employed in change detection. One is the availability of imagery and scale of the project, i.e. detail and extent of information required. The image data must be available for different periods and for the same area. In this study, aerial photographs of the Sigatoka Coral Coast, Fiji during 1967, 1978, 1986 and 1994 were compared. The other main requirement is that data should be obtained with comparable characteristics and attributes and those images are acquired with the same resolution. Resolution means how much image detail an image can hold. There are four types of resolutions of a remote sensing system; they are spectral, spatial, temporal and radiometric.

Spatial resolution describes how much detail of a photographic image is visible to the human eye. The higher the resolution the clearer an image is and the lower the resolution the more picture is unclear. For example a 2 m-resolution image shows more clear features than a 4 m-resolution image. An EROS-sat 2 m resolution showed much clearer features than a 4 m-resolution IKONOS image. Temporal resolution is defined as the frequency at which images are captured in a specific place on the earth. The more frequent the image is captured the finer the temporal image is said to be. Spectral resolution is defined as number and size of the bands that can be recorded by a sensor. Sensor recorded images in bands can be either three bands or four bands. For example
the IKONOS image purchased for this study is in three bands. The last is radiometric resolution or the degree of sensitivity of the sensor to incoming radiance. One of the ways to ensure the images have the same resolution is to use the same remote sensing system (sensor, time of day, time of year, etc.) for both sets of data. Failure to satisfy these conditions may lead to error in data outputs. It is also critical to consider differences in environmental characteristics, such as haze, between the data sets. If comparable image data are not available, a less-automated approach to mapping change should be taken (Lillesand and Kiefer 1994).

4.5 Validation of Process Accuracy

Throughout this project it was essential that the accuracy of various inputs processes and interpretations of data was assessed and maximised. The three steps at which accuracy could be compromised are as follows:

1. Data Input

The information (data used) taken from RS images and analysed in a GIS depends on certain factors that need to be considered. The mangroves and coastline data were digitised and the rural development areas were cut. The aerial photographs have different scales and were scanned to standardized resolutions to improve accuracy. The scanning resolution used is discussed on Section 4.7.2. The geometric rectification allows all images to be adjusted to a single scale and resolution in order to be used for analysis. The hotspots, cloud cover and low contrast areas on the aerial photographs are omitted. This reduces the inaccuracy of using coastline, mangroves and rural development areas. The images have to be correctly rectified before use (Refer to Section 4.7.3). A standard procedure for the rectification process needs to be followed correctly at all times.
2. Processing methods (i.e. rectification)

One method of image rectification is called polynomial rectification. This means the accuracy of using Polynomial Rectification for correcting the IKONOS satellite image is determined by some factors. The accuracy is calculated from the provided ground control points (GCPs) and it determines how far the GCPs actually are placed by the equation applied. It also sees if it is the best accuracy the correction can have. The accuracy has to be determined by checks. The analysis section in chapter 5 (Section 5.5-Coastline Analysis, p. 131) explains on the error values of IKONOS satellite image rectification.

Another type of rectification is called Rubbersheet rectification. The rubbersheet rectification determines the accuracy of the resulting image by using a tool called the Link and Unlinks viewers’ tools under the ERDAS Image tools. Using the Link/Unlink viewer tool the reference and rectified layers have to be link together. The location of an area selected should be on the exact location on both the reference and rectified images.

The multi-temporal images also help in getting the accurate resulting image for analysis. To explain further, the multi-temporal image now has three layers of different years. So if these layers are not fitted together then the images are not correctly rectified (Pouncey et al. 1999).

3. Interpretation of findings

The digitising of coastlines and mangroves deals with object interpretation which caused confusion at times. The accuracy of digitising mangroves and coastlines has an error value of ±2 m. This is discussed under Section 4.9-Data Analysis. This was due to poor quality of some of the aerial photos. The vegetation lines for coastlines were sometimes unclear whether it’s a vegetation line or high water mark. The getting of output images not exactly on the same area for rural development analysis was caused by the handling of coordinates. Even not getting the exact cut area, the changes were still identified. On
the other hand, the mangrove data, generally difficult to determine whether it’s the whole mangroves sites or some other forests grow with it. These are some of the problems came across while doing this analysis but managed to overcome it with the help of software and human resources. The aerial photos of poor quality are omitted.

Determining the accurate length of the coastline is important for such coastal zone management applications as shoreline classification, erosion, biological resources, habitat assessment, and for the planning and response to natural (e.g. storm surges) and manmade disasters (e.g. oil spills). The increasing use of spatial data and GIS by organizations and researchers is a valuable tool for coastal zone management. The effectiveness of the results obtained by using a GIS is dependent upon the quality of the data that goes into these systems. These are data known as spatial data, since each geographic feature in the database has its own geographic coordinates such as longitude and latitude. Another important aspect of spatial data is that of scale. As with a map, spatial data contains geographic information that is limited to the scale of the database. For example, a 1:100,000-scale map does not show as much detail as a 1:50,000 scale map because it displays an area that is four times smaller. The reduction of detail on maps is known as map generalization. Map generalization not only limits the amount of information that can be shown on a map, but it can also limit the accuracy of a map. The same is true of spatial data. Spatial data is simply information about the location, shape and relationships amongst geographic features usually stored as coordinates. They are in the form of points, lines, polygons or pixels. This work demonstrates how three different types of spatial data produce different results for coastline change, rural development areas and area of change on mangroves areas of particular concern along the Sigatoka Coral Coast, Fiji. Table 5 shows the level of accuracy of data and processes used while doing this research.
**Table 5: Level of accuracy of data and processes used**

<table>
<thead>
<tr>
<th>Data and Technique Used</th>
<th>Level of Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Public Works Department and GPS surveyed Roads</td>
<td>±5 m</td>
</tr>
<tr>
<td>2. Scanning of aerial photographs</td>
<td>±1-2 m</td>
</tr>
<tr>
<td>3. Geo-referencing of IKONOS image</td>
<td>±4 m</td>
</tr>
<tr>
<td>4. Rectifying Aerial photographs</td>
<td>±0 m</td>
</tr>
<tr>
<td>5. Digitising</td>
<td>±2 m</td>
</tr>
</tbody>
</table>

### 4.6 Data Preparation

This section describes the technical steps taken to analyse the aerial photographs. It also shows the study areas for coastline, mangroves and rural development areas. It also shows some examples of the analysis results.

#### 4.6.1 Aerial photographs to digital coastlines, mangroves and rural development areas

The following section describes how Geographic Information System software is used to derive digital coastlines, delineate boundaries of mangrove areas and rural development areas from aerial photographs. This detailed process is followed for each photograph to ensure consistency and accuracy in the mapping of historical change.

First, the photos are scanned and stored as Tagged Image File Format (TIFF) images, a type of image file format that allows image to be opened both in ERDAS Imagine Analysis software and also in the Map Info Environment. The next step is to register the photos to the local map projection, which is called the Pacific Standards Transverse Mercator WGS 72 coordinate system using reference marks and ground control points. A process called rubbersheet around the aerial photographs based on the control points then digitally stretches the image. Once the photos are rectified, they are compiled to create a mosaic. The mosaic consists of individual photographs joined together to form a single image of a segment of the whole study area. The mosaic image also undergoes
cutting to include just a segment of a coast. Coastline reference features, including the vegetation line, are drawn from the cut and mosaic images.

The digitising process is accomplished with the mosaic and cut displayed as a backdrop image. The operator traces the features of the vegetation based on the appearance of the background image. This process also allows the operator to zoom in to identify the features clearly on the beach. The resulting data is a vector, or line coverage of the vegetation line, that can be included in the GIS database and used for coastline change analysis. The topographic map sheets of L29 and M29 with 1:50 000 scale were used as guidance for digitising mangroves and locating rural development areas such as villages and settlements.

4.6.2 Flow Charts for Steps for Data Preparation

This section lists these technical steps in flow charts and then in the later section these technical steps are explained in detail.

![Flow Chart 1: Geo-referencing IKONOS image](image)

Figure 35: Flow Chart 1: Geo-referencing IKONOS image
Figure 36: Flow Chart 2: Geo-referencing aerial photographs
4.7 Steps of Data Preparation

The flow chart shown in Figure 31 shows the steps taken to geo-reference the aerial photographs using the 4 m coloured IKONOS image with the overlaid PWD roads and GPS surveyed roads. Below are explanations of all the steps taken.

4.7.1 Data Acquisition

The IKONOS satellite image has clear features like houses, forest areas and roads that are easily identified. These features are useful during the rectification process and also for analysis.

Historical aerial photographs were purchased from the aerial photo section of the Lands Department of the Fiji Government. The Land Resources Planning Section of the Ministry of Agriculture and Resettlement Unit of Fiji also supplied aerial photographs for this study.

The aerial photographs were purchased depending on the factors listed below.

- Covered the area of interest—All the aerial photographs purchased all covered the study area.
- Covered a long time period (e.g. 1950s-1994)
- Were of good quality—the 1954 aerial photographs are omitted due to poor quality so only the 1967, 1978, 1986 and 1994 air photos were used in this study. The 1954 aerial photographs were seen as poor quality because a lot of contrast on the images. The white areas seen on the aerial photographs can be cloud cover during the time the photos were taken.
4.7.2 Scanning of Maps and Aerial Photographs

The scanning exercise was needed to create image, which was subsequently used for digitising work. The image backdrop is the resulting image created after geo-referencing and rectifying. This image backdrop is explained later in this chapter. The standard resolution for scanning these aerial photographs was 600 and 1200 dots per inch (dpi) in order to retain high optimal resolution. The 600 dpi resolution was required for the 1967 and 1978 and 1200 dpi was required for the 1986 and 1994 aerial photographs. These aerial photographs were scanned using standard flat bed scanner, A3 size. Once these aerial photographs were scanned, the resolution of the image became approximately 1 m. These figures are highlighted in bold on Table 6. The accuracy of determining the features on the ground is approximately 2 m in pixel. These figures are shown too under the heading “Accuracy on the ground” in Table 6. Table 6 also shows the results of accuracy and pixel size on the ground using scanning resolution of 600 dpi for all aerial photographs. The results from using 600 dpi 1: 24 000 and 1: 26 000 and 1200 dpi for 1: 54 000 and 1: 50 000 is more accurate compared to using only 600 dpi for scanning all aerial photographs. So the scanning resolution size of 600 dpi for 1: 24 000 and 1: 26 000 and 1200 dpi for 1: 54 000 and 1: 50 000 were used in this thesis study. Table 6 also depicts that the distinguishable of features on an aerial photograph depends on the quality of the aerial photographs but mathematically (theoretically) the objects should be distinguishable at 1 m apart after scanning at the selected resolutions, at 600 and 1200 dpi. The interpretation of the three data, coastline, mangroves and rural development sites was easy and took only a short time as the features are distinguishable at that level. The aerial images don’t appear blurry at that 1-2 m pixel size. But this analysis doesn’t need to zoom that far as the clear images produce after scanning and rectification is clear enough to identify the three data (coastline, mangroves and rural development sites) used for this research.
Table 6: The standard scanning resolution for each year with their different scale.

The scanning resolutions, scale and pixel resolutions in bold are the ones used for this research.

<table>
<thead>
<tr>
<th>Year</th>
<th>Scale</th>
<th>Pixel size on the ground, m</th>
<th>Accuracy on the ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>24000</td>
<td>1.0</td>
<td>2.03</td>
</tr>
<tr>
<td>1978</td>
<td>26000</td>
<td>1.1</td>
<td>2.20</td>
</tr>
<tr>
<td>1986</td>
<td>54000</td>
<td>2.3</td>
<td>4.57</td>
</tr>
<tr>
<td>1994</td>
<td>50000</td>
<td>2.1</td>
<td>4.23</td>
</tr>
</tbody>
</table>

scanning resolution, dpi 600
pixel size on image, mm 0.042333
<table>
<thead>
<tr>
<th>Year</th>
<th>Scale</th>
<th>SCANNING RESOLUTION USED</th>
<th>Pixel size on the ground, m</th>
<th>Accuracy on the ground</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Scanning resolution, dpi</td>
<td>Pixel image</td>
<td></td>
</tr>
<tr>
<td>1967</td>
<td>24000</td>
<td>600</td>
<td>0.042333</td>
<td>1.0</td>
</tr>
<tr>
<td>1978</td>
<td>26000</td>
<td>600</td>
<td>0.042333</td>
<td>1.1</td>
</tr>
<tr>
<td>1986</td>
<td>54000</td>
<td>1200</td>
<td>0.021167</td>
<td>1.1</td>
</tr>
<tr>
<td>1994</td>
<td>50000</td>
<td>1200</td>
<td>0.021167</td>
<td>1.1</td>
</tr>
</tbody>
</table>
4.7.3 Geometric Image Rectification

Geometric correction allows the process of linking each picture element (pixel) with the x and y co-ordinates of the required map projection (Luis and Jose 2004). Rectification transforms the source image, which contains the source Ground Control Points (GCP), to the referenced image, containing the reference GCP, but within a different grid.

Geometric Correction was required for both the satellite images and aerial photographs due to some valid reasons. Both the images contain a number of geometric distortions that are unavoidable during the recording process and also due to the shape and rotation of the earth. An uncorrected image will therefore bear a different geometry to that of a map and consequently be hard to use in a compatible manner (Alasdair 2000). Therefore rectification was performed on these aerial photographs and IKONOS image.

Other reasons that geometric rectification is needed for both the IKONOS satellite image and aerial photographs in this research are also stated below.

I) To compare images to the field data and topographic maps
II) To allow precise analysis information when comparing layers within aerial photographs

1) Polynomial rectification of second degree is used for rectifying the IKONOS image. This polynomial rectification of second degree was performed for the IKONOS image to register the image to the real world coordinates. The bilinear interpolation was used as a resampling method, an image processing end method while doing the correction in ERDAS Imagine Analysis. Bilinear interpolation uses the weighted average of the nearest four pixels to the output pixel and produces a smooth image compared to the stair step effect caused by the Nearest Neighbor resampling method. However, bilinear interpolations have the disadvantage of altering the original data and reducing contrast by averaging neighboring values together. It is also computationally more expensive than nearest neighbour (Forstreuter 2000). The overlay of the IKONOS image with the PWD and GPS surveyed roads layers is shown in Figure 37.
Figure 37: The rectified IKONOS image with the PWD and GPS surveyed road layers
2) **Rubber-sheeting rectification** is used for rectifying the aerial photographs for this research. Unlike the polynomial correction methods, the rubber-sheet correction method transfers every ground control point exactly to its defined destination. Between three ground control points the software applies a linear transformation ensuring that the edges match exactly. There is no need to cut an image into sub-images. However, depending on the terrain, many ground control points are required.

In order to check for the accuracy of image rectification both the reference image and the rectified image have to be displayed using the ERDAS Imagine analysis tool. Then using the Link/Unlink Viewer tool one location in the reference image should be at the exact location as the rectified image. If not then the images need to be re-rectified.

The Ground Control Points were located on cultural features like houses, intersection of roads and new GPS surveyed roads, on the junctions of two or three roads. After all the GCPs have been located then the images have to be resampled. Resampling is the process of assigning of data values (DNs) to the pixels on the new grid of the transformed image by extrapolation from the original file. The IKONOS image and aerial photographs both used the *nearest neighbour* resampling method. The nearest neighbour approach uses the value of the closest input pixel for the output pixel value. The pixel value occupying the closest image file coordinate to the estimated coordinate was used for the output pixel value in the geo-referenced image. One of the advantages of using nearest neighbour is that output values are the original input values. It is easy to compute and faster to use. On the other hand it produces a choppy stair stepped effect in the image.

Once all the aerial photographs are geographically referenced, they have to be stitched to one homogeneous layer. ERDAS module Mosaic stitched these layers together to one layer for each of the four years. An example of a mosaic image is shown in Figure 38.
Figure 38: The 1967 mosaic image with the PWD and GPS surveyed roads layer overlaid on top
3) **Mosaicing** of images using ERDAS Imagine allows cutting of the overlapping parts and also smoothens the transition between different images. In cases where mosaic is not needed, the rectified layers were just cut straight away after being geo-referenced. Such cases include where the portion needed is just in one layer.

4) **Cutting** of images allows portions with change to be shown clearly in the change detection maps. The cutting of image also shows the area of interest. This process is also done in ERDAS software (Forstreuter 2000).

The mangrove areas, coastline and rural development areas within the study area were then digitised using Map Info. Within this study area there were four mangrove areas. Likewise for the coastline data, the mosaic images of the four years were cut into smaller portions and then digitised. The cutting of these coastline portions into smaller areas was done in order to clearly show the areas of coastal erosion and accretion. Accretion is a term used for areas where building of sand or accumulations of sand are found. Erosion is a term used to areas where sand has been removed or washed away. The rural development areas, which include the resorts areas and villages, were also chosen and cut to show areas of change within these four years.

**4.8 Production of Multi-Temporal Images**

The next step was the creation of a multi-temporal image, that is the combination of three single-layers taken at different times to one three-layer image file. The point is to create a coloured image from three black and white aerial photographs of three time periods. Using the Layer stack tool in ERDAS, the three black and white aerial photographs of three time periods were stacked together.

For example this was done for the creation of multi-temporal image of Nasinu Town, in Fiji. The multi-temporal image of Nasinu was created in order to visualise and map the squatter settlements growth over township. The 1973, 1986 and 1998 black and white aerial photographs were corrected and the three layers were assigned with colours. The
1998 was assigned the red band, the 1986 layer was assigned the green band and the 1973 layer was blue (See Figure 39 and Table 7). (Source: Forstreuter et al. 2002)

![Figure 39: The multi-temporal image of Nasinu town, Suva](image)

**Table 7: The visualisation of changes in the Multi-temporal images**

<table>
<thead>
<tr>
<th>Colours</th>
<th>Changes in the Multi-temporal image (Change detection image)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Houses built between 1986 and 1998</td>
</tr>
<tr>
<td>Green</td>
<td>Houses or Roofs built between 1973 to 1986</td>
</tr>
<tr>
<td>Blue</td>
<td>Houses built before 1973</td>
</tr>
<tr>
<td>Black</td>
<td>The location of vegetation on all the three years, 1973, 1986 and 1998-black spots in all three years will appear black in the change detection image</td>
</tr>
<tr>
<td>White</td>
<td>Houses built or already there in all the three years, 1973, 1986 and 1994- white areas in all the three years will appear white in the change detection image.</td>
</tr>
<tr>
<td>Magneta</td>
<td>Houses seen only in 1973 and 1998</td>
</tr>
<tr>
<td>Yellow</td>
<td>Houses seen only in 1986 and 1998</td>
</tr>
<tr>
<td>Cyan</td>
<td>Houses seen only in 1973 and 1986</td>
</tr>
</tbody>
</table>
If features are white in all three-image layers they will appear white in the composite image also. If features are shown dark in all three layers they will also appear dark in the change detection image. If features are white in two of the three image layers they will appear in the additive mixed colour of the two corresponding layers (Forstreuter et al. 2002). So the different colours can be used to determine changes. Finally these multi-temporal images and the black and white image layers were imported into Map Info for analysis measurement of the changes in the 3 coastal parameters:

1) Coastline
2) Mangrove
3) Rural development including hotel areas and village areas

4.9 Data Analysis and Detection of Changes

The change detection analysis measures the amount of changes over different time periods for mangrove extent, coastline position and area of rural development. There are three ways of measuring and visualizing changes using these data. They are:

1) Use of multi-temporal images,
2) Toggle or Overlay between images recorded in different periods
3) On-screen digitising and quantitative area comparison

4.9.1 The use of the Multi-Temporal Image

The multi-temporal image created was based on the fact that a) vegetation absorbs sunlight and b) clearings and corrugated iron roof reflects sunlight. So while linking the layers to different colour displays, these areas show the colour intensive while vegetated areas are shown dark. A roof that was built between 1986 and 1998 will be shown intensive in the red channel while this place is shown dark in the blue and the green channel. The result is red in the multi-temporal image. A white colour on the image signifies high reflection from all the different layers, which shows houses being built
before 1973. To sum it up, the multi-temporal image created shows white areas with high reflection in both the green and the red layer and will have a mixed colour from both layers.

### 4.9.2 Toggle between the Layers

The toggle of image means cutting of three image data from three different time periods on the same area. Using ERDAS these image data were cut and resampled. These image data were put together and changes were detected across these different time periods. The increase and decrease in number of houses in different years were analysed in rural development areas. An example of toggle between layers is shown in Figure 40.

![Figure 40: The toggle of Korotogo images](image_url)
The three images shown are showing Korotogo settlement and Outrigger resort from 1978, 1986 and 1994. The arrow in the 1978 image is showing a cleared area around the Korotogo mangrove. In the 1986 image there are two arrows showing the changes that took place. The long arrow showed more houses being built in 1986 compared to the 1978, when there were only few houses. The second arrow shows that a re-growth of mangrove took place on the same area that was cleared in 1978. The 1994 image shows more and more houses being built as shown by the long arrow. The short arrow in the 1994 image still shows the clear cut that was also in the 1978 and 1986 images.

4.9.3 On-screen digitising and quantitative area digitising

This involves the digitising of these three data in Map Info. Using the tools in Map Info, mangrove data were digitised in polygons, coastline in continuous lines. These digitised layers show areas of change when overlaid together and also in quantitative figure.

Overlay is a process, which involves the integration or combination of different data layers or maps. Using more than two maps, a new map layer can be produced by overlaying the new output layer with the attributes of each layer. This detection of change in quantitative figure is made possible using Map Info tools. An example is shown in Figure 41, showing mangrove forest of Yadua along the study area.

![Figure 41: The digitising and overlay of the mangrove of Yadua/Yalasuna](image)

Overlay of 1967 with 1986
Figure 41 shows the 1967 and 1986 digitised mangrove layer of Yadua village along the study area. It clearly shows the regrowth in 1986 when overlaid with the 1967. The overlapping green mangrove cover areas are the regrowth areas. The Yadua village is shown in Figure 11 of Chapter 3.

1) **Coastline Analysis**

Another example shows the on-screen digitising and overlay to determine the area of change by the coastline analysis in Figure 42. Changes of coastline were visible through a typical example shown here in Namatakula.

Figure 42: The aerial image backdrop of Namatakula with digitised coastlines.
The 1986 and 1994 coastlines of Namatakula are shown above overlaid on top of the 1986 aerial photo. It shows movement of coastline in between these two years at an estimated rate of 4 to 12 m within the period of eight years taking into account the error values of +/-4 m. So the rate of change is approximately 0.5 m/y to 1.5 m/year from 1986 to 1994. There is receding (from 1986 to 1994) area on point A and accretion area on point B (from 1986 to 1994) between these years in Namatakula. Receding areas are movement of sand from high to lowland beach areas caused by heavy rain, rivers and floods to name a few. Accretion is the accumulation of sand on beach areas caused by rivers, waves and heavy rains. Accretion and receding processes that took place in Namatakula are caused by the two rivers that run along these areas.

Figure 43: Areas that are under study for coastline analysis
The areas that are under special consideration for coastline analysis for this research are shown in Figure 43. There are five areas that are chosen for this coastline analysis based on the quality of the corrected aerial photographs. The areas chosen for this analysis have been chosen according:
• Areas within the study area, from Fijian Resort to Namatakula
• Sites, which have good quality of aerial photographs, areas where coastline can be digitised and analysed.
• Areas that have vegetation located on the beach, since this research is using the vegetation line as the coastline. Areas that have the road running along the beach are omitted.

2) **Rural Development Areas Analysis**

A typical example of rural development area along this study area is shown in Figure 44. This is Naviti Resort in 1978 and 1994. The 1978 aerial photo shows only a few houses and more forest areas. The 1994 aerial photo shows an increase in number of houses and clearing of forests for buildings for the Naviti Resort. The studied areas for this rural development analysis are shown in Figure 45.

![1978 and 1994 aerial photos of Naviti Resort](image)

Figure 44: The Naviti resort area in 1978 and 1994
Figure 45: Areas studied for rural development areas analysis

With the use of GIS the toggle of images can be done in the Map Info environment. There were four rural development areas chosen for display. These areas were chosen according to the availability of clear images that clearly show the settlements and hotels along the study site. They are Tagaqe, the Resort areas, area that most resorts and hotels of Sigatoka Coral Coast are located, Sigatoka Town and the Fijian Resort.

3) Mangrove Analysis

The mangrove analysis also uses digitising of areas into polygons to get the quantitative figure in hectares using Map Info. It also uses the overlay process to show and measure the area of change in hectares in the different time periods. An example of digitise mangrove areas is shown in Figure 46.
Under the Mangrove Analysis in the Results chapter the data are displayed as

1) Graphs of the quantitative figure of mangrove digitised layers
2) Overlay of mangrove layers and coastline data in different years with approximate areas of change displayed.
3) Toggle of layers chosen for rural development showing change in settlement and forest cover areas
4) Multi-Temporal Image of mangrove and rural development areas in different years to visualize changes.

*Figure 46: The digitised and overlay of mangrove layers of Korotogo.* The second image is illustrating the overlay between 1978 and 1994 and the area is where there is regrowth of mangrove by 1994.
4.10 Quantifying Changes Overtime

In order to quantify the changes, the mangrove vegetation and coastline were digitised in the Map Info environment and then changes were calculated. The rural development areas were not digitised but were cut and displayed using ERDAS Imagine analysis tools. The quantitative data were useful to know the amount in figures of mangrove that has been removed or re-grown within the years.

The mangrove areas were digitised in polygons. Using the drawing tools in Map Info, a polygon tool was selected to digitise around the mangrove area. The digitised mangrove layers were then shaded in colours. These shaded mangrove layers were then compared and overlaid on top of each. Overlaid mangrove layers in different time periods showed mangrove areas that were removed and also areas that regrew.

The area of change was calculated using Map Info. The pointer tool in Map Info was used to double click on the mangrove polygon layers in order to get the area of change. The area of change will not be shown if there were some unnoticed cuts with the digitised mangrove layers. The snap button in the Map Info environment is recommended while digitising. It makes sure that ends of digitised layers snap to each other before continuing with the digitising.

One of the difficulties while digitising layers in aerial photographs is to differentiate mangrove from the other forest areas or vegetation. This is more difficult where aerial photographs have low contrast. This is one of the limitations of using aerial photographs.

The coastline layers were digitised using continuous lines in the Map Info environment. The rectified images were first cut in ERDAS Imagine analysis software. The cut image was then imported as a geo-tiff file to the Map Info environment. Geo-tiff file means the geo-referenced Tag Image File Format (geo-tiff). This file format can be opened in Map Info. The geo-tiff file was then opened and displayed using real world coordinates.
The line tool in the Map Info was then used to draw the coastline, which follows the vegetation line on the aerial photographs.

Digitising of the coastline on these aerial photographs was time consuming. This was due to the contrast of the aerial photographs that made it difficult to determine the difference between the vegetation, beaches or shade. The digitised coastline layers were then overlaid together with others in different years to show areas of accretion or erosion. This study just shows overlays of coastline in different years and approximate change in different years. This is because of the limitations of using the aerial photographs.

The rural development areas were chosen where the villages and hotels are clearly shown. The chosen area was then cut using ERDAS essentials tool. These rural development areas were then displayed and compared in different years. The arrows in Figure 45 image photo were then used to signify whether there was an increase or decrease in houses and also removal of forest or replanting of forest. For instance at the Naviti Resort, it was displayed that in 1978 there were few houses and more forest areas but in 1994 there were increased in the number of houses and excessive removal of forest. Altogether there were four development areas chosen along this study site. These rural development sites were chosen where degree of contrast is high and the image is clear.
Chapter 5 Results and Discussion

This chapter provides the description of measurement of change and presents all the results for mangrove, rural development areas and coastline position. It also presents discussion of the results of the analysis.

5.1 Change in areas vegetated by mangrove

The mangrove analysis displays all the digitised mangrove areas in different time periods with their graphs.

5.1.1 Korotogo

The images shown below are showing the digitised mangrove areas of Korotogo from 1978, 1986 to 1994. The examples of on-screen digitizing are shown first under Figure 47 then its opaque coloured polygons. The area is located next to the Outrigger Reef Resort redeveloped recently in order to cater for the increasing tourists visiting Fiji.

The Korotogo area vegetated by mangrove

![1978 Korotogo Mangrove Area](image1.png)

![1986 Korotogo Mangrove Area](image2.png)
Figure 47: The digitised mangrove areas of Korotogo

Figure 48: Quantitative analysis of Korotogo mangrove change

Quantitative analysis of mangrove in Korotogo showed a decrease of mangrove area in 1986 and an increase again in 1994. The mangrove area is mapped from where the coastline on the beach area is up to 2 km inland where the mangrove. The estimated loss of mangrove between 1978 and 1986 is 1.55 ha. The rate of change is estimated at 0.19 ha/yr from 1978 to 1986. So there was a deforestation or cutting down of mangrove
from 1978-1986 and regrowth in the 1990s. The development of the Outrigger Reef Resort that started from the 1980s has caused decrease in mangrove in Korotogo in 1986. Mangroves were cut down to create more space for building more hotel rooms. An estimated growth of mangrove in the 1990s was approximately 2.15 ha with the rate of increase of 0.27 ha/yr from 1986 to 1994. The increase in 1994 showed that some of the Non-Governmental Organizations (NGOs) helped this Korotogo community replant mangrove cuttings onto their beaches. This replanting was done in the years 1993 to 2000. Although this replanting was not in the years (1986-1994) studied it shows an awareness of the importance of mangrove, which implies cutting would have been reduced in the study area and the natural regeneration to dominate.

5.1.2 Lawalawa (Naevuevu)

![Figure 49: The digitised mangrove areas of Naevuevu](image)

Figure 49: The digitised mangrove areas of Naevuevu
This is the second mangrove area that was chosen for this analysis. It is one major mangrove area. It is located beside Naevuevu village. The quantitative figure of these four layers showed decrease and increase in the mangrove areas throughout these years. From 1967 to 1978 there was an estimated loss of 0.72 ha in the Naevuevu mangrove area. The rate of change depicts a mangrove loss of 0.06 ha/yr from 1967 to 1978. However there was a small increase through regrowth from 1978 to 1986 with an estimated figure of 1.07 ha. The rate of change showed a regrowth of 0.13 ha/yr from 1978 to 1986. An increase again happened between 1986 and 1994, in 1994 a total of another 0.65 ha, an area of regrowth. The analysis showed a regrowth of 0.08 ha/yr from 1986 to 1994. The digitised mangrove areas are shown from 1967, 1978, 1986 and 1994.

**5.1.3 Yadua/Yalasuna**

The area is located beside Yadua settlement near the Sigatoka Sand dunes. It is not a big mangrove area like the Lawalawa mangrove in Naevuevu and Korotogo, the two biggest mangrove areas considered in this study. Shown in Figure 52 is the bar graph of change at Yalasuna from the years 1967, 1986 and 1994. The Yalasuna mangrove area increased from 1967 to 1986 by an estimated figure of 0.21 ha. The analysis showed that
the regrowth area of 0.01 ha/yr from 1967 to 1986. From 1986 to 1994 there is a mangrove loss of approximately 2.29 ha and the rate of change depicts a loss of 0.28 ha/yr. The digitised mangrove areas are shown from 1967, 1986 and 1994. The 1978 mangrove was not digitise due to poor quality of the aerial photo.

![Figure 51: The digitised mangrove areas of Yadua/Yalasuna](image)

![Figure 52: Quantitative analysis of Yadua/Yalasuna mangrove change](image)
5.1.4 The Sigatoka River

1967

1978

1986
This is the fourth mangrove area that is located in the study area. It is located beside the Sigatoka River approximately 80 m from Sigatoka town. Shown in Figure 54 the quantitative figure for mangrove-digitised area of the Sigatoka river from the 1967, 1978, 1986 and 1994 years. There were more mangroves in the 1967 compared to other years with a slight decrease of 0.32 ha in 1978 then a decrease again to 1986 by 0.19 ha and regrowth again in 1994 with an estimated increase of 0.2 ha. The analysis showed a mangrove loss of 0.2 ha/yr from 1967 to 1986 and a regrowth of 0.2 ha/yr from 1986 to 1994.
Figure 55: Quantitative analysis of all the mangrove areas

Figure 55 compares the quantitative figure of all the mangrove study sites including Korotogo, Naevuevu, the Sigatoka River and Yadua/Yalasuna mangroves. It clearly shows that Naevuevu has a large mangrove area with 50 to 53 ha while the two Yadua/Yalasuna and Sigatoka River from 15 to 35 ha. The Sigatoka River has less than 5 ha in all the years, with an estimated range from 2 to 3 ha. The Naevuevu mangrove experienced loss of mangrove from 1967 to 1978 then slight regrowth from 1978 onwards. The Korotogo mangrove showed that there was mangrove loss from 1978 to 1986 but regrowth from 1986 to 1994. The Yadua/Yalasuna showed regrowth from 1967 to 1986 but loss from 1986 to 1994. The last is the Sigatoka River Mangrove, which showed that there was loss from 1967 to 1986 and a slight regrowth from 1986 to 1994. Table 8 shows the calculation of mangrove change for the study mangrove sites.
Table 8: The calculations for mangrove change

<table>
<thead>
<tr>
<th>Names of the Areas</th>
<th>Figures</th>
<th>Calculations</th>
<th>Area of Change</th>
<th>% Of Area of Change</th>
<th>Area Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Sigatoka River</td>
<td>Figure 52a</td>
<td>1978-1967 2.662-2.981 ha</td>
<td>-0.319 ha</td>
<td>-12.0%</td>
<td>Small Area from 2 – 3 ha</td>
</tr>
<tr>
<td>The Sigatoka River</td>
<td>Figure 52b</td>
<td>1994-1967 2.669-2.981 ha</td>
<td>-0.312 ha</td>
<td>-11.7%</td>
<td></td>
</tr>
<tr>
<td>The Sigatoka River</td>
<td>Figure 52c</td>
<td>1986-1978 2.467-2.662 ha</td>
<td>-0.195 ha</td>
<td>-7.9%</td>
<td></td>
</tr>
<tr>
<td>The Sigatoka River</td>
<td>Figure 52d</td>
<td>1994-1986 2.669-2.467 ha</td>
<td>0.202 ha</td>
<td>7.6%</td>
<td></td>
</tr>
<tr>
<td>Korotogo</td>
<td>Figure 49a</td>
<td>1994-1978 20.72-20.12 ha</td>
<td>0.6 ha</td>
<td>2.98%</td>
<td>Medium Area from 18 – 31 ha</td>
</tr>
<tr>
<td>Korotogo</td>
<td>Figure 49c</td>
<td>1994-1986 20.72-18.57 ha</td>
<td>2.15 ha</td>
<td>11.6%</td>
<td></td>
</tr>
<tr>
<td>Korotogo</td>
<td>Figure 49d</td>
<td>1986-1978 18.57-20.12 ha</td>
<td>-1.55 ha</td>
<td>-7.7%</td>
<td></td>
</tr>
<tr>
<td>Yadua/Yalasuna</td>
<td>Figure 51a</td>
<td>1994-1967</td>
<td>-2.08 ha</td>
<td>-6.8%</td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Location</th>
<th>Year Range</th>
<th>Area Change</th>
<th>Percentage Change</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yadua/Yalasuna</td>
<td>1986-1967</td>
<td>0.21 ha</td>
<td><strong>0.68%</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30.72-30.51 ha</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yadua/Yalasuna</td>
<td>1994-1986</td>
<td>-2.29 ha</td>
<td><strong>-7.5%</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28.43-30.72 ha</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naevuevu</td>
<td>1978-1967</td>
<td>-0.72 ha</td>
<td><strong>-1.4%</strong></td>
<td>Large Area &gt; 50 ha</td>
</tr>
<tr>
<td></td>
<td>51.08-51.80 ha</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naevuevu</td>
<td>1986-1978</td>
<td>1.07 ha</td>
<td><strong>2.1%</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>52.15-51.08 ha</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naevuevu</td>
<td>1994-1967</td>
<td>1 ha</td>
<td><strong>1.9%</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>52.80-51.80 ha</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naevuevu</td>
<td>1994-1986</td>
<td>0.65 ha</td>
<td><strong>1.3%</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>52.80-52.15 ha</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2 Overlay of images on mangrove and coastline data with its area of change shown and approximate areas of change in quantitative figure.

The overlay of mangroves showed all the four mangrove sites. The overlays are either between 1967 and 1978, 1986 with 1994, 1967 with 1994 and 1978 with 1986 layers. From the overlays then the area of change is calculated in the Map Info environment and displayed on the different mangrove areas. Figures 56 to 59 show the overlaid digitised mangrove outlines of the four mangrove sites. The digitised mangrove outlines show the accuracy of digitising and the opaque overlays clearly show the area of change.

5.2.1 Korotogo

The overlay of 1994 mangrove area on top of the 1978 mangrove area is shown in Figure 56a. Figure 56a shows an increase or regrowth in 1994 as shown by the dark pink areas. The regrowth area is clearly shown when the 1978 is overlaid on top of the 1994 mangrove in Figure 56b. The area of change and extended area in 1994, which is in pink in Figure 56b (2) is approximately 0.6 ha. Figure 56a is the overlay of 1994 on top of 1978 mangrove layer on the 1978 aerial backdrop. Figure 56b is the overlay of the 1978 on top of 1994 mangrove layer on the 1994 aerial backdrop.

Figure 56a (1) Figure 56a (2)

Figure 56a: Overlay of 1994 with 1978
Figure 56b (1)  Figure 56b (2)

Figure 56b: Overlay of 1978 with 1994

Figure 56c (1)  Figure 56c (2)

Figure 56c: Overlay of 1986 with 1994
Figure 56c shows the overlay of the 1986 with the 1994 mangrove layer on top of the 1994 aerial image backdrop. The 1986 is in light pink and the 1994 is in dark pink color. The area of regrowth in 1994 is approximately equal to 3.83 ha that is quite visible in Figure 56c (2) in overlap dark pink areas.

Figure 56d (1)

Figure 56d: Overlay of 1978 on top of 1986

Figure 56e (1)

Figure 56e: Overlay of 1986 on top of 1978
Figure 56d shows the area being cleared in 1986 when overlaid with the 1978 image layer on top of 1986 aerial backdrop. The cleared area in 1986 is approximately 1.55 ha. Figure 56e shows the overlay of 1986 on top of 1978 on the 1978 aerial backdrop. It clearly show the mangrove area in 1978 before some deforestation took place in 1986. The digitised of these mangrove outlines were done in the entire four mangrove study sites before converted to opaque overlays to clearly show the area of change.

5.2.2 Naevuevu

The overlay in Figure 57a is the overlay between 1967 in green and 1978 in yellow on top 1978 aerial backdrop. There is a decrease in the mangrove area in 1978 so a slight removal of mangrove in 1978. Figure 57a illustrates the area being removed in 1978 with the 1978 overlaid on top of 1967 mangrove layer. The removed mangrove area is 0.72 ha (green areas when overlaid with 1967) which is shown on Figure 57a (2).

Figure 57a: Overlay of 1978 with 1967
Figure 57b: Overlay of 1978 with 1986

Figure 57b is the overlay of the 1978 on top of 1986 layer on the 1986 aerial image backdrop. There is an increase or regrowth of mangrove area from 1978 to 1986. The 1978 mangrove is in yellow and the 1986 in purple colour. The area being regrown is 1.07 ha which is shown by the purple layers in Figure 57b (2).
Figure 57c: Overlay of 1994 with 1967

Figure 57d: Overlay of 1986 with 1994

Figure 57c is the overlay of the 1967 on top of 1994 mangrove layer on the 1994 aerial image backdrop. There was a regrowth and replanting of mangrove in Naevuevu that is shown by the overlay in Figure 57c. The estimated figure of regrowth in 1994 is 1 ha.
which is visible in the light red areas in Figure 57c (2). The fourth overlay in Figure 57d is the overlay of 1986 with 1994 image on top of 1986 aerial image backdrop. The overlay showed an increase or more regrowth of mangrove from 1986 to 1994 with an estimated figure of 0.65 ha as shown by the light red areas in Figure 57d (2).

5.2.3 Yadua /Yalasuna

Figure 58a: Overlay of 1967 with 1994

Figure 58b: Overlay of 1967 with 1986
The overlay of mangrove area in Yalasuna between 1967 and 1994 on top of 1994 aerial backdrop is shown in Figure 58a. The 1967 layer is shown in orange and green is for the 1994 layer. The digitised image shows an increase in the mangrove areas by the year 1994 (green layers in Figure 58a (2). The area cleared in 1994 is approximately 2.08 ha. Figure 58b is the overlay between the 1986 and 1967 layer on top of 1967 aerial backdrop. It also shows an increase in mangrove areas of an estimated figure of 0.21 ha (which is visible in Figure 58b (2), the dark green layers). The overlay Figure 58c showed a decrease from 1986 to 1994, a decrease of an estimated 2.29 ha. The light green colours show the deforested areas in 1994 when the 1994 layer is overlaid on top. The 1986 aerial image is the backdrop for the overlay of 1986 and 1994.

5.2.4 The Sigatoka River

Figure 59a (1)
Figure 59a: Overlay of 1978 on top of 1967 mangrove layer

Figure 59b: Overlay of 1994 on top of 1967 mangrove layer

Figure 59a shows the overlay of 1978 with the 1967 mangrove layer. The overlay shows a decrease from 1967 to 1978 of 0.32 ha. The cleared areas are shown in Figure 59a (2).
(the blue areas). The overlay of the 1994 with the 1967 mangrove area of the Sigatoka River is shown in Figure 59b. The 1967 mangrove is in light blue while the 1994 in purple colour. The overlay shows a slight decrease in the mangrove areas between the two years. The overlay depicts that there was a process of deforestation between these years from 1967 to 1994. The area of change between these two years is 0.31 ha (Figure 59b (2)).

Figure 59c (1)

![Figure 59c (1)](image)

Figure 59c (2)

![Figure 59c (2)](image)

Figure 59c: Overlay of 1986 on top of 1978 mangrove layer
The 1978 (orange) and 1986 (green) mangrove layers were overlaid on top of the 1978 aerial backdrop. In showing the overlay of 1978 with the 1986 image in Figure 59c, the overlay is showing the decrease in mangrove is 0.19 ha (Figure 59c (2). The overlay of 1994 (purple) with the 1986 layer (green) showed an increase of mangrove area with an estimated figure of 0.2 ha. This is shown in Figure 59d and more visible in Figure 59d (2).
5.3 The use of Multi-Temporal Images

Another data analysis method that was discussed earlier under the Methods and Techniques chapter is the use of Multi-Temporal Images to show changes on mangrove.

Mangrove Analysis
The four mangrove areas already discussed are shown again here with their multi-temporal images. The multi-temporal images visualise changes qualitatively on all areas.

5.3.1 Lawalawa (Naevuevu)

Figure 60: The multi-temporal image of Lawalawa mangrove
The multi-temporal images that are created for this analysis have the

1978-assigned the blue colour
1986-assigned the green colour
1994-assigned the red colour

The red areas in the multi-temporal image of Naevuevu in Figure 60 showed all parts reflected white in the 1994 image and which are dark in the corresponding images of 1986 and 1978. The green areas are parts only shown white in the 1986 image and are dark in the corresponding images of 1978 and 1994. The blue areas are parts shown white in the 1978 and are dark in the corresponding 1986 and 1994 images in the change detection image. The dark areas are areas that are shown dark in all the three layer images. The subset of the change detection image showed that the large areas in red are cleared mangrove area in 1994. The green areas are cleared mangrove area in 1986. The blue areas are cleared mangrove area in 1978.

The dark areas are the Naevuevu mangrove areas. The multi-temporal image shows that all the three layers have dark tone in all the years, 1978, 1986 and 1994. It shows these three years with its untouched mangrove, based on the fact that vegetation absorbs sunlight so they are shown as the dark tone areas. On the other hand, clearings and corrugated iron roofs reflected sunlight and will be shown in its colour intensive.
5.3.2 The Sigatoka River

Figure 61: The multi-temporal image of the Sigatoka river mangrove

The multi-temporal image in Figure 61 showed a large red area that signifies mangrove area being removed between 1978 and 1986 area. The 1986 image clearly depicts a large container area of mangroves being removed in the area. In 1978, there was a small portion of an area being cleared. This multi-temporal analysis can be prove by looking at Figure 54 which describes the same situation. Naturally, not all images are suitable as clouds, cloud shadow; hot spots can influence the image illumination in a way that image colors do not reflect the land cover. So for this red area on the multi-temporal
image of the Sigatoka River half the area is cleared between 1978 and 1986 and half the area is a hotspot area.

5.3.3 Yadua/Yalasuna

The multi-temporal image of Yadua/Yalasuna Figure 62 showed that mangrove was present in the three layers and regrowth of mangrove within the two years. The green area beside this mangrove area is an area removed in 1986 and more houses built or established in Yadua. The red area pointed on the multi-temporal image showed that part of the mangrove being removed in 1994. The area being regrown in the years 1986 and 1994 as shown by blue colours, that is 1967. The blue areas signifies that there was no mangrove in 1967 then regrowth took place in 1986 to 1994. This can be proved in Figure 52, quantitative analysis of Yadua/Yalasuna mangrove change. There was few mangrove in 1967 and increase in 1986 and 1994. This analysis can be proved too by information gathered from the Yadua villagers. OISCA assist them with the implementation of a mangrove replanting project during these years.
Figure 62: The multi-temporal image of Yadua/Yalasuna mangrove
5.3.4 The Korotogo

Figure 63: The multi-temporal image of the Korotogo mangrove

The Korotogo Multi-temporal image in Figure 63 showed that the blue areas being removed before 1978 and the green areas being removed in the 1986-year and the pink (magenta) areas regrown in the year 1994. The change detection image is an ideal tool
for visual interpretation of mangrove area. It highlights all changes qualitatively like areas that been removed in different years, between years and areas that regrown. It also highlights houses being built in a particular year and within the years. To create multi-temporal image, areas of hotspots and cloud cover are omitted.

5.4 Toggle of Images in different time periods

5.4.1 Tagaqe

Figure 64 shows changes in the number of houses and also forest cover. The 1978 image shows there were few houses located at the corner of Tagaqe, (left arrow). There were about 27 houses altogether in 1978. The 1986 image was not displayed because the aerial photo is not clear. By 1994, there were signs of more houses being built. The three arrows on the 1994 image show this. The extension of housing areas along the road is evident in the 1994 photograph. There were about 80 dwellings in the 1994 image. There was more forest cover in 1978 but in 1994 due to extension of buildings, more forest areas have been removed so less forest area in 1994.

![Figure 64: Tagaqe settlement area from 1978 to the 1990s](image)
5.4.2 Resort Areas

The Resort area is another area that was analyzed. This is the area where Tubakula Resort, Sand Beach Cottage, Reef Resort, Handicraft, Vakaviti Cottage and Crows Nest are located. Change detection maps show that there was more forested area in 1967 and about 56 dwellings. By 1978 onwards to 1994 there was an increase in the number of houses and hotels and restaurants being built in this area. In 1978 there were about 63 dwellings, in 1986 about 71 dwellings and in 1994 there were about 96 dwellings altogether. The area now seems to be overcrowded putting pressure onto the resources resulting in lots of deforestation and potential loss of wild life and living organisms in this area. Figure 65 shows the aerial photographs of 1967, 1978 and 1994 showing change for this area. The channel located in this area called Ibulu bay was narrow in 1967 as shown by the arrow in the 1967 image (Figure 65). In 1978 it expands and in 1994 it is wider, a sign of erosion, see the red arrow.
5.4.3 Sigatoka Town

Sigatoka Town was another area that was chosen for rural development analysis. Aerial photo analysis shows that in 1967 there were fewer houses about 66 dwellings and there were lots of forest around the Sigatoka town area, including coconut plantations, scattered forest areas and medium forest and cultivated areas. The arrow in Figure 66 (1967) shows this. Then in 1978 scattered forest and medium forest areas have been removed and coconut plantations areas destroyed and more houses about 83 in total. The
1986 image shows a little regrowth of forest in the medium forest areas and many more houses and bigger buildings have been built and the area seems to be overcrowded with houses. There were about 120 houses altogether in the 1986 image. By 1994 more and more houses were built totaling 165 dwellings, extending to the west of the town; also more medium forest has been cut down for building purposes and also the town looks congested with buildings. The increased in the number of arrows for each image showed the increase of houses from 1967 to 1994.

Figure 66: Sigatoka town from the 1960s to the 1990s
5.4.4 The Fijian Resort

In 1967 before the resort was built, the aerial photo shows different types of forest cover, which ranges from medium to scattered, some coconut plantations and grassland areas. There were about 43 dwellings counted on the 1967 aerial photo. Mangrove and sugar cane areas are located along the main highway beside this area. By 1978 some trees have been removed and there is a sign of progress of hotel development carried out in this area. Another 20 dwellings were built in 1978. 1986 and 1994 images show that most medium and scattered and coconut plantations areas being removed and more buildings being built.

Figure 67 shows image of the Fijian Resort in 1967 and the second image is showing the 1978 image. The two red arrows in both images are marking the changes. The longer arrow in the first image shows Yanuca Island covered with forest and the second shorter arrow is pointing at some houses there in 1967. The second image’s arrows show the areas now being cleared and more houses being built. The second set of images under Figure 67 shows houses being built on Yanuca Island by 1986.
Figure 67: The Fijian resort from 1960s to the 1990

The geo-referenced images from different years to be displayed alternatively (toggled) on a computer screen allowed a visual assessment of the changes which included increased housing and reduced vegetation. This technique has been fully applied but is not reflected in our research due to obvious hardcopy restrictions or presentations.

5.5 Coastline Analysis

The aerial photographs vegetation line are digitised and overlaid on top of an image backdrop and compared with the other different time periods. The approximate quantitative figures of change in between years are also shown. The analysis shows the coastlines movement in between years, if it has moved inland or outward, the approximate quantitative change in between years and also areas of erosion and accretion are shown. The estimated total error values of $\pm 13$ m are also taken into account while finding the quantitative area of change. The error value for geo-referencing the IKONOS image is taken into account in this analysis. The error value is approximately $\pm 4$ m. There is no error value of rectifying aerial photographs while using the rubbersheet method in ERDAS.
The areas around the Fijian Resort are omitted in this coastline analysis due to availability of poor quality photos. The Fijian Resort aerial photographs have too much contrast and high reflection from the road along the beach.

5.5.1 Naevuvenu

Figure 68: The coastline analysis of the Naevuvenu village

Figure 68 shows the coastline of Naevuvenu in 1967, 1978 and 1994. The 1967 coastline is in green colour, the 1978 in blue and the 1994 in red colour. Figure 68 shows that the coastlines change in between years are not the same. It shows that the coastline change on area in front of Sila and Tore Bay in front of Naevuvenu from 1978 to 1994 is approximately 13 to 33 m accretion; to the east of Naevuvenu. The Bay in front of Naevuvenu generally no change except for west end of the bay has moved inland 13 to 31 m. The East end of the bay has large area of accretion of approximately 30 m (17-43 m)
decreasing to 10-20 m as one moves further east along the coast. So taking into account the ±13 m error values, so the coastline movement from 1978 to 1994 ranges from 23 to 33 m. From the coastline analysis above in Figure 68 the Naevuevu area shows that coastline has been extending outward to the sea. This analysis depicts that more mangrove or vegetation cover growing along the beach areas of Naevuevu.

5.5.2 Korolevu
Figure 69: Coastline analysis of Korolevu area

Figure 69 (1) shows the Korolevu area on 1994 image backdrops and Figure 69 (2) shows the Korolevu area on 1967 image backdrops. The 1994, 1986 and 1967 coastlines were digitised and overlay on top of the 1994 image backdrop. These coastlines of 1967, 1986 and 1994 were digitised since they were on good aerial photographs. The 1978 image was not digitised because the aerial photographs were of poor quality. The 1986 coastline was digitised but not right up to the end of Korolevu because of the difficulty in detecting the vegetation line in the 1986 aerial photo.

The 1967 and 1994 image show that the coastline of the area to the west and east ends of the map has shown extensive erosion of 20 to 30 m in recent years. In the Korolevu Bay Area in front of the old resort and where the road follows the water the shorelines has been stable. Erosion is one of the problems that is taking place in this area. Using Map Info software the approximate distance of retreat is roughly 20 to 28 m. Figure 69 (2) show an accretion area in 1986 approximately 2.86 ha.
5.5.3 Komave
Figure 70: Coastline analysis of Komave village

Figure 70 (1) shows the Komave coastline in 1978, 1986 and 1994 on top of the 1994 image backdrop and 70 (2) shows coastline in 1978 and 1986 on top of 1986 aerial backdrop and 70 (3) shows coastline in 1978 and 1986 on top of 1978 aerial image. The coastline shows that it is generally moving outward to the sea in some areas. From 1978 to 1986 the coastline moved outward to the beach by approximately 20 m, 40 m and 60 m. This change showed an erosion area in Komave that happened in 1978 to 1986. By 1994 coastline has moved inland by approximately 20 m. When taking into account the error values of (± 13 m) the movement is between 7 to 33 m. The rate of change is 0.86 to 4.13 m/yr from 1986 to 1994.

5.5.4 Korotogo

Figure 71 (1) shows the 1967 aerial photo as a backdrop to 1967, 1978 and 1986 coastlines of Korotogo and 71 (2) shows 1994 aerial photo as a backdrop to 1967, 1978 and 1994 coastlines. Figure 71 (2) show accretion area of 0.30 ha. The image clearly showed minor movement in coastline between 1967 and 1978. However for the
Outrigger Resort at Korotogo greater change is shown there. The coastline extended to the sea approximately 20 m, which is between (7 – 33 m) taking into account the estimated error values of ±13 m. The replanting of mangroves existed as a result of one of the projects that were undertaken there in the 1994 by the Institute of Applied Sciences, University of the South Pacific. The red arrow shows accretion through an accumulation of sand in the 1980s.

Figure 71: Coastline Analysis of Korotogo area
Korotogo 2

Figure 72 shows the 1967 and 1994 coastline overlay on the 1994 image backdrop. The analysis shows on A-arrow that the 1994 coastline has moved inland approximately 40 m. The A arrow states 40 m but taking into account the error value which is ±13 m, so it is 40 + or –13 m and the approximate area of change ranges from 27 to 53 m. The A arrow showed an eroded area. The B-arrow shows that the 1994 coastline moved outward into the sea approximately 30 m. The 1994 coastline has moved outward to the sea approximately 26 to 34 m from the 1967 coastline. It showed an accretion area, an accumulation of sand caused by the river that runs from the mouth of the mangrove area.

Figure 72: Coastline analysis of another part of Korotogo
5.5.5 Malevu

Figure 73 shows a part of Malevu areas. The analysis shows that the coastline moved inland from 1967 to 1978 by approximately 10.8 to 29.2 m taking into account the estimated error value of ±13 m. The rate of change is 0.98 m/yr to 2.65 m/yr from 1967 to 1978. Then it moved back outward at an approximate rate of 12 to 20 m. The rate of change is between 1.09 m/yr to 1.81 m/yr.

Figure 74 shows another part of Malevu area with the 1967 and 1978 coastline. There is not much change and the approximate change between 1967 and 1978 is -3 to 23 m. The rate of change is between -0.27 m/yr to 2.09 m/yr. Figure 75 shows another part of Malevu with 1967 and 1978 coastlines overlaid on top of 1967 image backdrop. The red arrow is pointing at an area that shows no vegetation in 1967 and a regrowth in the 1978. So that is the only part of vegetation left in both the years. On the 1967 photo was
swampy land and still some vegetation on this area but in the 1978 there is less vegetation found in this area.

Figure 74: The coastline analysis of another part of Malevu

Malevu 3

Figure 75: Another part of Malevu showing the 1967 and 1978 coastlines
5.6 Discussion Section

This last section discusses the methods and data that were used in this research. It also discusses and compares the results gathered from this research with other researches that were done in the past using the same method and techniques. It also describes the results gathered from other studies in relation to this study using other methods and techniques.

5.6.1 Methods and Techniques used in this Research

The image processing techniques employed in this study provide a viable tool for reconstructing the poorly documented history of the Sigatoka Coral Coast mangroves, rural development areas and coastline. The comparable high spatial resolution of the IKONOS image and aerial photographs is clearly advantageous, and the combination of these two image sources takes advantage of the ease of acquisition and precise geo-registration of satellite imagery and the availability of aerial photographs over a much longer time period. The methods used here can clearly be applied to monitoring the historical change of other mangroves, coastlines and rural development areas.

5.6.2 Data Used:

The two major data used for this research are Aerial images and an IKONOS satellite image.

1) Aerial Images

There are advantages of using aerial photographs for this research; first, their availability, that is from the Lands Department Aerial Survey section in Fiji. They are readily available at a range of scales. Economically, aerial photographs are available at affordable prices. The synoptic viewpoint allows detection of small-scale features and spatial relationships that will not be seen on the ground. Aerial photographs are available
at present and also used as a historic record. These features allow aerial photographs to be chosen as the major image data for this study.

There is one major problem found while using these aerial photographs. There are a number of hotspots and poor contrast found on these aerial photographs. Low contrast created difficulties while using the aerial photographs. It obscures features on the ground, which decreases the ability to locate features correctly. This is the biggest problem found while using the Aerial photographs and one of the factors that contributes to the choosing of sites for analysis depending on the quality of these aerial photographs.

Though this problem can be seen as a major one, aerial photographs have proved to be still the most useful source of information. Aerial photographs have been used a long time before satellite images came into existence in the 1970s. In 1970s the first satellite image was captured but at a low resolution that is not usable. Nowadays, aerial photographs are still widely used locally and internationally. The satellite images on the other hand are also good source but they are not are available at good resolution. For instance, the Landsat, Orb View or the IKONOS satellite image.

5.6.3 IKONOS Satellite Image Data

In this research the multi-spectral IKONOS image with a 4 m resolution and 1 m panchromatic channel was used. It was used together with the PWD roads layer of Fiji and the new GPS surveyed road layer of the Sigatoka Coral Coast of Fiji to provide the source of reference points for rectification of historical aerial photographs.
5.6.4 Multi-Temporal Images

The multi-temporal images provide the tool to

1) **Visualise inaccuracy of geometric rectification**

This occurs when two features are not on the same position in the multi-temporal image. For instance the roads layer, if overlaid in different years and are in different places then the rectification is incorrect and needs to be done again.

2) **Visualise areas of change**

The three colours (RGB), red, green and blue, signifies change that takes place in those three different time periods. Additive colours are also created by these three channels, which signify change between these years. The change can be either cleared land or removal of forest, regrowth of land cover, urbanization and either increase or decrease in number of houses within the different time periods.

5.6.5 Summary of the Study’s Results

This section compares the results gathered with the other results gathered of the same research using the same technique.

1) **Mangrove Analysis**

The results showed the percentage increase from 1.2% to 17.1% and percentage decrease from 1.4% to 12.0% in mangroves on Naevuevu, Korotogo, the Sigatoka River and Yadua/Yalasuna mangrove sites from 1967 to 1994.

The results showed the percentage increase from 1.2% to 20.6% and percentage decrease from 1.4% to 10.7% in mangroves on Naevuevu, Korotogo, the Sigatoka River and Yadua/Yalasuna mangrove sites from 1967 to 1994.
In Naevuevu there was a percentage decrease of 1.4%, from 1967 to 1978, from 1978 to 1986 there was a percentage increase of 2.1% and from 1986 to 1994 there was another 1.3% increase. These changes are quite small and depicts that there was removal of mangrove and this was balanced by natural regeneration.

For the Sigatoka mangrove area there was a 10.7% decrease from 1967 to 1978 and another 7.3% decrease again from 1978 to 1986. However from 1986 to 1994 there was a 8.2% increase. So there was more deforestation from 1967 to 1986 and more regrowth or replanting from 1986 to the 1990s. The statistics depicts that this Sigatoka mangrove has undergone lots of changes either decrease or increase throughout the studied periods. This mangrove area has been affected mostly by the development of the Sigatoka town. As shown by the analysis from the 1967 to 1986 more cutting of mangroves to give more space for the extension of the Sigatoka town.

The Korotogo mangrove analysis shows a 7.7% decrease from 1978 to 1986 and a big increase of 11.6% from 1986 to 1994. Korotogo village leaders became concerned about mangrove cutting to dye tapa cloth in the late 1980s and this led to a ban on cutting and even some replanting that began in the early 1990s. USP did the first replanting with the Korotogo villagers in 1993.

The last is Yadua/Yalasuna mangrove; there was a small increase of 0.68% from 1967 to 1986 and a decrease of 7.5% from 1986 to 1994. This analysis shows that there was less removal of mangrove in the early years compared to the recent decade where some removals of mangroves have been found.

i) Naevuevu Mangrove Area

The mangrove areas of Naevuevu decrease in 1978 then increase slightly in 1986 and experience a major increase in 1994. Some of the possible reasons are outlined below.
First, before 1978 the main road link through the Sigatoka Coral Coast was the old highway between Suva and Nadi town. In 1978, the road was upgraded and in many places redesigned with the construction of the new Queen’s highway. Many mangrove areas, as well as other areas of forestry were removed to make way for the road development.

The number of houses has also increased in every year. Until now as quite visible in the rural development areas analysis, the number of houses continues to increase every year. The cutting down of mangroves by villagers continues in order to have a big area for the village to build houses and to cater for the increasing of population.

Another reason mangroves were removed was that the villagers use mangroves for firewood. Most villagers do not have access to gas stoves, primus as substitutes for cooking so they still use firewood for cooking. The increasing number of people also contributes to the removal of mangroves. More people moving into the village raise a greater demand for houses and food.

Another reason for more deforestation than regrowth between the 1960s to the 1980s was outlined by the Foundation of the People of the South Pacific Report. One of the reasons outlined for deforestation in the 1970s was that ladies from Vatulele Island came there to cut down mangroves to take it to their island. They use these mangroves for making masi, the Fijian traditional cloth (FSP 1999).

Natural causes also destroy mangrove areas on rare occasions. Strong winds, big tidal waves and cyclones, have uprooted a lot of mangrove trees in the previous years. Lately in the year 2000 the Partners in Community Development have assist the people of Naevuevu to replant mangroves in areas where mangroves used to be in the previous years (FSP 2003).
**Impact on the environment**

Cutting of mangroves has a great effect on the villages itself. Strong winds were experienced from the sea in the previous years. Big tidal waves have changed their shorelines by moving sand to other places and leaving the area idle. The coastline has been moving inward mostly because of natural effects. One of the reasons this is happening because of excessive cutting of mangroves, which protects the shorelines from big tidal waves and also from strong winds. Mangrove roots hold the sand together, so when mangroves are removed the sand is easily carried away by wind and waves.

There are less fish to cater for the villagers, because mangroves are a major habitat of marine organisms especially fishes and crabs. Once mangroves have been cut, marine organisms decrease in numbers.

**ii) The Sigatoka Mangrove Area**

One of the reasons behind a removal of mangrove in the 1980s was extension of Sigatoka town. Mangrove areas were removed to build more houses and shops. This area was cultivated too by local farmers. The Sigatoka River can be one of the factors too that contribute to the decrease in this mangrove because it lies next to the Sigatoka River.

**iii) The Korotogo Mangrove Area**

The developments of the new Queens Road and the Outrigger Hotel in the 1990s caused a lot of deforestation on the Korotogo mangrove area. Mangrove areas and forest were removed to create space for building to cater for the increasing number of tourists. In the 1990s a project was undertaken in Korotogo village to plant mangrove seedlings along the beach to protect the village, Outrigger Resort hotel and the road from the big tidal waves. Research has found that shorelines have been moving inward and one solution is through replanting of mangroves.
iv) Yadua/Yalasuna Mangrove Area

Upon information gathered through interviews, the Yadua villagers rely on mangroves for firewood. The mangrove area here has fewer disturbances as was shown in Figure 45.

2) Coastline Analysis

Section 5.5 shows that coastlines never remain static. The coastline changes range from 0.1 m to 40 m in Naevuevu, Korotogo, Komave and the Outrigger, the Vakaviti, Tubakula and the Crows Nest Resort. Historical reviews show that the study area has been affected by forestry, small scale cultivation, large scale gravel extraction from within the creek and the building of the Queens Highway which resulted in an increased sedimentation and erosion rates at study sites. All these activities have affected and contributed to coastline changes. Coral extraction has been carried out in most sections of the reef along the study sites, this reduces the effectiveness of the reef to protect the coast from the destructive energy of storm waves.

3) Rural Development Areas

The rural development areas analysis showed increases in the number of houses and also lots of new hotel buildings through the studied periods. This was evident in all the study sites, Tagaqe, Resort areas, Sigatoka town and the Fijian Resort. In the early period in the 1960s all these sites were mostly vegetated. From the 1970s onwards, the development of the Queens Highway and these big hotels caused cutting of mangroves and forest cover. This took place in Tagaqe where the Hideaway Resort was built, The Resort areas where the Outrigger Reef Resort, the Crows Nest, Waratah Lodge, Bedara, Tubakula and Vakaviti Resort were located and likewise for the Fijian Resort and the Sigatoka town. People coming to work in these hotels have also built houses.
5.6.6 Linking Results/Surveys with ICM on the Sigatoka Coral Coast

The results obtained from this research will be valuable to coastal managers of the Sigatoka Coral Coast ICM committee for decision-making. This information will help them have an idea of how much the coastline moved in previous years. It will help them draw up management strategies. The rural development analysis results provide them with information of the fast increase in the number of houses throughout the years and at the same time more cutting down of trees for extension of houses. The mangrove analysis results enlighten coastal managers and the ICM committee on changes that took place throughout the years. The changes are either regrowth and cutting or removal of mangroves.

This method was used in Tongatapu in Tonga for coastal change detection and also in Tagaqe, Fiji. Aerial photographs of 1968 and 1990 with the 2000 IKONOS of image were corrected and analyzed in the Map Info Environment. The result showed that in the 1960s very few clearings are visible and the coastline is intact. However, in the 1990s the clearings increased and open water stands near the village in Tongatapu and the coastline still intact. In the 2000 IKONOS image the clearings increased further, the last mangrove towards the sea has been removed and the seawater erodes the area further (Forstreuter 2001).

The South Pacific Geosciences Commission (SOPAC) conducted a study in Tagaqe village along the Sigatoka Coral Coast. GIS tools were used for detecting coastal changes. Aerial photographs were rectified and coastline for 1951, 1967, 1978, 1985 and 1990 were drawn and analyzed. Results show that coastline has not remained static but has changed substantially through time (Pitman et al. 2002).

The GIS and RS techniques were also used to analyze the increase in number of houses in Nasinu Town in Suva, Fiji and also to find changes on land-cover and urbanisation rate for the Suva Peninsula. Both these researches used aerial photographs as the main data for analysis and the use of multi-temporal images to visualise changes. The analysis
for Nasinu Town showed increased in houses over the years while the Suva Peninsula analysis showed cleared vegetation in the latest year, 1994. The method and data used are currently one of the ways that was recommended to analyze coastal change in Pacific Island Countries, where aerial photographs are the only readily available source of historical information.

Other research that uses the same method also produces good results. This method was used in two coastal communities of Georgia namely the Wassaw and St Catherine Island. The topographic sheets of the 1850s of these two islands were used to depict the shoreline changes. Two shorelines (1850s and 1920s) were digitised for Wassaw and St Catherine Islands in the Arc Info software. The results indicated long-term erosion or dynamic stability range from –1.2 to +0.6 m/y for the Wassaw Island and –1.6 to –10.1 m/y on 60y timescales for St Catherine Island. However, there was still some error due to the times these T-sheets were developed and the multiple projections and datum updates these T-sheets have undergone (Langley et al. 2003).

In Madagascar, Africa, multi-temporal images created through using of Landsat Images of 1973, 1985 and 1999/2000 were used to detect land cover change between the three dates (CIPEC 2005). In Uganda, Africa, the 1950 aerial photograph, 1974 Landsat image and 1995 aerial photograph were used. The main purpose of was to delineate the forest reserves on the multi-temporal images (CIPEC 2005).

5.6.7 Other Methods Used

Other researches related to this study but using different methods to analyze coastal changes are also discussed. These types of researches have been undertaken in the past in most countries and also in Fiji. These studies mostly deal with mapping of shoreline changes due to high rates of coastal erosion experience in most areas. Instruments used consist of bathymetry survey and also LIDAR, which can measure volume of eroded sand at the coast (Leatherman 2003).
Shoreline change analyses are often based on data derived from a variety of sources including historical maps (topographical – map sheets), aerial photographs, conventional GPS ground surveys and laser altimetry data. For instance studies on the Oregon coast in the US Pacific Northwest (PNW) indicate that erosion is caused by coastal expansion from construction of homes and condominiums. The site in PNW was chosen as it experiences a lot of erosion problems particularly in response to El Niño (Allan et al. 2003). Aerial photographs and topographical map sheets were used for this analysis.

5.6.8 Alternative Data and Methods

There are other data that can be used apart from using aerial photographs. A number of high-resolution satellite images for vegetation change detection and mapping have been used in the Pacific. Multi-spectral QuickBird data have been ordered for the first time in for Pacific Island countries and will used to map landslides in Rabi Island, Fiji (Forstreuter 2001). QuickBird panchromatic sensor features a 1 m resolution and a four-band multi-spectral sensor having a resolution of 4 m (Lillesand et al. 2004).

The IKONOS image for the Sigatoka Coral Coast has a 1:10 000 scale and was used as a reference layer for geo-referencing the aerial photographs of the Sigatoka Coral coast and could be used for change detection purposes. The spatial resolution for this IKONOS image is 4 m for the multispectral channels blue, green, red and infrared and 1m for the panchromatic channel. This image was purchased and arrives as Geo-TIFF format direct readable by ERDAS Imagine (Forstreuter 2001).

EROS-A1 image data are another satellite image that has been used for the first time in Suva, Fiji to develop a cost effective alternative to pan sharpened IKONOS multispectral images. This satellite image only provides panchromatic (black and white) data and its spatial resolution is 1.8 m. This image can be used as an alternative to IKONOS. It can be imported as generic binary data and is stored as unsigned 16 bit (Lillesand et al. 2004).
Additionally, another satellite just launched recently is OrbView-4. It provides multi-
spectral images with 4 m resolution covering blue, green, red and infrared. The other
images that are under investigation are also outlined. One of these images is radiometric
high-resolution images and another is the ENVISAT, a satellite recently launched, will
provide hyper-spectral image. The investigating of this satellite is currently done by
SOPAC to guide local fishing vessels and also this satellite image will be useful for
sustainable management of the marine environment of the Pacific (Lillesand et al.
2004).

However, sometimes these data are difficult to purchase because of the time taken to
process it. Most of these data are purchased either through joint operation between
governments and institutions. In this type of analysis and research these types of satellite
image of different time periods are also needed. For instance the QuickBird data is the
best one since it has a 1m resolution with four multi-spectral bands (Lillesand et al.
2004).
Chapter 6 Conclusions

6.1 Conclusion

Coastal zones are complex places. They are physically dynamic, subject to multiple resource demands, carry risks for coastal populations and are ecologically very important. The complexity of coastal zones makes them inherently difficult to manage; however, good quality and timely information can assist better decisions. This places a particular importance on managing information. The Sigatoka Coral Coast in South West Viti Levu, from Namatakula to the Fijian Resort, faces particular challenges related to the management of resources, including population growth, increasing tourism pressure, economic restructuring and a legacy of pollution.

The major coastal problems are management problems, the overuse and misuse of resources by resource owners and the inability of coastal managers to implement awareness training to help resource owners. With the continuation of such problems the future social and economic livelihoods of coastal people along the Sigatoka Coral Coast in Fiji can be adversely affected. Local populations still practise semi-subsistence fishing so the management of marine resources and community fisheries is fundamental to long-term food and financial security. Community-based management is thus emphasized as the major tool in ensuring the protection and sustainable use of coastal resources.

This study looked closely at the implementation of ICM on the Sigatoka Coral Coast. The main aim of ICM is for resource owners, coastal managers and decision makers to solve coastal problems. One action is training of resource owners on the sustainable use of their resources to cater for future generations. The other major task is to document historical information useful to decision makers. The information gathered will help forecast future changes. In order to document this historical information, change detection maps were created using RS and GIS technology. Aerial photographs were the main image data used. Geographic Information Systems (GIS) are useful for ICM
purposes; GIS is interdisciplinary, holistic and facilitates integration of data and interests. GIS is increasingly seen as a key tool in the preparation, delivery and monitoring of ICM programmes.

GIS can be used to assist in any situation in which spatial data is important. GIS tools like the ERDAS Imagine Analysis software and Map Info software show promising results for deriving coastline, mangrove and rural development areas of change using aerial image data. Table 9 summarizes the strengths and weaknesses of using RS and GIS.

**Table 9: Strengths and Weaknesses of using RS and GIS for ICM on the Sigatoka Coral Coast.**

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
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<tbody>
<tr>
<td>1. Availability of Aerial Photographs from 1950s to 1994.</td>
<td>1. Some of these aerial photographs were omitted due to high contrast of the photos, cloud cover that makes it difficult to identify features. For instance the set of 1950 photos.</td>
</tr>
<tr>
<td>2. Availability of the software for correcting aerial photos and digitizing data for analysis such as ERDAS Imagine and Map Info.</td>
<td>2. Ground control is not accurate enough due to errors in correcting ±2 m to ±4 m.</td>
</tr>
<tr>
<td>3. Change detection maps developed from the coastline, mangroves and rural development areas.</td>
<td>3. There is difficulty in developing change detection maps on high contrast and hotspots areas.</td>
</tr>
</tbody>
</table>
6.2 Summary of Contributions

This thesis identified that using change detection maps utilizing RS and GIS technology is one way of helping local communities have some idea of how their resources have been changing in the past, especially change detection maps developed for mangrove areas, rural development sites and coastline study areas. A recognized concern now for ICM is deterioration of the studied four mangrove areas. The largest mangrove area studied was Naevuevu with more than 50 ha of mangrove area. The other three mangrove sites were Yadua/Yalasuna with 28 to 35 ha, Korotogo from 18 to 25 ha and the last site, the Sigatoka River with the least mangrove area from 2 to 3 ha. Naevuevu and the Sigatoka River showed decline in mangroves from 1967 to 1978. The Yadua/Yalasuna area shows a major decline in mangroves from 1986 to 1994. Mangroves have been removed for many purposes, including for firewood and to build houses. However, there has been some replanting of mangroves, shown by the regrowth areas on the change detection maps and also from the graphs showing the increase in the mangrove areas through time. The regrowth of mangrove areas from 1986 to 1994 was evident in the three sites, Naevuevu, Korotogo and the Sigatoka River. Non-Government Organizations (NGOs) such as Organization for Industrial, Spiritual and Cultural Advancement (OISCA), Wildlife Conservation Society (WCS), Partners in Community Development Fiji (PCDF) and the Institute of Applied Sciences (IAS), University of the South Pacific (USP) with the Tourism and Hotels Association assisted with replanting of mangroves by providing seedlings. Replanting of mangroves along the beaches also took place before 1994 at two study sites, Naevuevu and Korotogo.

The four areas analyzed for the rural development analysis were Tagaqe, the Resort sites, Sigatoka town and the Fijian Resort. The site with the largest number of dwellings is Sigatoka town and the least is the Fijian Resort. The number of houses increases every year in all these study sites and is one of the factors that contribute to the removal of mangroves along the Sigatoka Coral Coast. The increase in population in a particular village contributes to the increase in number of houses.
There were five sites studied for coastline analysis: Naevuevu, Korolevu, Komave, Korotogo and Malevu. The analysis showed that the coastline of the Sigatoka Coral Coast has never remain static, either moving inland or outward to the sea. There are areas of erosion and accretion. The coastline changes in quantitative figures from 1967 to 1994 ranges from 0.72 m to 1.48 m/yr. The total coastline change during the historical period ranges from 10 to 20 m, for example from 1967 to 1978 at Malevu (Figure 67). The clearing and replanting of forest and mangroves along the coast and through natural processes might contribute to these coastline movements.

**6.3 Future Research**

There is an increasing need for the baseline information and science based decisions for policy making in the Sigatoka Coral Coast. Information on land use and land cover change and coastline are critically important. Most coastal and resource managers have recognized the value of this type of information for resource management and sustainable development. The information gathered from this research through the use of GIS and RS is important to forecast future changes especially for mangroves, coastline and rural development areas. One is the working together of the non-governmental organizations (NGOs) and government departments with the communities. Some of the projects that have been set up are replanting of mangroves, waste management project, compost toilet, live rock study, integrated coastal management and locally managed marine areas.

This thesis recommends that other lowland areas like the Sigatoka Coral Coast can use RS and GIS techniques. RS and GIS are suitable for this type of research, but users should be well trained with the technique, software, geography, cartography and information sciences. The user should be familiar with all the tools of GIS software. Good results are obtained through technical expertise and accurate data.

Aerial photographs are an important adjunct to maps as they provide an accurate historical record of the land at the time they were taken. Aerial photography has been
used to create accurate maps of Fiji’s coastlines since the late 1930s and became the sole source for coastal mapping in 1980. The 1-2 m resolution of aerial photographs used in this research mapped all the features, mangroves, coastline positions and rural development sites for this study. For future research aerial photographs are still highly recommended unless they are not available then satellite images with 2-4 m or better may also be used for similar research: ASTER, IKONOS, Orb View and QuickBird satellite images are examples of these satellite images. Nowadays, good quality satellite images with less than 1 m to as high as 60 cm resolutions are readily available but only for certain periods and at various costs. For instance the QuickBird satellite image is available at 60 cm resolution. Some of the features of coastal zones that is suitable to map and analyse using this 60 cm resolution satellite image are landuse types, vegetation types, tracks, water quality and marine habitats.

The RS/GIS technique and use of aerial images have worked well in this research analysis. The techniques based on multi-temporal, multi-spectral, satellite-sensor-acquired data have demonstrated potential as a means to detect, identify, map and monitor coastal changes. The RS/GIS technique has been used worldwide to monitor changes especially in coastal zones. The remote sensing images of good resolutions are easy to detect features. The object features are easy to analysed or monitor once detected.

The ERDAS software corrects both the IKONOS and aerial photographs. The 1-2 m resolution was the best resolution available for this analysis, but any increased resolution is suitable for this type of research. The Map Info software draws the mangrove areas in polygons, coastline positions in polylines and illustrates the rural development sites. Using the ruler in Map Info software measures the change between the coastline positions in different time periods and clicking on the polygon depicted mangrove polygons areas of change. There is no modification or improvement on the method widely used by other research. However, there were some differences noted: one, the use of software for different tasks. Some researches used other software for correcting images apart from ERDAS. Drawing of coastline changes in polygons in Arc View
software was done in some other studies apart from drawing lines in Map Info and putting together in different time periods to measure area of movement. Two, other researchers identified the coastline as the high water mark whereas the vegetation line was used in this project. Three, other researchers used ASTER, QuickBird and Landsat images for analysis rather than aerial photos. Apart from those differences mentioned, the RS images and GIS method used were considered appropriate to use especially in other parts of Fiji and other Pacific Island Countries, where aerial photographs are normally available at reasonably low cost.

There are some limitations to using aerial photos and the change detection map technique that can be identified. One problem of the 1954 image was the low contrast and hotspots areas found which meant this photo was disregarded. Second, other sectors not studied by this thesis but needing special attention are forest cover change, population increase and new developments in the study area. These sectors need attention as removal of forest cover was observed as one of the major factors in pollution along the Sigatoka Coral Coast. The increase in population is one of the influences that caused an increase in number of houses in the rural development sites. This is a major concern and future research should determine the modern population of these places as the latest population survey was done back in the 1990s. The associated construction of new houses and hotel developments taking place is also seen as one of the reasons why mangroves are being cut down for further expansion.

The results gained from this research could lead up to identify major factors that contributed to these changes. Strategies can then be identified and implemented to help minimize these changes on mangroves, coastlines and rural development sites.
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