

Building an approach for monitoring climate change impacts on tourism resources in developing countries

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

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Abstract

The tourism industry is important for many state economies. Tourism relies on resources that attract tourists and thus generate income. Ensuring these resources are sustainable through preservation, maintenance, and optimal utilisation is vital to the continuation and health of the tourism industry. Monitoring of resources is equally important for good management; changes and threats to tourism resources occur for many reasons, including anthropogenic activity or/and climate change, and monitoring enables efficient responses.

The research described in this thesis focused on resources in developing countries, which are believed to be relatively vulnerable to climate change. Developed countries have more ability to prepare for, adapt to, and recover from problems induced by climate change due to their greater human, technological and financial resources. Developing countries, including Arab countries, need more research about ways to sustain their tourism resources. This research aimed to build an approach that can be used by developing countries whose tourism resources are likely to be impacted by climate change. Two case studies were involving in this research – one to develop the approach (Fujairah) and one to validate it (Turkey). The Emirate of Fujairah was used to develop methods for tourism managers to use geospatial information to monitor climate change impacts on tourism resources.

The case study location, Fujairah, is one of the seven emirates forming the United Arab Emirates (UAE). In contrast to its fellow UAE member emirates of Abu Dhabi and Dubai, Fujairah has no known reserves of oil or natural gas; instead, the government of Fujairah aims to make tourism to key component of economic development. Fujairah has natural assets, many associated with its strategic placement in the Gulf of Oman, which makes it a highly desirable tourist destination. It is also home to beautiful beaches and colourful coral reefs which offer opportunities for snorkelling and scuba diving as well as passive leisure activities.

Hot springs, waterfalls, and abundant animal and bird life also attract visitors. Heritage villages, forts and castles, the Fujairah museum, archaeological sites, spectator sports such as bullfighting and boat racing, and excellent shopping at low prices add to the tourist experience.

Tourism resources in Fujairah were initially categorised into three groups: natural, cultural and built-up resources. These resources were input to a geodatabase using a Geographic Information System. The locations of those tourism resources and land use in Fujairah in general were mapped. Next, SimCLIM software was used to project climate change effects in the short term (to 2030) and long term (2070) using 1990 as the baseline. These projections incorporated changes in temperature, sea levels, precipitation and other climate variables. Based on the A1FI (fossil intensive) emission scenario with a high level of climate sensitivity results revealed, for example, that average air temperatures in Fujairah are predicted to increase by more than 5°C by 2070. In addition, the recurrence frequency of an average maximum daily temperature over a 7-day consecutive period of more than 45°C may increase seven-fold by 2030. These and other projected results were then used inside the Rapid Assessment Program to assess the potential impacts of those effects on the emirate's tourism resources. The results show that climate change effects will threaten tourism resources in Fujairah in multiple ways. The predicted increase in temperature and the acidification of the ocean will impact tourism resources most severely. These impacts can be attributed to the fact that high temperatures are already problematic for tourism in the region, while coral reefs are vulnerable to ocean acidification. Next, an approach for monitoring the temporal changes occurring to the tourism resources in Fujairah was introduced. Because effects are sometimes minimal in the short term, relying on human observation is impractical; a Terrestrial Laser Scanning based technique was employed for micro change detection.

All the methods described above were combined in a framework that can be used in a generic way by developing countries. The applicability of the approach was tested and validated using data from Turkey. The results of this research can be used by decision-making authorities in developing countries to monitor their tourism resources and develop adaptive and mitigation measures to maintain and sustain those resources in the face of climate change impacts. Directions for possible future research are also presented.

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List of Abbreviations

ALS	Airborne Laser Scanners
ALSM	Airborne Laser Swath Mapping
AM/FM	Automated Mapping/ Facilities Management
CAD	Computer-Aided Design
CMIP	Coupled Model Intercomparison Project
COHESIE	(Dutch) COmmunicatiemiddel voor HErsturcturering in Steden in een Interactieve contExt – a communication tool for interactive urban redevelopment
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DEM	Digital Elevation Model
DPSIR	(Framework) Driver-Pressures-States-Impacts-Responses
FAO	United Nations Food and Agriculture Organisation
FAR	IPCC's Fourth Assessment Report
FIMF	Fujairah International Monodrama Festival
FTAA	Fujairah Tourism and Antique Authority
GCC	Gulf Cooperation Council
GCM	Global Climate Models
GDP	Gross Domestic Product
GNI	Gross National Income
GEV	Generalized Extreme Value
GHG	Greenhouse Gas
GIS	Geographical Information System
GPS	Global Positioning System
HDI	Human Development Index
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging
LIS	Land Information System
LocCLIM	Local Climate
LULC	Land Use and Land Cover
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MSL	Mean Sea Level

NASA	National Aeronautics and Space Administration
NOAA	The National Oceanic and Atmospheric Administration
PET	Potential Evapotranspiration
RAP	Rapid Assessment Program
RCM	Regional Climate Model
RP	Return Period
SimCLIM™	Climate simulation software
SLR	Sea Level Rise
SRES	Special Report on Emissions Scenarios
SSGI	Sites of Special Geological Interest
SST	Sea Surface Temperature
TAR	IPCC's Third Assessment Report
TLS	Terrestrial Laser Scanning
TOPIC	Thematic Orientation on Project definition in an Interactive Context
UAE	United Arab Emirates
UAV	Unmanned Aerial Vehicle
UNDP	The United Nations Development Programme
UNEP	The United Nations Environmental Program
UNFCCC	The United Nations Framework Convention on Climate Change
UNWTO	United Nations World Tourism Organisation
VLM	Vertical Land Movement
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WRI	World Research Institute
WTTC	World Travel and Tourism Council

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Building an approach for monitoring climate change impacts on tourism resources in developing countries

Chapter 1 Introduction

1.1 Motivation and scope of research

Tourism has become a very important source of income for many countries, and this can lead to the protection of the resources that attract tourists. Designating protected areas in both land and marine parks has aided in sustaining biodiversity and ecosystems, which in return attracts visitors (Naughton-Treves, Holland and Brandon 2005); In Sweden, for instance, it was noticed that increased protection leads to increased visitor numbers to its national parks (Fredman, Friberg and Emmelin 2007). The tourism industry depends on the availability of attractive resources indoors or outdoors, natural, artificial and cultural. Protecting resources from deterioration is vital for sustaining the tourism industry.

Data from the United Nations World Tourism Organization (UNWTO) reveal that developing countries are keen to promote tourism and that tourist numbers have risen dramatically in recent years (UNWTO 2012). This brings challenges for the maintenance and management of tourism resources. In general, developing countries lack the infrastructure, knowledge base, expertise, legislation, and documentation required to manage tourism resources. As a result, these countries and their tourism sectors are vulnerable to many potential risks which affect their sustainability.

Climate change is one of the major threats to natural and other resources worldwide, and therefore is an issue of great importance to the tourism industry. Research exploring how changing climatic conditions will impact upon tourism resources, and producing methods that allow development of responses to climate change effects, is vital. This research focuses on building an approach that can be used by developing countries whose tourism resources may be impacted by climate change. The approach considers how future climate change will impact upon tourism resources, as well as how to monitor the change occurring in those resources. It thus enables insight into the possible adaptation and mitigation measures that could be taken from a resource management perspective. The results of this research are expected to aid decision-making authorities by offering a newly developed approach for maintaining tourism resources and thus sustaining the tourism industry.

The scope of the research described in this thesis includes:

- Identifying important tourism resources through the development of a comprehensive geodatabase;
- Making projections for future climate change effects;
- Evaluating and assessing the potential impacts on tourism resources due to projected climate change effects;
- Presenting techniques for the measurement of potential climate change impacts;
- Developing an approach for monitoring tourism resources change.

Two aspects of tourism in relation to climate change were beyond the scope of this research (see Figure 1-1). Climate change could deter tourists from visiting developing countries (directly: through impacts such as high temperature; indirectly: through cost, as flying is likely to become very expensive). In addition, in response to climate change, tourists might change their behaviour in relation to how they use tourist resources or the mixture of tourist resources they 'consume'. These behavioural and economic factors were not studied, as they are outside the author's area of expertise. The second omitted aspect was the role of tourism in exacerbating climate change through the use of greenhouse gas-emitting transport. This aspect was also deemed to lie outside the field of research. Also outside the scope of research was the human impact (direct) on tourism resources – through polluting or damaging the resources.

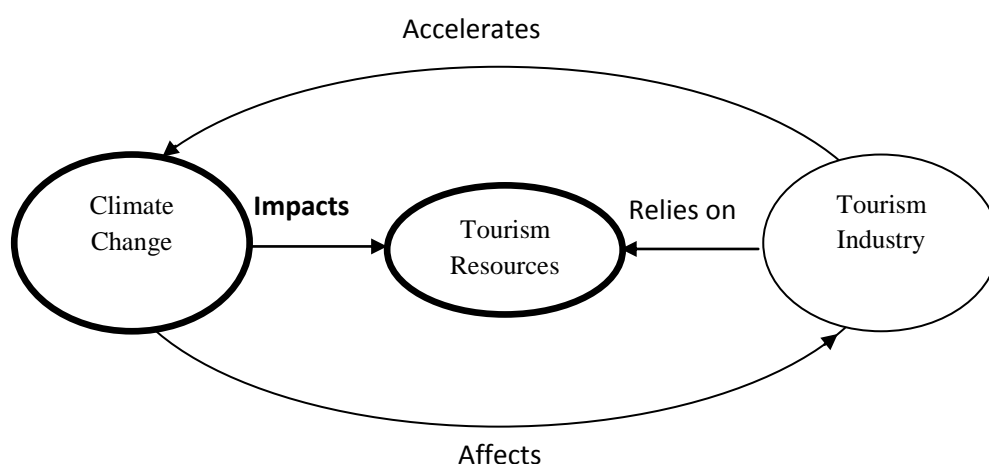


Figure 1-1 Tourism Resources and Climate Change Effects

1.2 Rationale for the research

Currently, there is global concern about the ability of developing nations to face the effects of climate change. Climate change impacts economic sectors such as industry, transport, energy, agriculture and tourism in different ways.

Many developing countries have faced major natural disasters in recent years: for example, flash floods in Thailand in 2010 and 2012 (Pierdicca et al. 2013), landslides in southern Colombia in 2012 (Signs of the Times 2012), typhoons in the Philippines in 2009 (Alojado 2010), and cyclone Gonu in 2007 in the UAE (Foster et al. 2011). All these disasters resulted in tremendous damage to property and infrastructure. Such events are likely to be more frequent and devastating due to climate change (Beniston et al. 2007). These events forced governments to recognise the need for a clear framework for measuring, predicting and managing the impacts of climate change (Hitz and Smith 2004; Mirza 2003; Thuiller et al. 2008).

Tourism resources are affected by extreme weather conditions and the accumulated results of long-term climate change (Mishev and Mochurova 2010; Yu, Schwartz and Walsh 2009). Such impacts need to be quantified for future planning and mitigation purposes using suitable change detection methods. Hence, developing an approach for monitoring change in tourism resources is vital for developing countries to maintain their tourism industry and income.

According to Scott (2011), addressing climate change is a prerequisite to sustainable development, especially for tourism, which is considered among the economic sectors least prepared for the risks posed by climate change. Weaver (2011) reviewed 128 English-language peer-reviewed journal articles on the relationship between climate change and tourism published between 1986 and 2009. Sixty-six percent were classified as studies of the potential impacts of climate change on destinations or changing visitation patterns, while 15% focused on the contribution of tourism to climate change through greenhouse gas (GHG) emissions (Weaver 2011).

Developing countries are sensitive to the importance and potential of tourism to their nations' economies, their local communities' livelihoods and their biodiversity (Amelung, Blazejczyk and Matzarakis 2007). Focusing on tourism resources now is important because of the prompt (i.e., the impacts are going to be felt shortly after the climate change) and visible impact of changing climate.

1.3 Tourism and tourism resources

Tourism is defined as the activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes (Peeters, Szimba and Duijnsveld 2007). Tourism is important to the economies of many nations, generating employment, income, development and (potentially) sustaining the environment. Advances in technology and reductions in cost have made global tourism extensive and more convenient. According to UNWTO (2012), the total number of international tourist arrivals in the year 2011 was 980 million, up from 674 million in 2000. The increasing importance of tourism has been particularly noticeable in the Middle East, which received 55.4 million visitors in 2011 compared to 24.1 million in the year 2000 (UNWTO 2012).

The Cooperation Council for the Arab States of the Gulf (GCC) recognises tourism as an industry of growing importance. The GCC union includes members from the Arabian Peninsula, namely Bahrain, Kuwait, Oman, Saudi Arabia, and the UAE; all are developing countries. These countries are moving away from oil dependency by diversifying their economies to include tourism as a source of income (Fasano and Iqbal 2003). In the UAE, the number of foreign visitors reached nine million in 2010 with a projected rise of 3% annually (Siddiqi 2011). The total contribution of travel and tourism to the UAE's GDP was 13.5% in 2011 (World Travel and Tourism Council 2012). Despite the UAE's heavy involvement in the lucrative energy export industry, some regions within the UAE do not rely upon oil, including the Emirate of Fujairah (the emirate used as a case study in this research). During the 15 years from 1996 to 2010, the number of tourists visiting Fujairah increased from under 50,000 per annum to over 400,000 (Fujairah Statistics Centre 2010). Thus tourism has become an important part of Fujairah's economy and a major driver of its economic growth.

The UAE is located midway between Europe and Asia, making it an important hub for air travel and a convenient stopover destination for travellers. The UAE's largest and best-known emirates – Dubai and Abu Dhabi – also offer an attractive tourist landscape, including an array of luxury hotels and popular shopping malls, many world-class events and festivals, and heritage attractions (Henderson 2006). In contrast, the Emirate of Fujairah attracts visitors more interested in cultural attractions and natural resources.

Tourism has two main components: the tourists themselves and the tourism resources available. Although there is no agreed definition for the term 'tourism resources', Ivanovic

(2009) defined a tourism resource as “any factor – natural or man-made, available within a country, region or area – which makes a positive contribution to tourism (p.111)”.

Natural resources are considered the most important tourist drawcards and can be divided into two categories: living and non-living resources (Barletta and Costa 2009; Holden 2005). Living tourism resources refer to flora and fauna, while the non-living includes natural features such as springs, rivers, beaches, mountains and glaciers.

Tourism resources are the major focus of this research. It should be noted that in this thesis, tourism resources include living things, landscapes, and artificial objects and places as well as activities and events that attract the interest of tourists. Those resources are not to be confused with the facilities needed to provide services for tourists, such as hotels, car parks, restaurants and cafes, and infrastructure such as water, electricity and police. Such facilities are not part of this research.

Tourism management is a critical part of the tourism industry as resources need to be protected and preserved while maintaining their capacity to provide tourists with a quality experience (Weaver and Oppermann 2000). Tourism management must continually assess the potential impact of any threat to the quality and quantity of the available resources. As stated previously, global climate change has become a major threat to the sustainability of tourism resources; hence, monitoring of changes in tourism resources is an important element of their management. Impacts from climate change on tourism resources can only be managed properly if their state is monitored, either to confirm that the management is working or to detect that change is taking place so management can adapt in order to stop these changes.

1.4 Climate change and tourism

Climate change is a topic of immense global importance. Increasing amounts of atmospheric GHGs due to human activity are thought to be the major driver of climate change in the form of global warming (Battisti 2009). According to the Intergovernmental Panel on Climate Change (IPCC), climate change is already having measurable impacts (Braasch and McKibben 2009).

Climate change impact can cause major issues such as flooding, especially for countries surrounded by sea. Sea level rise has many associated impacts such as damage to coastal areas and small islands, salinisation of groundwater, disrupting the flow of estuaries and coastal rivers as well as eroding and increasing the salinity of tidal wetlands and mangrove forests

(Andersen, Svinth and Pejrup 2011; Nicholls 2002). Tourism will be affected by loss of beaches and coral reefs, destroyed amenities, and other infrastructure damage. For example, El-Raey (1997) studied the vulnerability of Egypt's coastal area (the Nile delta coast, in particular) to sea level rise (SLR) and shows that a sea level rise of 50 cm by 2050 will seriously affect cities such as Alexandria, Rosetta and Port Said, and over two million people will have to abandon their homes. This anticipated disaster will cause the loss of 214,000 jobs and over US\$35 billion in land-values, property and tourism income.

Tourism and other resources must be protected from the threat posed by climate change. However, most developing countries lack the necessary infrastructure to monitor, model and manage these threats. This is particularly important for highly vulnerable developing countries such as the UAE, the location of which between the Gulf of Oman (Indian Ocean) and the Arabian Gulf makes it extremely likely to be impacted heavily by sea level rise (Dougherty et al. 2009).

1.5 Objectives and research questions

The overall aim of this thesis is: *“To build an approach for decision makers such as tourism managers to monitor changes on tourism resources due to climate change impacts, in developing nations, using geospatial information”*. Using the Emirate of Fujairah as a case study for developing the approach and then using the Republic of Turkey to test and validate the approach, the three research objectives were:

- (i) To identify and map Fujairah's tourism resources
- (ii) To project the effects of climate change and assess their impact on Fujairah's tourism resources
- (iii) To propose and present a method for monitoring change in Fujairah's tourism resources for the purpose of quantifying the potential impacts of climate change.

In order to achieve these objectives, the research addressed the following questions:

1. What is a tourism resource?
2. What are the different types of tourism resources that exist in Fujairah?
3. How well do Fujairah's tourism resources typify the tourism resources in developing countries?
4. How can a comprehensive geodatabase assist in identifying changes in tourism resources?

5. What datasets and information are important in projecting future climate change?
6. How will climate change affect Fujairah over the mid-term and long-term respectively?
7. Which tourism resources in Fujairah might be impacted by climate change?
8. What are the tools available for future climate change projections, impact assessment, impact analysis and change detection?
9. What are the most appropriate tools and techniques for future climate change projections, impact assessment and analysis, and change detection?
10. How can changes in tourism resources be monitored?
11. Who might be using the results of this research and how will they benefit from it?

1.6 General approach

The research questions listed above are comprehensively addressed in subsequent chapters of this thesis. The research used a spatial approach as both climate change effects and tourism are geographic concepts. The thesis begins by presenting the overall aim from a generic developing countries context, then moves to the selected case study (the Emirate of Fujairah), and then tests the applicability of the developed framework by applying it to a different developing country (Turkey). A flowchart describing the research is depicted in Figure 1-2 (see list of abbreviations for definition of acronyms).

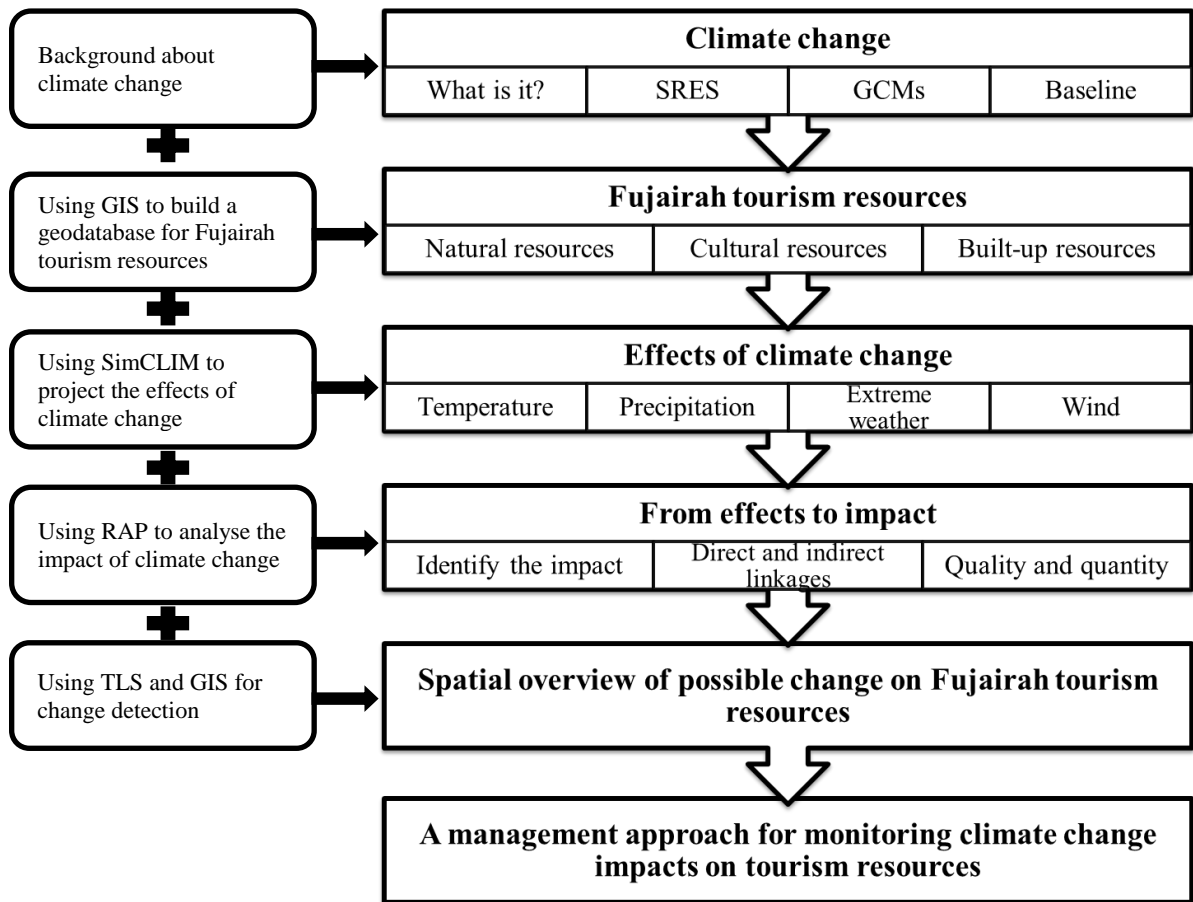


Figure 1-2 How the research progressed towards a developed framework

1.7 Overview of the thesis

This chapter provided an introduction to the research topic, including the motivation for and scope of the research, tourism and tourism resources, and the link between climate change and tourism. The overall aims of this research, its key objectives and the related research questions have been clearly outlined.

In Chapter 2, the findings of a literature review on the topic are presented. An introduction is given to tourism and climate change in developing countries. Also, the chapter distinguishes between the tourism resources of less-developed and more-developed nations. Then it presents an overview of climate change and its scientific underpinnings, including key spatial and temporal definitions. Climate change projection is discussed in detail, including the Intergovernmental Panel on Climate Change (IPCC's) definitions of climate change and related parameters such as emission scenarios, climate sensitivity and global climate models. The effects of climate change on tourism resources and the tools and techniques for future climate change projections, impact assessment, and impact analysis are all discussed. Change detection and relevant tools are also presented.

Chapter 3 describes the methodology employed in the research. It details how the construction of a comprehensive geodatabase was used to identify and geographically map the important tourism resources of the case study region, Fujairah. It also includes reasons why the case study is representative of other developing nations. It justifies the selection of tools for climate change projection, assessing and analysing impacts of climate change on Fujairah's tourism resources, and monitoring for detection of changes to tourism resources.

Chapter 4 provides a detailed description of the Emirate of Fujairah and discusses its geographical and geological setting. It then provides data about Fujairah's socio-economic features, statistics and its tourism resources. The major land uses, notably the industrial, commercial, agricultural/fisheries, and recreational sectors, are identified. Lastly, Fujairah's current climate is highlighted.

In Chapter 5, the different types of tourism resources in Fujairah are described (natural, cultural and built-up). Then the challenges in managing tourism resources faced by Fujairah are discussed, including the limitations of its current databases with respect to tourism resources. These limitations are addressed by identifying and mapping its important tourism resources and using a comprehensive geodatabase.

Chapter 6 details the spatial and temporal effects of climate change in Fujairah. The climate variables considered include temperature, precipitation, wind, sea level rise, ocean acidification and extreme weather events such as droughts and flash floods. It also discusses the methods and parameters associated with climate change projections. Finally projections for Fujairah using time horizon of 2030 and 2070, are made using a climate change projection tool.

Chapter 7 presents an approach to assess the potential impacts of climate change effects on Fujairah's tourism resources. It describes the building of a conceptual model incorporating the relationships between the tourism resources and climate change effects. An analysis of this model is carried out using a specialised software tool. Finally, potential impacts of projected climate change effects on several types of Fujairah's tourism resources are described and discussed in depth.

In Chapter 8, methods for monitoring the change in Fujairah's tourism resources are presented through a pilot study. Both a micro change detection technique (i.e., changes of millimetres) and a macro change detection technique (i.e., changes of metres) are presented in order to

demonstrate the approach. Fujairah Fort, a historic structure of great cultural significance, is used to demonstrate the building of a 3D model in a point cloud using terrestrial laser scanning (TLS) technology. A baseline model is produced so future changes in this resource (e.g., from wind erosion) can be monitored with a second time scan to detect the changes.

Chapter 9, starts with an overview of the work from previous chapters. It then integrates the processes to develop a generalised approach to monitor changes in tourism resources for use in other developing countries. The proposed framework is discussed, including how the developed approach can be applied elsewhere. The applicability of the framework is validated using another developing country as a case study (i.e., Turkey). The adaptability of the framework for used by other countries is also discussed.

Chapter 10, the concluding chapter, summarises the results of this research by succinctly presenting the research outcomes, stating their limitations and the constraints encountered during the research, a discussion of the key results, and finally, directions for future research.

Chapter 2 Climate Change Monitoring: Concepts, Definitions and Tools

2.1 Introduction

This chapter presents a review of literature related to the management and monitoring of climate change impacts on tourism resources. It begins with an exploration of the importance of tourism in developing countries, then gives an overview of climate change and its scientific foundations, including associated spatial and temporal definitions. A review of climate change projections and the associated uncertainties is presented. The existing literature about the impact of climate change on tourism resources and the methodologies for assessment of such impacts are also discussed. Finally, the chapter reviews the tools and techniques of spatial analysis (including GIS-based geodatabases), micro and macro scale change detection, projection of climate change and evaluation of its impacts.

2.2 Tourism and climate change in developing countries

Prior to reviewing the importance of tourism and climate change to developing countries, it is necessary to define the term 'developing countries'. International organisations such as the World Bank, the United Nations Development Programme (UNDP), and the International Monetary Fund (IMF) categorise countries differently (see table 2-1). Some countries, such as the UAE, are called 'developed' by the UNDP but 'developing' by the IMF (Nielsen 2011). According to James (1998), developing countries often have significant political, economic and environmental problems.

Table 2-1 Country classification systems used by selected international organizations

	IMF	UNDP	World Bank
Terms for 'developed countries'	Advanced countries	Developed countries	High-income countries
Term for 'developing countries'	Emerging and developing countries	Developing countries	Low- and middle income countries
Development threshold	Not explicit	75 th percentile in the HDI distribution	US\$6,000 GNI per capita in 1987-prices
Subcategories of 'developing countries'	(1) Low-income developing countries (2) Emerging and other developing countries	(1) Low human development countries (2) Medium human development countries (3) High human development countries	(1) Low-income countries (2) Middle-income countries

Source: (Nielsen 2011)

Developing countries, including Arab countries, need a better understanding of how to sustain their economic resources (Tolba and Saab 2009). As noted earlier, some developing countries (e.g. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) formed an economic and political union called the GCC in 1981 (Reiche 2010). These countries are rich in gas and oil yet are called developing countries (Ministry of Energy 2007; Reiche 2010). Whether a country can be considered to be ‘developing’ depends upon each country’s government’s opinion, or on their economic structure, despite having the high incomes which are characteristic of developed countries (Nielsen 2011; Soubbotina and Sheram 2000). The GCC countries are rapidly diversifying their economic sectors to include real estate, tourism and industrial production so they do not rely so heavily on oil (Al-Abed et al. 2008). Therefore, the GCC countries can be considered ‘developing’ in the sense that tourism and other infrastructure is being developed.

Tourism is becoming enormously valuable to developing countries. It is a source of jobs and income, and may encourage environmental protection (Honey and Gilpin 2009). In addition, tourism is a tool for economic development and it helps countries move away from dependency on specific sectors such as agriculture (Tooman 1997; Vaugeois 2000). According to the United Nations World Tourism Organisation (UNWTO), the share of international tourist arrivals received by developing countries has steadily risen from 31% in 1990 to 47% in 2010 (UNWTO 2011).

A study of tourist numbers in the UAE in 2009-10 showed an increase in 2010 of the number of people visiting it from the United Kingdom (UK), United States of America (USA), China and Russia, and as a result the total spending of those visitors in the UAE rose (Siddiqi 2011). The UAE tourism sector is estimated to grow by 5% per annum from 2007 through to 2016 (Al-Abed et al. 2008). In 2011, the total contribution of travel and tourism to the UAE’s gross domestic product (GDP) was 13.5% (World Travel and Tourism Council 2012).

Tourism resources make developing countries attractive destinations for visitors. These resources include natural and cultural resources, heritage and archaeological sites, water resources and people, landscape, seas and mountains, man-made buildings and special events. Tourism resources are however, highly vulnerable to climate variations (Dwyer et al. 2009). Beach and mountain tourism, for instance, rely heavily upon the weather in both the short and long term (Buzinde et al. 2010; Ruiz et al. 2008). Heritage and archaeological sites are under threat of erosion from winds (Hussein and El-Shishiny 2009). As noted earlier, tourism

resources can be divided into two categories: living and non-living resources (Barletta and Costa 2009; Holden 2005). Living tourism resources are flora and fauna, while ‘non-living’ includes other natural features such as springs, rivers, lakes, deserts, grasslands, mountains and glaciers as well as cultural resources. Tourism resources can also be categorised into attractions, and services and facilities (Community and Economic Development 2012). Tourist attractions include natural phenomena such as landscape scenery, waterfalls and beaches, as well as recreational activities, historic sites and cultural event such as special events and festivals. Tourist services and facilities include accommodation, convention/meeting facilities, food service establishments, shopping services, transportation and infrastructure, and the tourist industry labour force.

According to Wall (2007), tourism is at more risk from climate change than other economic sectors. Natural resources are likely to be more at risk from climate change than cultural or historical resources (Hoegh-Guldberg et al. 2007). In addition, the impact of climate change is affecting the lengths of seasons, longer summers may reduce the number of visitors to some tourist destinations (Parmesan 2006; Wall 2007).

Overall, there are few differences between the fundamental types of resources of developed and developing countries – they all have resources based on land and water, culture, and heritage. Nevertheless, many developing countries are tropical while many so-called developed countries are largely temperate, so their natural resources are somewhat different (climate, coral, plant and animal species, etc.). Of course, the differences between developed and developing countries, by definition, mean that there are differences in their ability to turn local resources into tourism products due to differences in human resources, capital, and availability of local markets.

In terms of vulnerability to climate change, both tourism resources in developed and developing countries are under threat, but developed countries have more ability to prepare, adapt and recover due to their greater human and financial resources.

2.3 An overview of climate change

The term ‘climate’ refers to average weather patterns over a long period of time and is measured by variables such as mean temperature, precipitation, humidity, wind and seasonal timing, while ‘climate change’ refers to substantial and non-temporary changes in the distribution of weather patterns over extended periods (IPCC 2007a). More precisely, climate

refers to changes in average weather conditions or changes in the distribution of weather around those average conditions (e.g., a lower or higher number of extreme weather events). Climate change occurs due to many factors, such as oceanic processes, variations in the amount of solar radiation received by the Earth, plate tectonics and volcanic eruptions, as well as anthropogenic events affecting natural systems (Dawson and Spannagle 2009). Due to growing evidence of the atmospheric effects of large and increasing greenhouse gases (GHG) emission resulting from human activities and the consequent political and social focus on the problem, the terms ‘climate change’ and ‘anthropogenic climate change’ have largely become synonymous. The United Nations Framework Convention on Climate Change (UNFCCC) defined climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition that of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods” (United Nations 1992).

Natural ecosystems and the human economies that rely on these ecosystems are directly influenced by climate. Any change in the climate will affect many aspects of life such as where and how people, plants and animals live, food production, availability and use of water, and potential for disease and other health problems. Thus, climate change is regarded as one of the main issues the world faces today. However, there exists wide disagreement among world leaders in relation to the mitigation steps required to be adopted by different nations. For example, at the Copenhagen Climate Conference held in December 2009, there was disagreement between the developed and developing countries about the responsibilities of the latter towards mitigating climate change. While the developed countries requested the developing countries undertake more proactive measures to limit GHG emissions, developing countries demanded that substantial aid be directed towards reforming their industrial sectors to enable them to adapt (den Elzen et al. 2011).

Although climate change is usually discussed in global terms, its impacts can vary from one region to another. This knowledge is important because locations that are valuable for the economy, such as tourism resources, are vulnerable to climate change in varying degrees, warranting specific proactive and adaptive measures for mitigation of such impacts.

2.3.1 The role of science in climate change

Scientists actively work to understand past, present and future climate by using observations and theoretical models. As a result there is considerable knowledge available about climate change related issues. The leading scientific research authority on global climate change is the IPCC, an international organisation to which climate scientists contribute on a voluntary basis. The IPCC was set up by the UN Environmental Program (UNEP) and the World Meteorological Organization (WMO) in 1988 as a result of growing concerns about the impacts of climate change (McCarthy et al. 2001).

There are various theories about why climate changes naturally (Prokoph, Fowler and Patterson 2001; Rohde and Muller 2005; Sepkoski 1989). These theories and factors can be broadly classified into two categories: (a) theories based on the Earth's geography/topography (b) astronomical theories. The former set of theories stem from the pioneering work of Joseph Fourier (Lam and Fong 2011) who established the laws of heat diffusion in 1822, which explain how heat is redistributed on the earth's surface by the atmosphere and the ocean and contributes to climate change. Fourier also discussed the critical role played by the greenhouse effect in shaping the climate (Fleming 1999). Astronomically-based climate change theories begin with Joseph Adh mar, whose theory explains glacial climate change from changes in the direction of the earth's axis over a period of time (known as precession) (Hilgen 2010). This theory was extended by James Croll using the periodic changes in the earth's orbit over time (eccentricity cycle) and the changes in the angle that the earth's axis makes with the plane of the earth's orbit (obliquity) (Hilgen 2010; Khodri et al. 2005).

However, the most prominent theory of climate change was developed by Milankovitch (Khodri et al. 2005). Milankovitch's theory is based on Adh mar's and Croll's previous work and provides a comprehensive explanation of the causes of long-term climate change. It states that as the earth travels through space around the sun, cyclical variations in *eccentricity*, *obliquity*, and *precession* of earth-sun geometry combine to produce variations in the amount of solar energy that reaches earth, which in turn contributes to climate change (Banerjee 1994; Kukla and Gavin 2004).

While the theories discussed above deal with natural climate change, change in climate is also human induced. Human activities have caused enormous changes in land cover and the nature of the landscape and its functioning, and produce emissions of carbon dioxide, methane and

other gases which alter atmospheric chemistry and ultimately impact on climate (Pitman and de Noblet-Ducoudré 2012).

2.3.2 Effects of climate change

The effects of climate change include variations in air and sea surface temperatures (SSTs) and precipitation, sea level rise, ocean acidification, extreme weather events (such as heat waves, droughts, flash floods and storm surges), seasonal shifts and variations in wind speed. These are briefly discussed below.

(1) Variations in temperature

Temperature is a physical property of matter which is capable of quantitatively expressing the notions of hot and cold (Habiyaemye et al. 2012). Temperature changes related to climate include variations in average (mean), minimum and maximum air temperature as well as SST (Lea, Pak and Spero 2000; Rosenzweig and Tubiello 1996).

(i) Air temperature

This corresponds to the average kinetic energy of the molecular motion in the atmosphere and is measured in a shaded enclosure at a height of approximately 1.2m above the ground (Australian Bureau of Meteorology 2011). The rise in mean global air temperatures being observed at present is a manifestation of global warming. An increase of 0.6°C in the mean global air temperature was reported in the periods 1990-2009, and mean global air temperature is expected to increase in the future (Habiyaemye et al. 2012). Any change in the minimum and maximum air temperatures plays an important role in determining shift in seasons (as discussed in (7) below) as well as the melting of polar ice-caps and glaciers.

(ii) Sea surface temperature

This is the temperature of the uppermost layer of the ocean, typically only a few tens of metres thick (Kucera 2009). Changing SST will damage marine ecosystems and enable the development and intensification of tropical cyclones (Byju and Prasanna Kumar 2011; Vecchi and Soden 2007). Also, changing SST influences coral growth and coral bleaching (Crabbe 2008), negatively affecting fishery and tourism. Global SST is approximately 1°C higher than 140 years ago (Dailidienė et al. 2011).

(2) Variation in precipitation

Precipitation is part of the water cycle in which water vapour cools and condenses as it rises, and includes rain, hail and snow (Liu et al. 2012).

Approximately 505,000 km³ of water falls as precipitation each year – 78.8% of it over the oceans (Gopi 2009). Climate classification systems such as the Köppen system make use of average annual rainfall in order to differentiate regions with various climates (Peel, Finlayson and McMahon 2007).

(3) Sea level rise

The largest impact on coastlines due to rising global temperatures comes from sea level rise (McLeod et al. 2010). Sea level rise directly impacts human populations (in coastal regions and on islands) and natural environments, including marine ecosystems (Bosello, Roson and Tol 2007). The main factors contributing to sea level rise are the thermal expansion of the oceans, melting glaciers and melting icecaps (IPCC 2007b; Titus and Narayanan 1996).

Global mean sea level rose at an average rate of 1.7 ± 0.3 mm per year from 1870 to 2004 (Church and White 2006). Moreover, Holgate and Woodworth (2004) found evidence that coastal sea level was rising faster than global mean sea level. This is significant as more than 50% of the global population lives in coastal areas (McGranahan, Balk and Anderson 2007). It has been calculated that a 0.5m rise in the global sea level is expected to put 92 million people at risk from flooding by the year 2025, mostly in developing countries (Pender 2008).

(4) Coastal erosion

Coastal erosion is the permanent loss of land along the shoreline (Komar 2011). This is observed as the landward movement of the shoreline vegetation. Coastal erosion has serious consequences for many nations. For example, China's future socio-economic development in coastal cities is threatened by coastal erosion (Cai et al. 2009).

(5) Ocean acidification

Ocean acidification is the decrease in the pH level of ocean water due to the absorption of anthropogenic carbon dioxide (CO₂) from the atmosphere and the formation of carbonic acid (Caldeira and Wickett 2003). Between 1751 and 2004 the mean pH of the ocean surface decreased from 8.25 to 8.14, representing an increase of nearly 30% in oceanic acidity (H⁺ ion concentration) (Jacobson 2005). Ocean acidification is a major threat to coral reefs and food chains connected with oceans, so poses negative consequences for reef-associated fisheries, tourism, coastal protection and people (Hoegh-Guldberg et al. 2007).

(6) Extreme weather events

These are meteorological, hydrological, climatological or related phenomena that cause damage to human lives and/or property (Simpson, Weissbecker and Sephton 2011). They can also be described as high-intensity occurrences of a particular event, more frequent, uncommon events and large spatial effects (Ranger, Muir-Wood and Priya 2009). The IPCC recently released a special report on such event called *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (Field et al. 2012). The report's conclusions about five kinds of risks, in order of the certainty of their prediction, are: it is virtually certain that increases in the frequency and magnitude of warm daily temperature extremes and decreases in [the frequency and severity of] cold extremes will occur in the 21st century on a global scale; it is very likely that heatwaves will increase in length, frequency, and/or intensity over most land areas; mean sea-level rise will contribute to upward trends in extreme coastal high water levels in the future; it is likely that the average maximum wind speed of tropical cyclones will increase throughout the coming century, although possibly not in every ocean basin; the global frequency of tropical cyclones will either decrease or remain essentially unchanged; and the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe.

(i) Heatwaves

Heatwaves refer to long periods of abnormally high temperatures, although there is no universal definition of a heatwave due to definitions of 'high' temperatures being different at diverse geographic locations (Stovall 2011). According to Karl and Knight (1997), a heatwave can be defined as the hottest spell, in term of average minimum temperature, of three consecutive days every summer. Along with excessive heat, heatwaves may be accompanied by high levels of humidity.

(ii) Droughts

A drought occurs when a region undergoes a deficiency in its surface/underground water supply due to consistently receiving below-average precipitation (Mishra and Singh 2010, 2011). Droughts can have a substantial impact on the ecosystem as well as on the agricultural sector of the affected region. Although droughts can persist for many years, shorter but intense droughts can cause significant damage and thereby affect the economy (e.g., agriculture) and hence tourism (Luo, Yuan and Du 2012).

(iii) Flash floods

Flash flooding results when precipitation falls rapidly on either saturated or dry soil with poor absorption properties, usually without advance warning (Christensen, Stendel and Yang 2012). They are distinguished from regular floods by their occurrence within six hours of precipitation commencing (Lumbroso and Gaume 2012). Flash floods occur due to heavy rain associated with a storm or hurricane and their effects may be felt anywhere downstream, often many kilometres away from the rain event.

(iv) Storm surges

A storm surge is a result of an offshore rise of water usually associated with a low pressure weather system such as a tropical cyclone (Christensen, Stendel and Yang 2012). The strong winds then push on the ocean's surface causing the water to rise higher than the normal sea level (El-Reedy 2012).

According to the IPCC, around 46 million people per year worldwide are at immediate risk from storm surges (Stripple 2002). In the case of the UAE (where 85% of the population and activities are located in and around the coastal zone), a World Bank report has indicated that some 532 km² of coastal land (representing over 47% of the coastal region) and nearly all coastal farming land is subject to storm surges (Dasgupta et al. 2009).

(7) Shift in seasons

A shift in season can occur when there is an absolute and/or temporal variation in the maximum and minimum air temperature. Seasons are usually defined according to the dates corresponding to certain minimum and maximum temperatures (Linderholm 2006).

(8) Wind

Wind is defined as the bulk movement of air or the flow of atmospheric gases on a large scale (Azad and Alam 2012). In meteorology, winds are referred to by their strength and direction of origin. Short bursts of high-speed wind are described as gusts (Azad and Alam 2012). Wind erosion is a major factor in shaping landforms (Conan, Beeck and Aubrun 2012), and strong winds move sand from deserts to other regions far away (Al-Awadhi, Al-Helal and Al-Enezi 2005).

2.3.3 Key definitions related to climate change

It is important to distinguish between temporal and spatial definitions with respect to climate change.

2.3.3.1 Temporal definitions

The key climate change terms used with respect to time are climate, weather, baseline year, and short and long-term climate change.

(a) Climate vs. weather

The term ‘weather’ is used to describe specific conditions of the atmosphere at a particular place and time, measured in terms of temperature, precipitation, cloudiness, humidity, air pressure and wind (US Global Change Research Program 2009). In contrast, climate, according to the WMO, refers to the average weather of a region over a long period of time, usually 30 years (Chandrappa, Gupta and Kulshrestha 2011). The UNFCCC has yet to define the term climate. Scientists try to analyse overall trends and patterns in climate variation with the objective of identifying long-term effects on the planet’s living species. A change in climate can have a series of effects on human health, water supplies, crop yields, animal life, and economic resources such as tourism (NASA 2012).

Weather is always variable; ‘climate variables’ move around a mean value. It is the variability that carries risks, and it is the risks that society adapts for. People have already adapted to variations in weather in the sense that they lower their risks to acceptable levels (i.e., flooding once every 100 years).

(b) Baseline period

To establish a benchmark for comparing climate change scenarios generated by climate modelling, it is imperative that a reference period is determined. The choice of this reference baseline period has traditionally been dependent on the availability of climate data. Examples of such baseline periods are 1931-1960 (Leemans and Solomon 1993), 1951-1980 (Smith and Pitts 1997) and 1961-1990 (Hulme et al. 1999; Kittel et al. 1995). Each of these periods was used to define the observed climate. The later (1961-1990) periods are more likely to cover anthropogenic activities as well (IPCC 2007b).

The IPCC’s baseline period of 1961-1990 has become the most widely used for global climate change research (Engler et al. 2011; Houghton et al. 2001). The climate scenarios modelled using the 1990 baseline are used to predict expected future conditions at specific locations

(UNEP 2008). Sometimes earlier periods are used for specific purposes such as studying drought, but this use is usually controlled by the availability of historical observed data (Hulme 2001).

(c) Short-term climate change

This refers to the short-term variation of climate change effects. However, ‘short-term’ has been used in a variety of ways in the literature. For example, Chown and Smith (1993) and Schultz (2008) defined ‘short-term’ as 40-50 years from the baseline, while Neil, Arnell and Tompkins (2005) and Yeh, Wetherald and Manabe (1984) defined it as 20-30 years from the baseline. In the context of this thesis, ‘short-term’ is taken to be 40 years from the baseline.

(d) Long-term climate change

This refers to the long-term variation of climate change effects. Similar to ‘short-term’, ‘long-term’ has been defined in a variety of ways in the literature. For example, Hasselmann et al. (2003) defined ‘long-term’ as 70-100 years from the baseline, while Ahas (1999) defined it as 80-90 years from the baseline. In this thesis, ‘long-term’ is taken to be 80 years from the baseline.

2.3.3.2 Spatial definitions

All climate systems are linked through global wind and current circulation patterns. The most important spatial definition in relation to climate change relates to ‘global’ vs. ‘local’ change. Although climate change is thought of as a global problem, the effects of climate change are ultimately localised, with each area being affected differently. Further, as all global data come from local observation stations, this focusing on local aspects of climate change makes it possible to take small-area, locally appropriate actions towards mitigation or adaptation as required (Solecki 2001).

This concept of global and local perspectives is of utmost importance in climate change analysis, because – although analysis of short-term climate change effects is important for many countries – short term effects may not always be readily observable on a local scale. This, however, should not be viewed as a barrier to climate change research, as an analysis of the same effects from a global point of view will help towards understanding the climate change trend from a local perspective (Sovacool and Brown 2010).

2.4 Projecting climate change

The literature on climate change uses the term ‘projection’ in both generic as well as specific terms. In general terms it is defined as ‘any description of the future and the pathways leading to it’ while in specific terms it is used to refer to model-derived estimates of future climates (Carter et al. 2007). Note that the latter definition is the one used by the IPCC.

A projection may serve as the raw material for a scenario (i.e., description of a possible future state of the world). However, scenarios often require additional information (IPCC 2011). Global climate projection depends upon the *emission scenario* and *climate sensitivity* (Watson 2002). As a result, the outcomes are usually in the form of conditional expectations, that is, how the outcomes differ depending on certain input criteria.

2.4.1 Emission scenarios

Future GHG emissions are considered to be the product of very complex dynamic systems, determined by driving forces such as demographic and socio-economic development and technological change (Avignon et al. 2010). How these driving forces will change in future is highly uncertain. Emission scenarios are alternative images of how the future might unfold in terms of sources of anthropogenic GHG emissions, and are used as tools for analysing how these driving forces may influence future emission outcomes and to assess the associated uncertainties (van Vuurena et al. 2003). They assist in climate change analysis, including climate modelling and the assessment of impacts, adaptation, and mitigation.

Emission scenarios were first developed by the IPCC in the period 1990-1992; IPCC Scenarios (IS92) were released in 1992 (IPCC 2000) to enable development of models for projecting climate change on a global scale. The first Special Report on Emissions Scenarios (SRES) was released in 1998, with the intention of enabling scientists to participate in research and provide feedback on these scenarios (IPCC 2000). Table 2-2 shows the important milestones in this continuous process up to the point of releasing the last SRES in March 2000.

Table 2-2 Milestones in developing the Special Report on Emissions Scenarios (SRES)

Year	Event
1992	IPCC released IS92 emission scenarios to be used in conjunction with global circulation models (GCMs)
1995	Evaluation of the earlier IPCC IS92 emissions scenarios

1996	IPCC decided to develop a new set of emissions scenarios
1998	The IPCC Bureau agreed to make the unapproved, preliminary scenarios available to climate modellers for review and comments through an open process via the SRES website
2000	Release of the final SRES, in which a new set of scenarios were released

Source: Adapted from IPCC (2000)

A schematic illustration of SRES scenarios is shown in Figure 2-1. As briefly stated in section 2.4, a *scenario* is a projection of a possible future state of the world under a changing climate. A *storyline* is a qualitative narrative of a scenario (or scenarios) which highlights the main characteristics, dynamics, and relationships among the key driving forces. A *scenario family* is one or more scenarios that have the same demographics, politico-societal, economic and technological storyline (Dougherty et al. 2009; IPCC 2000).

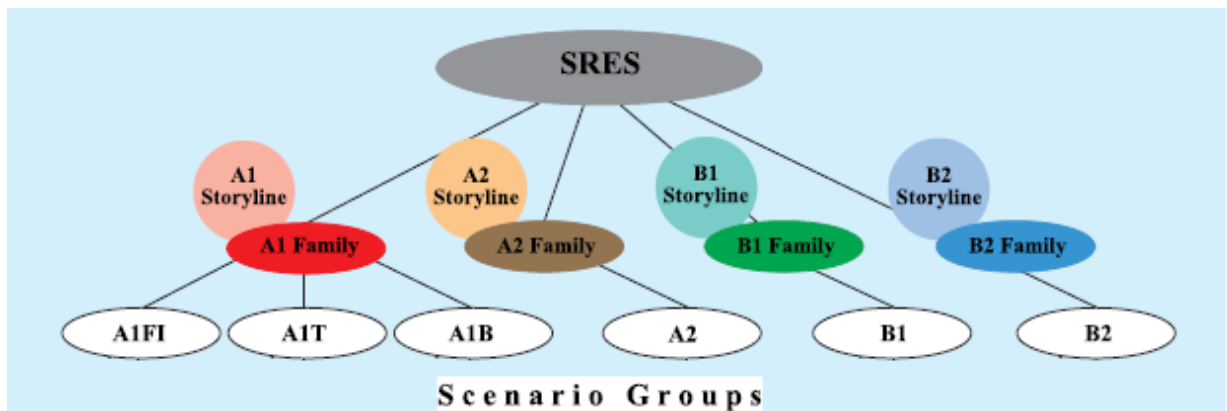


Figure 2-1 The four SRES storylines and scenario families (IPCC 2000)

According to figure 2-1, six emission scenario groups are drawn from the four families. Each storyline (family) represents different demographic, social, economic, technological, and environmental developments. One group in each of A2, B1 and B2, and three groups within the A1 family, characterise alternative developments of energy technologies: A1FI (fossil-fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel) (IPCC 2000). Broadly speaking, the storylines can be considered to combine two sets of divergent tendencies: one set relating strong economic and environmental values, and the other relating to increasing globalisation and regionalisation. The storylines and scenario families (according to Nakicenovic et al. (2000)) are summarised below.

A1: A future world possessing (i) very fast economic growth, (ii) a global population that peaks mid-century (i.e., 2050) and declines thereafter and (iii) the rapid introduction of new and more efficient technologies – events that possess a high probability of occurrence.

A2: A heterogeneous future world with (i) a continuously increasing global population and (ii) regionally oriented economic growth that is more fragmented and slower than in the rest of the storylines.

B1: This corresponds to (i) a convergent world with the same properties of global population as in the A1 storyline, but (ii) with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.

B2: This corresponds to (i) a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, (ii) with continuously increasing population (lower than that of A2, however) and (iii) intermediate economic development.

Figure 2-2 shows predictions of global CO₂ emissions under the four emission scenarios. It shows in greater detail the ranges of total CO₂ emissions for the six groups of scenarios that constitute the four families (the three scenario families A2, B1, and B2, plus three groups within the A1 family A1FI, A1T, and A1B). For instance, in the year 2100 the A1FI emission scenario assumes that CO₂ output ranges between 25 and 35 gigatonnes of carbon per year (GtC/yr) whereas B1 assumes that the CO₂ emission scenario will be between two and 10 gigatonnes of carbon per year.

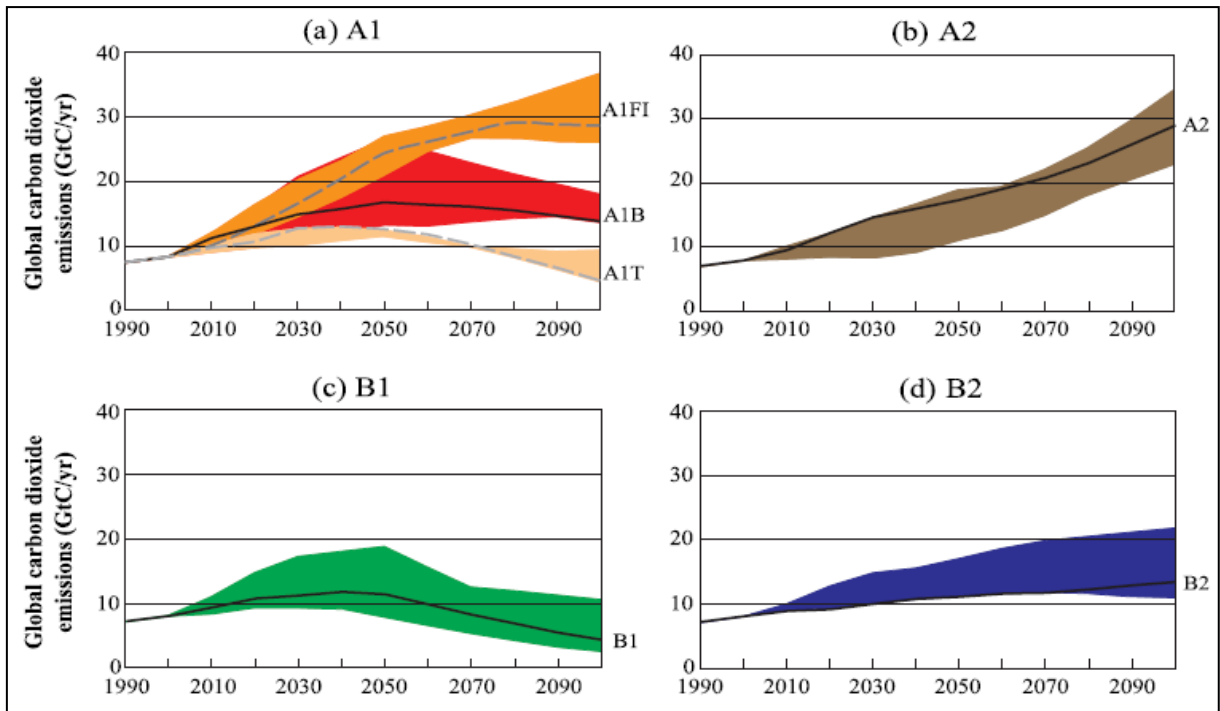


Figure 2-2 Four global emissions scenarios (IPCC 2000)

More than 20 years have passed since 1990, the baseline year for the IPCC emission scenarios. Thus scientists have since gathered about 20 years of measurements of CO₂ and global mean temperatures. The CO₂ measurements can be compared with the emission scenarios: observed vs. predicted. Due to the fact that the global mean anomalies in CO₂ and temperature from 1990 to 2012 have been shown to be consistent with the projections made using the A1FI emission scenario (NASA 2012, NAOO 2012), the GHG emissions path the world is following at present is considered to be A1FI.

2.4.2 Climate sensitivity

Climate sensitivity is a concept that deals with the uncertainty about how the earth's climate system will respond to an increase in atmospheric CO₂. To quantify the relationship between CO₂ and global temperature, the IPCC runs General Circulation Models (or Global Climate Models – GCMs) for a given sudden increase in CO₂, instead of using one of the IPCC SRES emission scenarios. The most commonly used sudden increase is a doubling of CO₂; the result is expressed as an increase of global average temperature for a doubling of CO₂. This doubling is likely to occur in the near future (Tonga et al. 2009). This value was estimated, by the IPCC's Fourth Assessment Report (FAR) to be in the range 2 – 4.5°C with a best estimate of approximately 3°C while being considered very unlikely to be less than 1.5°C (IPCC 2007b).

It should be noted that each of the different GCMs will produce a different change in temperature by doubling GHG emissions (abbreviated to ΔT_{2x}). Thus IPCC uses a range of ΔT_{2x} , from low (two-thirds of the models predict it is higher), through medium (the most likely value) to high (two-thirds of the models predict it is lower). For FAR these values are set to 2.0, 3.0 and 4.5°C respectively. Some models employ even higher sensitivities (Hegerl et al. 2006). An important change between the Third Assessment Report (TAR) and FAR was the upward shift of the ΔT_{2x} range (1.5, 2.6 and 4.5 °C in TAR).

2.4.3 Global Climate Models

GCMs represent the physics and dynamics of the earth-atmosphere system through a series of differential equations based on the laws of physics, fluid motion, and chemistry (Goudie and Cuff 2008). The aim of a GCM is to simulate conditions over a long period of time so that the simulated climate matches the actual climate of that period under a specified emission scenario. To run a model, scientists divide the planet into a three-dimensional grid as shown in Figure 2-3, apply the basic equations, and evaluate the results (Orr et al. 2001). Each of the components (atmosphere, land surface, ocean, and sea ice) has equations calculated on the global grid for a set of climate variables such as temperature and precipitation. Grid size is dependent upon the power of the computer that is available to solve these equations. Finer resolution means a larger number of grid cells and requires a super-computer to perform the simulation (NOAA 2011).

These models are capable of calculating winds, heat transfer, radiation, relative humidity, and surface hydrology within each grid and evaluating the interaction with neighbouring points. However, as climate simulations often cover decades or centuries of system evolution, they are less accurate than weather forecasting (Parker 2010).

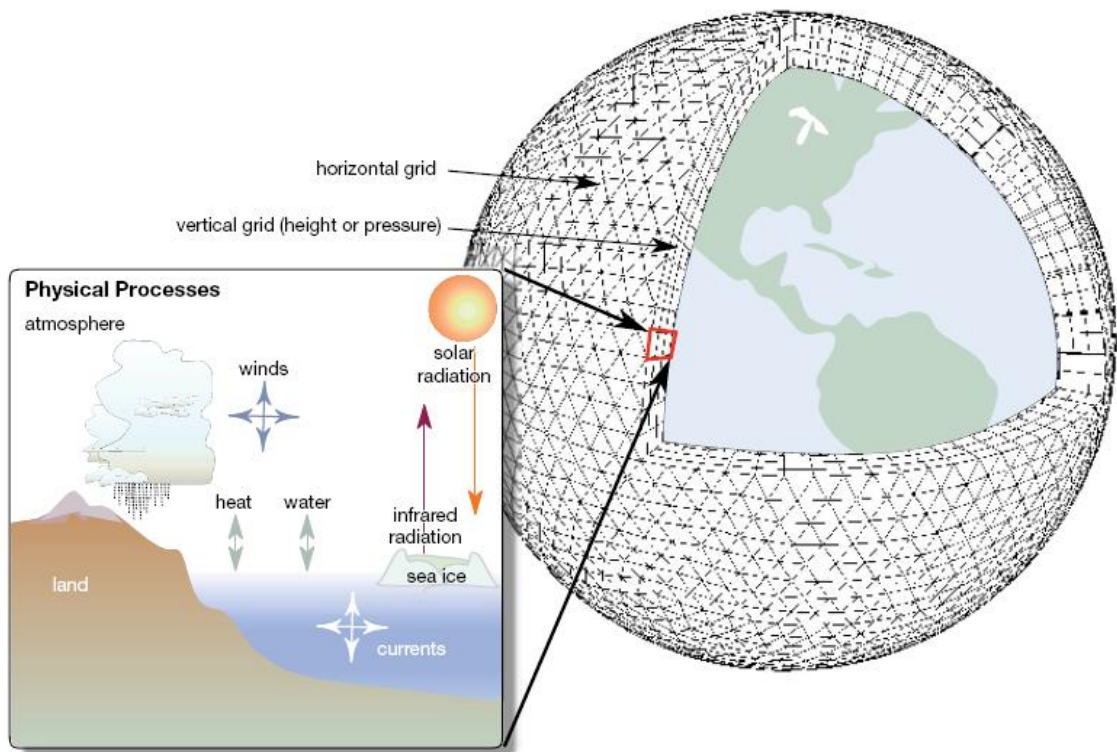


Figure 2-3 Schematic illustrating how the earth is represented by a series of grid cells in global climate models (Australian Bureau of Meteorology and CSIRO 2011)

Currently available GCMs described in the IPCC's FAR are listed in table 2-3.

Table 2-3 Currently available GCMs

Originating Group(s), Country	Model
Bjerknes Centre for Climate Research, Norway	BCCR
Canadian Climate Centre, Canada	CCCMA T47
Meteo-France, France	CNRM
CSIRO, Australia	CSIRO-MK3.0
CSIRO, Australia	CSIRO-MK3.5
Geophysical Fluid Dynamics Lab, USA	GFDL 2.0
Geophysical Fluid Dynamics Lab, USA	GFDL 2.1
NASA/Goddard Institute for Space Studies, USA	GISS-E-H
NASA/Goddard Institute for Space Studies, USA	GISS-E-R
LASG/Institute of Atmospheric Physics, China	FGOALS
Institute of Numerical Mathematics, Russia	INMCM
Institute Pierre Simon Laplace, France	IPSL
Centre for Climate Research, Japan	MIROC-H
Centre for Climate Research, Japan	MIROC-M
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, Germany/Korea	MIUB-ECHO- G
Max Planck Institute for Meteorology DKRZ, Germany	MPI-ECHAM5
Meteorological Research Institute, Japan	MRI
National Centre for Atmospheric Research, USA	NCAR-CCSM
National Centre for Atmospheric Research, USA	NCAR-PCM1
Hadley Centre, UK	HADCM3
Hadley Centre, UK	HADGEM1

Sources: (National Climate Change Adaptation Research Facility 2011a)

2.4.4 Downscaling

Downscaling is the process in which the resolution of a pattern (expressed in the size of the grid-cells, either in kilometres, metres or degrees) increases. For example, the process of taking a global pattern with a resolution of $0.5^\circ \times 0.5^\circ$ (approximately 100 x 100km) and transforming this into a pattern with a resolution of 1km x 1km is termed downscaling. To determine the downscaling process, additional data is usually required such as the topography of the terrain, local observations, and the outputs of other models (Wilby and Wigley 1997). Downscaling has an important role to play in climate change analysis through increase in

spatial resolution. In GCMs, for example, downscaling process transforms GCM output to a resolution useful for impact analysis (Atkinson 2013).

2.4.5 Pattern scaling

Pattern scaling is the methodology in which a ‘normalised’ pattern (which describes a change in a local climate variable per unit change in global mean temperature) is multiplied (‘scaled’) with the projected global temperature to obtain the projected local change of the climate variable (Cabr e, Solman and Nu nez 2010). This ratio works well for estimating mean temperature changes for which the regional changes are linearly related to the global mean temperature changes (Mitchell 2003).

2.4.6 Uncertainty in climate change projections

The degree to which a future state of a climate system is unknown is called uncertainty (Berkes 2007). Uncertainty can result from lack of information or from disagreement on what is known or even knowable (Solomon et al. 2007). According to Pittock (1995, p. 1) major sources of uncertainty in relation to projection of future climate change arise from the following:

- (a) Uncertainties about future GHG emissions and concentrations;
- (b) Limitations on the physical representations of processes and assumed spatial patterns when developing GCMs;
- (c) Differences between models as to the spatial patterns of local climate change for a given global warming; and
- (d) Other less quantifiable uncertainties, such as the effect of changes in ocean circulations, natural climate variability, and changes due to other pollutants such as sulphate particles.

Uncertainties associated with climate change projections can be visualised in multiple ways. Figure 2-4 depicts projections of the climate variable ‘change in global temperature’ from 1990 to 2100 at three sensitivities.

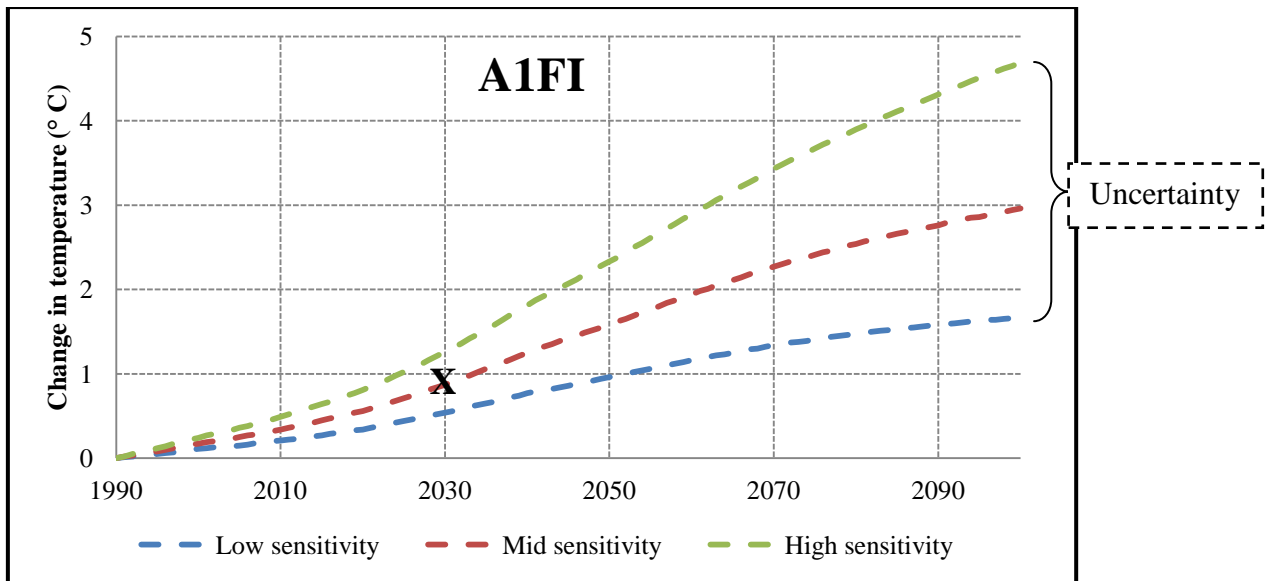


Figure 2-4 Uncertainties associated with climate change projections

In figure 2-4 the specified point X has a coordinate of (year 2030, change in temperature 1°C). Its uncertainty arises from the confidence in selecting the sensitivity level (low, medium, high). This uncertainty can be expressed in two ways:

- (a) The vertical difference between the green and blue lines at the specified point (year, change in temperature; e.g., 2030, 1) corresponds to the uncertainty associated with the change in temperature in the year 2030, lying between $1 \pm 0.5^\circ\text{C}$.
- (b) The horizontal difference between the green and blue lines at the specified point (year, change in temperature; e.g., 2030, 1) corresponds to the uncertainty associated with the time period (between 2025 and 2050) by which the change in temperature will be equal to 1°C.

Methods available to reduce such uncertainties are discussed in Section 2.4.7.

2.4.7 Ensembles

In order to deal with uncertainty, scientists (Ghile and Schulze 2009; Murphy et al. 2004; Parker 2010; Strauch et al. 2012; Zhang et al. 2012) suggest the use of ensembles. Ensembles (groups of models) are increasingly being recognised in the climate change adaptation and risk assessment literature as an appropriate method for managing uncertainty in GCMs, that is, the range of possible outcomes based on the choice of GCM patterns in an analysis. Note that, while it is possible to create ensembles for most climate change effects, in some cases ensemble models cannot be used due to the non-existence of corresponding local (pattern-scaled) information or corresponding GCMs (Parker 2010).

The convergence of the results for climate change projections using different ensembles of GCMs for a given emissions scenario is of importance in determining their suitability. In other words, the closer the results are, the more reliable the selected ensembles for projection purposes (Zhang et al. 2012). Therefore, using ensembles increases the confidence levels of the results obtained.

How ensembles were used to reduce uncertainty in this research is discussed in chapter 3.

2.5 Assessment of the impact of climate change on tourism resources

In section 2.1 and 2.2 it was noted that tourism is an industry of increasing economic importance worldwide. Many regions that only a few years ago were inaccessible to most tourist, such as the Middle East and Africa, are now popular holiday destinations (Jones and Phillips 2011). The UNWTO calculated the monetary value of tourism in 2009 as more than USD \$1 trillion (approximately USD\$3 billion a day), accounting for ‘30% of the world’s exports of commercial services’ and ‘ranking fourth after fuels, chemicals and automotive products’ (UNWTO 2010, p. 2).

Climate change is looming as a major threat to the sustainability of the tourism industry and is a major concern for countries that rely on tourism as a primary source of income (Hall 2011; UNEP 2008). The tourism industry is increasingly important to the Middle East (Honey and Gilpin 2009). The average annual growth rate for the Middle East during 1990-2010 was 9.6% and the number of visiting tourists increased from 9.6 million to 60.3 million (UNWTO 2011). This growth outpaced that in the popular tourist destinations of Europe, the Americas, Africa, East Asia and the Pacific (UNWTO 2010).

The impacts of climate change on tourism are likely to manifest in different ways depending on local conditions (Viner and Agnew 1999). Most of these impacts are due to indirect stresses placed on the existing environmental systems and tourism resources. The highest impact is expected to come from higher temperatures and rising sea level (Amelung, Nicholls and Viner 2007; Phillips and Jones 2006). According to the IPCC scenarios, several other projected impacts are unavoidable; these include coral bleaching, species extinction, water scarcity and risk of drought in some regions, increased risk of wildfire and coastal damage from floods and sea level rise (Parry et al. 2007).

Dougherty et al. (2009) noted that some communities have attempted to protect themselves against potential coastal impact by constructing hard structures like sea walls. However, it has

become clear that even with plentiful funding, coastlines may not be effectively protected by hard structures and could be better protected by ongoing ‘soft’ protection measures such as beach nourishment and wetland restoration (Greene 2002). Unfortunately, decision-makers are persisting with hard structures due to the lower maintenance costs. Appropriate design and implementation of such mitigation techniques is also reliant on accurate knowledge of coastal dynamics, which may not be readily available (Dougherty et al. 2009).

One of the UAE’s main tourism resources is coral reefs; these have already been severely impacted by the effects of climate change. Corals are vulnerable to thermal stress and have been affected by the rise in SSTs. In both 1996 and 1998 the UAE experienced major coral bleaching events due to abnormal rises in seawater temperatures (by over 2°C). Increases in SST of 1–3°C will result in more major coral bleaching events (Dougherty et al. 2009).

2.6 Assessment of macro and micro impacts in resources

Three terms are used in meteorology to define scale: microscale, mesoscale and macro/synoptic scale. According to the American Meteorological Society’s *Glossary of Meteorology*, macro scale refers to synoptic events occurring on a scale of thousands of kilometres, such as warm and cold fronts. Whereas, the mesoscale is defined as the 2–2000 km scale, with sub-classifications of meso- α , meso- β , and meso- γ scales referring to horizontal scales of 200–2000 km, 20–200 km, and 2–20 km, respectively. Microscale is defined to be less than 2 km (American Meteorological Society 2011). However in change detection where changes are of centimetres that count as significance impact those scale are not very often used (Smith et al. 2008). In this thesis a change of 1m and above is referred to as a macro impact and a change of less than 1m as a micro impact.

Macro changes to tourism resources occur due to extreme weather conditions or the accumulated results of long-term climate change (Mishev and Mochurova 2010; Yu, Schwartz and Walsh 2009). Such impacts need to be measured for future planning and mitigation purposes using suitable change detection methods. In contrast to macro changes, micro changes to tourism resources occur due to slow variations in climate effects (Becken and Hay 2007; Phillips and Jones 2006). Micro impacts also need to be quantified for future planning and mitigation purposes using suitable change detection technologies.

Various tools and techniques are available to monitor and assess both macro and micro impacts and are discussed in the next section.

2.7 Review of tools and techniques

This research required the use of tools and techniques for spatial analysis, macro and micro change detection in tourism resources, projecting future climate change effects, and assessment of impacts from such climatic effects. These methods, along with their merits relative to other possible choices, are described in the following sections.

2.7.1 Tools for spatial analysis and macro scale change detection

This research encompassed comprehensive spatial analysis, modelling and macro scale change detection in relation to tourism resources. These components involved tasks such as:

- (i) Construction of vector data models (point, line or polygon) depicting land use and land cover (LULC), infrastructure (e.g., airports and ports) and building of a geodatabase including the distribution of the tourism resources within the Emirate of Fujairah (the case study).
- (ii) Constructing the spatial distribution of climate change effects in raster format including the creation and visualisation of flood models based on a Digital Elevation Model (DEM).
- (iii) Creation of maps in raster format based on aerial and satellite images for macro change detection in Fujairah's tourism resources.

Several applications that could be used for such tasks are described in the literature (Ahuja and Habibullah 2005; Goodchild 2009b; Tsay et al. 1993), such as Land Information Systems (LIS), Automated Mapping/Facilities Management (AM/FM) and Geographic Information Systems (GIS).

An LIS is a tool consisting of an accurate and reliable land record cadastre. Associated attribute and spatial data stored within an LIS provide a base for integration into other geographic systems and use in land-use mapping. This enables the creation, updating, storing, viewing, analysing and publishing of land information (Nahrin and Shafiq-Ur-Rahman 2009).

Automated Mapping/Facilities Management (AM/FM) is a set of tools capable of manipulating geospatial data associated with public utilities such as gas, electric, water and telecommunications (Xing et al. 1998). All AM/FM systems have a graphical component and a database component. The graphical component deals with data which can consist of different types of real-world entities or objects represented graphically by shapes or geometries (Ekanayake et al. 2012). The database component stores the attribute data for the

real-world entities that need to be captured or managed as a part of the digitisation process (Schwartz 2005). The data are stored in an underlying geospatial database which also maintains the associations between the graphical entities and the attributes.

A GIS is defined as a computer system designed to capture, store, manipulate, analyse, manage and present all types of geographical data (Goodchild 2009a). In the simplest terms, GIS is a combination of cartography, statistical analysis and database technology. GIS is a proven tool for digitally mapping plus analysing sites and locations of interest. It offers many advantages over analogue maps. Analogue maps have limited functionalities and lack functions such as overlaying of multiple layers of information, which are now widely used (Pauschert et al. 2011). Both LIS and AM/FM systems are specialised forms of GIS.

Due to its functional completeness, researchers have successfully used GIS-based spatial geodatabases for tasks in environmental science (Hadeel, Jabbar and Chen 2011; Mozgoviy et al. 2007), planning (Worrall 1994; Xiang 1996), policy-making (Tulloch et al. 2003) and disaster management systems (Shamshiry et al. 2011). Section 2.7.1.1 presents a detailed discussion on GIS.

2.7.1.1 Geographic Information Systems (GIS)

Modern GIS use digital information created using various digital methods. One method of data creation is digitisation, where a hard copy map or survey plan is transferred into a digital medium through the use of a computer-aided design (CAD) program, and geo-referencing capabilities (Chang 2011). Most GIS data now come from digital sources.

The ability of GIS to integrate spatial data from different sources, with different formats, structures, projections and levels of resolution is a powerful aid to spatial analysis. GIS is not only a digital store of spatial objects (points, lines and polygons) but is capable of spatial analysis based on the interactions between these objects, including the relationships between objects defined by their location and geometry. In addition, the features of GIS include support for the transfer of data to and from analytical packages (Payn et al. 1999).

2.7.1.2 Building a Geodatabase using GIS

A geodatabase is a collection of geographic datasets of various types and has the ability to store several types of information in either raster or vector format (ESRI 2012). The data are stored inside a personal geodatabase (such as Microsoft Access).

The availability of high-resolution satellite imagery like IKONOS (Goetz et al. 2003) and QuickBird (Coops et al. 2006) makes it easy to provide more detailed spatial information in the form of a comprehensive geodatabase; doing this involves mapping locations of interest and combining those maps with detailed site-specific information. This may include geospatial data such as digital elevation model (DEM), data obtained using satellite imagery, biophysical data such as land use/land cover maps, tourism resource maps (point format, distribution of scenic spots) as well as municipal boundary maps (Chen, Li and Wang 2009).

Steps involved in building a GIS geodatabase include identifying the study area, collecting spatial and attribute data and developing a database, defining the coordinate system, feature mapping (such as digitising maps to extract features) and generating outputs (Chen, Li and Wang 2009). Attribute data provide more information about features. For example, attribute data could include information about hotels (rating, cost, number of rooms, restaurants) and roads (width, one way or two, length).

Geodatabases have been used in tourism management previously. Sadoun and Al-Bayari (2009) used GIS to build a model for tourism industries (services) for officials and conservationists of historic sites in Jordan. Li, Hui and Zhaoping (2010) relied on GIS to build a tourism resources management information system for Liaoning, China that showed the distribution of tourism resources, history and travel information.

GIS has been used for tourism planning (Hasse and Milne 2005), tourism infrastructure (Boers and Cottrell 2007), agriculture (Mendas and Delali 2012; Mori, Kato and Ido 2010) and ecology (Hugh-Jones and Blackburn 2009; Martens and Huntington 2012). GIS has also been used for tourism information searching as part of a digital tourism information system (Chang and Caneday 2011; Chen 2007). Chhetri and Arrowsmith (2008) discussed how a GIS might be used to measure the recreational potential of natural tourist destinations in western Victoria, Australia; they developed a GIS-based model that has spatially translated subjective evaluations to a mapped surface of recreational potential that can be used as a planning tool for resource allocation.

2.7.1.3 Using GIS for macro change detection

Monitoring sites of interest requires the capture of spatial and temporal data. To this end, GIS is highly appropriate as it has the ability to deal with large volumes of diverse data that are geographically distributed and occurring over time (Payn et al. 1999). GIS can be used to

measure the amount of change and often technologies are used to detect the change, e.g., TLS, remote sensing, surveying, photogrammetry.

Change detection is an important process in monitoring and managing natural resources because it is capable of providing a quantitative analysis of change occurring with time (Gamanya, De Maeyer and De Dapper 2009). As an example, coastal areas may undergo constant but slow changes and therefore Kasawani (2010) conducted GIS-based change detection for the shoreline of Setiu Lagoon, Malaysia, which is rich in coastal resources and natural biodiversity. Using GIS, the boundary was digitised, and the data edited and transformed into coastline maps for the years from 1980 to 2004 to detect changes.

Erener, Düzgün and Yalciner (2012) used GIS to detect rapid changes in Land Use/Land Cover (LULC) that adversely affect the environment. The temporal and spatial characteristics of urban expansion have been explored by using remote sensing integrated with GIS (Wang, Ju and Li 2009).

2.7.2 Tools for micro scale change detection

Micro changes and minute degradation of tourism resources can be detected and measured using total-stations (usually in conjunction with a Global Positioning System – GPS), airborne Light Detection and Ranging (LiDAR) or TLS (Kang and Lu 2011).

2.7.2.1 Traditional surveying using total stations

A total station is an electronic optical instrument used in modern surveying and can be used in conjunction with GPS (Lemmens 2011b). It employs an electro-optical distance metering method, whereby it emit laser beams and detects light reflected off the target objects and makes measurements by calculating the deviation of the wavelength of the reflected light. Total stations are able to measure distances to an accuracy of 2–3 mm and horizontal/vertical angles to an accuracy of a few seconds of arc (Nainwal et al. 2008).

Total stations are mainly used by land surveyors and civil engineers, either to record features as in topographic surveying or in determining features associated with roads, houses or boundaries (Heritage and Hetherington 2007). They are also used by archaeologists to record excavations and to take measurements in places of interest (McPherron 2005).

Total stations have certain disadvantages such as requiring line of sight, observations, low sampling rate, less vertical elevation accuracy as well as continuous accumulation of errors during the measuring process (Arias et al. 2005; Cuypers et al. 2009).

2.7.2.2 Global Positioning System

Global positioning system (GPS) is a navigation, timing and positioning system which consists of three main parts: satellites, ground tracking monitoring station and customer stations (Tsui 2005). In recent years, GPS has widely been applied in land change survey fields, such as resources management, urban planning and landscape construction (Xu 2012). It has many advantages over traditional survey techniques. Real-Time Kinematic GPS (GPS-RTK) is a more secure and fast method which has advantages of shorter observation time, high positioning accuracy, and direct measurement of exact coordinates in the field (Sun et al. 2010; Xu 2012). However, the control on which it depends is typically set using static GPS. Indeed, Real Time Kinematic GPS can provide real-time corrections, giving up to centimetre-level accuracy (Gao et al. 2011).

GPS can be combined with other methods such as tilt meters (an instruments used to measure small changes in the tilt of the earth's surface) to produce a highly precise monitoring system (Davis et al. 2000).

2.7.2.3 Airborne Light Detection and Ranging

Airborne Light Detection and Ranging (LiDAR – also called airborne laser scanning or ALS) is an optical remote sensing technology fitted to aircraft and used for surveying and mapping; it can measure the distance to or other properties of a target by illuminating it (see Figure 2-5) with light, often using pulses from a laser (Suárez et al. 2005). LiDAR technology is used in geomatics, archaeology, geomorphology, seismology, forestry, remote sensing and atmospheric physics, atmospheric research and meteorology (Ismail and Manaf 2011). It has found applications in Airborne Laser Swath Mapping (ALSM) and laser altimetry.

Airborne Light Detection and Ranging has also been used extensively in atmospheric research and meteorology. Downward-focused LiDAR instruments fitted to aircraft are used for surveying and mapping – an example being the NASA Experimental Advanced Research LiDAR (Brock et al. 2004). In addition, LiDAR has been identified by NASA as a key technology for enabling autonomous precision landing of future robotic and crewed lunar vehicles (Amzajerdian et al. 2011). LiDAR has many applications in the field of archaeology,

including aiding in mapping features beneath forest canopy and providing an overview of broad, continuous features that may be indistinguishable on the ground (Crow et al. 2007). LiDAR enables archaeologists to create high-resolution DEMs of archaeological sites that can reveal micro-topography otherwise hidden by vegetation (Liu 2008).

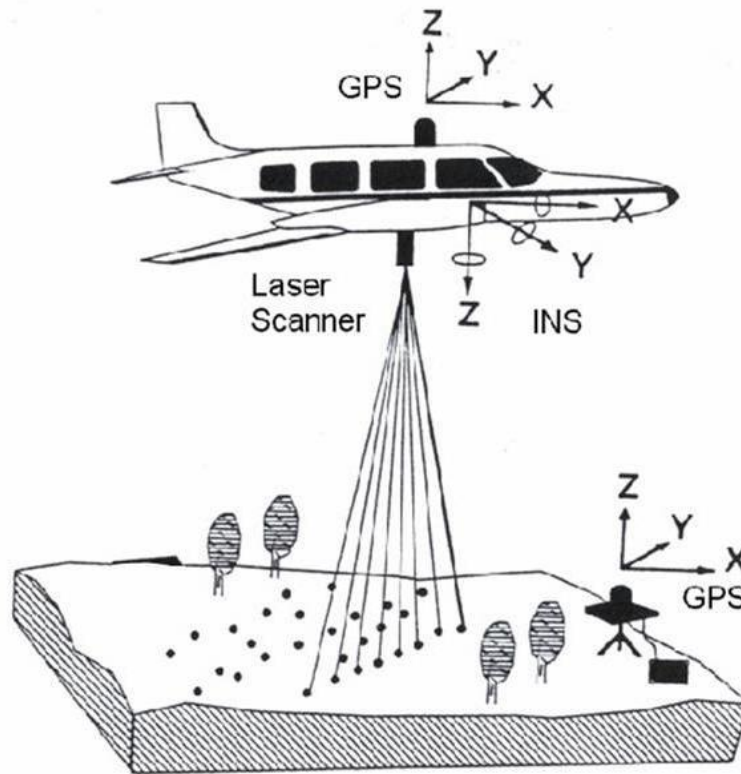


Figure 2-5 Schematic of LiDAR process (Kao et al. 2005)

2.7.2.4 Terrestrial laser scanning (TLS)

Ground based LiDAR is known as Terrestrial Laser Scanning (TLS). It operates by collecting data from a given area by taking millions of vector measurements from an instrument resulting in a three-dimensional (3D) image. This is achieved by emitting laser pulses and then analysing the properties of the pulses reflected by the surface or object. This rapid capture takes place at a safe distance from the object being scanned and the spatial data are collected through horizontal and vertical swathes of user-defined intensity and accuracy. The scanning process generates an accurate cloud of points (Pu and Vosselman 2009).

Multiple scans are usually required to obtain a complete dataset for an object; thus, an observation network of multiple observing ‘stations’ is required. To build the final 3D (point-cloud) model, the point clouds originating from the local coordinate systems of each station

are transformed into a common coordinate system by matching the overlap points (reflective identifiers placed prior to scanning) among different scans. These reflective identifiers are called ‘control targets’, and the process of generating the complete 3D point-cloud model by transforming to a common coordinate system is known as ‘registration’ (Lemmens 2011a). This is depicted in Figure 2-6.

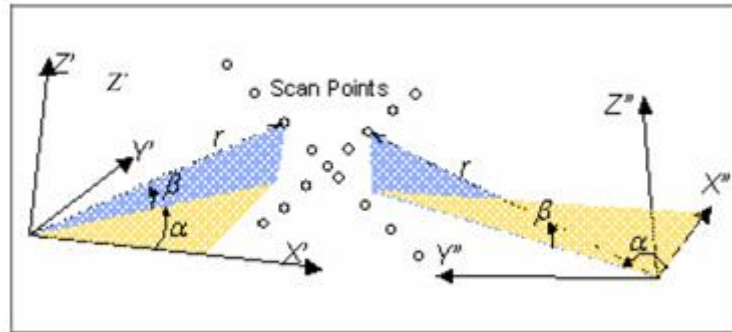


Figure 2-6 Transforming of point-clouds from different stations to a common coordinate system (Hsiao et al. 2004)

Once the 3D model of the point cloud data is developed, it can be used for various analysis purposes such as change detection (discussed in Chapter 8) by comparing similar models obtained over time using future TLS scans. These comparisons usually involve complex algorithms based on mathematical techniques (discussed in Section 2.6.3).

TLS has been successfully applied in the documentation of historic buildings, archaeological features and natural features all over the world and is expected to become the future standard tool for high-resolution 3D documentation (Brenner, Dold and Ripperda 2008; Lermaa et al. 2010). It is suitable for swift collection of reliable high-resolution data and can save hundreds of person-hours of effort. The scanned data can also be used for restoration planning and creating virtual reality models. In addition, terrestrial 3D laser scanning is currently being applied in areas such as architecture (e.g., facade scans) (Moorthy et al. 2011), project visualisations (e.g., complex buildings such as mosques and heritage buildings) (Armesto-González et al. 2010), infrastructure (e.g., views of complicated structures such as bridges and tunnels) (Lubowiecka et al. 2009), volume and deformation measurements as well as archaeological preservation (Bremer and Sass 2012).

Detection of changes relies upon point-to-point comparison in 3D space. This involves either measuring the amount of change in a point between one scan and another, or simply detecting whether a point in the reference scan exists in the scan being analysed or vice versa. Their

union depicts the overall change while their exclusion reveals only the static objects in the scene. Models for change detection are capable of accommodating all the features of a scan (Levin and Filin 2010).

Notable advantages of 3D laser scanning include its capability for full coverage, high-speed operation, and the ability to operate in hazardous environments due to its remote-capture functionalities.

2.7.2.5 Comparison of tools for micro change detection

Three techniques (total stations, LiDAR and TLS) that could be used for micro change detection were presented above. Table 2-4 summarises the advantages and disadvantages of each technique.

Table 2-4 Comparison of tools for micro change detection

Technique Feature	Total Stations	LiDAR (airborne)	TLS
Spatial Resolution/precision	Very high (e.g. 1-2 mm)	High (e.g. Horizontal 8cm, Vertical 5cm)	Very high (e.g., 1-2 mm)
Angular coverage	full coverage (i.e., 360°)	Width approximates to flying height (i.e., 60°)	full coverage (i.e., 360°)
Spatial coverage	Lowest coverage	High spatial coverage since taken from air – but weather dependent (ex: rain)	limited
Accuracy	Highest accuracy	Low	High
Remote capture possible?	Yes	Yes	Yes - Requires targets to connect scans
Cost	Low	Medium	High
Data Storage	Low	Very high	Medium

For site investigations, TLS is generally more economical than other options. The key difference between TLS and ALS is that the TLS scanner is mounted to a tripod on the ground, providing an improved view of vertical features, whereas ALS are mounted in an aircraft and looks down, providing a better perspective on horizontal features (Olsen, Butcher and Silvia 2012).

For a temporal analysis of tourism resources, changes occurring over extended time periods need to be identified quantitatively (Macleod and Congalton 1998). Macro change detection is carried out by obtaining a series of images of a selected site at different points in time and then comparing them using GIS-based spatial analysis tools (often involving image subtraction) or by visual comparison (Li, Onasch and Guo 2008).

Detection of micro changes in tourism resources essentially consists of point-point comparison in 3D space (such as the 3D point-cloud data obtained using TLS). This involves either measuring the amount of change for a point from one scan to another or simply detecting whether a point in the reference scan exists in the scan being analysed or vice versa.

2.8 Tools for climate change projections

The UNFCCC's *Compendium on Methods and Tools to Evaluate Impacts of, and Vulnerability and Adaptation to, Climate Change* describes several methods and tools for making climate change projections (UNFCCC 2008). It includes a description of each tool, including its scope, appropriate use and application as well as key inputs and outputs. The main tools available for making projections of future climate change are MAGICC, LocClim and SimCLIM (UNFCCC 2008). A brief description of each of these software tools is presented below, noting their advantages, weaknesses and limitations.

2.8.1 MAGICC/SCENGEN

Model for the Assessment of Greenhouse-gas Induced Climate Change/Regional Climate SCENario GENerator (MAGICC/SCENGEN) is a coupled, user-friendly interactive software suites that allow users to investigate future climate change and its uncertainties at both the global-mean and regional levels (Wigley 1995). MAGICC and SCENGEN are managed by the Climatic Research Unit of the National Centre for Atmospheric Research (NCAR).

Outputs from MAGICC include estimates of GHG-induced climate change. These outputs are then used as input into SCENGEN to generate a range of geographically explicit climate change projections for variables such as temperature and precipitation, changes in their variability, and a range of other statistics.

The software also allows the users to model changes in GHG concentrations, global mean surface air temperature, and sea level resulting from anthropogenic emissions of many gases including CO₂, methane (CH₄), and nitrous oxide (N₂O). Figure 2-7 shows two screen captures from the MAGICC/SCENGEN simulation environment.

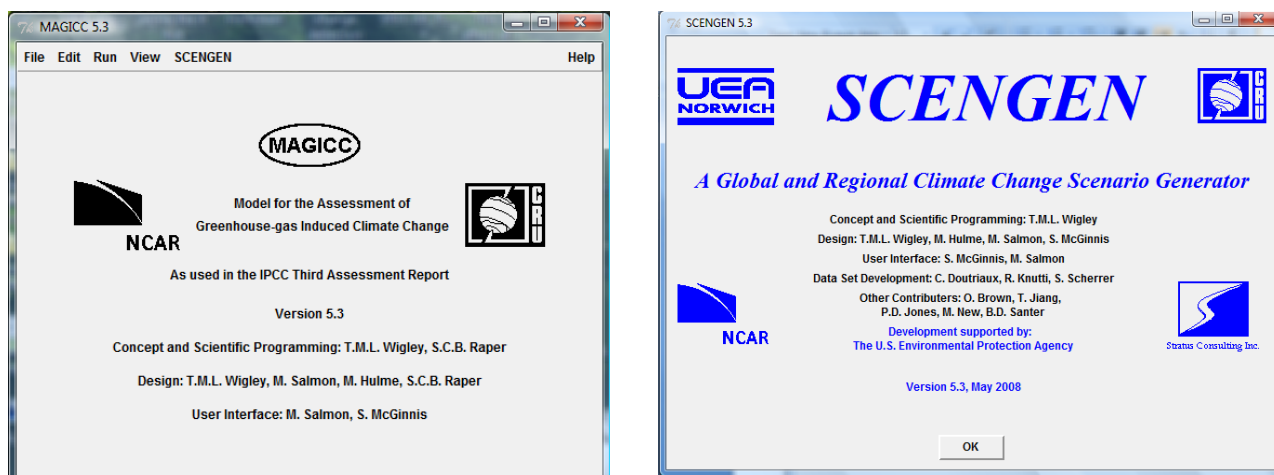


Figure 2-7 Screen-captures from MAGICC/SCENGEN

The key feature of MAGICC/SCENGEN is its ability to compare the projected global-mean temperature and sea level under one of two different emissions scenarios. The year 1990 is taken as the default baseline year while 2100 is the default projection (output) year. These are definable by the user.

Apart from construction of simple climate change scenarios, SCENGEN is also capable of producing spatial patterns for changes in inter-annual variability, two different forms of signal-to-noise ratio (to assess the significance of changes), probabilistic output (the default being the probability of an increase in the chosen climate variable) and a wide range of model validation statistics for individual or combination of models in order to facilitate the selection of models for scenario development (Li, Mills and McNeil 2011).

The disadvantage of MAGICC/SCENGEN is that SCENGEN (the scenario generator) produces outputs (projections) for global to regional scales at coarse resolutions (2.5 x 2.5 degrees latitude/longitude). Therefore SCENGEN is not suitable for small area where the change is minute.

2.8.2 LocClim

LocClim (Local Climate Estimator) is a software tool for spatial interpolation of agro-climatic data developed by the UN Food and Agriculture Organisation (FAO) (Dogan 2007). It is capable of estimating climatic conditions at locations for which no past observation data are available and provides nine different spatial interpolation methods (including thin-plate splines) (Dogan 2007). To achieve this, the programme uses the 28,800 stations of FAOCLIM

(a CD-ROM with world-wide agro-climatic data) 2.0, the global agro-climatic database maintained by the FAO's Agrometeorology Group.

LocCLIM allows users to interpolate their own data and prepare grid maps at any spatial resolution. Thus climate maps at any spatial resolution corresponding to average monthly climate conditions can be produced and the data can be exported for further processing on other software packages. Inputs can be taken from the screen output (location specified either by co-ordinates or by a click on a map) or from the user-provided ASCII files. Output can be in the form of ASCII files or a user-defined geo-referenced grid. Figure 2-8 shows screen-captures obtained from LocCLIM.

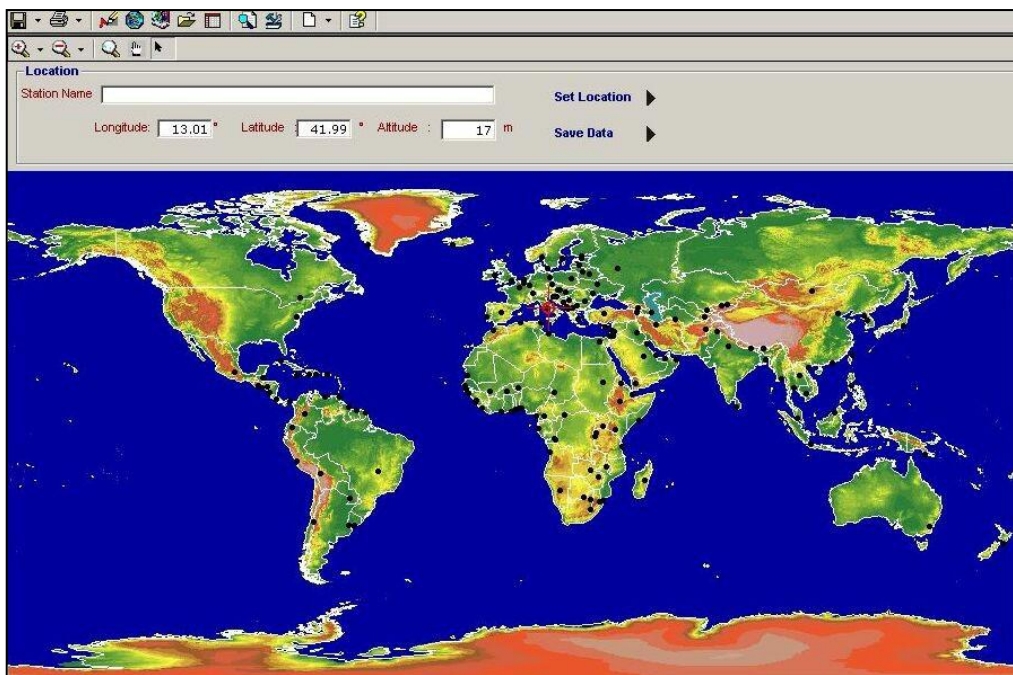


Figure 2-8 Screen-captures from LocCLIM

LocCLIM has been used for various purposes such as determining average precipitation for wet seasons as well as potential evapotranspiration in dry seasons (Ethiopian Rainwater Harvesting Association 2010). Bernardi, Gommès and Grieser (2006) explained how LocCLIM was used for local climate-induced-disease mapping. However, LocCLIM lacks the ability to use ensembles (group of projection models) and projections for extreme weather events.

2.8.3 SimCLIM

SimCLIM is a climate simulation software package originally developed by the International Global Change Institute (IGCI, University of Waikato, New Zealand) and maintained by

CLIMsystems Ltd., New Zealand (McLeod et al. 2010). It is designed to make projections of future climate under various assumptions, projection models (GCMs) and emission scenarios. As well as individual GCMs, it can use ensembles of GCMs (see section 2.4.7).

SimCLIM allows customisation by individual users through the importation of local data. Such models can include elevation site (DEM) and specific observation data (local data), as well as patterns of climate and sea level changes obtained using all 21 GCMs defined by the IPCC (Warrick et al. 2005). In addition, SimCLIM has the capability to examine a vast range of climate parameters. This includes the use of an extreme event analysis tool which can determine the probability of occurrence of a particular extreme event (like heavy rainfall or extreme temperature).

SimCLIM has been used in many and diverse applications. For example, using the climate and sea-level rise generators, SimCLIM has been used to assess coastal flood risk from tropical cyclones and river flooding in the Cook Islands and the Federated States of Micronesia (Warrick et al. 2005). Applications using the readily available generic tools in SimCLIM include the projection of rainfall effects on the Border Ranges World Heritage Area in Queensland, Australia (Warrick 2007), and the risks of climate variability and change to domestic water supply tank systems in South East Queensland (McLeod et al. 2010).

The major advantages of SimCLIM include its flexibility in generating scenarios and examining uncertainties and its ability in both time-series and spatial analyses (Warrick 2009). In addition it allows the user to examine climate variability and extremes, as well as long-term change. These attributes make SimCLIM a very useful simulation and projection tool for climate change effects. An example of a SimCLIM analysis is shown in Figure 2-9.

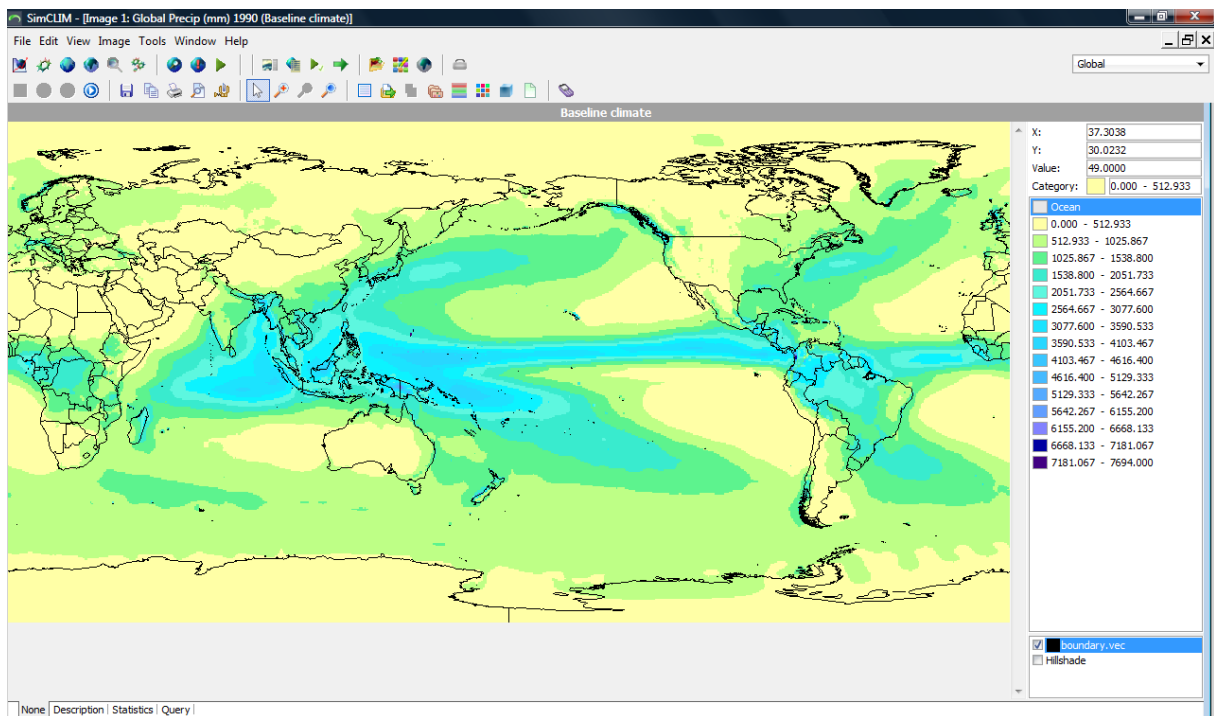


Figure 2-9 A screen capture from SimCLIM

Some of the other key features of SimCLIM are the capability to make projections for climate variables with outputs depicting their spatial distribution; the ability to overlay, and incorporate shape and vector files; the ability to include DEMs; and inclusion of tools for importing and exporting data –such as GIS. SimCLIM is user-friendly, flexible and fast, and is regularly maintained and updated.

SimCLIM, however, has several potential drawbacks. For example, the coastal erosion model included in SimCLIM only considers a modified version of the Bruun Rule (a rule that explains erosion by sea level rise); accuracy could be improved if other shoreline models were included, such as a process based model (Cowell et al. 2006; Ranasinghe, Callaghan and Stive 2012). SimCLIM also has limitations relating to the quality of the input data and tools. Furthermore, SimCLIM uses the pattern-scaling approach to generate scenarios which assumes patterns of climate change remain constant over different forcing and time periods (McLeod et al. 2010; Ramieri et al. 2011).

2.8.4 Comparison of tools for projecting climate change

Three software tools (LocCLIM, SimCLIM and MAGICC/SCENGEN) that could be used to project climate change effects have been presented above. Table 2-5 summarises the advantages and disadvantages of each.

Table 2-5 Comparison of tools for projecting climate change

Technique Feature	MAGICC/SCENGEN	LocCLIM	SimCLIM
Ability to overlay	No	No	Limited (shape files, hillshade)
Importing / exporting data	Limited	Limited	Extensive
Inclusion of IPCC GCM models	Yes (but only for global 0.5 x 0.5 degrees resolution)	No (this is a current climate database)	Yes (and also possible to use downscaled patterns higher than 1x1 km)
Projections for extreme events possible?	No	No	Yes, two methodologies
Projections possible under different emission scenarios and climate sensitivities?	Yes	No	Yes

Inspection of Table 2-5 confirms that SimCLIM’s features are superior to those of the other tools. SimCLIM’s advantages make it an appropriate tool for this research.

2.9 Tools for Modelling and Assessing Impact of Climate Change

Whilst the above models predict changes in climate, tools are also required to model and assess the impact of climate change on tourism resources. These include TOPIC (Thematic Orientation on Project definition in an Interactive Context), COHESIE (Dutch: COmmunicatiemiddel voor HErsturcturering in Steden in een Interactieve contExt) and RAP (Rapid Assessment Program), the details of which are outlined below. These tools, in addition to being able to model and assess the impacts of climate change, are capable of aiding decision/policy-making via interactive processes.

2.9.1 TOPIC

TOPIC is a tool that enables users to record and structure information on an issue thematically. For example, it can assist with the generation of a well-founded problem definition, the definition of a clear set of goals and criteria, and the outline of an appropriate plan of action through a structured way of organising information in a thematic, hierarchical (items within themes), and causal manner (cause and effect loops) (Most 2004). TOPIC can aid communication and decision-making for issues such as climate change.

TOPIC's built-in GIS capabilities enable cartographic information to be processed. For example, TOPIC supports modelling of complex information structures (knowledge acquisition) as well as navigation in and visualisation of complex information structures (Delden et al. 2008; Most 2004).

2.9.2 COHESIE

COHESIE is built on TOPIC. It is capable of managing information gathered in interactive processes and was developed to support participatory, qualitative modelling (Delden et al. 2008). Being able to store and structure such knowledge and information makes COHESIE capable of improving communication between stakeholders, and it has been used effectively to this end in many applications (Botterman, Hooghe and Reeskens 2009; Roes 2009). COHESIE was developed in collaboration with the International Centre for Integrated assessment and Sustainable development (ICIS).

COHESIE is capable of being used in any interactive policy-making, decision-making, planning, and research or management process. Besides textual information, it can accommodate other data formats such as documents, drawings and photos as well as enabling representations using conceptual models (termed "fuzzy cognitive maps") in which it is can perform simple qualitative calculations (Delden et al. 2008).

2.9.3 Rapid Assessment Program

Rapid Assessment Program (RAP) is a software intended for rapid, integrated policy analysis (van der Werff ten Bosch and Kouwenhoven 2004). RAP facilitates building of a qualitative conceptual model on the basis of the qualitative relationship between components via a graphical interface. This makes it possible to identify whether the user's current understanding of the system (i.e., the problem setting) is complete and coherent. Furthermore, the RAP software guides the user or users through several steps in which the problem analysis is made and goals are defined, and these are later used to work out the effect of possible measures, combinations of measures (strategies) and autonomous developments (scenarios) (Kouwenhoven et al. 2005).

The RAP methodology follows several steps, starting with "Problem Definition" (see Figure 2-10). In this initial step, the problem is defined, as well as the goals associated with solving this problem. For example, according to the figure below the problem is how to find a balance between the benefits and costs of a conservation project. Defining the problem is best done in

a meeting or a workshop because this will allow the sharing of views and supporting the agreed approach. RAP's step-wise procedure allows the user to enter variables and relations between them in a square influence matrix (Grosskurth 2008).

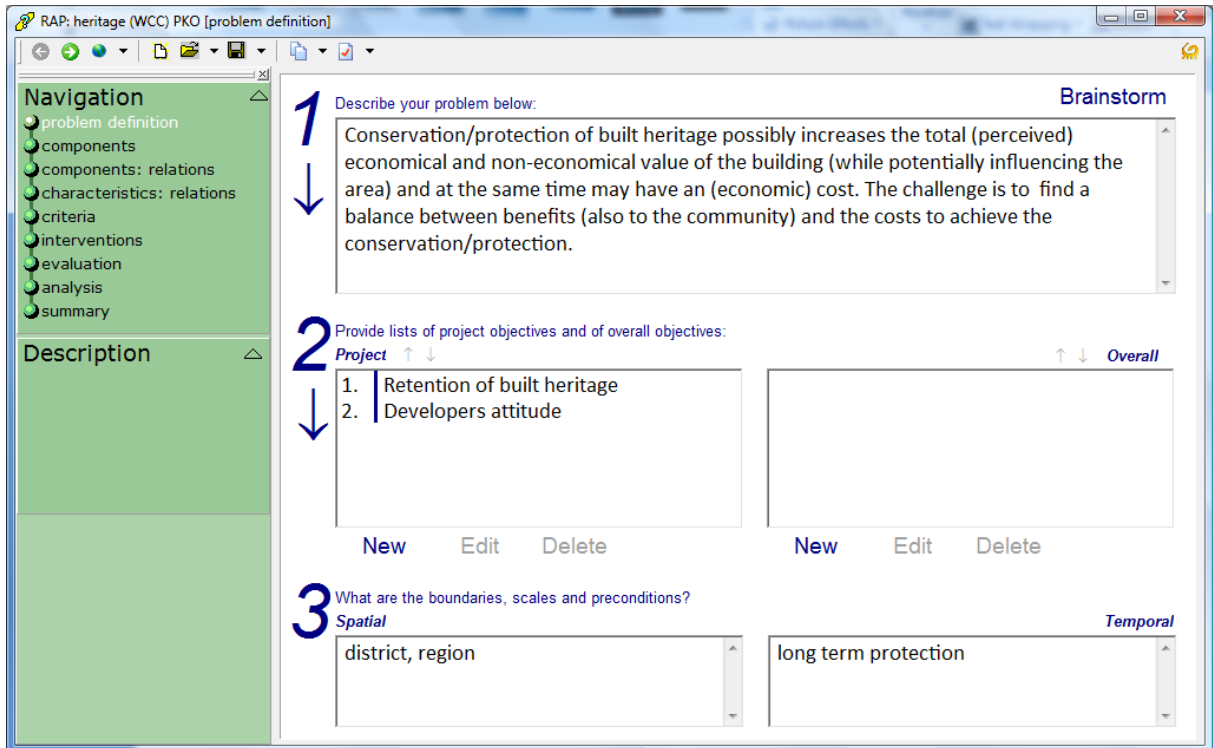


Figure 2-10 Screen capture of the RAP interface

RAP builds the conceptual model stated above using the Driver-Pressures-States-Impacts-Responses (DPSIR) framework which is based on system dynamics theory. System dynamics is an aspects of system theory as a method for understanding the dynamic behaviour of complex systems (Radzicki and Taylor 2008). The DPSIR framework states that drivers will put pressures on states that will change (show impacts), therefore responses correspond to the management options to deal with undesired changes (Grosskurth 2008; Maxim, Spangenberg and O'Connor 2009). RAP enables the user to visualise complex and generally qualitative relationships between system components and then provides an understanding of the impact of interventions on each component and on the system as a whole. In addition, RAP consists of consistency-checking tools that can identify unintended (feedback) relationships within the system components as well as any contradictions in the models developed. RAP is developed and managed by the Resource Analysis Group (Kouwenhoven et al. 2005).

2.9.4 Comparison of Tools for Modelling/Assessing Impact

Table 2-6 summarises the relative advantages and disadvantages of the three tools (TOPIC, COHESIE and RAP) for modelling and assessing climate change impact presented in the preceding sections.

Table 2-6 Comparison of tools for assessing climate change impacts

Technique Feature	TOPIC	COHESIE	RAP
Building of conceptual model	Limited	Domain limited (City districts)	Yes
Graphical interface	Yes	Yes	Yes
Qualitative analysis possible?	Limited	Limited	Yes
Quantitative analysis possible?	Limited	Limited	Limited (the cross-correlation matrix is quantitative)
Merge of parallel stakeholder inputs possible?	No	Yes	Yes
Possible to analyse higher order responses of the system?	Limited	No	Yes

2.10 Summary

This chapter reviewed the literature on tourism in developing countries in light of future climate change. An overview of climate change was presented and related modelling parameters were discussed, as well as the uncertainties involved in climate change modelling, how these can affect results and how they can be minimised.

Published information shows the tourism industry is a major source of employment and income; it is enabling countries to diversify their economies and encourages protection of the environment. The tourism industry in the Middle East is growing faster than ever before and has become the main source of income for some of the region's developing countries. In these countries, natural and cultural resources are the primary attractions for tourists.

Global climate change due to either natural or anthropogenic causes is likely to impact on tourism resources. This is a concern for most developing countries, including the UAE; the individual emirates have recently sought to diversify their economies through promoting tourism, thereby reducing their reliance on fossil fuel production. As such, a thorough

understanding of the potential impacts of future climate change effects is essential for sustainable diversified economies in the UAE and other developing countries.

Developed countries are already evaluating mitigation techniques for impacts from potential climate change effects by using various modelling and projection tools (MAGICC/SCENGEN, LocCLIM, SimCLIM). Spatial analysis tools can be used in conjunction with climate projection software to visualise the potential influences of climate effects on individual tourism resources. Analysis of the impacts of climate change effects is possible through the use of change detection technologies (total stations, airborne LiDAR, TLS) as well as conceptual modelling and impact analysis tools (TOPIC, COHESIE and RAP), all of which have specific advantages and disadvantages.

Chapter 3 Research Methodology

3.1 Introduction

The previous chapter discussed the issues associated with possible impacts of climate change may have on tourism resources. In particular, tourism resources in developing nations such as UAE are susceptible to climate change impact.

In this chapter, an approach to specifically determining these impacts associated with climate change, and assessing their differential impact across a geographic area using two case studies, is explained. The first case study was used to build the approach, and the second for testing and validating the approach. The first case study was the Emirate of Fujairah in the United Arab Emirates (UAE) and the second the Republic of Turkey.

The basis for selection of those study areas is explained in this chapter. In addition, this chapter outlines the overall methodology that has been applied in this research, consisting of a five stage approach. The term 'stages' here refers to steps of the process for building an approach for monitoring changes of tourism resources due to impacts of climate change. Those five stages are: identifying of various types of tourism resources and store them in a geodatabase; project effects of climate change and map those effects; analysing possible impact of climate change on tourism resources; monitoring tourism resources changes; and developing a framework. Information about each stage (step) is also included in this chapter.

3.2 The proposed steps toward monitoring tourism resources changes

In order to ascertain the change that might occur to tourism resources, a plan needs to be created. This plan is intended to explain how to monitor changes in tourism resources resulting from the impact of climate change. It is proposed that to develop a framework that can be used in developing countries, it is essential to know the magnitude of the change and when it will occur. Furthermore, monitoring of the changes at either micro or macro scales is needed. But when monitoring tourism resources changes it is unlikely that all resources will be monitored at the same time period or for the same reason that caused the resources to change. For example, monitoring change in beaches (i.e., coastline change) due to sea level rise or storms is different from monitoring drought that resulted from low rain for a long period. Moreover, an impact analysis will be needed prior to the start of monitoring so the relationship between each tourism resources and the climate change effects can be studied. To determine the impacts of climate change, a projection of future climate is vital. This

projection of climate change effects is inherently spatial and can be stored in a geodatabase. Using GIS to build a geodatabase that includes the location of tourism resources in the case study and enables the projection of future climate change effects helps to determine the way to monitor tourism resources.

A flowchart depicting the overall methodology used is given in Figure 3-1.

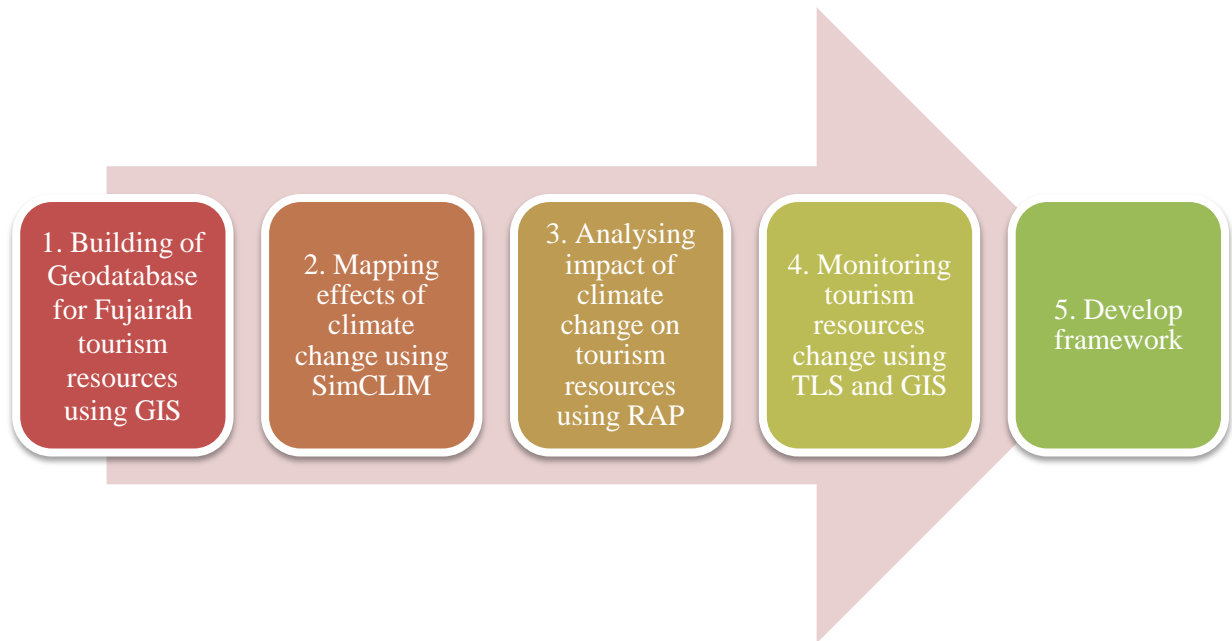


Figure 3-1 The proposed five stages toward monitoring tourism resources changes

The initial stage (1 in the Figure 3-1 above) of building an approach for monitoring climate change impact on tourism resources involved the identification of important tourism resources in the Emirate of Fujairah. This was achieved by collecting spatial and attribute data to build a map of tourism resources using a geodatabase. Tourism resources were identified under various categories.

The next stage (2) involved using appropriate software to model future climate change effects with respect to the various tourism resources. This modelling included projections for important climate change effects on average climate (temperature, precipitation, wind), extreme weather (droughts, flash floods, storm-surges) and ocean related changes such as SLR, ocean acidification and SST increase.

In the third stage, comprehensive analysis and assessment of climate change impacts on Fujairah’s tourism resources were utilised. RAP, a tool with the capability to link between the effects of climate change and its consequences, was selected.

Stage four describes the methodologies used for change detection in tourism resources (both micro and macro scale) and the quantification of likely climate change impacts on Fujairah's tourism resources.

The last stage (5) used the outputs of previous stages to develop a new approach (the framework) that can be used by developing countries.

3.3 Case study approach

The use of a case study was a practical necessity, as it was not possible to study all developing countries in achieving the objective of this research. As already noted, the first case study allowed the building of the monitoring approach and the second enabled that approach to be validated.

In general, developing countries are highly vulnerable to the impacts of climate change. Their vulnerabilities is due to physical and geographical factors and their dependence on resources that are sensitive to changes in climate (Adger et al. 2003). In addition, developing countries have low capacity to cope with climate change, both technologically and financially (Tolba and Saab 2009). The Emirate of Fujairah was selected as the case study for this research to build the proposed framework because it:

- Is part of a developing country. The UAE is a young country and its infrastructure is generally inferior to that of a developed nation. The Emirate of Fujairah has no fossil fuel resources (in contrast to Dubai and Abu Dhabi) or other high-value natural resources and is thus representative of many developing nations.
- Is already subject to effects of climate change such as SLR, rising temperatures, a decrease in average precipitation, and flash floods due to occasional extreme rainfall events.
- Has faced three major natural disasters in recent years: flooding from the storm surge in 1990 then cyclones Gonu (2007) and Finite (2009) caused severe damage to properties and infrastructure (Fritz et al. 2010).
- Has a tourism industry that plays an important role in the economy and is considered a priority by the government. The notable increase in the number of hotels (see section 4-3) plus other major coastal projects being undertaken are indicators of Fujairah's booming tourism industry (Fujairah Statistics Centre 2010).

- Has both natural (e.g., beaches and waterfalls) and cultural (e.g., forts, ancient mosques and heritage villages) tourism resources that are vulnerable to climate change.
- Despite the Government of Fujairah recognising the need for a framework for managing the effects of climate change, it is yet to implement mechanisms for monitoring changes occurring to its tourism and related resources.

Fujairah is typical of a developing country which has limited natural resources but is increasingly dependent upon tourism. Turkey (officially called the Republic of Turkey), a country located in western Asia, has also benefited greatly from tourism over the last two decades (Okumus et al. 2012). Turkey was selected as the case study to validate the developed approach.

Developing countries in situations similar to Fujairah and Turkey will be able to access and implement the framework developed through this research.

3.4 Building a geodatabase of tourism resources

The projections for future climate change are discussed in Chapter 6, while their impacts are detailed in Chapter 7. In order to determine these projections and impacts, it was first necessary to build a geodatabase of Fujairah's major tourism resources. This was done by creating a GIS capable of handling layers for each tourism resource type as well as climate change effects. This geodatabase simplified the data management by integrating land use maps, the locations of tourism resources and spatially projected climate change effects.

Global climate change models have shown that different locations will experience climate change in varying amounts. In addition, at a local scale, certain events will impact differentially on tourism resources, depending on their location. For example, ocean temperature changes will impact heavily on coral reefs, yet may not have any impacts on beach activities. Increased storm events may impact upon mud-brick forts on denuded mountain sides, but may have little impact on hotel accommodation or museums.

The first step in building the geodatabase was the definition and identification of tourism resources. As stated in chapter one, a tourism resource can be define as “any factor - natural or man-made, available within a country, region or area - which makes a positive contribution to tourism” (Ivanovic 2009, p. 111). Examples of cultural tourism resources are the local

handicraft or production traditions, rural landscapes, heritage buildings, activities connected with the local agricultural culture, settlements in the countryside including traditional settlements, and entertainment areas or thematic parks (Tsartas 1999). Infrastructure supporting tourism resources, such as car parks and restaurants, are considered to provide services to those tourism resources and are not tourism resources themselves. All sites that had a potential to be tourism resources were considered.

GIS is a useful tool for storing and spatially analysing tourism resources. Importing data into the GIS from remotely sensed data provides high resolution imagery that can aid in the identification of resources. GIS, with its capability of overlaying data as well as analysing both attribute and spatial data, was used in this research for building a geodatabase of Fujairah’s tourism resources.

Building the geodatabase involved four steps:

- 1) Identifying geographical areas within the Emirate of Fujairah.
- 2) Plotting the distribution of Fujairah’s tourism resources by identifying their geographical locations – based on data obtained from the Fujairah Tourism and Antique Authority (FTAA) and the Fujairah Municipality.
- 3) Updating the catalogue of tourism resources by identifying resources not listed in the data already obtained. This involved collecting spatial and attributes data from other sources, primarily IKONOS satellite images, which were obtained by courtesy of the Fujairah Statistical Centre. The data obtained are summarised in Table 3-1.

Table 3-1 Data used in geodatabase construction

Data Type	Image Resolution	Image Format	Digital/Analogue (hard copy)
Topographic map	5 m	Contour line	Digital
Satellite (IKONOS) image (2010)	1 m	TIFF	Digital

- 4) Building the geodatabase using ArcGIS software.

The geodatabase construction process is summarised in a flowchart shown in Figure 3-2.

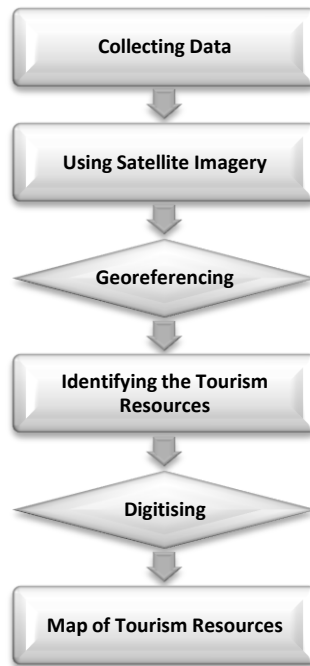


Figure 3-2 Methodology of mapping tourism resources

3.5 Determining climate change

Climate change, as discussed in chapter 2.3.1, is a naturally occurring event. However, in recent times human-induced climate change has led to significant and unnatural global warming.

This research aims to determine the effects of climate change on tourism resources. In order to achieve this, it will be necessary to project future climate scenarios and then assess the impact of the changes in climate on tourism resources.

3.5.1 Projecting future climate change effects

To analyse the impacts of climate change effects on Fujairah’s tourism resources, it was essential to be able to project these effects for a specific future year or a period; doing so constituted the second objective of this research. Projecting climate change effects shows the change in the climate at a given point in time compared to a baseline date.

As noted in Chapter 2, several techniques and tools enable useful projections of climate change effects. After careful consideration of the strengths and weaknesses of the different software (Table 2-5), SimCLIM (Figure 3-3) was selected for this research. SimCLIM contains a custom-built GIS and can be applied to any geographic area and provide results at useful spatial resolution.

SimCLIM is a computer-based modelling system for examining climate change effects both temporally and spatially. It is a customised GIS which includes tools for the spatial analysis of climate, climate change and climate variability as well as the capacity to analyse the associated impacts on various geo-spatial entities. SimCLIM’s ‘open-framework’ feature makes it easy for the user to customise. This aids in the assessment of local climate change effects and impacts.

SimCLIM uses various built-in and user-importable data, models and parameters for projection of climate change effects. A screen capture of the SimCLIM environment is shown in Figure 3-3. The software has functions available on the toolbar such as global projection, spatial scenario generator, site specific scenario generator and view patterns. Amongst a range of applications it can be used to assist in climate proofing across various sectors including: Water, Agriculture, Health, Ecosystems, coastal zone issues such as sea-level rise and coastal erosion (CLIMsystems 2011).

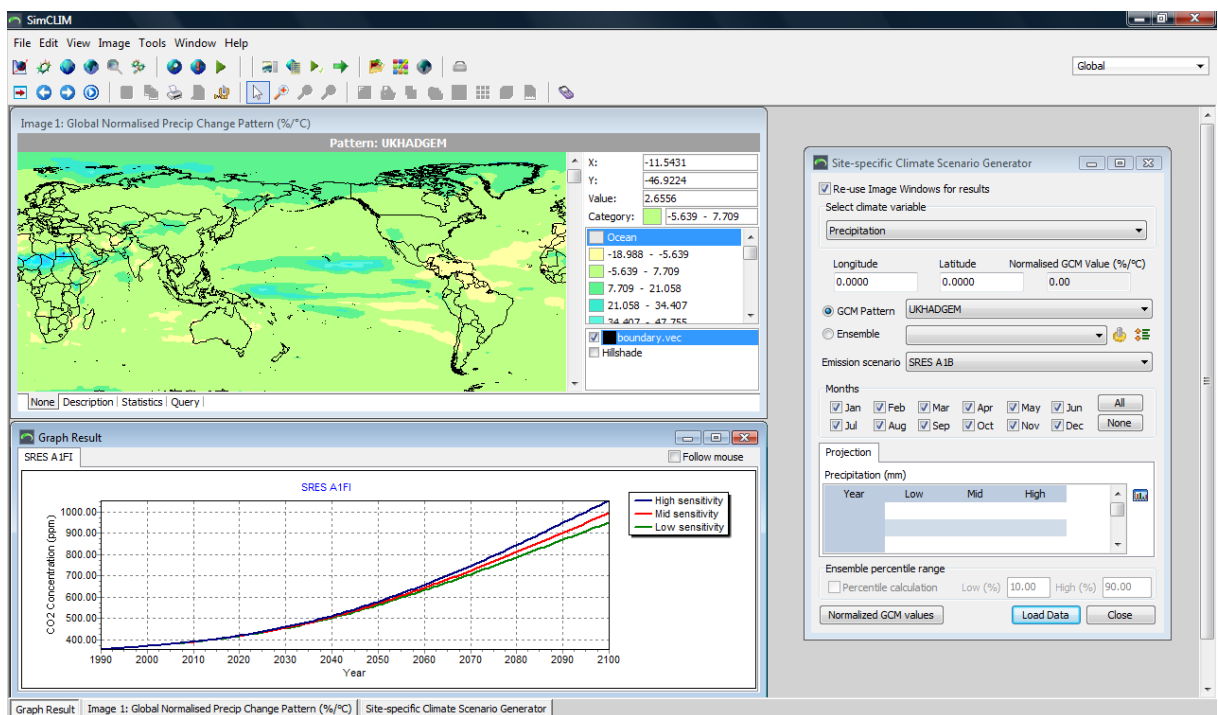


Figure 3-3 Interface of SimCLIM

Chapter 2 described how SimCLIM uses both global and local climate data for future climate effect projections. The local data sets required as input to make projections for Fujairah included daily minimum and maximum temperatures and also daily precipitation. This data was sourced from Fujairah International Airport and also from the nearby weather station at Ras Al Khaimah International Airport (approximately 30 km away from Fujairah). Data were

available from Fujairah International Airport from the year 1995, whereas data collected at Ras Al Khaimah Airport began in 2000, too recent for modelling. Unfortunately, the Fujairah Airport data had missing data for some years and so the Ras Al Khaimah data were used to fill these gaps.

In order to project future climate change effects, certain parameters had to be set within the SimCLIM environment. The A1FI emission scenario was used during all of the Fujairah SimCLIM simulations, as it corresponds to a future world of rapid economic growth, increased social and cultural interaction and rapid introduction of new and more efficient technologies (IPCC 2007a). The A1FI emission scenario corresponds to the path that the world is currently following, and the Global CO₂ concentration and temperature from 1990 to 2012 (Earth System Research Laboratory 2012; McGee and McGee 2012) are consistent with the projections made in SimCLIM using that scenario. The combination of A1FI and high climate sensitivity defines the worst case scenario.

To project future climate change effects with SimCLIM, the following inputs were required (CLIMsystems 2011):

- 1) The emission scenario
- 2) Climate sensitivity
- 3) GCM (or an ensemble of models)
- 4) Baseline year
- 5) The time horizon.

These inputs are fully detailed in chapter 6. For all the effects, the emission scenario and the climate sensitivity was set to A1FI and 'high' respectively, with a baseline of 1990. The number of GCM models used was based on the maximum number (21) of available patterns in SimCLIM obtained from the Coupled Model Intercomparison Project phase 3 (CIMP3) experiment (used for the IPCC's 4th Assessment Report), an open database of GCM results (CLIMsystems 2011).

An example of setting up a projection of a climate change effect within the SimCLIM environment is shown in Figure 3-4. It starts with selecting the study area (e.g., Fujairah), then the climate variable required, selection of the year (i.e., whether the baseline year or a future year), then selecting a GCM pattern or an ensemble, next selecting the emission

scenario and climate sensitivity, future climate or change from baseline, and finally the months for which scenario data will be produced.

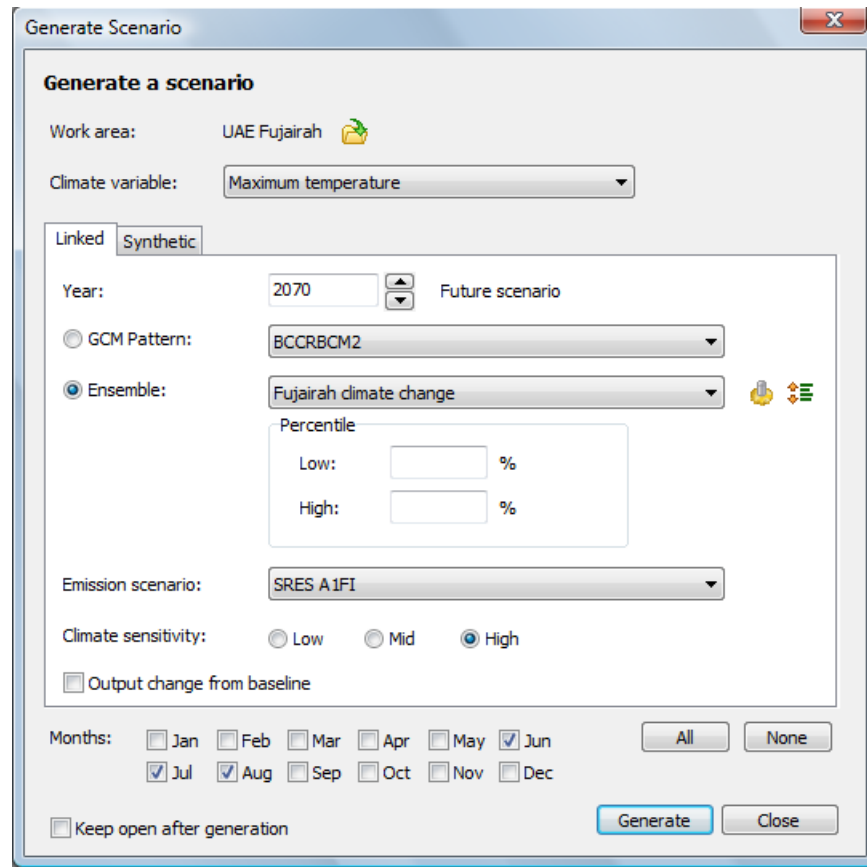


Figure 3-4 Preparing the projection of a climate change effect, performed with SimCLIM

Increased atmospheric CO₂ will increase ocean-dissolved CO₂, which leads to ocean acidification (DoneyFabry, et al. 2009). However, the current version of SimCLIM cannot project ocean acidification. Therefore, a projection of ocean acidification by the World Research Institute was used in this research (detailed in Chapter 6).

The selection of short-term or long-term projection is mostly to do with the climate mechanisms. Extreme weather changes due to climate change are about weather, which changes faster than climate (as climate is average weather). Even short-term projections already show big shifts in extreme event magnitude and frequency. Hence a time horizon of 40 years from the baseline (i.e., the year 2030) was selected for projection purposes because this amount of time is what managers require to prepare for action/response (Wall 1998).

Climate change proceeds more slowly than weather change, thus the long term is appropriate for projection effects of climate change. A time horizon of 80 years from the baseline (i.e., the year 2070) was selected for climate change projections.

3.5.2 Assessing and evaluating potential impacts of climate change

Once climate change predictions across the study area were determined and geographically synthesized using the geodatabase, it was necessary to assess how climate change is going to affect individual tourism resources. Thus, after projecting the effects of climate change, the impact of these effects on tourism resources was identified. This was done by examining qualitative and quantitative aspects of tourism resources.

This research aimed to assess the impacts of climate change effects on Fujairah's tourism resources with the intention of devising a system for monitoring the expected change in those resources. The key aspect of this process was identification of the tourism resources that are impacted by a given climate change effect as well as estimating the importance of that impact.

To estimate the impact of climate change effects on tourism resources in Fujairah using the RAP process involves setting up a multi-step conceptual model (van der Werff ten Bosch and Kouwenhoven 2004). These steps were used in the analysis presented in Chapter 7.

A brief description of the steps involved in RAP follows.

1. Problem and goal definition

The first step is a definition of the problem at hand. Each decision-maker looks at the problem from a different perspective and interprets it differently; thus a clear *description of the problem* was the key step. In the case study, climate change-induced damage to Fujairah's tourism resources is both a short-term and long-term issue.

2. Model building: components, characteristics and relationships

In the second step the elements of a qualitative model were set up, beginning with the 'components' that relate to the problem. The components in this case were climate change itself (e.g., extreme weather, and average climate and ocean-related change effects) plus the tourism resources that are under consideration. These components were further characterised to better define the system in relation to the problem. This process is aided by the graphical interface in RAP in which colours can be used to discern groups of components that are more alike. Next the relationships between characteristics and their strengths were defined.

3. Defining the criteria

After the model (components, characteristics and relationships) is built it can be applied. First, however, criteria (or indicators) need to be chosen to identify the achievement of the goals

specified in the problem definition. The criteria are taken from characteristics in the model that best signal the changes in the system.

4. Defining the exogenous change in RAP

RAP uses the concept of ‘cases’ – the combination of one or more internal interventions (e.g., government policies) and external influences (e.g., climate change). Because of the focus of this thesis on the impacts of climate change effects on tourism resources, no internal interventions were considered. Therefore, the cases defined within RAP only reflect the external influences, meaning the changes in climate and weather. The external influences include all climate change effects such as decrease in precipitation, increase in temperature, acidification of the ocean and SLR.

5. Evaluation Process

After completing the first steps of RAP, it was possible to calculate how climate change effects were transferred through the cause-effect pathways as defined by the relations between the characteristics. A cause-effect pathway describes the chain of changes in characteristics. Because many different pathways exist, RAP keeps track of the largest changes, both negative and positive. The results are presented in an evaluation table, with the range-of-change per criterion for each of the cases.

6. Analysis of the conceptual model

RAP provides various tools for analysing the properties of the DPSIR model in order to assess its quality and performance: a consistency check; a cross-correlation matrix; the shortest pathway functionality; the back-tracking functionality; and the driver-state impact visualisation functionality.

Chapter 7 details a practical implementation of the RAP process, including an extensive discussion of each step.

3.6 Detecting change in tourism resources

The Emirate of Fujairah has been an increasingly popular tourist destination over the past decade. It boasts numerous natural and cultural tourist attractions. Given the increasing importance of tourism for the economy of Fujairah, it is essential that its resources are protected and regularly monitored in order to maintain their continuance as tourist attractions and economic assets. Detecting and tracking changes occurring to these resources over extended periods of time is critical.

As stated in Chapter 2, change detection in tourism resources can be broadly categorised as micro (small-scale) and macro (large-scale). Examples of micro change include small changes in the structures or surfaces of forts and ancient mosques due to effects such as sand-storms and temperature variations. Examples of macro change include changes to beaches (due to coastal erosion) and loss of area of vegetation (from droughts).

3.6.1 Using TLS for micro change detection

Micro scale changes to tourism resources occur due to fast weather impacts (like rapidly changing temperatures and wind gusts) as well as slow and/or relatively less intense variation in climate effects such as rising temperature (resulting in degradation and structural cracks), wind gusts (resulting in ongoing erosion) and sandstorms (resulting in degradation). Several technologies are available for micro detection of such changes: total stations, airborne LiDAR, airborne and terrestrial photogrammetry and TLS. After consideration of the merits and advantages of these technologies, the TLS technology was selected for detecting micro changes in Fujairah's built tourism resources.

3.6.2 The TLS procedure

The procedure for the quantification of climate change impacts on the Emirate's tourism resources required the development of TLS-based 3D models for several identified sites.

(i) Site identification

An initial reconnaissance mission to Fujairah enabled selection of multiple sites of interest based on international tourism significance, geographical location, and the need to evaluate a mixture of resource types (natural and cultural resources). Due to the resource and time constraints associated with the field component, it was decided to limit the number of sites to five.

(ii) Scanning the sites

The 3D models of various sites generated by the TLS enabled comparisons with future scans of the same sites for the purpose of change detection. The steps involved in developing 3D point cloud models using TLS are pre-scanning, scanning and post-scanning, and are explained below.

Pre-scanning: This stage comprised the decision-making on the use of the TLS equipment with the following criteria:

- Selecting the scan resolution
- Choosing the station locations
- Positioning the control targets
- Deciding on the process for geo-referenced survey control.

Scanning: This stage comprised setting up the equipment (tripod, scanner and the control laptop containing the scanner software) and then performing the scanning survey.

Post-scanning: This stage consisted of transferring the point clouds data from the data recorder to the processing software and then manipulating these to construct 3D point-cloud models. The target was registered, and the data edited (noise removal) to achieve the best 3D model.

(iii) Performing Micro Change Detection

Micro change detection of the TLS scan data is performed using mathematical algorithms such as the ‘subtraction method’. However, note that micro change detection for tourism resources in Fujairah was beyond the scope of this thesis. This was because only a baseline scan (using TLS) could be obtained and micro change detection would require longitudinal future scan data taken at intervals of years. Baseline TLS scanning of tourism resources was carried out in Fujairah in January 2012.

3.6.3 Using aerial and satellite imagery in GIS for macro change detection

Macro changes to tourism resources occur due to slow effects like SLR and ocean acidification as well as sudden and/or extreme weather effects such as droughts (resulting in reduced areas of vegetation) and storm surges (resulting in severe coastal erosion). Macro change can be detected using spatial analysis techniques. In this research, GIS-based techniques were used to demonstrate the process of macro change detection in relation to tourism resources in the Emirate of Fujairah. Use of Landsat data was not appropriate (although this type of data was available for past years) because it does not show changes of less than 30 metres.

GIS-based macro change detection can be performed by comparison of aerial imagery obtained at successive points in time. This process (in the case of raster aerial images) involves spatial analysis using map algebra with cell-by-cell subtraction (Wang and Pullar 2005). A detailed explanation of the technique can be found in Chapter 8. GIS-based techniques were used for demonstration of the process of macro change detection in the

tourism resources in Fujairah (note that only a demonstration of the technique was performed due to the lack of longitudinally-collected imagery for comparison).

3.7 Developing the monitoring approach

After all four stages (mapping tourism resources, projecting climate change effects, assessing the impacts of climate change, and monitoring the change in tourism resources) were complete, they were integrated in sequence. This framework was then tested on a second developing country to determine its broader suitability and adaptability. Turkey was selected as a test case study, a highly suitable choice as it is known for the richness of its tourism resources and because the tourism industry is one of its main sources of income (Okumus et al. 2012).

3.8 Summary

This chapter presented the methodology used to carry out the research described in this thesis. It contains a description of methods for monitoring the impacts of climate change effects on tourism resources in developing countries, using the Emirate of Fujairah as a case study, and techniques used in developing monitoring of changing tourism resources.

A GIS-based geodatabase was constructed to identify and locate important tourism resources in Fujairah. Then, SimCLIM was used to project future climate change effects. Next, RAP was employed to build a qualitative conceptual model (DPSIR) of the potential impacts of climate change on tourism resources and predict the likely consequences of changes in climate, allowing assessment of the impact of the drivers and pressures (climate change effects) on the states (tourism resources of Fujairah).

Due to its speed and accuracy of data capture as well as its ability to obtain scans covering 360° views, TLS was used to create a baseline for future identification and measurement of changes in tourism resources in Fujairah. GIS-based spatial analysis tools were employed for macro scale detection.

The remaining chapters concern the application of the methods described above. Tourism resources are mapped, climate change effects projected, the impacts of climate change assessed and change in tourism resources monitored; when integrated, these processes create a framework that can be used by any developing country. Turkey was selected to validate and demonstrate the framework.

Chapter 4 Case Study: The Emirate of Fujairah (UAE)

4.1 Introduction

The Emirate of Fujairah is a political territory of the UAE – a federation of nations that obtained independence on 2nd December 1971. The UAE is one of the youngest countries in the world. Its location between Asia and Europe makes it a perfect stopover point for international flights. As a consequence, the country plays an important role in trade between these regions. Facing the Gulf of Oman and the Indian Ocean, the Emirate of Fujairah has open access to the ocean, resulting in it being one of the busiest ports in the world, primarily as it is the departure point for oil exported by the UAE (a pipeline from Abu Dhabi goes through Fujairah) to the rest of the world (Abdurrah 2011; Hellyer 2005).

The UAE consists of a federation of seven emirates: Abu Dhabi (the capital), Dubai, Sharjah, Ajman, Umm al-Qaiwain, Ras al-Khaimah and Fujairah. The economies of the three best-known emirates (Abu Dhabi, Dubai and Sharjah) were built on fossil fuels, in sharp contrast to that of the Emirate of Fujairah which has no known reserves of oil or natural gas. As a consequence, the government of Fujairah is compelled to build a strong economy based on its strategic location and its (non-oil) natural resources. To this end, the government formed the Fujairah Natural Resources Corporation to conduct earth-related studies (e.g., research and geological surveys for the development of mining) and geological research (e.g., drawing geological maps) (Tourenq et al. 2009; Vij and Vij 2012).

The following sections provide an overview of the geographical and geological aspects of the Emirate of Fujairah, its location with respect to its neighbouring emirates, its socio-economic features, and land use and climatic conditions.

4.2 The geographical and geological features of Fujairah

Unlike the six emirates of the UAE which have coastlines on the Arabian Gulf (also known as the Persian Gulf), the Emirate of Fujairah is on the east coast of the UAE facing the Gulf of Oman (Kamoun, Werghi and Blushi 2010). Fujairah lies between latitudes 25° and 26° North and between longitudes 56° and 57° East (see map in Figure 4-1). The total area of Fujairah is about 1488 km², which is only 1.8% of the total area of the UAE; its coastline is approximately 70 kilometres long (Fujairah Statistics Centre 2010).

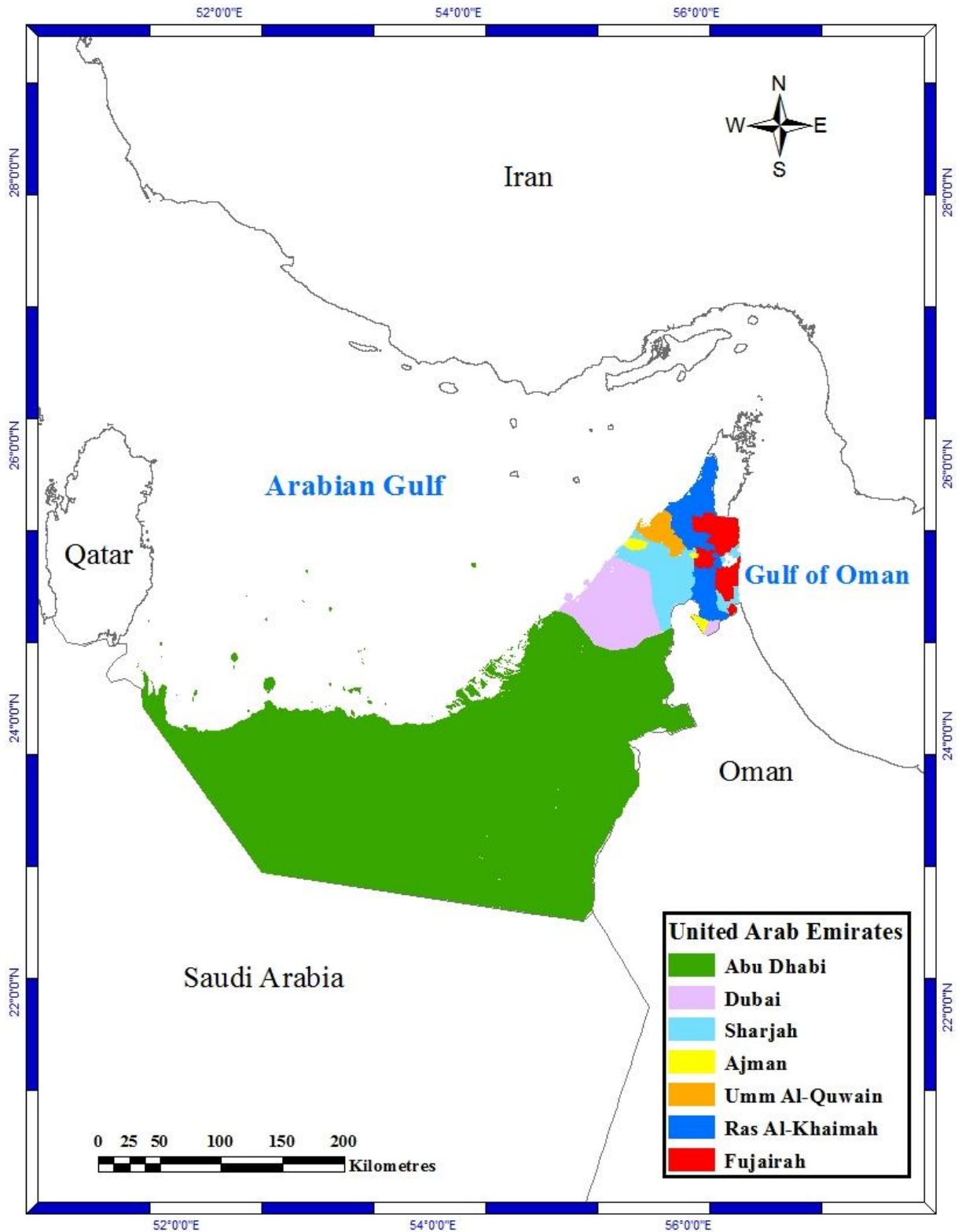


Figure 4-1 Map of the UAE showing the location of the Emirate of Fujairah

IKONOS satellite images obtained in 2010 (provided by the Fujairah Statistical Centre) reveal that the majority of the useable land in the emirate is located in the coastal zone within five kilometres of the coast. Therefore a high population concentration exists and intense

anthropogenic activities occur in the coastal zone. In particular, the IKONOS images show the concentration of tourism resources near the coastal zone. Moreover, most of the emirate (about 80%) is mountainous and most of the remaining land lies along the coastal belt (Hassani 2007). Furthermore, the area between the coast and mountains is densely populated, making it even more vulnerable to an extreme weather and catastrophic event.

With regard to its geological settings, the Emirate of Fujairah is characterised by chains of mountains (e.g., the Hajar Mountains), waterfalls, wadis (valleys), and hot and cold springs, as well as sandy beaches such as those at Dibba, Bidiyah, Sharm and Al-Aqah.

Fujairah's mountains lie very close to the coast. The width of this coastal plain ranges from one kilometre (in the north) to five kilometres (in the south). The closeness of the mountains and the sea presents opportunities as well as threats. The opportunities include the ability for tourists to enjoy both the sea and the mountains within a small geographical area. The threats are in the form of susceptibility to SLR, flash flooding and other damaging effects associated with climate change.

The Hajar Mountains (literally meaning Stone Mountains) belong to the highest mountain range in the eastern Arabian Peninsula, and are an integral part of Fujairah's spectacular geology, essentially delineating Fujairah from the rest of the UAE.

The Hajar Mountains are the location of 45 Sites of Special Geological Interest (SSGI) identified by the 2006 British Geological Survey of Fujairah (Styles et al. 2006). These mountains give rise to the emirate's unique geo-diversity. These key sites merit preservation because they exemplify typical lithologies or structures that are unique to Fujairah and attract geologists and tourists alike.

4.3 Socioeconomic features

The discovery of oil in Abu Dhabi and Dubai in 1960 led to the UAE becoming one of the most developed economies in Western Asia, ranked 7th in the world on Gross Domestic Product (GDP) per capita in 2011 (International Monetary Fund 2011). As part of the UAE, the GDP of Fujairah has increased dramatically in the last 10 years. For example, its GDP was 4361 million Dirhams (equivalent to USD \$1188 million) in 2001, but rose to 6804 million Dirhams (USD \$1854 million) by 2005 and 10,884 million Dirhams (USD \$2966 million) in 2010 (Fujairah Statistics Centre 2010).

Figure 4-2 illustrates the rate of growth for the population of Fujairah since 1975. In 1975 Fujairah was home to fewer than 17,000 people, but the population rose to more than 176,000 in 2010 (Fujairah Statistics Centre 2010). This substantial increase in the population has inevitably put pressure on natural resources such as fresh water and farmland.

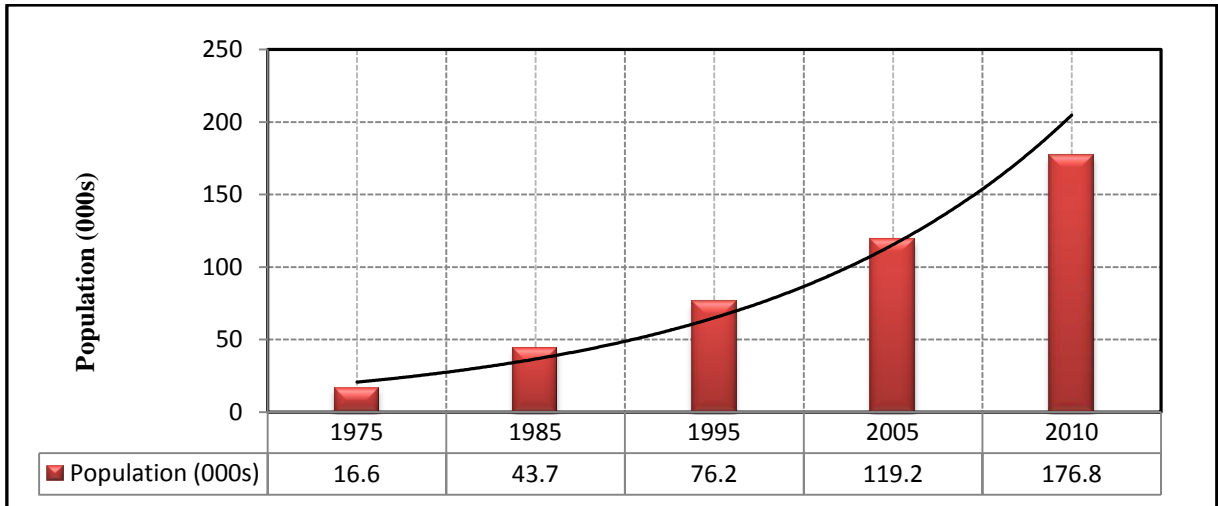


Figure 4-2 Fujairah’s population growth, 1975-2010

The UAE Government has managed the income obtained from oil resources wisely and has diversified its economy by investing in its population. Many essential services have become readily available and the quality of many public sectors has improved markedly, such as the health and the transport sectors. In Fujairah, particularly, education and health are being given maximum attention. As a result hospitals are plentiful and well-equipped and Fujairah residents are increasingly well-educated.

The governments of the UAE, including that of Fujairah, support the agricultural sectors in various ways. Farmers are provided with free pesticides and fertilisers and other forms of government assistance: some agricultural products, such as dates, are purchased by the government for export. Over the last three decades the government has given citizens land to farm, which they use to graze sheep or grow crops. This practice has resulted in the expansion of farming along the coast of Fujairah. There were 3999 farms in 1995 and 4267 by 2010 (Fujairah Statistics Centre 2010). The increased productivity of farms means that fresh fruit and vegetables are available to both locals and tourists at affordable prices.

The fishing industry has received special attention from the government similar to the assistance provided to the agricultural sector. Fishermen are subsidised in many ways, including the provision of free boat engines and other equipment required for fishing. This has

provided benefits for tourism as well, as visitors to Fujairah can enjoy fresh seafood at prices more affordable than those in the other emirates. Tourists can also enjoy local fishing experiences and pleasure cruises.

The increased number of tourists visiting Fujairah, as well as the rise in the number of hotels, is a clear indicator that the tourism sector is flourishing in the emirate. Figure 4-3 shows the numbers of hotels and tourists in Fujairah in recent years.

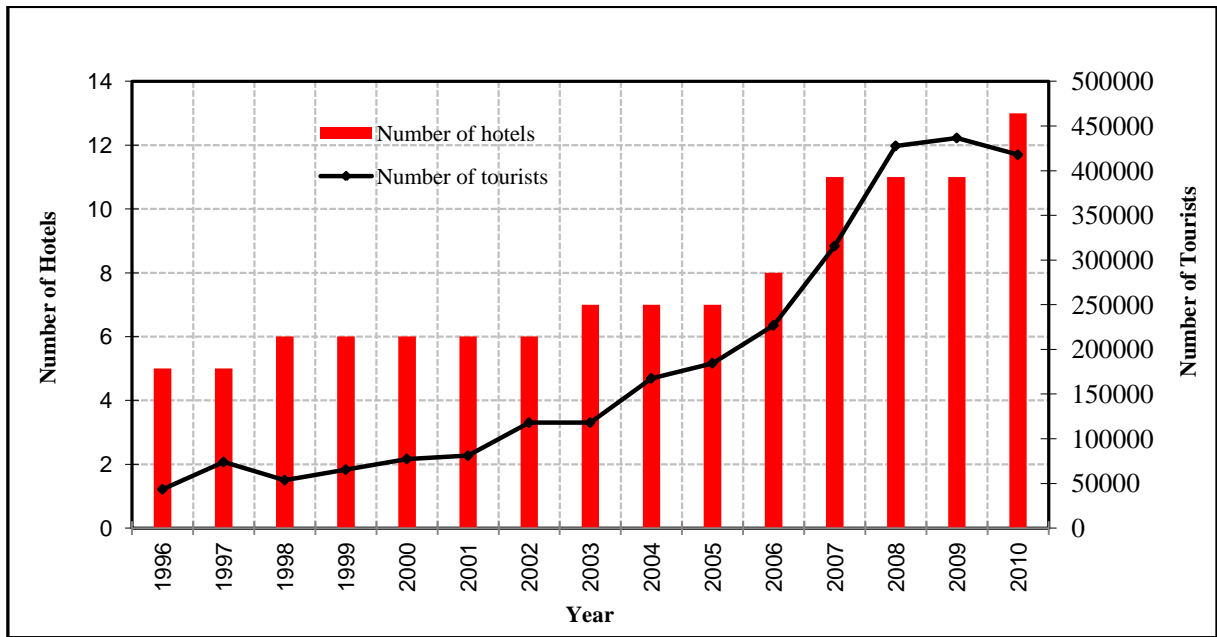


Figure 4-3 Tourists and hotels in Fujairah, 1996- 2010 (Fujairah Statistics Centre 2010)

Fujairah has two ports and one international airport. The main port of Fujairah Port was established in 1978. Since then the number of commercial vessels visiting Fujairah Port has increased dramatically, from 925 vessels in 1995 to 2923 in 2010 (Fujairah Statistics Centre 2010). The purpose of the visit for each vessel varies: some arrive for bunkering (taking on fuel) while others are loaded with cement. Fujairah’s port is now the world’s second largest bunkering port after Singapore (Abdurrah 2011). The potential for Fujairah to receive large numbers of seaborne tourists is gradually increasing (Foster 2011), and Fujairah Port’s location on the Indian Ocean means it is gaining more attention as an alternative to the Caribbean as a cruise destination. Cruise lines such as Costa Cruises and Royal Caribbean International have begun offering cruises to the Gulf region (Foster 2011).

Tourism is a major component of the government’s policy of economic diversification and one of the keys to the emirate’s economic growth (Elango and Hussein 2006). Government support for the tourism sector has not been limited to infrastructure development such as

building of hotels and shopping malls, but also aims to provide tourists access to the emirate's cultural resources. The government supports many cultural festivals designed to showcase Fujairah's rich cultural heritage for the benefit of the population and tourists alike (Anwar and Sohail 2004b). The optimal use of natural and cultural resources is of utmost importance to the emirate's tourism industry in the long term.

4.4 Tourism in Fujairah

Although the economies of the three best-known emirates of the UAE (Abu Dhabi, Dubai and Sharjah) are built on fossil fuels, the Emirate of Fujairah has no known reserves of oil or natural gas. As a result, the government of Fujairah is compelled to build a strong economy based on its strategic location and its natural resources. These natural resources include waterfalls, wadis, beaches, mountain lookouts and cultural resources such as ancient mosques, forts and festivals. In addition, tourism in Fujairah is focusing on providing tourists with an authentic Arabic experience (in contrast to many of the experiences available in Abu Dhabi and Dubai). Fujairah also collaborates with the other emirates to provide tourism opportunities throughout the entire UAE. The Fujairah government has made tourism an economic priority (Anwar and Sohail 2004a).

Fujairah's coastal assets, notably its golden beaches (e.g., Al Aqah Beach and Dibba Beach) flanked by the Gulf of Oman and the Hajar Mountains, make it an attractive tourist destination. Fujairah's warm seas and coral reefs make it a great spot for fishing, diving and water sports. In addition, Fujairah boasts an exciting mixture of the old and (e.g., forts and heritage villages) and the new (ultra-modern shopping malls). Fujairah Fort, for instance, is over 340 years old and an important tourism site (Explorer Publishing 2006).

Despite being small in size, Fujairah has many archaeological and historical sites and has been visited by many scientific expeditions over the past few decades (Brass and Britton 2004; Hellyer 2005). The increasing number of tourists visiting Fujairah (rising from about 43,000 tourists in 1995 to 417,000 in 2010), as well as the rise in the number of hotels in the emirate, is a clear indicator that the tourism sector is flourishing (Fujairah Statistics Centre 2010).

Global climate change looms as a major threat to the emirate's flourishing tourism industry, because it has the potential to degrade natural, cultural and built-up resources. As a result, it has become of paramount importance to forecast the impacts of climate change on the

emirate's tourism resources, so appropriate steps can be taken towards mitigating such impacts and ensuring a sustainable tourism industry.

4.5 Land use

A brief description of land use in Fujairah is given below in order to provide context to the tourism industry in Fujairah.

4.5.1 Industrial land use

Although Fujairah does not have oil reserves, it possesses some of the world's most modern refineries and facilities for oil storage and export. This industry developed due to Fujairah's geographical position on the Indian Ocean and proximity to major oil-producing regions, allowing oil produced in the UAE to be efficiently loaded into tankers and transported around the world. Nevertheless, the Fujairah Government recognises that oil-dependent wealth generation has only short to medium-term economic benefits. It has now focused on investing in a diversified range of industrial sectors for its ongoing economic sustenance (Fujairah Freezone 2011). The percentage of total land used for industrial purposes was 3.5% in 1995 but rose to 7% in 2006 (Hassani 2007).

Fujairah's industrial sectors include mining and quarries, food and beverages production, textiles and furniture manufacture and production of building materials such as cement, tiles and marble. Since 1995, these industries have undergone exponential expansion in terms of number of sites as well as geographical coverage (Alhogaraty 2010).

4.5.2 Commercial land use

Commercial land in Fujairah encompasses commercial enterprises such as banks and the financial sector, retail and wholesale businesses, real estate and business offices, shopping malls and free trade zones.

Fujairah's retail and wholesale sector increased its contribution to GDP from USD\$148 million in 2001 to USD\$396 million in 2010 (Fujairah Statistics Centre 2010) and is considered a key driver of the commercial sector. A graph depicting the increase in the number of buildings belonging to the commercial sector as a whole in Fujairah is shown in Figure 4-4.

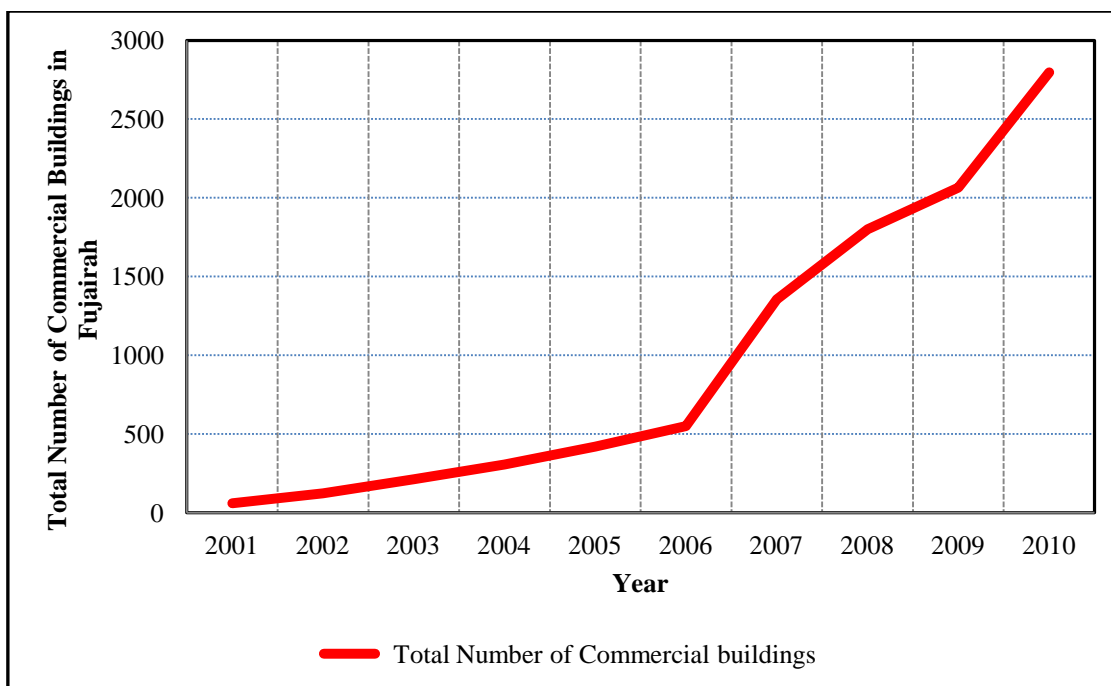


Figure 4-4 Commercial buildings in Fujairah, 2001-2010 (Fujairah Statistics Centre 2010)

4.5.3 Agricultural land use

Agriculture is one of the dominant sectors of Fujairah’s economy. Palm tree plantations account for around 42% of Fujairah’s agricultural land use (Alhammedi and Glenn 2008). Agriculture occupied 21% of Fujairah’s total land area in 1995 and increased to 26% by 2006 (Hassani 2007). Many farms still use methods that have been employed for centuries, being watered from underground springs, dams or by traditional irrigation water channels (called *Falaj*). Figure 4-5 shows a glimpse of a farm in Fujairah that cultivates palm trees and grass used for grazing goats and sheep.

The increase in the number of farms and the resulting land use in Fujairah can be seen in Table 4-1. Modern sprinkler irrigation systems are being progressively implemented, as is the provision of fertiliser and pesticides. Construction of dams, necessitated by the inherent aridity of the region and the expansion of the agricultural sector, has permitted an increase in agricultural land use (i.e., more water storage allows more land to be irrigated).

Table 4-1 Number and total areas of farms in Fujairah, 2000 – 2010

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Number of Farms	-	-	4286	4346	4316	4161	3342	3170	4165	4369	4267
Total Area (km²)	48.1	46	54.	53.2	53.6	48.3	53	53.2	44.9	45.5	45.2

Source: (Fujairah Statistics Centre 2010)



Figure 4-5 A Glimpse of the Fujairah's Agriculture taken in March 2012

4.5.4 Recreational land use

Land used for Fujairah's recreation sector has increased considerably during the past decade due to the expansion and development of the tourism industry. The total area of recreational sites was 494,636 m² in 1995 and increased to 574,068 m² in 2006 (Hassani 2007). This increase in land use was due to the building of restaurants, hotels, sports clubs, parks, cinemas, campsites and also the construction of corniches. Corniches (avenues that flank the sea) are an integral feature of Fujairah's coastal infrastructure; they incorporate children's playgrounds, provisions for fishing for leisure, and facilities for barbeques and gatherings. These are seen as important venues which add value to Fujairah's booming tourism industry. Major projects involving the construction of luxury hotels and holiday villas along the coastal belt of Fujairah have contributed to a substantial increase in recreational land use.

4.6 Fujairah's climate

The climate of the UAE and Fujairah is similar to that of other countries in the northern Arabian Peninsula, although the UAE has a slightly higher mean and minimum annual temperature. Due to its location in an arid region, Fujairah's climate is characterised by low rainfall and high humidity coupled with very high temperatures during summer and moderate weather during winter (Böer 1997).

Fujairah is classified as 'BWh' (arid, desert and hot) within the Group B zone (arid and semi-arid) according to the Köppen climate classification system (Peel, Finlayson and McMahon

2007) as depicted in Figure 4-6. This classification system, developed by the Russian climatologist Wladimir Köppen in 1900, is based on native vegetation, the average monthly temperature, and precipitation data (McKnight and Hess 2000; Tang and Hossain 2012).

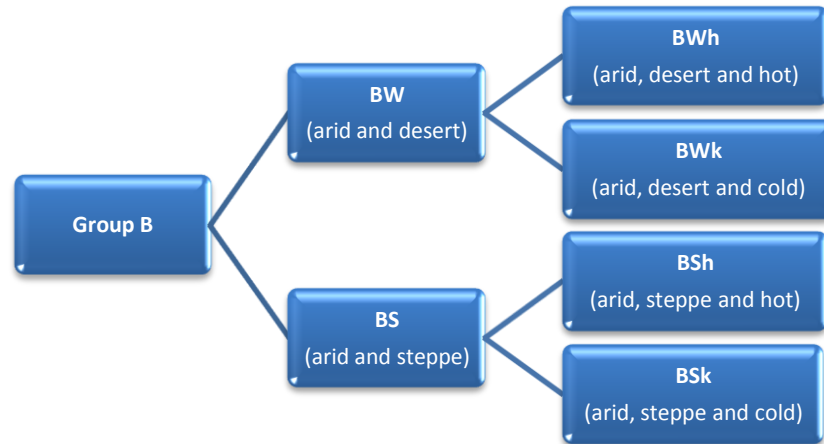


Figure 4-6 Classification of Zones in Group B Corresponding to Dry (Arid and Semi-arid Climates) to which Fujairah belongs (Peel, Finlayson and McMahon 2007)

4.6.1 Temperature

The UAE has two primary seasons, winter (from October to April) and summer (from May to September) and it experiences very high temperatures in the latter. During the last 15 years, the lowest temperature recorded in Fujairah was 11°C in January 2008 (Fujairah Statistics Centre 2009), while the highest, 50.2°C, was recorded in May 2009 (Fujairah Statistics Centre 2010). High summer temperatures are likely to affect the tourism industry, and it is important that the impact of even higher temperatures (due to climate change) is quantified for the purpose of planning and long term projections. This is because high temperatures can restrict outdoor working hours, which affects industries such as construction.

Apart from the obvious impact on human activities, extreme temperatures may be responsible for changing the condition of many tourism resources. For example, high temperatures result in increased evaporation of surface water which may reduce crop yields and also affect visits to places with scenic views. Monthly mean temperatures in Fujairah, averaged over the period 1995-2010, are shown in Figure 4-7.

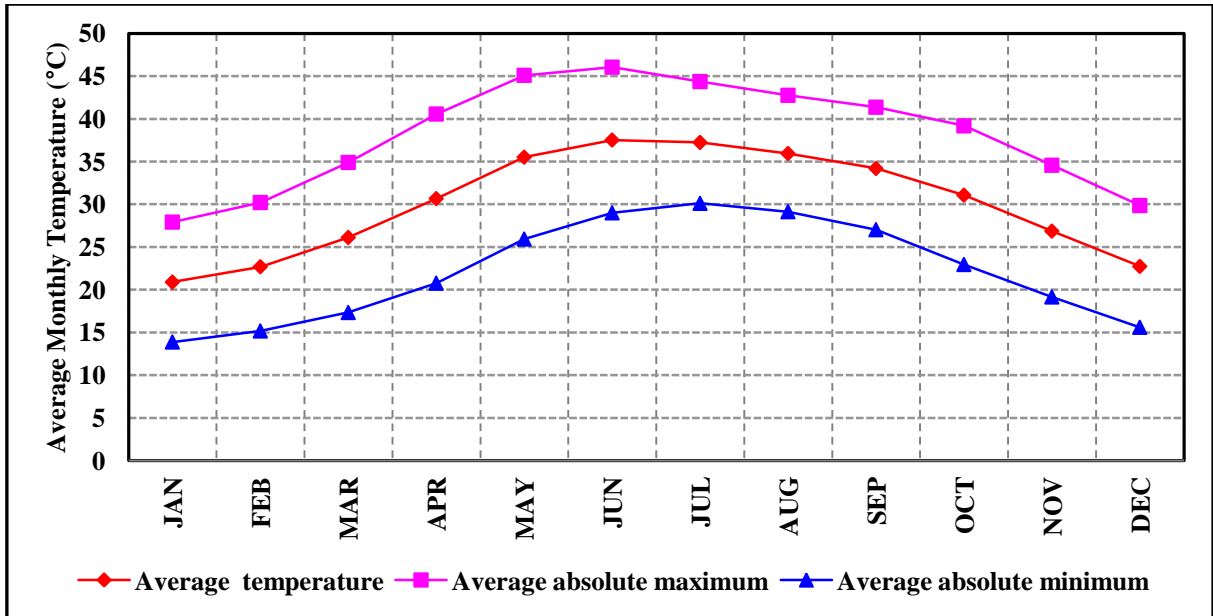


Figure 4-7 Monthly mean temperature in Fujairah 1995-2010 (Fujairah Statistics Centre 2010)

4.6.2 Rainfall

The UAE receives very little rainfall (less than 500 mm per year on average), and the long-term average for Fujairah is only 130 mm, as shown in Figure 4-8 (Fujairah Statistics Centre 2010). It varies substantially from one year to another. Fujairah's average yearly rainfall is slightly higher than in the rest of the UAE (see Figure 4-9); as a result, it generally has more surface and groundwater available for both domestic and irrigated agricultural purposes. It should be noted that mountain areas in Fujairah enjoy the highest percentage of its rainfall, followed by the eastern coastal areas and finally by the stony plains (UAE Ministry of Environment and Water 2006). It is also worth mentioning that the UAE government has tested artificial rain-making technology with moderate success during extreme climatic conditions (Jensen et al. 2003).

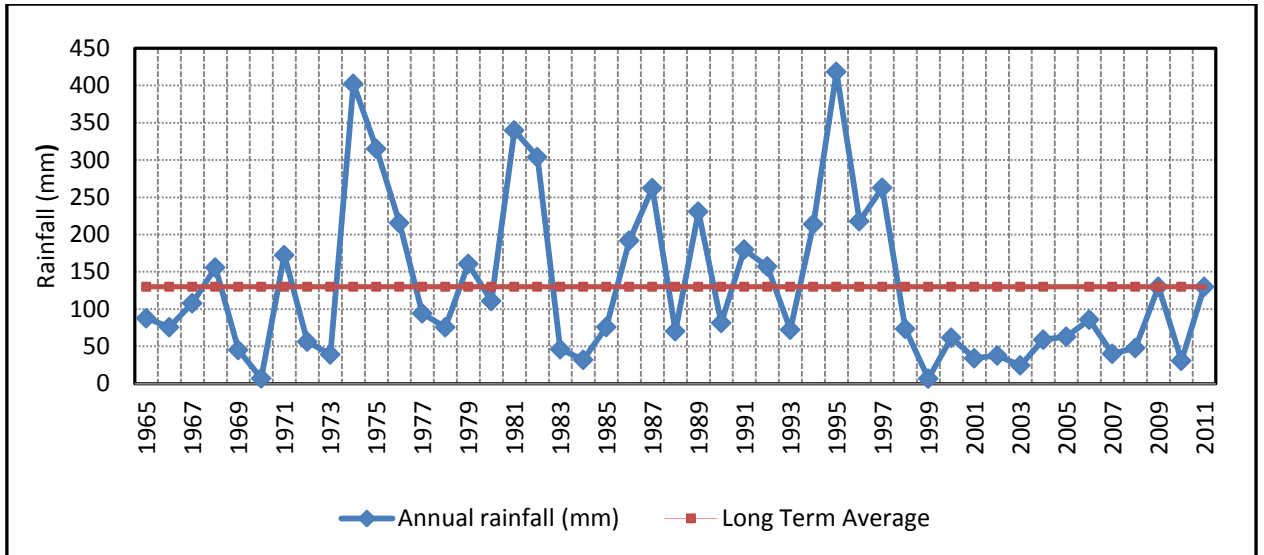


Figure 4-8 Annual rainfall in Fujairah, 1965-2010 (Fujairah Statistics Centre 2010)



Figure 4-9 Mean Annual Rainfall in the UAE in 1992 (UAE National Atlas 1993)

4.6.3 Humidity

Humidity plays a vital role in the tourism sector because it affects the comfort of tourists. The combination of high humidity and temperatures can be unpleasant and may deter tourists who are visiting outdoor destinations. The humidity in Fujairah and the rest of the UAE is often very high and even reaches saturation, especially in the coastal areas (Aspinall 2011). Annual

differences in humidity (together with that of temperature) are relatively small along the Fujairah coast when compared with areas further inland (Böer 1997). Figure 4-10 shows monthly relative humidity values in Fujairah averaged over the period 1995 – 2010.

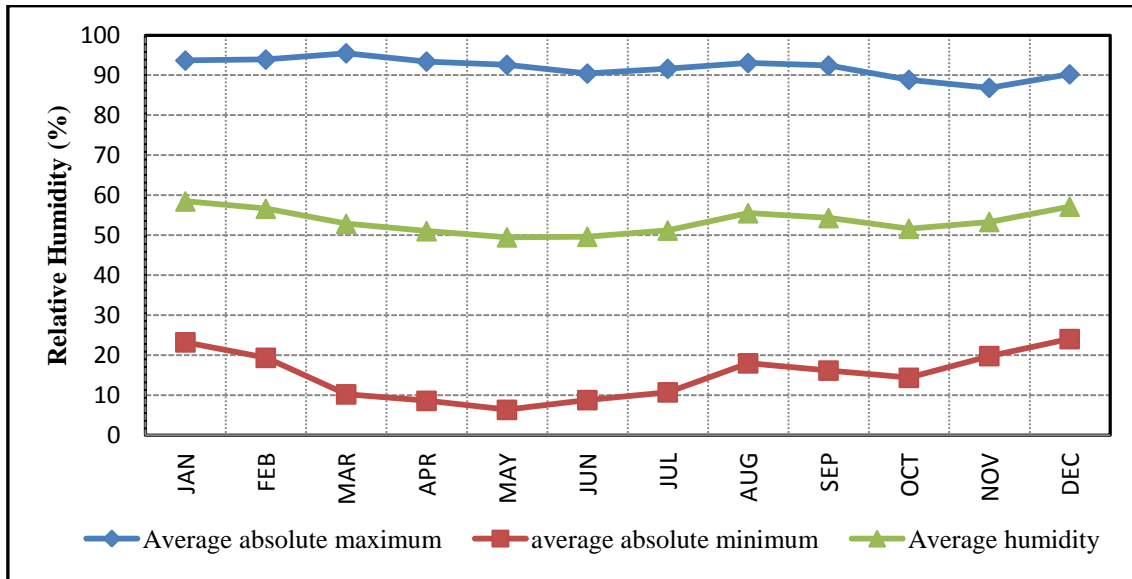


Figure 4-10 Monthly relative humidity levels (%) in Fujairah averaged over 1995-2010 (Fujairah Statistics Centre 2010)

4.7 Fujairah: typical of many developing countries

As described earlier, Fujairah is a developing nation. Its economy is based on natural resources. Fujairah has many attraction and events that can be used as tourist sites. Its cultural resources such as museum, forts and castle, ancient mosque and its authentic Arabic way add to its natural tourism resources like mountains and beaches. Thus Fujairah’s cultural and natural resources must be protected and monitored to ensure their sustainability and the sustainability of the income they generate.

Tourism resources in Fujairah are vulnerable to the impacts of climate change. As was shown above, an arid climate is already a problem for tourism, and an additional climate change will only have further negative impact. The absence of many factors (e.g., legislation, funding, knowledge base) that help to combat climate change impacts put Fujairah and similar developing countries at risk. In the IPCC’s assessment reports, developing countries are depicted as more vulnerable to the impacts of climate change than developed countries. Thus Fujairah is a useful case study for the impacts of climate change on tourism in developing countries.

4.8 Summary

This chapter introduced the Emirate of Fujairah and discussed aspects such as its geographical and geological settings, socio-economic features, land use and climate.

It was noted that Fujairah's geographical location in the Gulf of Oman enables it to be not only a socio-economic hub but also, due to its natural and cultural resources, a tourist attraction of growing importance in the region. It was highlighted that Fujairah experiences high temperatures, high humidity levels and low rainfall. The background information presented in this chapter adds context and will aid comprehension of the rest of the thesis relating to the impact of climate change on Fujairah's tourism resources.

Chapter 5 Developing a Spatial Database of Tourism Resources in Fujairah

5.1 Introduction

The previous chapter described the Emirate of Fujairah's geographical and geological features, socio-economic aspects, land use, tourism destination, climate and why it has been used as a case study to develop a method for assessing the impact of climate change on tourism resources in developing countries. It was noted that tourism plays an increasingly important role in Fujairah economy. As such, preserving Fujairah's tourism resources is of paramount importance – hence the need to assess the likely effects of climate change on those resources. The first step towards a change monitoring process is the accurate identification and understanding of Fujairah's tourism resources.

This chapter describes the types of tourism resources in the Emirate of Fujairah, the challenges faced by the emirate in managing those resources, and Fujairah's existing information on tourism resources. It then details the development of a comprehensive GIS-based tourism resource database. Finally, the chapter presents several GIS-based maps depicting the emirate's tourism resources. These maps were then used for the purpose of projecting future climate change effects in Fujairah (see Chapter 6).

5.2 Types of Tourism Resources in Fujairah

Tourism resources in Fujairah can be broadly categorised as natural, cultural and built-up. A brief description of the resources in each category is given below.

5.2.1 Natural resources

Natural resources refer to those resources which are part of the environment; in this context, they are the natural settings that stimulate tourists to visit. Features of Fujairah's environment include coastal landscapes, national parks, hot springs, mountain ranges and marine life.

Fujairah has many natural resources that attract tourists from all over the world. Natural littoral resources include diverse flora and fauna and the marine ecosystem. Mountain ranges, wadis (valleys that remains dry except during the rainy season) and hot springs are important land-based tourism resources (Sheppard and Salm 1988).

Fujairah's beaches are a major attraction for tourists from all over the world, and are made accessible and comfortable for visitors by seaside hotels such as the Le Meridien Al Aqah

Beach Resort and the Fujairah Rotana Resort. These hotels at Al Aqah Beach, appealingly situated between the Hajar Mountains and the Indian Ocean, give guests spectacular views. Camping is also permitted on Al Aqah Beach, and is especially pleasant in winter (October to March). Small islands near the coast add to the beach experience. Visitors are able to enjoy swimming, snorkelling and diving on colourful coral reefs with their rich biodiversity, or indulge in other beach activities such as playing volleyball, running and motorcycling.

Table 5-1 gives details of tourism resources located in Fujairah’s littoral zone, and Table 5-2 describes Fujairah’s land-based resources. Figure 5-1 shows images of two beaches in Fujairah.

Table 5-1 Natural Tourism Resources in Fujairah’s Littoral Zone

Resource	Description
Beaches	Sandy beaches and sand and cobble shores, suitable for walking, sightseeing, camping and swimming (Figure 5-1)
Islands	Snoopy Island is a small island just off the coast; it is rich in marine life and ideal for snorkelling. Bird Island is known for its diverse birdlife and is easily accessible
Sabkhas	Flat, salt-encrusted coastal plains of interest to geotourists
Coral Reef	Reefs are common along the Fujairah coast but rare elsewhere in the UAE
Seagrass	Grows along the Fujairah coast and provides habitat for marine life
Marine animals	Dolphins and endangered turtles live along the Fujairah coast

Table 5-2 Land-Based Natural Tourism Resources

Resource	Description
Wadis	Fujairah has more than 30 wadis (valleys that remains dry except during the rainy season)
Mountains	More than 80% of Fujairah is mountainous. Fujairah has two designated protected mountain areas to protect its flora and fauna
Springs	Fujairah has two springs, Ain al-Madab and Ain al-Ghammour. The former is a health spa with water rich in therapeutic minerals, while the latter is known for its therapeutic hot spring
Waterfalls	Fujairah has three waterfalls. The famous Wurayah Waterfall is located inside one of the protected mountain areas

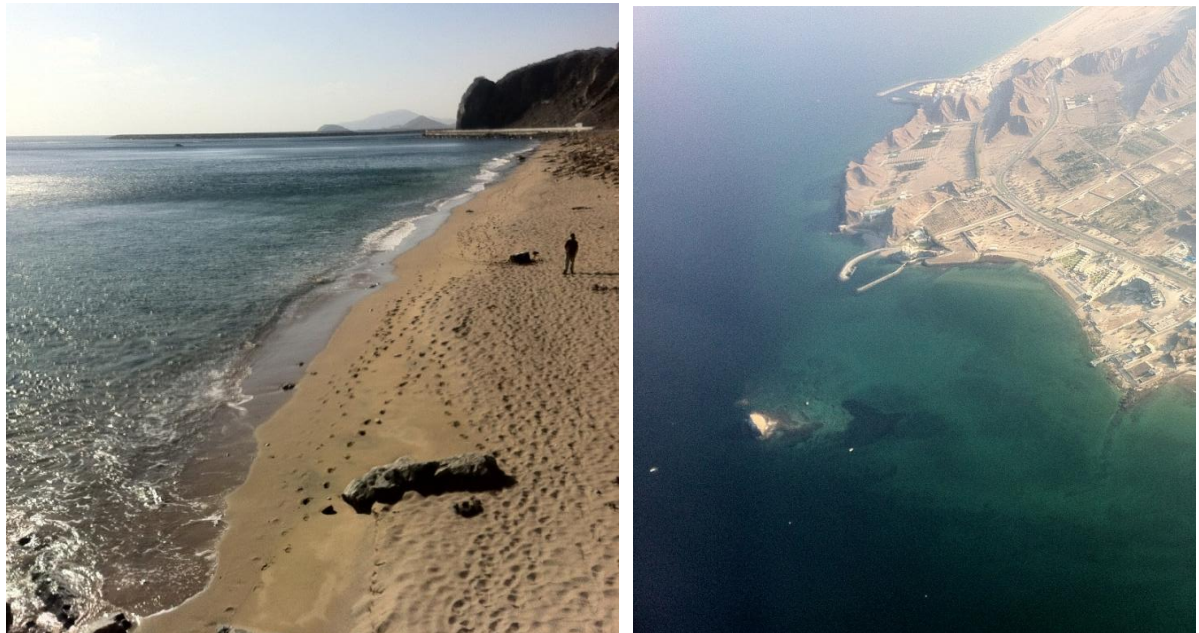


Figure 5-1 Two of Fujairah's beaches (January 2012)

5.2.2 Cultural resources

Cultural tourism resources in Fujairah include traditional, heritage and archaeological resources, as well as entertainment and lifestyle events.

Heritage villages, built specifically to protect and display Fujairah's traditional culture, demonstrate the knowledge and respect of the local people for their environment (Forman 1996; Picton 2010). They also serve to educate the people about the lives of the inhabitants and have become popular tourist attractions. While visiting the heritage villages, tourists have

the opportunity to witness traditional crafts, such as the production of mud bricks, ropes, pottery, palm-leaf mats, fishnets and agricultural implements (Ebrahim 1999). The palm tree is a particularly significant cultural artefact, adored and respected by the people of Fujairah for its many useful commodities, notably dates, which are highly nutritious and have been a staple food for millennia (Hellyer and Aspinall 2005; Vine 1996). Pre-modern residents also used the palm tree's trunk and leaves to construct dwellings and to cure skin diseases (Potts 2002).

Sports that are unique to Fujairah are another attraction for tourists. While other emirates such as Abu Dhabi and Dubai are famous for camel racing and falconry, Fujairah is popular for power-boating, traditional rowing boat regattas and bloodless bullfighting, which takes place in open areas every weekend (Hellyer 2005). An event that recently began to attract tourists to Fujairah is the Fujairah International Monodrama Festival, a major theatrical event held every two years (Fujairah International Monodrama Festival 2012).

International tourists to Fujairah enjoy seeing the construction of traditional fishing boats (known as Shasha) out of palm fronds at Fujairah Heritage Village. The Government of Fujairah subsidises local fishermen to continue their construction (Agius 2005; UAE National Media Council 2012). Similarly, the government sponsors locals to construct and maintain traditional houses (known in Arabic as 'arish) made of palm fronds (see Figure 5-2).



Figure 5-2 An 'arish house from inside (Collins 2012)

Fujairah's museum, ancient mosques, watch towers, and the historic forts and castles (see Figure 5-3) distributed along the coast and in the valleys, all attract tourists keen to appreciate the emirate's unique and colourful history, its ancient architecture and to acquire knowledge about the culture of the region.

In villages and towns, traditional Friday markets (known as *Souq ul Juma*) display local goods such as fresh fruits, vegetables, mountain honey, traditional wood sticks as well as locally designed swords. Visitors are not only international tourists but residents from other emirates who are attracted by the unique features of Fujairah's heritage displayed in these traditional markets (Fujairah Statistics Centre 2010).



Figure 5-3 Three of Fujairah's historic sites: Al Hayl fort, Al Badiyah Mosque and Bithna fort (left to right)

5.2.3 Built-up resources

Built-up tourism resources are buildings and other artificial structures and sights purpose-designed to attract visitors and tourists. Fujairah's built-up tourism resources include the Fujairah Trade Centre, the Fujairah Tower (which includes accommodation and shopping malls), sports clubs such as the Dibba Sports Club, the Fujairah City Centre Mall, diving centres, cinemas, hotels and restaurants, and public parks.

5.3 Current challenges in managing tourism resources

The natural, cultural and built-up resources described above form the basis of Fujairah's tourism industry. The protection of these resources is crucial to the continuation of tourism in the emirate. The Government of Fujairah is aware that tourism resources need better management and thus established the Fujairah Tourism and Antiquities Authority (FTAA) in 2009. The FTAA is yet to develop a long-term strategy for sustaining and protecting tourism resources; however, in February 2012 the FTAA began talks with a Dubai-based strategic hospitality and tourism consultancy firm to discuss such a plan (Fujairah Observer 2012).

Climate change looms as a major threat to the future of Fujairah's tourism industry; many of Fujairah's tourism resources are vulnerable to the impacts of climate change due to their geographical placement. SLR due to global warming and an increase in the incidence of flooding due to cyclones are examples of the impacts of climate change that may affect Fujairah. Storm surges could negatively affect coastal development and coastal communities (Lozano et al. 2004), posing a direct threat to tourism resources. This threat is compounded by Fujairah being located on the Gulf of Oman, which is increasingly being affected by events such as cyclones and seismic activities (Dougherty et al. 2009). Similarly, temperature plays a fundamental role in weather events and changes pose a risk for industries such as energy, agriculture and tourism. The spatial mapping of temperature is important for business planning, risk estimation and projecting profitability as well as many other managerial issues (Härdle and Osipenko 2012).

For this research it was important to develop a spatial database of tourism resources in order to assess the differential impacts associated to climate change. Existing data that were used or have potential for use in that process are described in the following section.

5.4 Existing data on Fujairah's tourism resources

The Fujairah Municipality and the Fujairah Statistical Centre have both been using GIS for the last decade (Yagoub and Engel 2009). However, its use to date has been exclusively for administrative functions. For example, the Fujairah Municipality currently uses GIS for land administration, while the Fujairah Statistical Centre uses the technology to carry out functions such as calculating population densities and determining the locations of facilities like schools and clinics. However it has not to date been used for the purpose of identifying tourism resources; in fact some tourism resources were not listed in the Fujairah tourism map produced by Fujairah Municipality.

Existing data about tourism resources in Fujairah suffers from gaps and problems. First of all, the oldest aerial photos (i.e., orthophotos) available for Dibba and Fujairah Municipality date from 1995; these photos are not in colour and have not been used in building a geodatabase. These photos have a spatial resolution of about 1m, so could be considered high-resolution images comparable to the 2010 IKONOS satellite images. Therefore the two sets of images could be included in a geodatabase and used for spatial analyses such as change detection of land use land cover (LULC), change detection of coastline shift, and measuring the physical entities of tourist sites.

Due to the Fujairah Municipality having developed and maintained the current GIS, there has been little opportunity to date for the storage and maintenance of tourism resources within that GIS. However, with greater integration between the Fujairah Municipality and the FTAA, opportunity exists to extend a corporate geodatabase to include spatial data relating to various tourism resources as well as key tourism events. Thus the notion of including tourism data in such a database is new and vital.

In this research, a geodatabase of tourism resources for Fujairah was developed. Apart from forming the basis for a future corporate GIS for Fujairah, this geodatabase enabled the emirate's various natural, cultural and built-up tourism resources to be geographically located. With their geographic location identified, it then becomes possible to identify climate change's impacts upon each of these resources. This is the first step in determining climate change impact on Fujairah's tourism resources.

5.5 Development of a comprehensive GIS-based tourism resource database

The geodatabase was built using a vector and raster model. The vector model consisted of grouped datasets corresponding to the type of tourism resources (i.e., natural, cultural and built-up), the associated land use and the related infrastructure. Each of these datasets contains multiple layers or feature classes, as depicted in Figure 5-4. The DEM was based on a raster model.



Figure 5-4 Geodatabase for Fujairah's tourism resources

Additional tourism resources data were collected as described below. This process included the collection of spatial data and attribute data, as well as data capturing and editing. The steps were as follows.

- (i) Spatial data were collected from the following government authorities: the Fujairah Statistical Centre (FSC), Fujairah Municipality, Dibba Municipality and the FTAA. These data included an IKONOS satellite image (georeferenced image of 1m resolution) obtained in 2010. Both land use information and the DEM were obtained from the Fujairah Municipality.
- (ii) Due to the high resolution of the spatial data obtained, it was possible to digitise imagery and maps in order to extract additional information such as the locations of tourist attractions.
- (iii) Attribute data corresponding to the tourism resources were also obtained from the sources listed in (i) above. These data were either descriptive in nature or specific information about demographics, tourism activities, etc.

The types of data collected are shown in Figure 5-5.

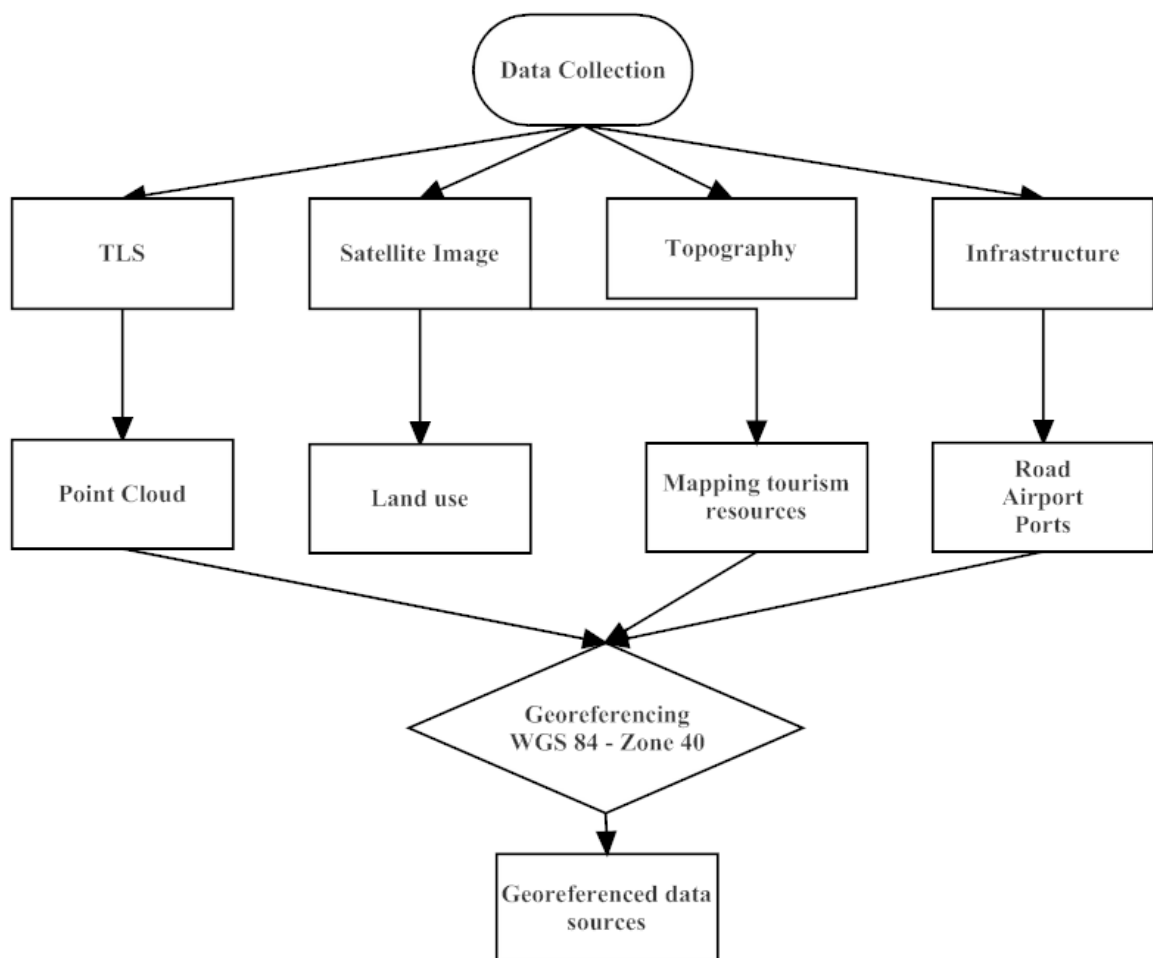


Figure 5-5 Methods of data collection and customising the geodatabase

(iv) The final step in building the geospatial database for Fujairah's tourism resources was implemented using ArcGIS (version 10) software. The process was as follows:

- a. Creation of a vector data model of Fujairah's tourism resources using a personal geodatabase in ArcCatalog-v10 software (see Figure 5-6)

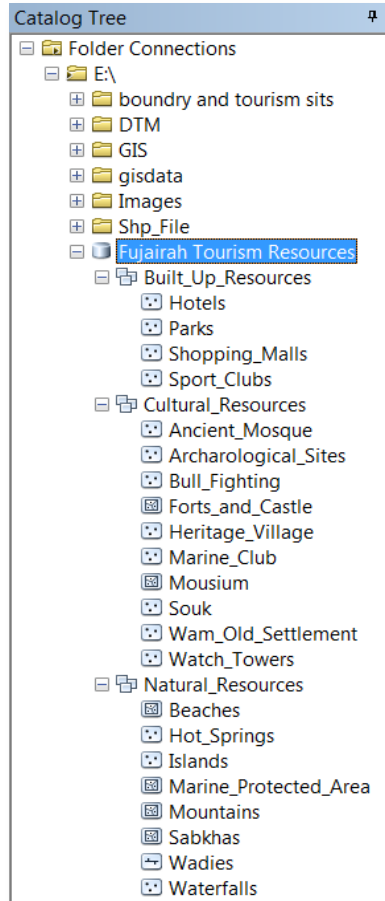


Figure 5-6 Creating the Geodatabase in ArcGIS

- b. Organising the data appropriately inside the ArcCatalog-v10 environment
- c. Building feature datasets, namely: 'Natural_Resources', 'Cultural_Resources', 'Built_Up_Resources', 'Land Use', 'Infrastructure' and the 'DEM'. The coordinate system (latitude and longitude) chosen was the World Geodetic System 1984 (WGS 84)
- d. Building the feature classes that constitute the layers inside the database. Details of these layers are presented in Table 5-3.
- e. Using ArcMap-v10 to map tourism resources/features within each layer of the geodatabase (where the layers comprise spatial information) using ArcMap-v10.
- f. Overlaying multiple layers for improved visualisation of the count and positioning of the tourism resources.

Table 5-3 Description of the dataset

Dataset	Dataset Description
Elevation	This corresponds to the DEM of the Emirate of Fujairah. The DEM consists of contour lines 5m apart
Land use	Vector dataset of land use in Fujairah – includes sectors such as industrial, commercial, residential, etc.
Infrastructure	Feature datasets displaying roads (as lines), airport and port, etc.

5.6 Land use map development

Land use maps depict the distribution of human activities and utilities. Land use maps are usually produced for the purposes of a government department or agency charged with development and thus information might differ from one land use to another for the same area. In this case the land use map developed was for the purpose of informing the tourists visiting Fujairah. These services (e.g., hotel and other accommodation) are not included as tourism resources but are important information for tourists.

A land use map was produced using ArcMap-v10 and was based on the author’s knowledge of the study area, but sector names and road and boundary areas were provided by the FSC. The digitising process was built on the IKONOS image taken in 2010. In addition to an overall land use map for the Emirate of Fujairah, land use maps were also produced for: Dibba, Dhadnah, Murbah and Fujairah City.

Figures 5-7 to 5-10 show an overall distribution of the facility (e.g., health use such as hospital and clinics, commercial use such as restaurants and shops, industrial use such as carpenters and car garages). It also shows maps with more focus (zoom) for both small and large scale. As a result, this gives more details for tourists to know the distance between tourism resources or services. This point of producing both small and large scale maps highlight the issue with choose of an appropriate scale and the importance of producing maps with different scales.

The maps in Figures 5-7 to 5-10 show the concentrations of settlement, population activities and services in Fujairah’s coastal zone – an area vulnerable to SLR and sudden floods from storm surges.

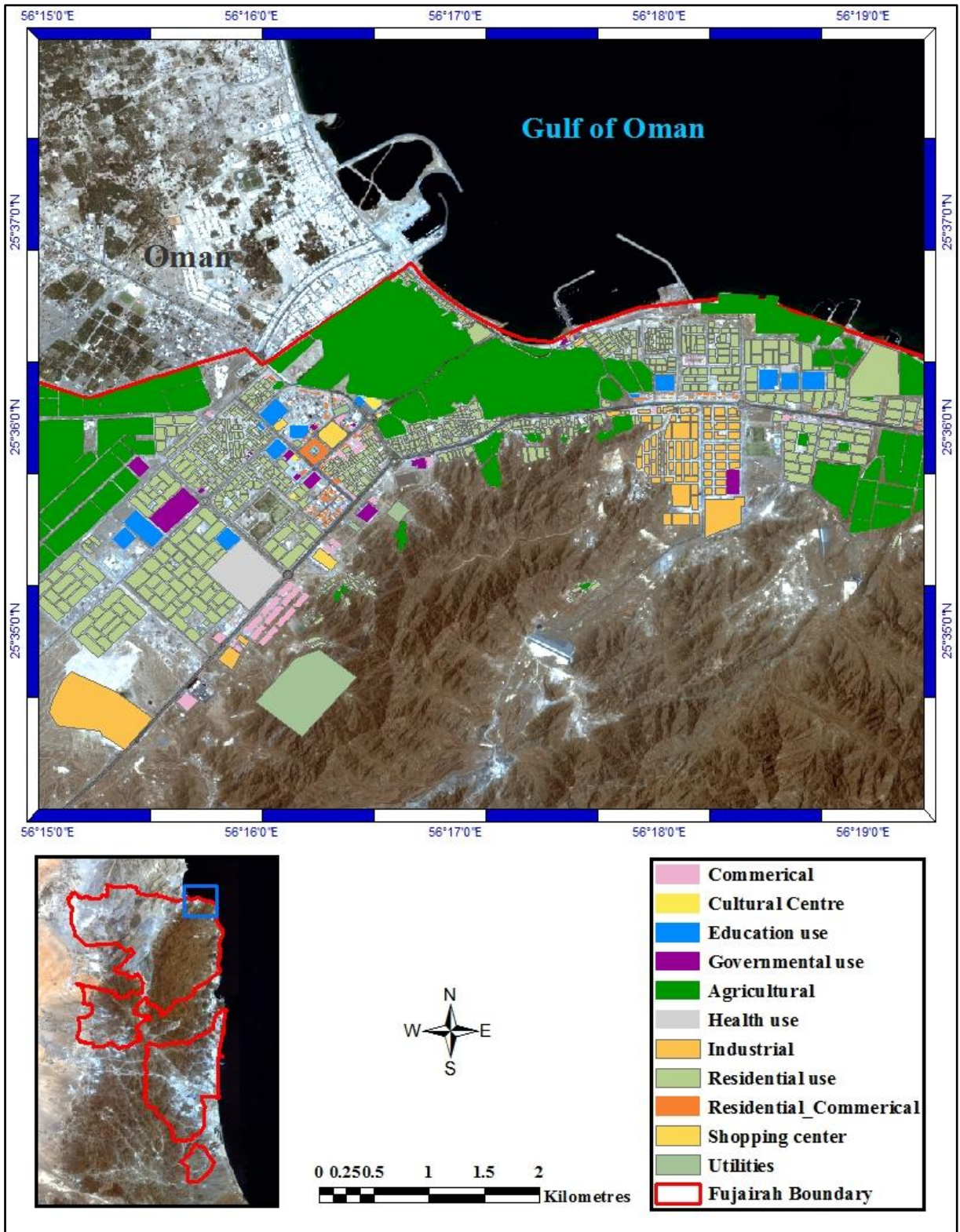


Figure 5-7 Satellite image with land use overlaid at Dibba city 2010

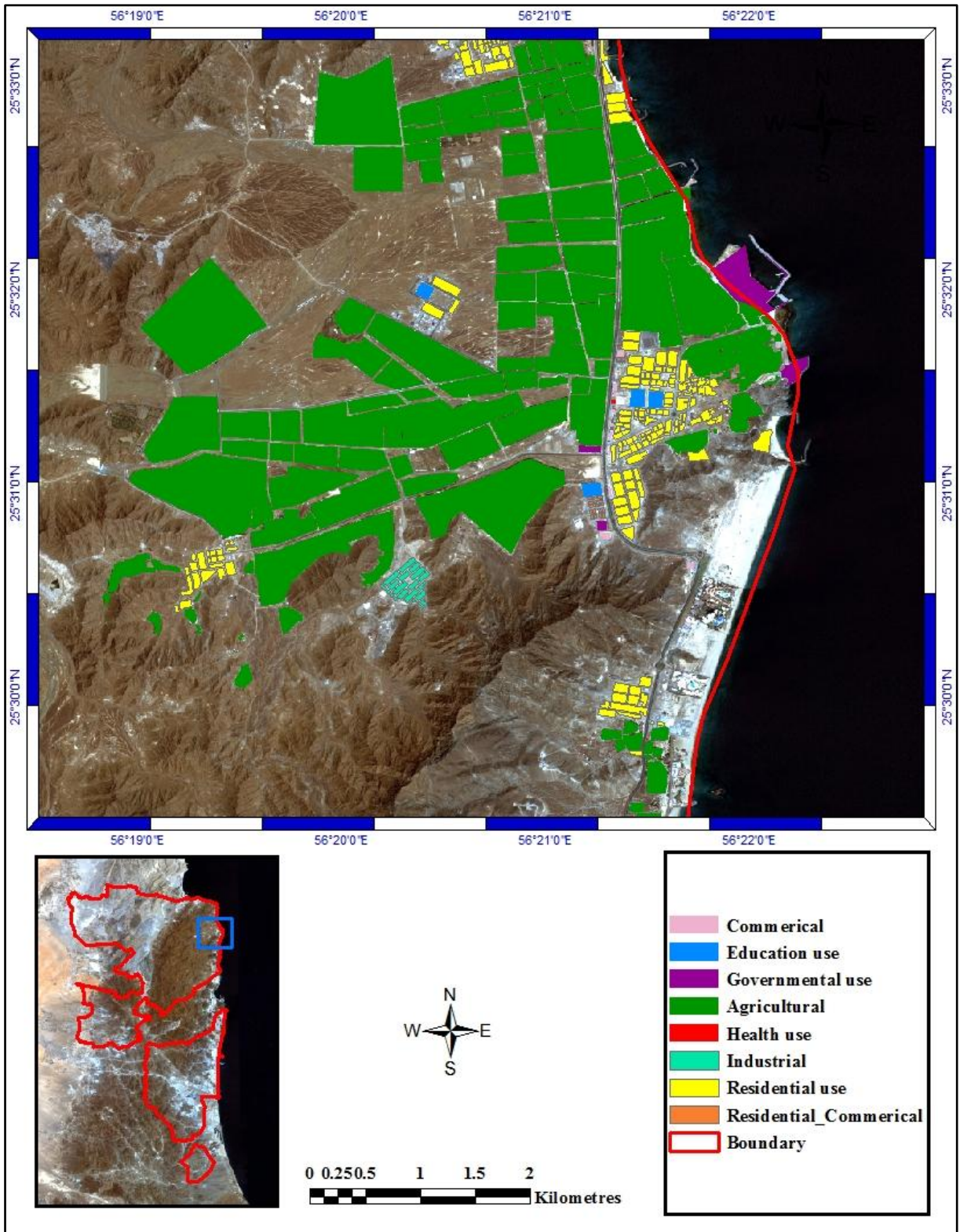


Figure 5-8 Satellite image with land use overlaid at Dhadnah 2010

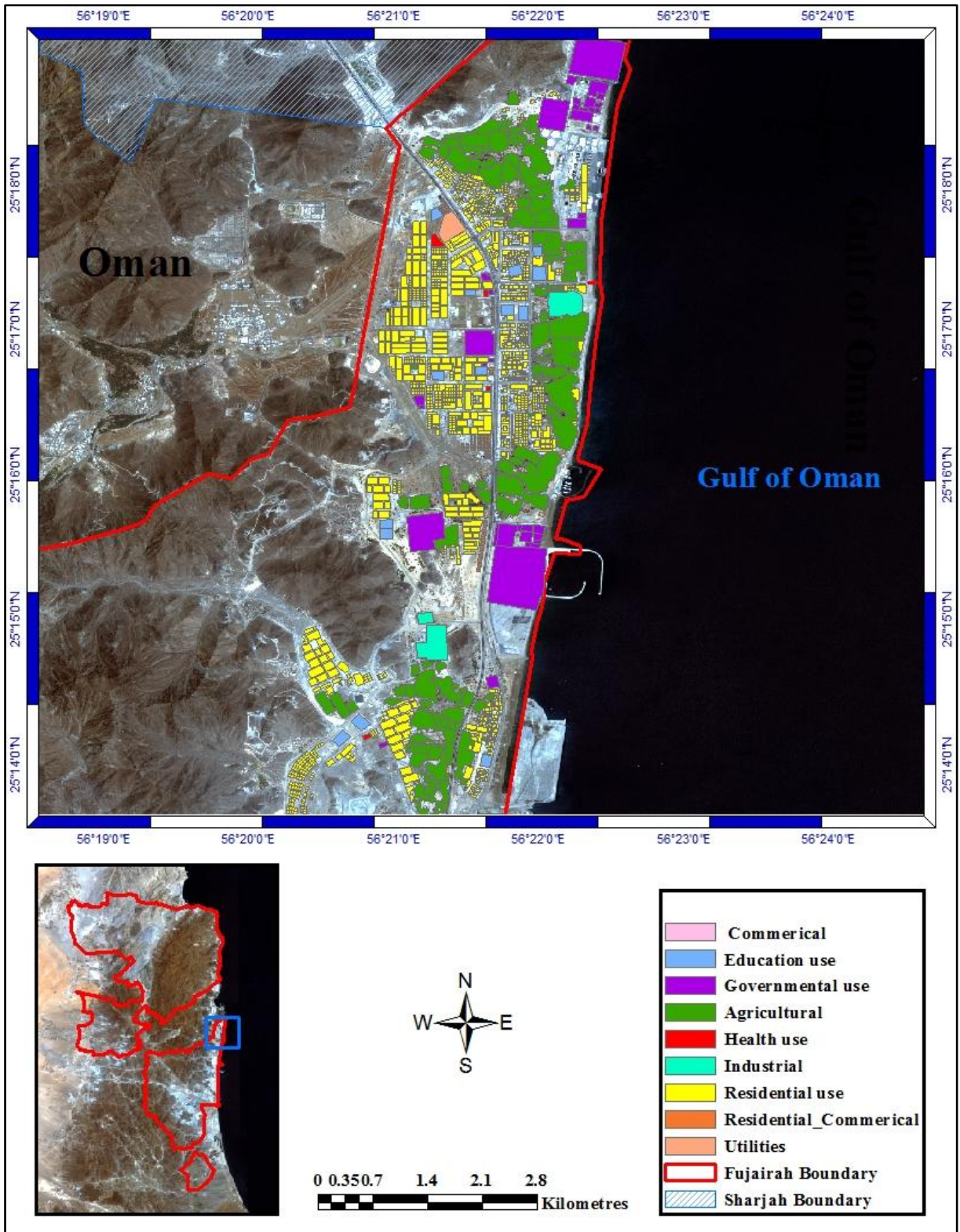


Figure 5-9 Satellite image with land use overlaid at Murbah city 2010

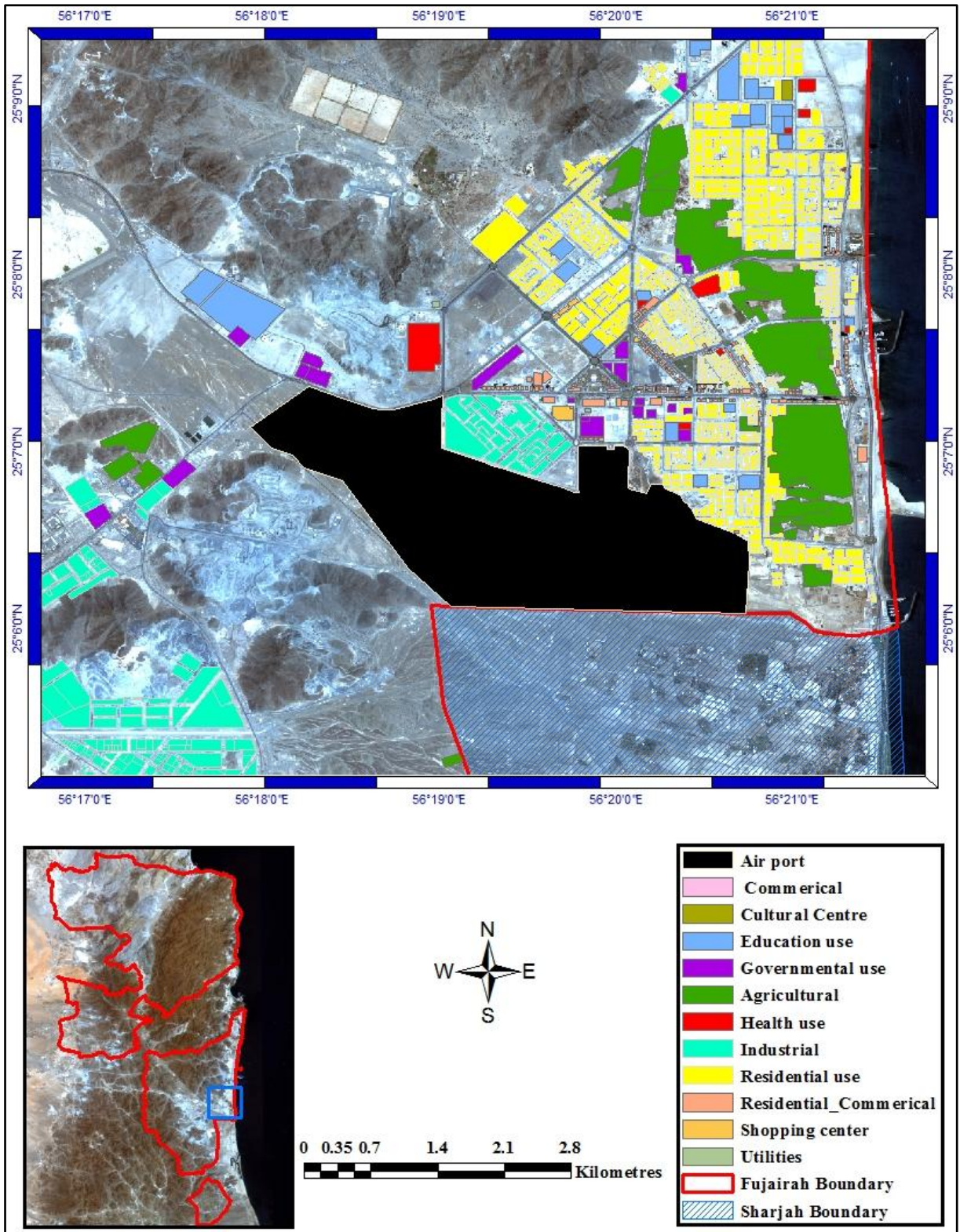


Figure 5-10 Satellite image with land use overlaid at Fujairah City 2010

5.7 GIS-based tourism maps

Several maps showing the distribution of natural, cultural and built-up tourism resources within the Emirate of Fujairah were created using the process described in section 5.5. These were used to project climate change effects using SimCLIM (described in Chapter 6). These maps are depicted in Figures 5-11 to Figure 5-15.

Figure 5-11 shows the distribution of different types of tourism resources within the Emirate of Fujairah. It can be seen that most of Fujairah's unique geological features are concentrated around the mountains, whereas most of the tourism resources are distributed along the coastal belt, making them potentially vulnerable to SLR and storm surges.

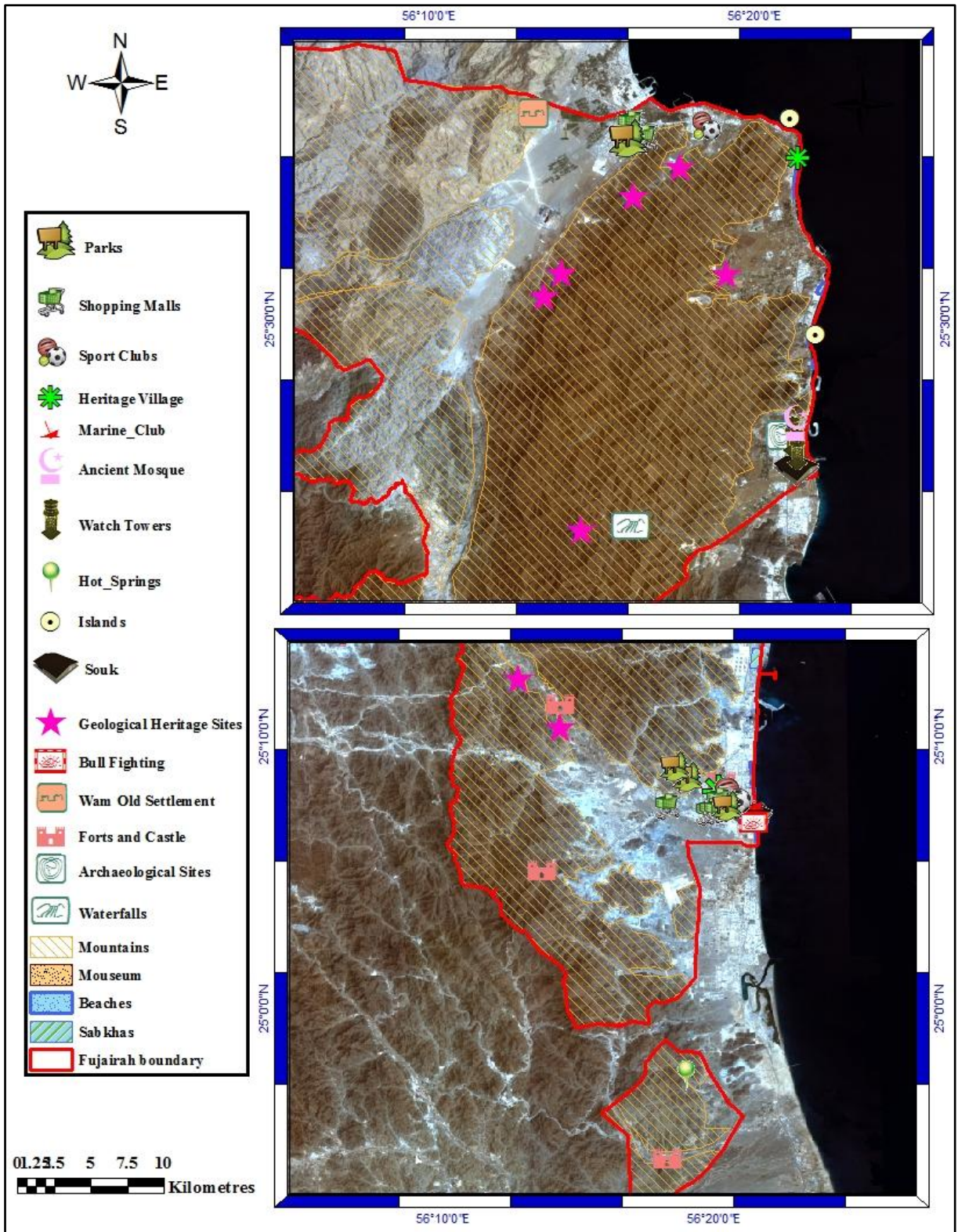


Figure 5-11 Key tourism resources within Fujairah north (top) and south (below)

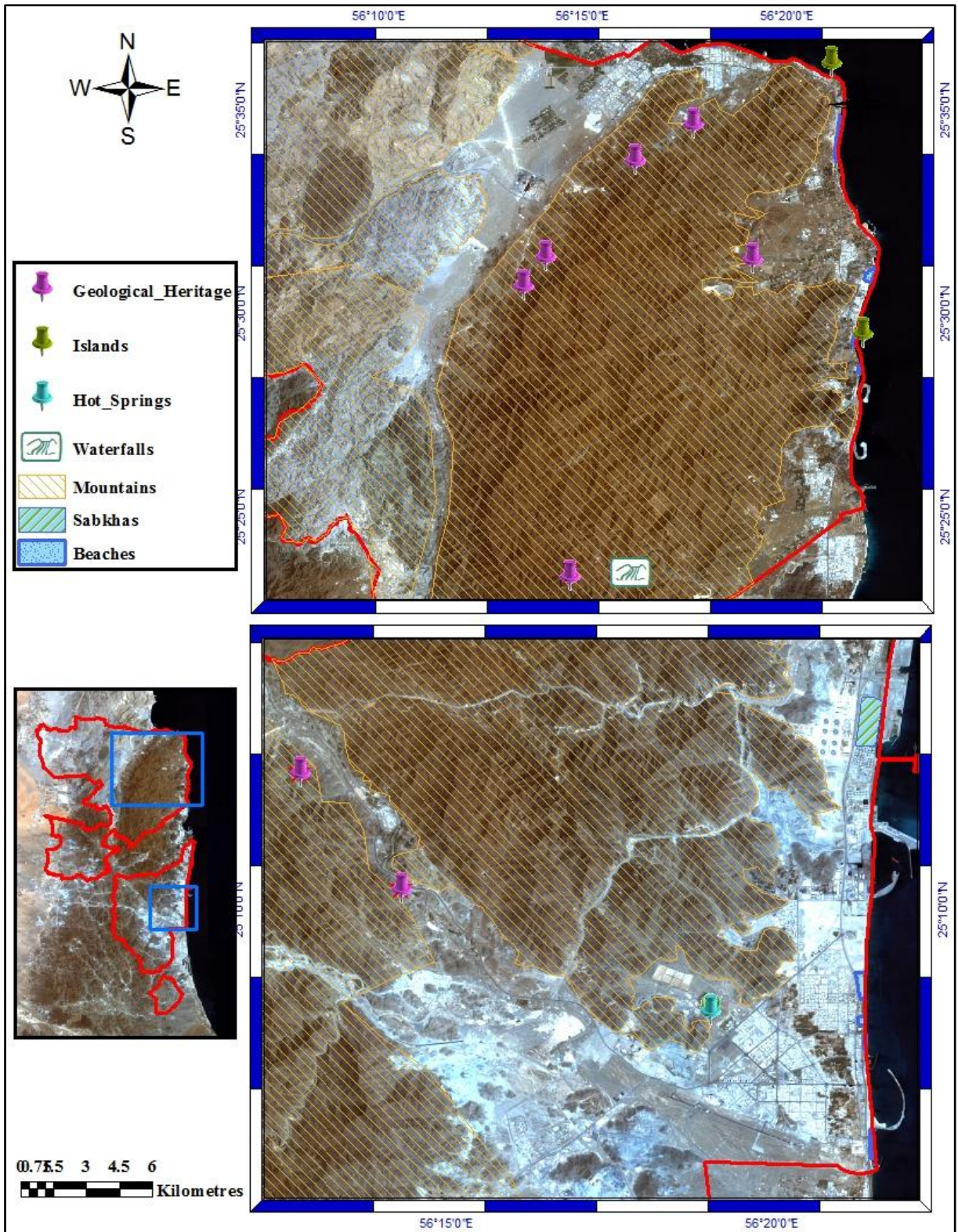


Figure 5-12 Natural tourism resources within Fujairah

Figure 5-12 shows the distribution of natural tourism resources within the Emirate of Fujairah. It depicts two islands in the northern part of the emirate; these are popular tourist attractions for activities such as snorkelling, swimming and fishing. Two hot springs are also

shown – one in the middle of the emirate, the other in the south; these are important ecotourism resources. Waterfalls are a potential tourist resource, and the streams that feed them are important for agricultural activities as well as sustaining the species living nearby and thus helping to maintain local biodiversity.

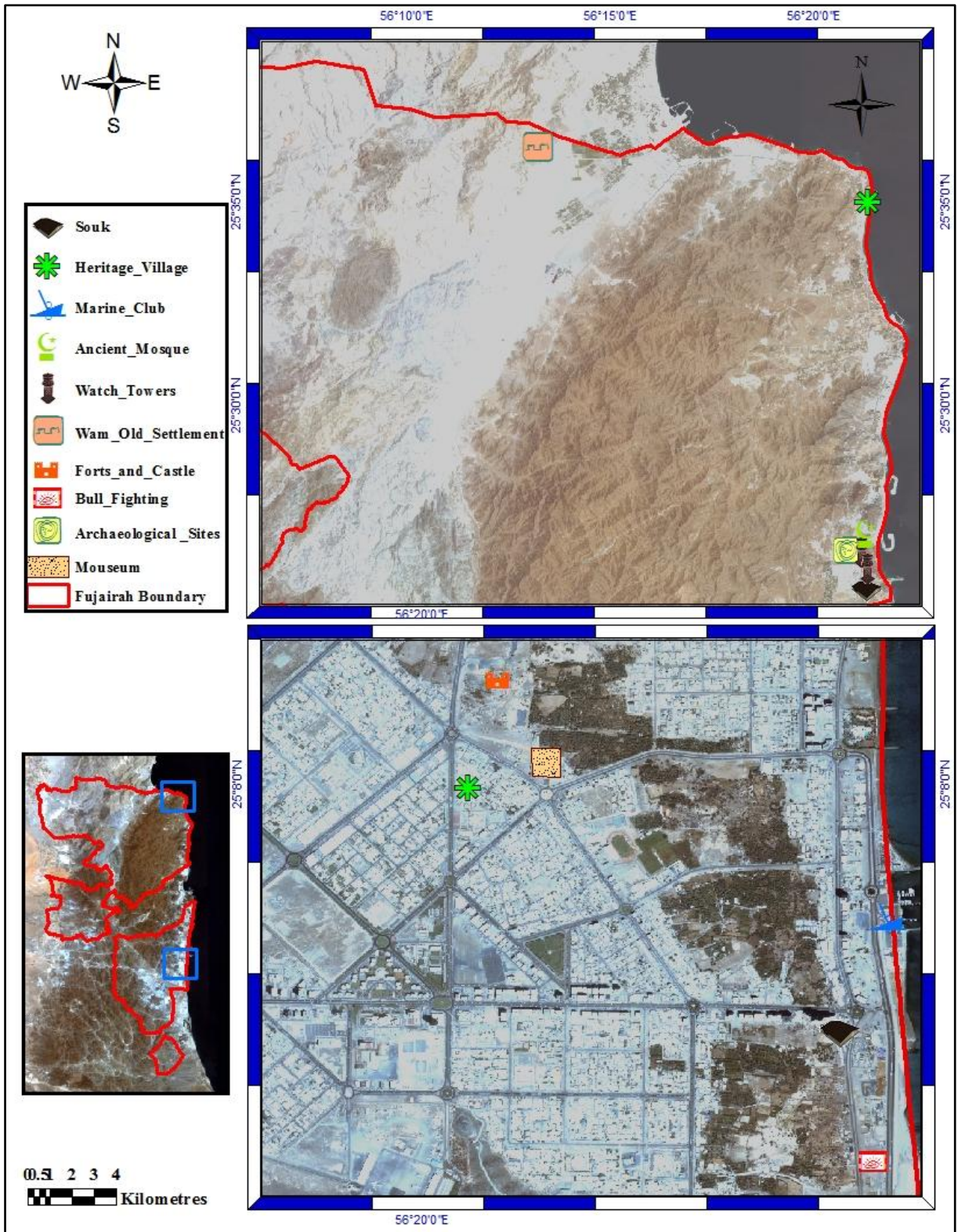


Figure 5-13 Cultural tourism resources within Fujairah

Figure 5-13 shows the distribution of cultural tourism resources. Forts and castles are distributed across the emirate. These cultural resources and associated events involve outdoor tourism so the potential impacts from the effects of climate change are considerable.

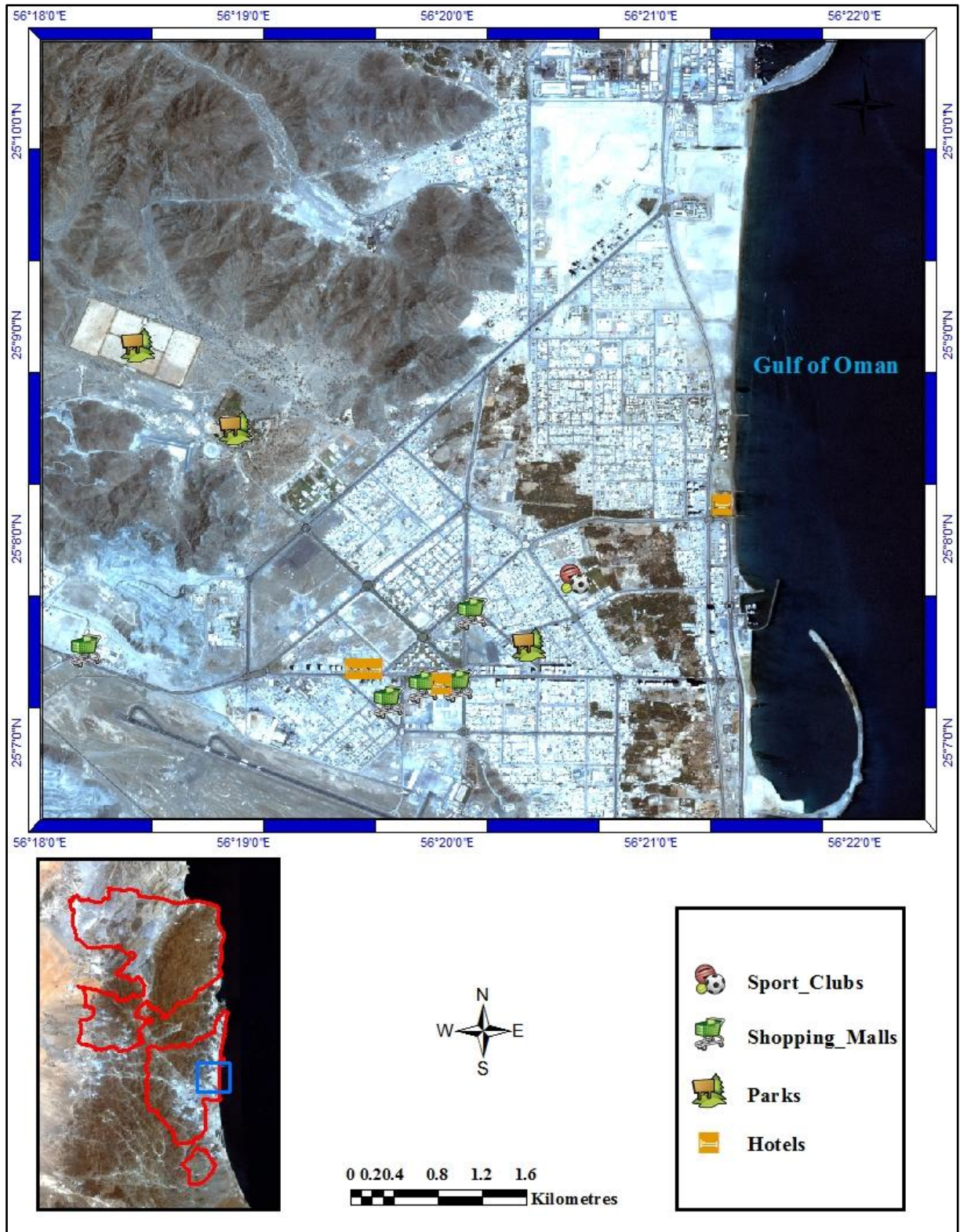


Figure 5-14 Built-up tourism resources in Fujairah

Figure 5-14 shows the distribution of built-up tourism resources within Fujairah. These include tourism facilities such as parks, hotels, restaurants and shopping malls. The southern part of Fujairah that is Dibba City is shown in Figure 5-15.



Figure 5-15 Built-up tourism resources in Dibba City

5.8 Summary

This chapter described the different types of tourism resources in the Emirate of Fujairah. They were classified under three main categories: natural, cultural and built-up. The climate

change challenges faced by Fujairah, especially from SLR and global warming and from cyclone events, were briefly discussed. The current databases about tourism lack information about tourism resources, partly due to lack of cooperation between different government agencies. In this research, a comprehensive GIS-based tourism resource geodatabase was developed, creating several maps that were subsequently used (as described in the next chapter) for the purpose of projecting future climate change effects.

Chapter 6 Determining Spatial and Temporal Effects of Climate Change in Fujairah

6.1 Introduction

In chapter 5 the tourism resources in Fujairah – categorised as natural, cultural and built-up – were identified. A GIS database (or geodatabase) of existing tourism resources in Fujairah was developed in order to clearly identify their spatial distribution. This distribution, plus data on the spatial variation of climate change effects, will enable precise monitoring and quantification of the impacts of these effects on tourism resources.

This chapter discusses the potential changes in climatic conditions in Fujairah together with their spatial variation over the middle- and long term. This information is then combined with the GIS-based distribution of tourism resources developed in chapter 5. The procedures and techniques adopted in making these projections are also presented.

A computer-based modelling system for examining climate change effects both temporally and spatially, SimCLIM, was selected to project future climate change. SimCLIM contains a custom-built GIS and can be applied spatially to any geographic area and spatial resolution. SimCLIM directly uses the results of the 4th Assessment Report (AR4) of IPCC (Warrick 2009) as well as the model outputs from the third phase of the Coupled Model Intercomparison Project (CMIP3) project produced for AR4. As noted in chapter 2, SimCLIM can be used to project future climate for both global and local areas.

6.2 Methods and parameters for climate change projection

In order to predict the effects of climate change, climate change modelling must be performed. SimCLIM software was used to project the future climatic conditions for the Emirate of Fujairah. Unique features of SimCLIM are (i) the ability to project changes in extreme events, both as a change in the return period (also known as the recurrence interval) and as the change in magnitude of the event for a given return period, and (ii) the ability to project local SLR, while taking into account local vertical land movement (VLM) processes (Warrick et al. 2009).

The input parameters required by SimCLIM to provide the projections of climate change as discussed in section 6.3, are:

- (i) Emission Scenario

- (ii) Climate sensitivity
- (iii) GCM pattern or ensemble
- (iv) Baseline
- (v) Time horizon.

These parameters are detailed in sections 6.2.1-6.2.5. Figure 6-1 is a screenshot of how the parameters are input into SimCLIM.

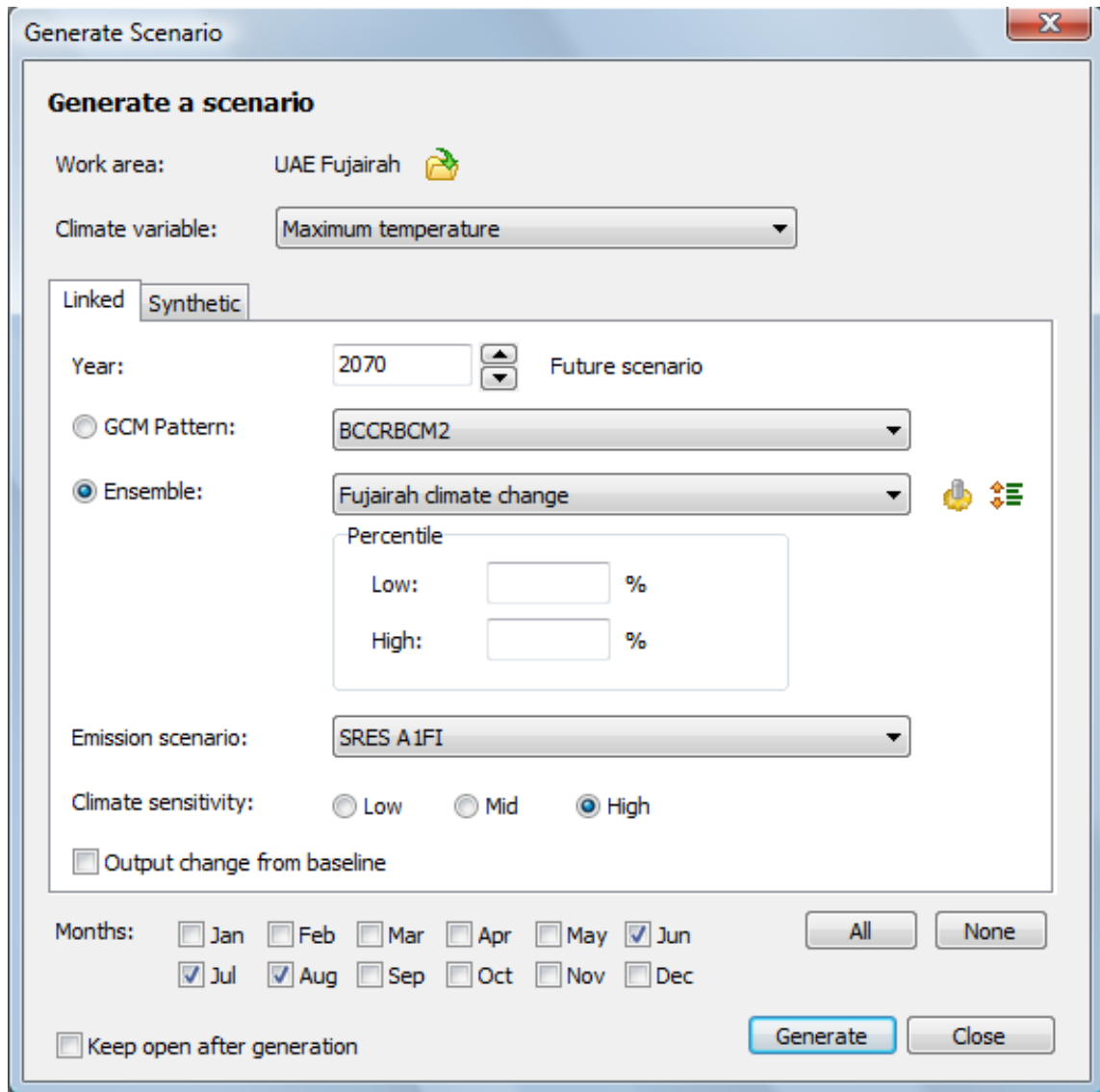


Figure 6-1 Screenshot showing SimCLIM interface and parameter specification

SimCLIM enables the user to project future climate selecting from models, scenarios and parameters that are defined and produced by the IPCC (Warrick et al. 2009). Using all possible combinations of these inputs would give rise to a very large set of results. The main objective of this research was to assess the potential impacts of climate change effects on

tourism resources in Fujairah; it was not feasible to comprehensively analyse how different models make different projections for future climatic changes. Therefore only a limited set of models and parameters was used during the simulations described in this chapter, with the focus on the more extreme possibilities. The model parameters required to provide projections of climate change are detailed next.

6.2.1 Emission Scenario

From the IPCC Special Report on Emissions Scenarios (SRES), the A1FI (fossil fuel-intensive) emission scenario (see section 2.4.1) was selected for this research because it most closely matches the emissions path that the world is following (comparing emissions paths with observations since 1990). This scenario allows for the highest emission of all SRES scenarios and describes a future world with (i) very fast economic growth, (ii) a global population that peaks mid-century (2050) and declines thereafter and (iii) the rapid introduction of new and more efficient technologies – events that possess a high probability of occurrence.

6.2.2 Climate Sensitivity

In order to deal with the uncertainty of how the climate system responds to an increase in CO₂, IPCC defined three levels of climate sensitivity: *low*, *medium* and *high*. These sensitivities describe how a doubling of atmospheric CO₂ increases the global mean temperature. These increases are based on runs from multiple GCMs (see section 6.2.3) in relation to the production of AR4. They correspond to a 95% uncertainty interval from these model runs. The findings ranged from 2.0°C (*low*) through 3.0°C (*medium*) to 4.5°C (*high*) (an upward shift from AR3 which used 1.5, 3.0 and 4.0); for more details see the table in Appendix A.

For the Fujairah projections the *high* sensitivity was selected, representing the worst case, in order to identify the maximum potential effects and thus the maximum impacts (important to consider from a precautionary approach) on tourism resources. This sensitivity was chosen to allow for better preparedness from a management perspective.

6.2.3 Global Climate Model

As described in section 2.4.7, using ensembles (sets) of GCMs is considered the best approach for climate projections and increases the level of confidence in the results. SimCLIM includes

all the GCM models available from the IPCC (see Appendix B for the complete list of GCM models). For the Fujairah projections, all available GCM results for a particular variable were used in an ensemble (Table 6-1) in order to achieve maximum accuracy and confidence.

Table 6-1 GCM Patterns used in the projection of climate change effects

Effect	No. of patterns used	Type	Justification
Air Temperature (mean, max and extremes)	21	Local (Fujairah)	The downscaled local GCM patterns for Fujairah are available from CLIMsystems Ltd (the creator of SimCLIM and a specialist company in this domain)
Precipitation	21		
Sea level rise	13	Global	No local patterns for Fujairah were available for Wind and Water Balance (as this requires solar data) No methodology exists for downscaling SLR, Extreme Precipitation and SST (because high resolution observations are not available). Thus relevant global patterns were used
Wind	19		
Water Balance	21		
Extreme values of precipitation (droughts and flash flooding)	12		
Sea surface temperature	21		

The global resolution is based on the resolution of the GCMs, 0.5° x 0.5° (which roughly corresponds to 50km x 50km: 40,000km around the equator over 360° means about 100km per degree, and less at higher latitudes). The local resolution is the result of choices made during the downscaling process: computational restrictions (higher resolution means more rows/columns, thus more cells, thus more memory and slower calculations), digital elevation information (which guides the downscaling process: higher elevations are cooler and impact precipitation patterns), and available local observations. For Fujairah the choices correspond to roughly 1km x 1km.

6.2.4 Baseline year

The IPCC-recommended baseline year 1990 was used. For climate variables (which represent ‘average weather’), the baseline is the average over the 30-year period from 1961-1990.

6.2.5 Time horizon

It was necessary to balance the increasing uncertainty of projecting climate change into the future with the fact that climate change is a slow process that only shows significant changes after a longer period. For this research the time horizon was set at 2070.

In addition, the year 2030 was chosen as a second time horizon for projection extreme events. This is because initial analysis of the extreme events under climate change showed that these are changing faster than average weather.

For the remainder of this chapter, a short form notation of models and parameters is used. For example, “*A1FI-high, 21-GCM ensemble-local, 2070*” means:

- Emission scenario: A1FI
- Climate sensitivity: high
- 21-GCM: an ensemble of 21 GCMs
- local/global: data specific to Fujairah or global data
- Projected year: 2070

6.3 Results

The SimCLIM results obtained from the projections using the above-mentioned models and parameters are presented below for each of the climate change effects.

6.3.1 Projections for Air Temperature

With respect to air temperature, the following were investigated using the models and parameters stated in Table 6-1:

- (a) The annual average mean air temperature (daily mean temperature, averaged over the year)
- (b) The annual average maximum air temperature (daily maximum temperature, averaged over the year)
- (c) Extreme high temperature (heat waves)
- (d) Shift of seasons.

(a) Projections for average air temperature

Figure 6-2 shows the increase in the projected annual average global mean air temperature between the baseline year 1990 and the year 2100 under different climate sensitivities. Figure 6-3 shows the projected annual average mean air temperature for Fujairah from 1990 to 2070 using SimCLIM (A1FI-high, 21-GCM ensemble-local). Figure 6-4 shows a spatial overview of the average temperatures in Fujairah at the baseline year (1990) and projected for 2070.

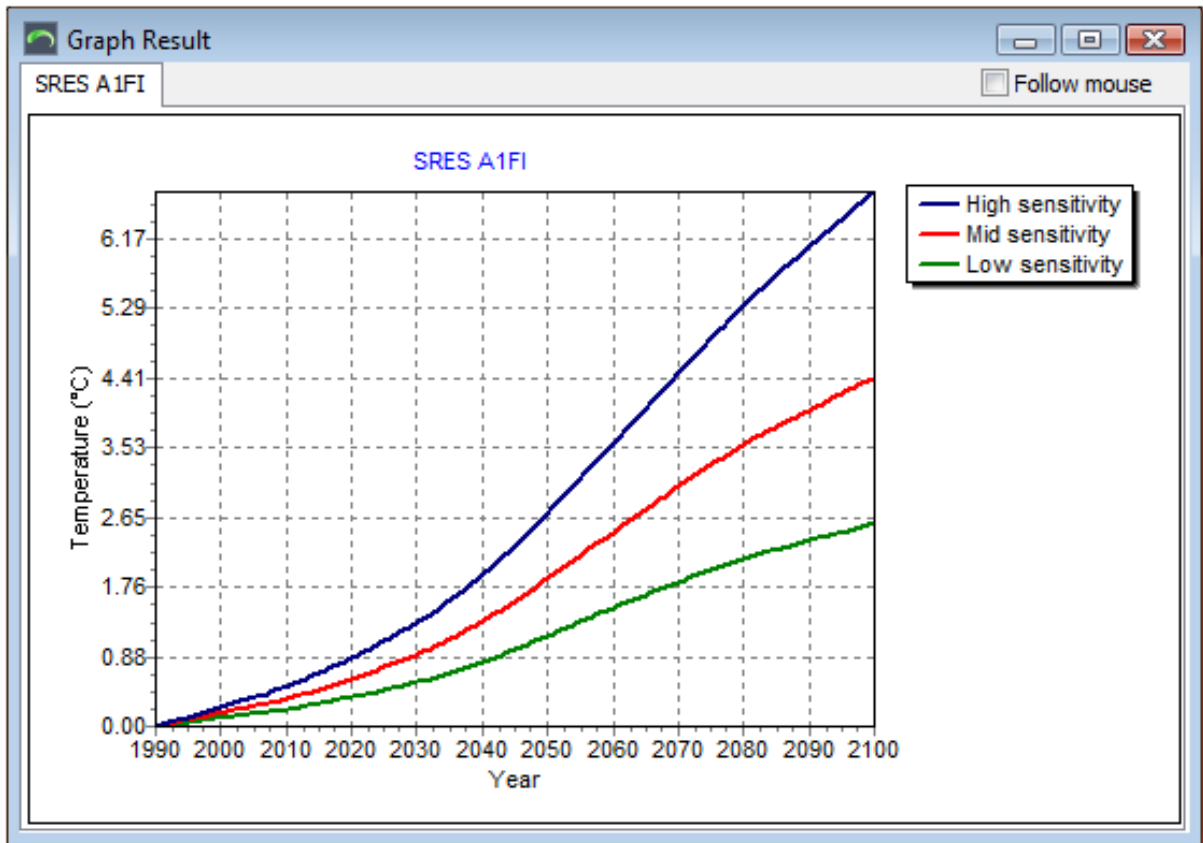


Figure 6-2 Projected change in global annual average mean air temperature (A1FI)

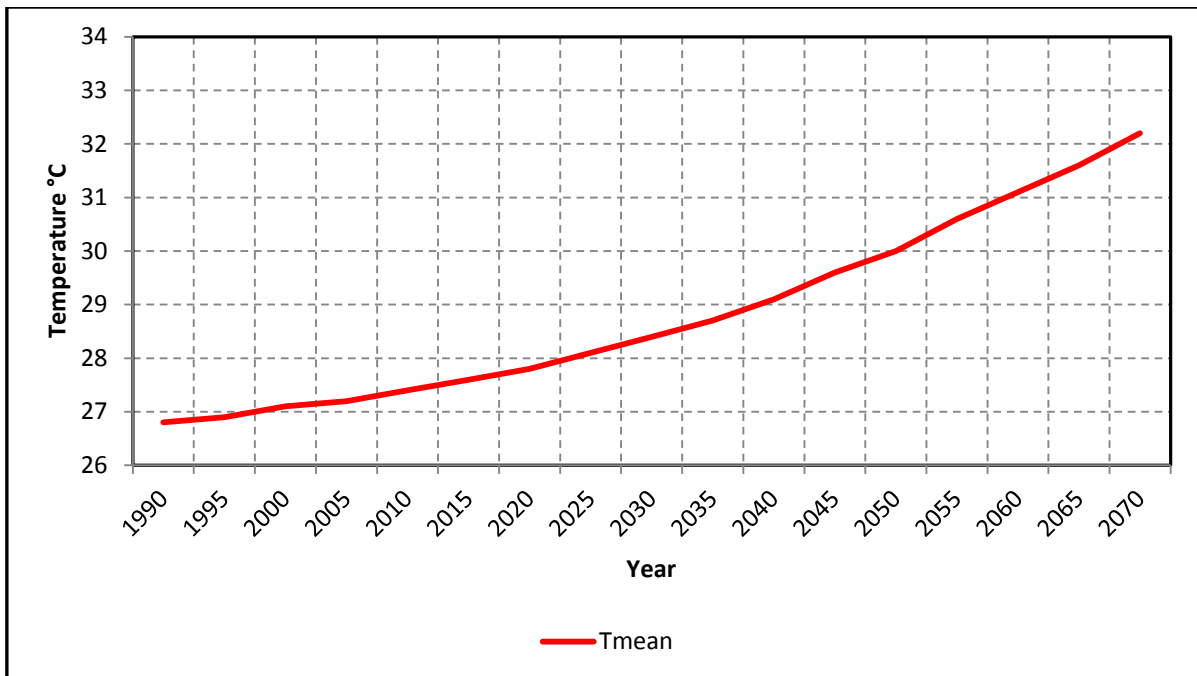


Figure 6-3 Projected annual average mean air temperature for Fujairah, 1990 - 2070 (A1FI-high, 21-GCM ensemble-local)

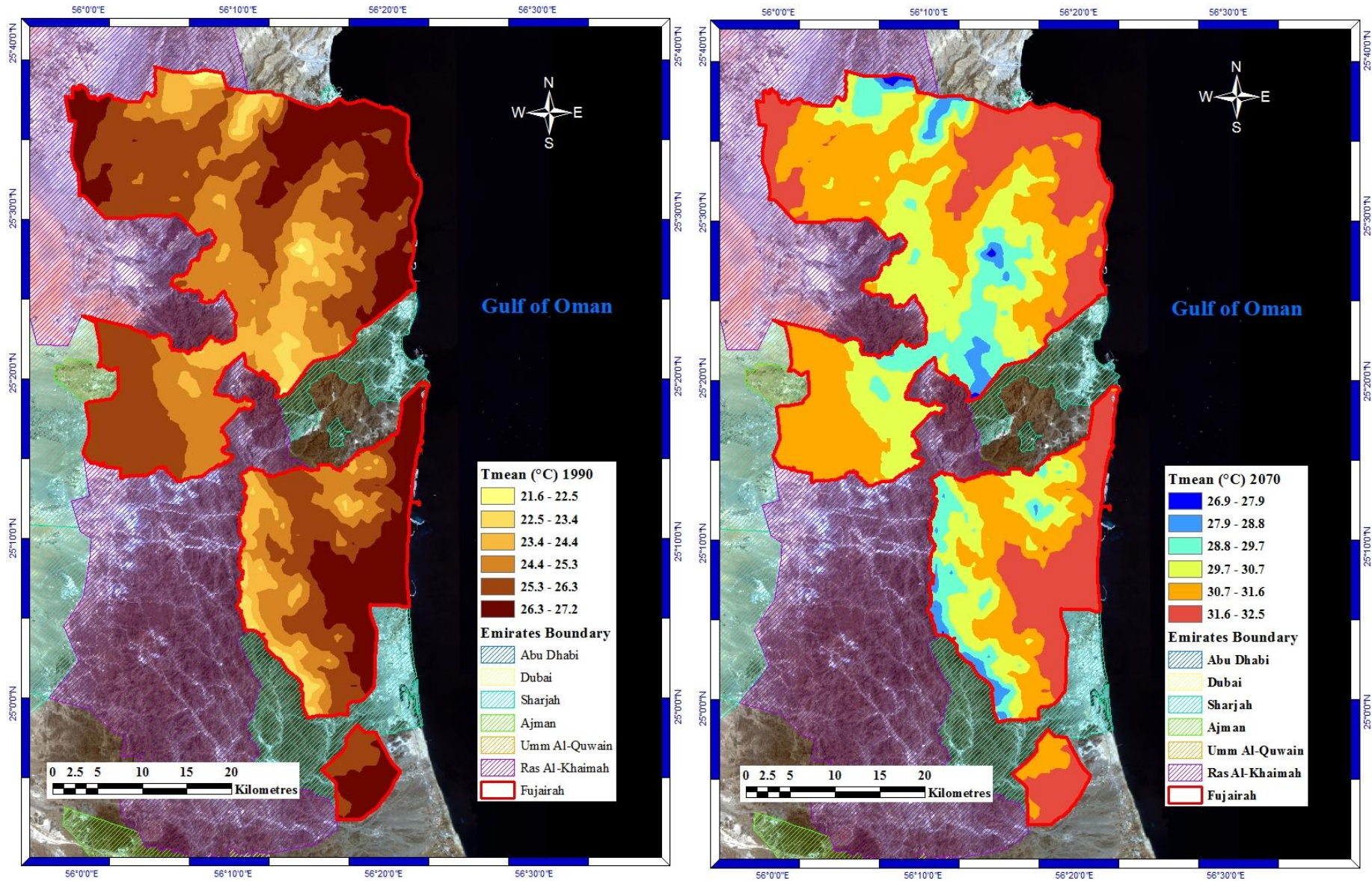


Figure 6-4 Baseline and projected spatial distribution of annual average mean temperature in Fujairah (AIFI-high, 21-GCM ensemble-local)

Figure 6-4 shows the projected increase in the average air temperature from the baseline (1990) to 2070. These increases exceed 5°C and are higher than the projected global (over all land and oceans) mean increase of 4.48°C. The majority of Fujairah’s natural tourism resources are located in the coastal area, at the waterfalls and in the mountains. Both the baseline and the projected annual average mean temperature values for these regions were generated with SimCLIM and are given in Table 6-2. Note the spatial variation in temperature.

Table 6-2 Change in Annual Average Mean Air Temperature (°C) in Fujairah from SimCLIM Simulation

Region of Resource	Position Long/ Lat (degrees)	Baseline (°C)	2070 (°C)	Difference (°C)
Coast	N 56.34 E 25.59	26.4	31.8	5.4
Waterfall	N 56.26 E 25.39	25.2	30.6	5.4
Masafi (Mountain Area)	N 56.11 E 25.29	24.9	30.4	5.5

(b) Projections for maximum temperature

For projection of the maximum temperature, the average maximum (daily maximum averaged on a monthly basis) over June, July and August (summer) was selected. This period was selected to show tourism resources management how high the maximum temperature is expected to be in this area. Figure 6-5 shows a spatial overview of the maximum temperatures in Fujairah averaged over these months at the baseline year and as projected.

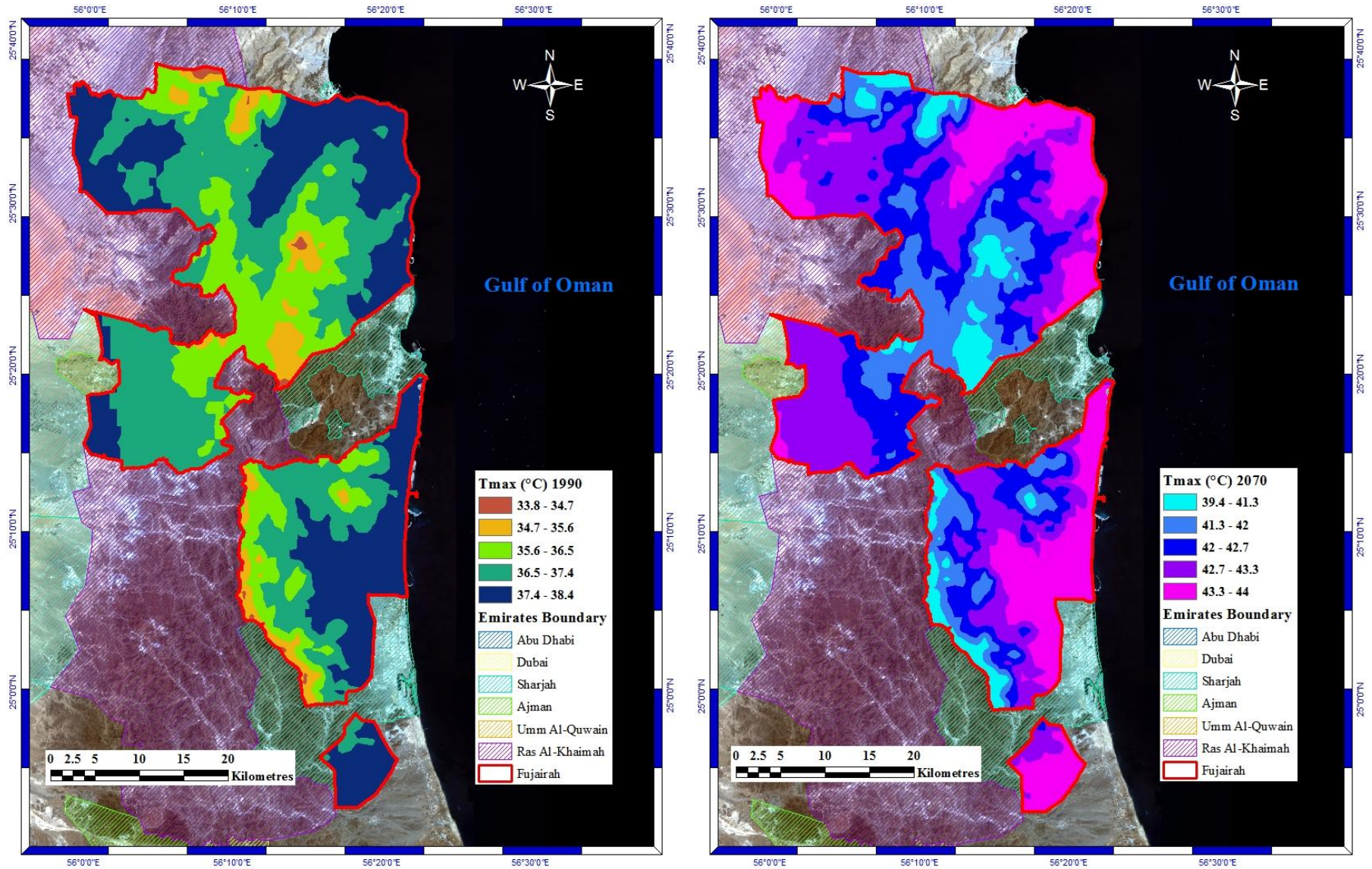


Figure 6-5 Spatial distribution of maximum air temperature in Fujairah (averaged over June-August) for the baseline and as projected (AIFI-high, 21-GCM ensemble-local)

Figure 6-5 shows the increase in the maximum summer temperature by 2070 from the baseline for Fujairah being more than 5°C. The baseline and projected maximum temperature values for the coastal region, at the waterfalls and in the mountains areas of Fujairah are given in Table 6-3.

Table 6-3 Change in Maximum Temperature (°C) in Fujairah averaged over June-August

Region of Resource	Position Long/ Lat (degree)	Baseline (°C)	2070 (°C)	Difference (°C)
Coast	N 56.34 E 25.59	37.6	43.1	5.5
Waterfall	N 56.26 E 25.39	36.7	42.3	5.6
Masafi (Mountain Area)	N 56.11 E 25.29	36.7	42.3	5.6

(c) Projections for extreme high temperatures (heatwaves)

A heatwave is a series of days with abnormally high temperature (Qipu, Ziwang and Xiaolan 2000). There is no international standard definition of a heatwave. The definition of a heatwave depends on the location. As an example, the Dutch Meteorological Institute (KNMI) defines a heatwave as a period of at least five days have a maximum temperature above 25°C of which at least three days with maximum temperature above 30°C (Hales, Edwards and Kovats 2003). This description of heatwaves is obviously inadequate for Fujairah, where daily temperature regularly exceed 40°C, and can exceed 50°C for several consecutive days. Therefore, a different number of days and maximum temperature should be used to define a heatwave in Fujairah. In this research, a heatwave in Fujairah was defined as a period of seven days for which the average maximum temperature is over 45°C.

Data collected between 1995 and 2011 at the Fujairah airport was used to analyse heatwaves. First the long-term normal was calculated for daily recorded temperatures from 1995 to 2011. The long-term normal for a specific day (e.g., the 6th of June) is the average value over all days (all 6ths of June) in the time series, and coincides with the definition of climate (“average weather). The long-term normal was used to identify the period in the year with the highest temperatures as well as their value, starting in May, 44-45°C.

Figure 6-6 shows the extreme high maximum temperature distribution for Fujairah based on observations from 1995 to 2011. An average maximum temperature of 45.5°C over a 7-day period occurs on average every 20 years, and 46.7°C every 100 years.

Under the A1FI climate change scenario, Figure 6-6 shows that by 2030 the projected recurrence frequency of a maximum daily temperature of 46.7°C (averaged over a seven day period), will be once every 14.1 years, compared to once every 100 years currently.

To project future extreme high temperatures, SimCLIM uses the perturbation method. This involves applying the monthly change factors for future climate scenarios to the historic observed daily data to form a new time series which is analysed for extreme events. A detailed explanation of how SimCLIM calculates this is provided in Appendix C.

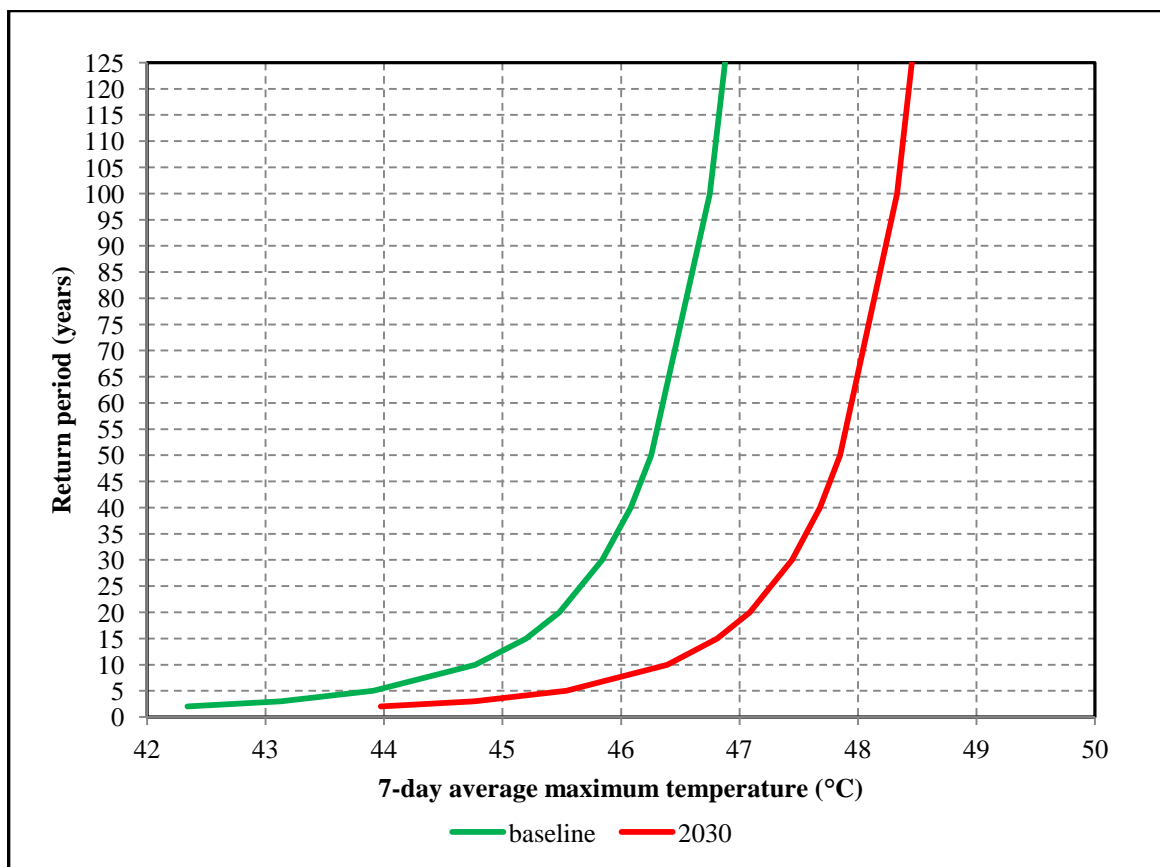


Figure 6-6 Extreme high maximum temperature (averaged over 7 days) for Fujairah, baseline and 2030 projections (A1FI-high, 21-GCM ensemble-local)

From a tourism resource management perspective, it is important to know that a notable increase in the frequency of heat-waves is projected for Fujairah. The impacts of this on tourism resources are discussed in detail in the next chapter. In addition, this could place extra burden on other government resources including hospitals, energy requirements (e.g. increased air conditioning) on which tourists rely. This is outside the scope of this research.

(d) Shift of seasons

If temperatures increase due to climate change, temperature thresholds for ecosystems could be reached at different times in the year. In order to model the shift in seasons, two variables need to be analysed:

- Distribution of maximum temperature over the year
- Distribution of minimum temperature over the year.

The shifts in the distribution of maximum and minimum temperatures over the year by 2070 were derived by perturbing observed data from the Fujairah International Airport for climate change.

Figure 6-7 shows the effects of climate change (A1FI-high, 21-GCM ensemble-local, 2070) on the long-term normal maximum (TMax) and minimum temperatures (TMin) at Fujairah Airport. The observed data used were from the period 1995-2011.

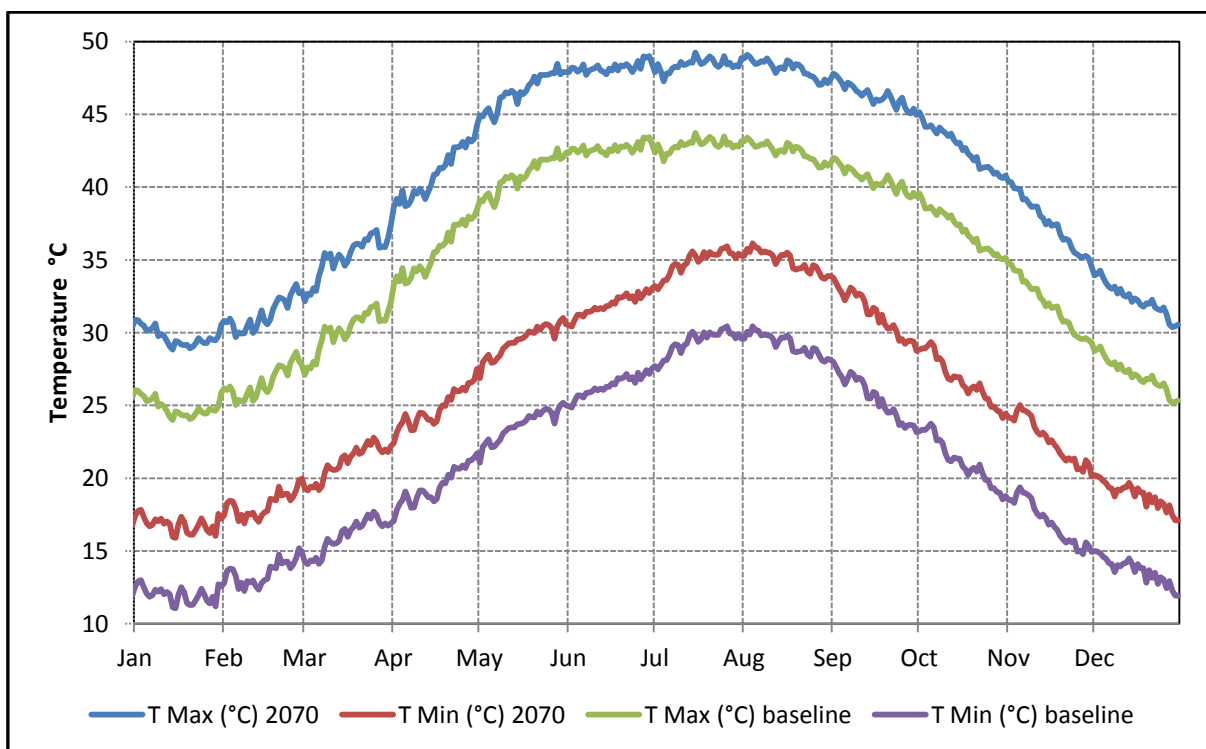


Figure 6-7 Distribution of minimum and maximum temperatures at Fujairah Airport projected for 2070 (A1FI-high, 21-GCM ensemble-local) compared to present (baseline)

Summer in the UAE is not officially defined by date or temperature. According to the Dubai Travel Agency, summer is the period when maximum temperature ranges between 36°C and 48°C from May to September (Beecher 2010). However by using Beecher's definition of the

summer season as the period when the maximum temperature exceeds 36°C, then currently summer in Fujairah extends from the 15th of April to the 20th of October. Figure 6-7 shows that by the year 2070 summer extends from the 15th of March to the 20th of November. Similarly, if the winter season is defined as the period when the maximum temperature is below 30°C, then at present the winter extends from the 20th November to the 15th of March, while by the year 2070 it will only extend from the 1st of January to the 31st of January.

This analysis demonstrates the effect of a change in the distribution of minimum and maximum temperature on changing the seasons, leading to longer summer periods and shorter winter periods. This change in the seasons will have both direct and indirect impacts on spatially diverse tourism resources such as agricultural crops (a tourism resource and marine life. These impacts will be discussed in the next chapter.

6.3.2 Precipitation-related projections

With respect to the climate change projections for precipitation in Fujairah, the following variables were investigated:

- (a) Total annual precipitation
- (b) The water balance (difference between precipitation and potential evapotranspiration)
- (c) Extreme high precipitation (flash-floods)
- (d) Extreme low precipitation (droughts).

The projections for (a), (b) and (c) were carried out using the models and parameters stated earlier (emission scenario, climate sensitivity, local or global data, number of GCMs used and projected year). For (d) no direct projections were possible due to scarcity of historic rainfall data over an extended period. Projections were replaced by analysis of the current situation and speculation on what might happen under different climate change scenarios.

(a) Total annual precipitation for Fujairah

As stated in chapter 4, Fujairah's climate is characterised by very little rainfall (the long-term average is only 130mm/yr). It was also noted that the mountain areas in Fujairah enjoy the highest proportion of rainfall in the UAE, followed by the eastern coastal areas and then the stony plains.

If the modest rainfall that Fujairah experiences reduces under future climatic conditions, less surface and groundwater will be available for both domestic and irrigated agricultural purposes, affecting the tourism industry both directly and indirectly.

Projections of reduced rainfall are demonstrated in the maps shown in Figure 6-8, which were obtained using projections for 2070 carried out in SimCLIM under the modelling conditions 'A1FI-high, 21-GCM ensemble-local'.

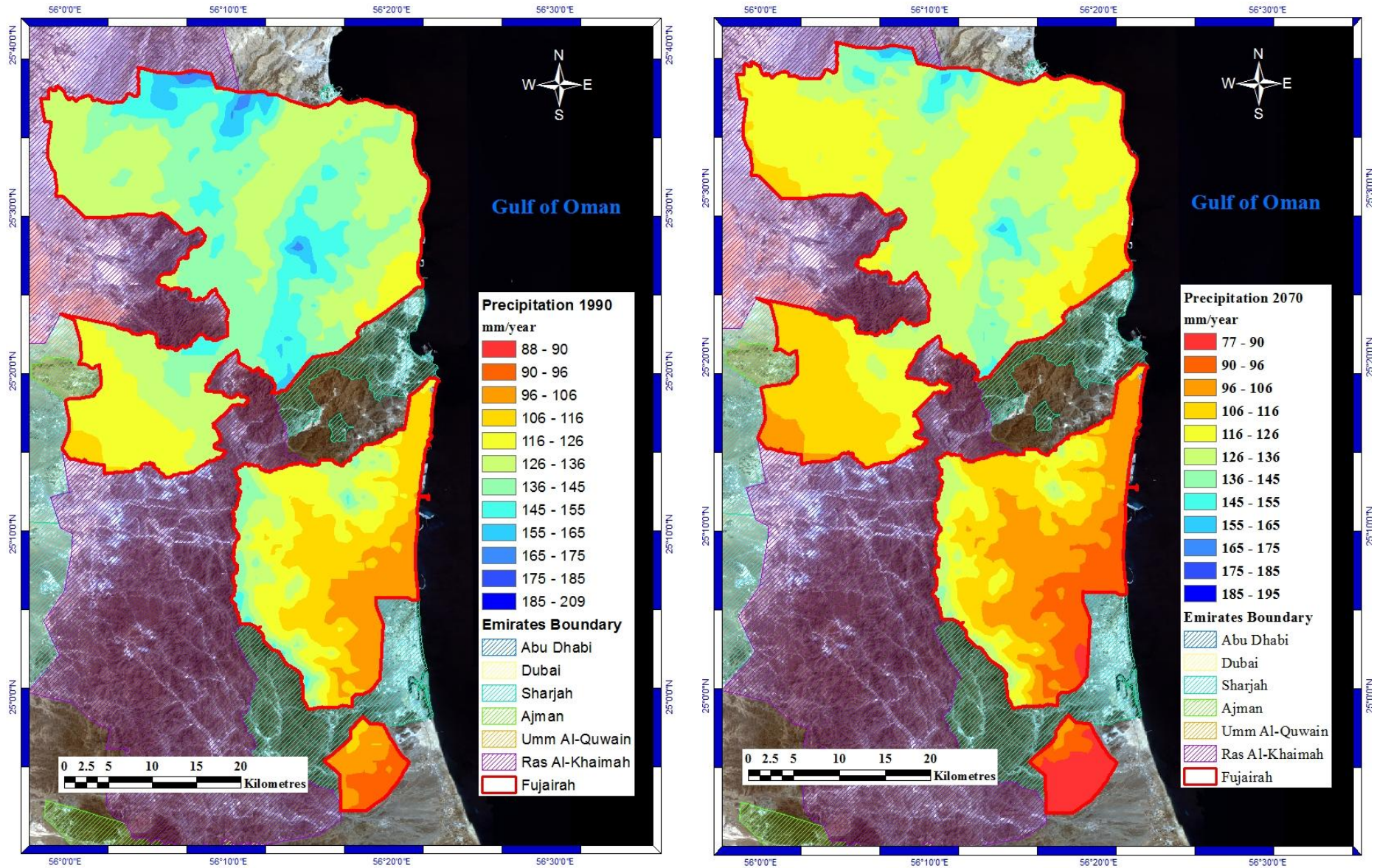


Figure 6-8 Precipitation (mm/year) Profile of Fujairah for 1990 and projected 2070 (A1FI-high, 21-GCM ensemble-local)

Table 6-4 shows how the projected precipitation levels for 2070 at three tourist regions differ from baseline levels. The precipitation levels in these regions may reduce by 9-12 mm/yr by 2070– a result that is of utmost importance to the tourism sector.

Table 6-4 Comparison of precipitation levels for three regions associated with tourism resources in Fujairah (A1FI-high, 21-GCM ensemble)

Region of Resource	Position Long/ Lat	Precipitation (mm/yr) at baseline	Precipitation (mm/yr) 2070	Difference (mm/yr)
Coast	56.34 25.59	133	124	- 9
Waterfall	56.26 25.39	134	123	- 11
Masafi (Mountain Area)	56.11 25.29	130	118	- 12

By comparing the baseline values with the projected values for the whole of Fujairah (see Figure 6-9), it can be seen that precipitation is likely to reduce between 5.8% and 11.3% by the year 2070.

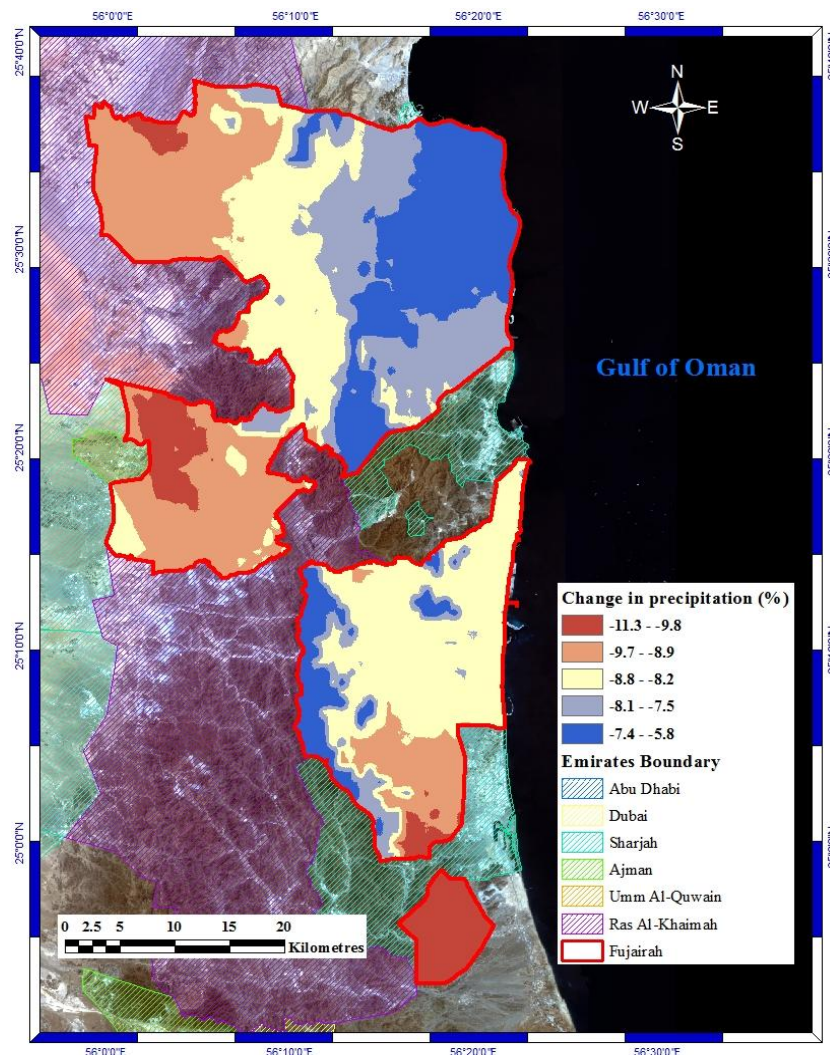


Figure 6-9 Percentage decrease in annual precipitation for Fujairah: baseline vs. 2070

(b) Projections for the water balance

An analysis of water availability is needed for tourism resources such as waterfalls and wadis. Evapotranspiration, which is dependent on temperature and solar radiation, must be considered as well as precipitation.

Because no solar radiation patterns were available for Fujairah, global patterns had to be used. For the baseline, the spatial variation of potential evapotranspiration (PET) is shown in Figure 6-10

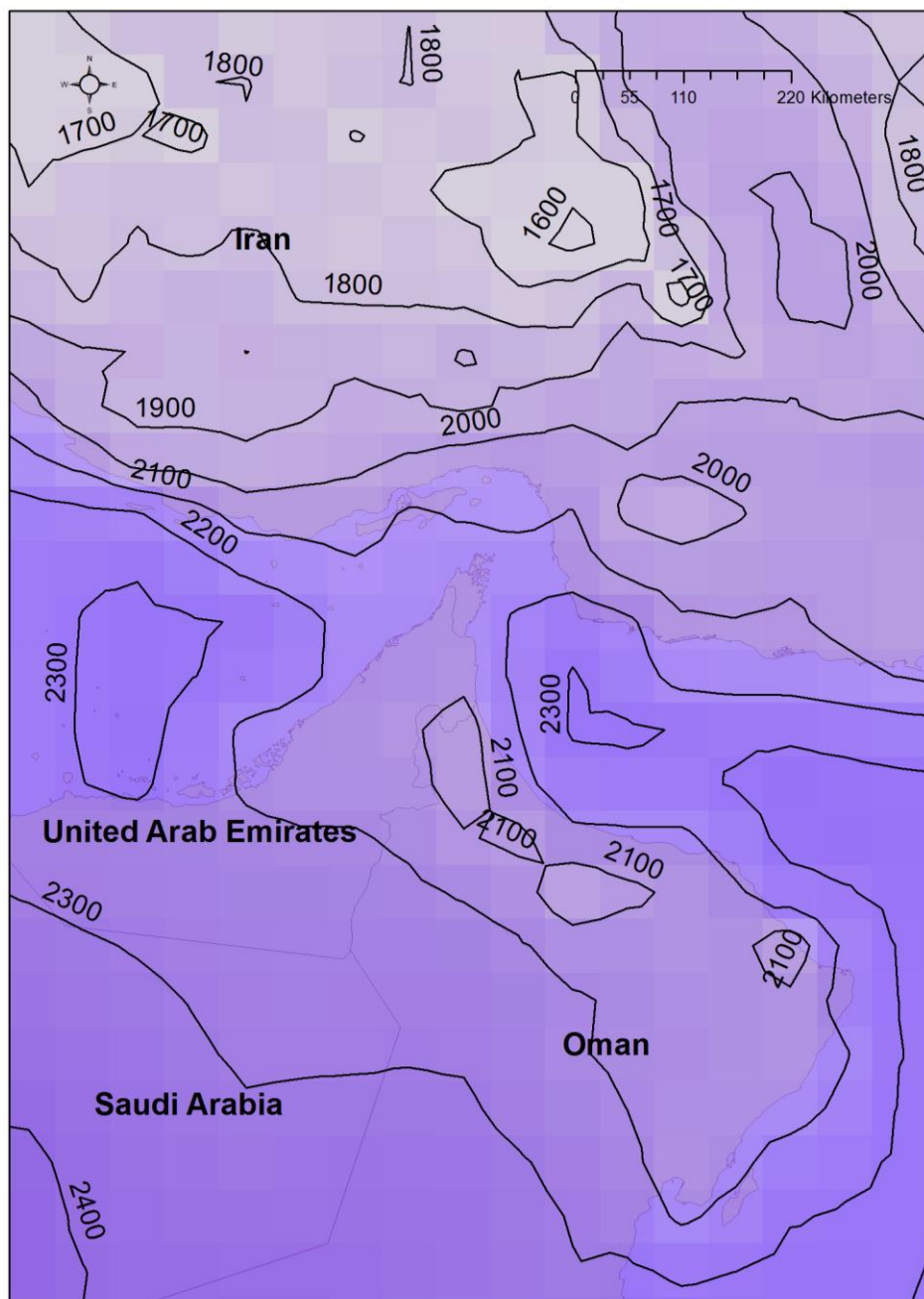


Figure 6-10 Spatial distribution of potential evapotranspiration for the Middle East region in mm in 1990

From Figure 6-10 it can be seen that PET (the amount of water that could potentially evaporate from ambient temperature and solar radiation) is strongly negative in the whole region, including Fujairah, underlining its arid character. For Fujairah, the evapotranspiration demand implies a yearly shortage of approximately 2000mm of rainfall. Figure 6-11 shows the change in PET between the baseline year of 1990 and the projected year 2070. The figure illustrates an additional increase in water shortage by the year 2070 (under the condition A1FI-high 21-GCM ensemble) compared to baseline shown in Figure 6-10. This additional shortage is due to an increase in temperature under climate change.

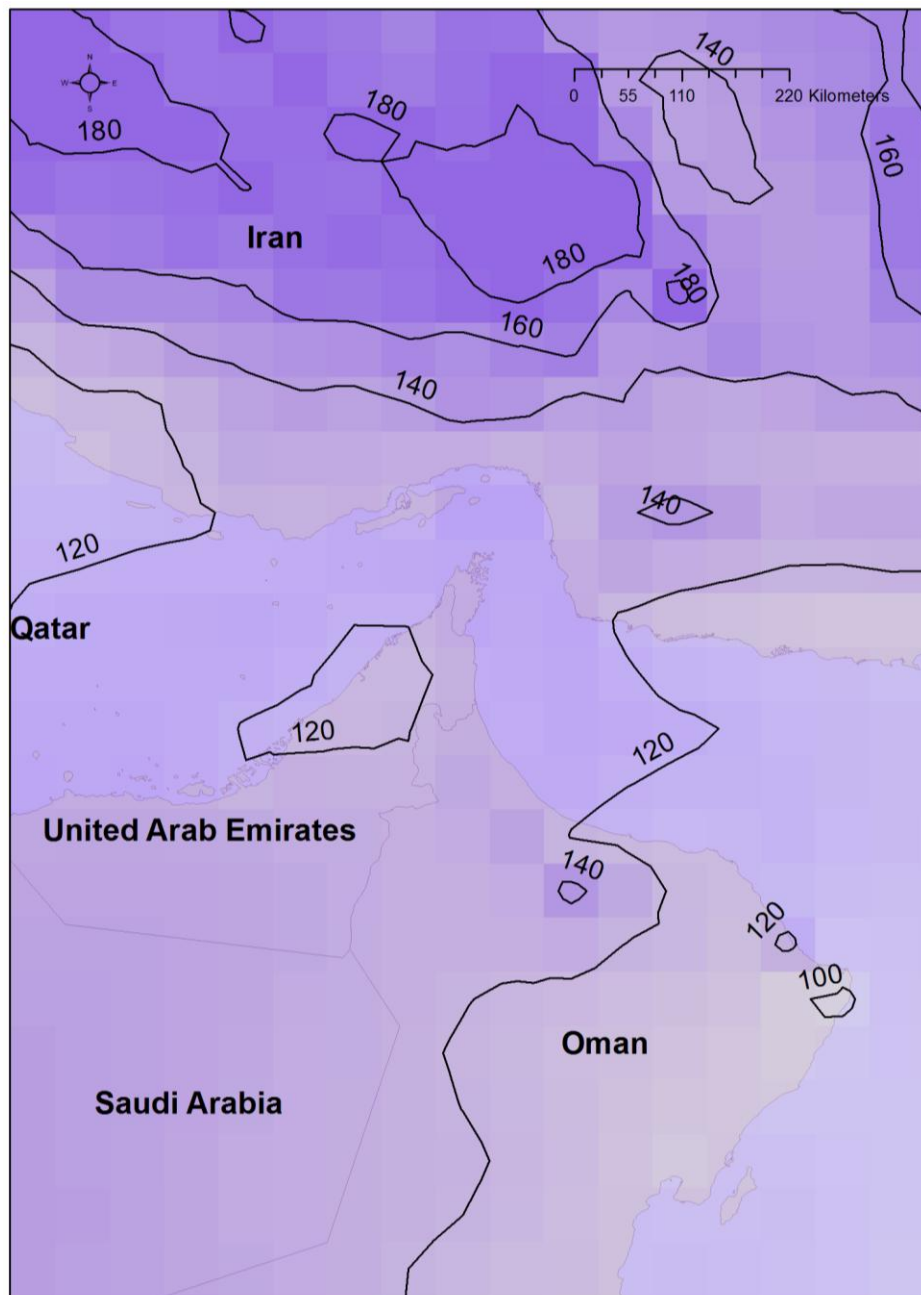


Figure 6-11 Change in the PET of the Middle East region 1990-2070 under A1FI-high, 21-GCM ensemble-global

Water availability from precipitation is predicted to decrease in Fujairah by 5.8-11.3% by 2070 (A1FI-high, 21-GCM ensemble-local). The change in PET is shown as about 136 mm in Figure 6-11, adding to the 2000 mm deficit shown in Figure 6-10. Thus the PET increases by 7% under that same A1FI-high scenario (i.e., 136 divided by 2000). The combination of the predicted reduction in precipitation (5.8-11.3%) and increased evapotranspiration (7%) gives an estimate of 13-18% for the total decrease in water available for the wadis and waterfalls. This change has considerable implications for specific tourism resources in Fujairah.

(c) Flash flooding (extreme high precipitation)

Climate change projections for Fujairah show a decrease in annual precipitation. Therefore one could expect that extreme rainfall events (which can cause flash floods) will also decrease (in intensity and/or frequency). However, worldwide events have shown that even when total annual precipitation decreases, there could still be more extreme rainfall events; that is, it does rain less, but when it rains, it rains harder (Alpert et al. 2004).

SimCLIM uses an approach based on a distribution change of high-rainfall events taken from GCMs with daily outputs. Twelve GCMs are available in SimCLIM for ensemble projections using this method. Figure 6-12 shows the distribution of extreme rainfall events (the highest rainfall event in a given year) both for the baseline and for 2030 (A1FI-high, 12-GCM ensemble-global).

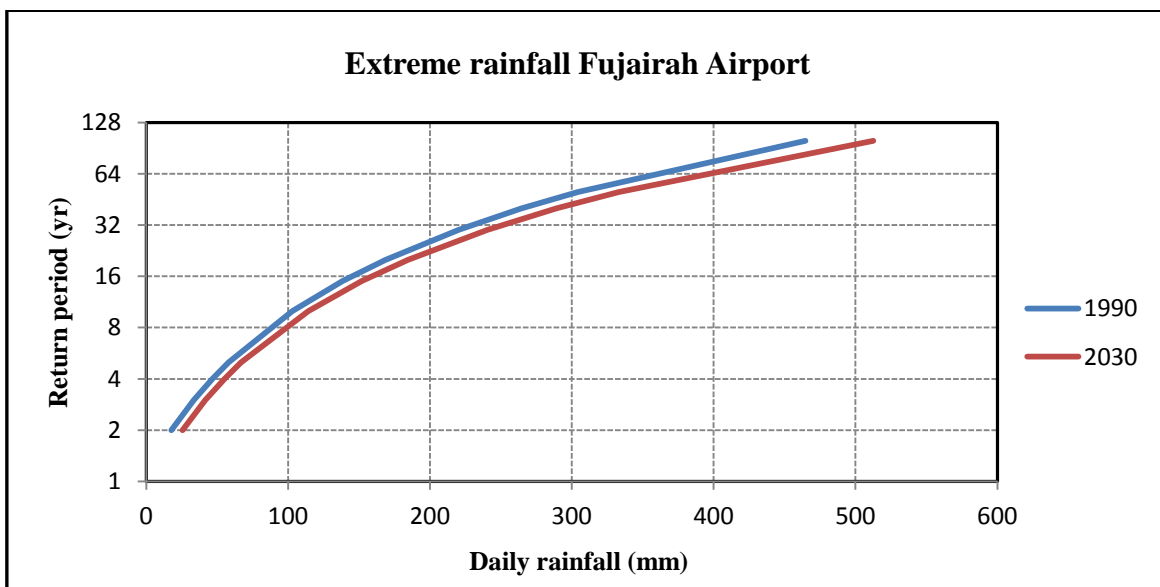


Figure 6-12 Shift in the distribution of extreme rainfall events, 1990-2030, Fujairah airport (A1FI-high, 12-GCM ensemble-global)

Figure 6-12 shows that: a) for a given extreme event (e.g., 100 mm of rainfall in one day), the Return Period (RP) becomes shorter (downward shift of the curve) and the event becomes

more frequent (e.g. from 10 years to eight years), and b) for a given RP (e.g., 16 years), the extreme event becomes more extreme (e.g., from 140 to 170mm of rain in one day) (curve shifts to the right).

It should be noted that the length of the observation period upon which these projection were based is short (1995-2011, or just 16 extreme events, one each year). This can result in an over-extrapolation of extreme event values for longer periods. For example, the 1 in 30 year event represents over 200mm of rainfall in one *day* (while the long term averaged *annual* rainfall for Fujairah is just 130mm).

(d) Droughts (extreme low precipitation events)

Droughts are prolonged periods of abnormally low precipitation (Zha et al. 2010). A drought analysis examines the number of consecutive days without rain. A realistic drought analysis requires continuous historic rainfall data over an extended period (Mishra and Singh 2010). However, many rainfall datasets contain missing data. A problem in the measurements taken at Fujairah Airport is that no distinction was made between ‘no rain was measured’ and ‘no measurement was taken’. The former means ‘0 mm of rain’, while the latter is probably due to equipment problems. As the precipitation time series data for Fujairah contains long periods of missing data (as shown in Figure 6-13(a), up to one year), information from the nearest alternative location, *Ras al Khaimah* Airport (Figure 6-13(b)), was used instead. It contained almost 10 years of data (still less than ideal for modelling).

Using SimCLIM the ‘accumulated dry days’ can be identified and plotted over time as shown in Figure 6-13 (b). The count of dry days increases as long as there is no rain, with a reset to zero with even the slightest amount. The peaks show the length of a rainless period in days.

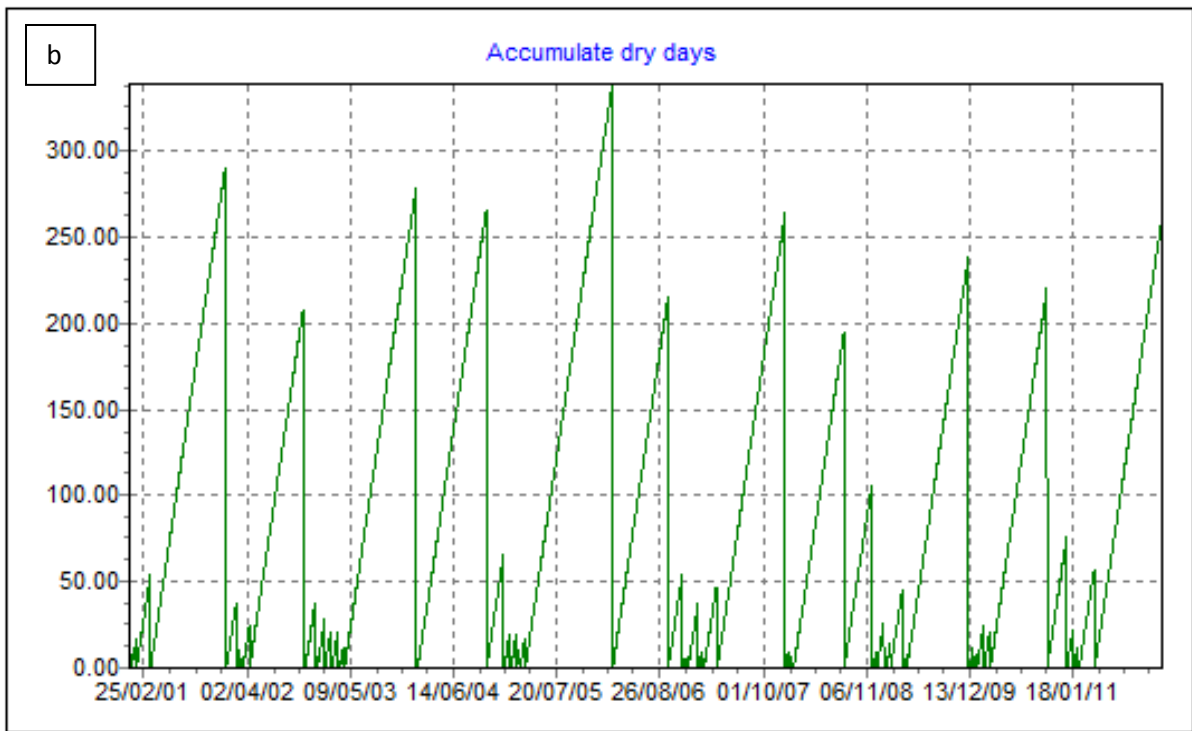
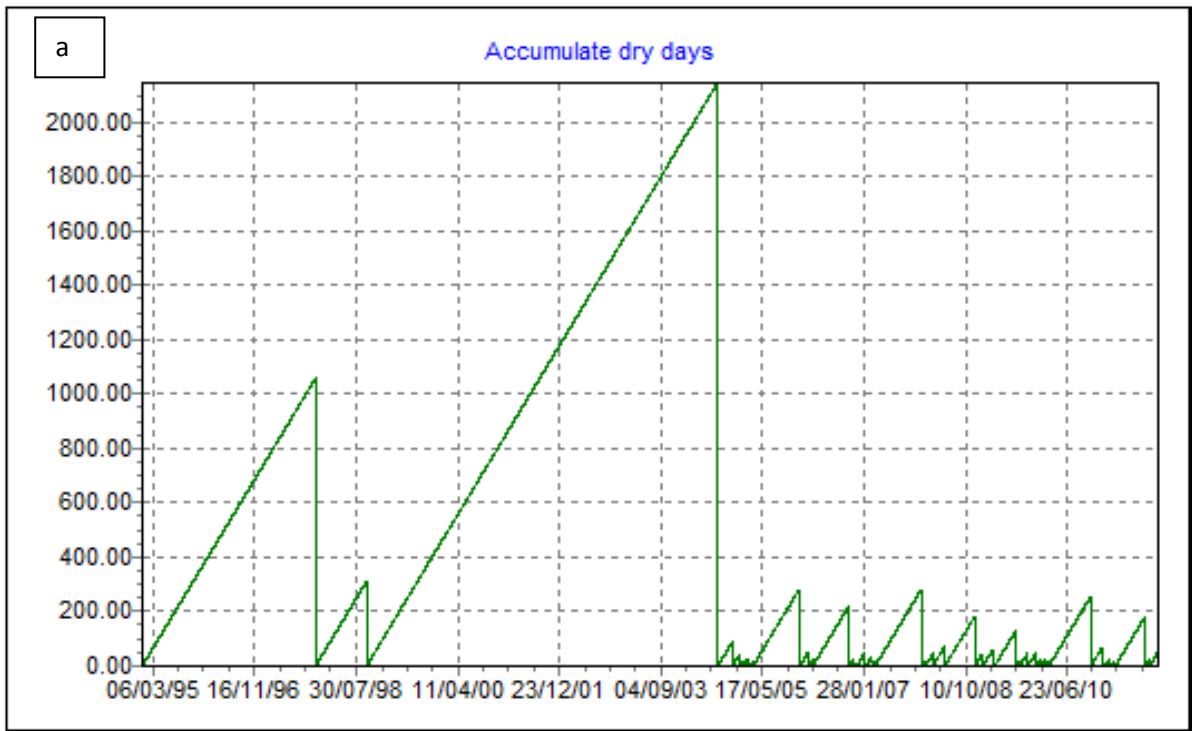


Figure 6-13 Accumulation of consecutive dry days for (a) Fujairah Airport (b) Ras al Khaimah Airport

The peaks can be considered extreme events and were analysed using SimCLIM as shown in Figure 6-14.

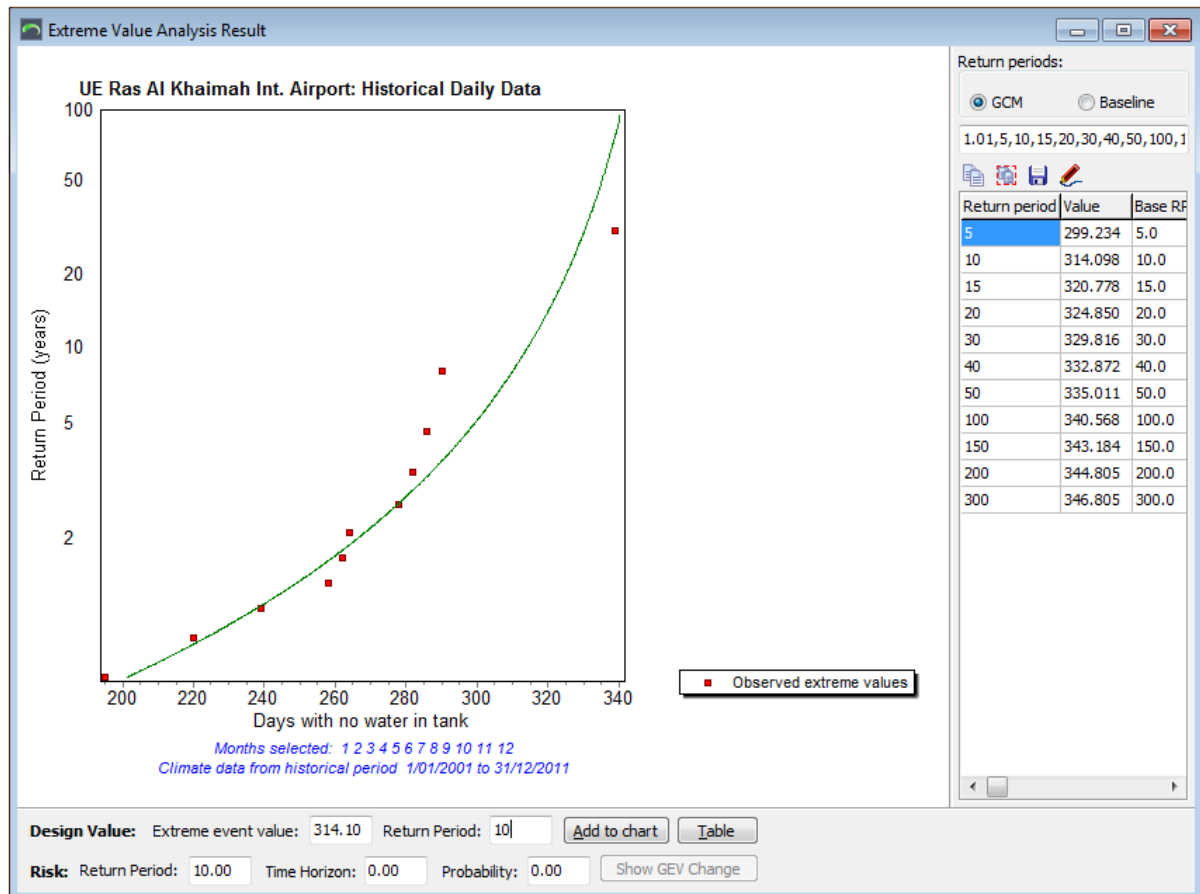


Figure 6-14 Length of the longest period without rain in a year, versus the return period of that event, Ras al Khaimah

Under climate change, Fujairah may experience a decrease in total annual rainfall of up to 11.3% (9-12mm, A1FI-high, 2070, 21-GCM ensemble), as mentioned in section 6.3.2. Although this might well result in a lengthening of dry periods, currently there is no method capable of projecting drought lengths. This is because GCMs are unable to reliably distribute rainfall over a month (although the ‘totals’ provided by these models are acceptable, the distribution of daily variations provided are not). In fact, to properly determine the length of future drought periods, the GCM’s would be required to model daily rainfall properly (as the fact that it rains or not determines the length of the drought period). Current weather models (short-term) and seasonal models (mid-term) already have great difficulties with modelling rainfall, let alone the long-term models. It is also very difficult to calibrate models without enforcing predetermined dry/wet patterns.

The Fujairah region is already experiencing significant droughts: some reservoirs are becoming dry (see Figure 6-15) and certain agricultural products such as palm tree plantations

are being severely affected (see Figure 6-16). The accurate projection of future droughts is critical for the Emirate of Fujairah, including for the effects of drought on tourism.



Figure 6-15 IKONOS image showing reservoirs and wadis affected by drought in Fujairah in 2010



Figure 6-16 Palm tree plantations severely affected by drought – photo taken in January 2013

6.3.3 Projection of sea surface temperatures

Sea Surface Temperature (SST) is the temperature of the top layer of the ocean. SST levels are an important aspect of the global climate, and these temperatures are usually documented on a monthly basis for observing slow variations as well as for projection purposes (Rayner et al. 2003). A common application is in seasonal forecasting of precipitation.

It should be noted that the construction of local SST profiles for the ocean around Fujairah requires observations; unfortunately, these data are not available. However, Figure 6-17 (obtained from the 'Global' image in SimCLIM) shows the SST profiles at the 1990 baseline using global data on SST levels. July has the highest (monthly averaged) SST levels around Fujairah and was selected for projection purposes.

The SST baseline and projection for Fujairah (July, 2070, A1FI-high, 21-GCM ensemble) are shown in Figure 6-17.

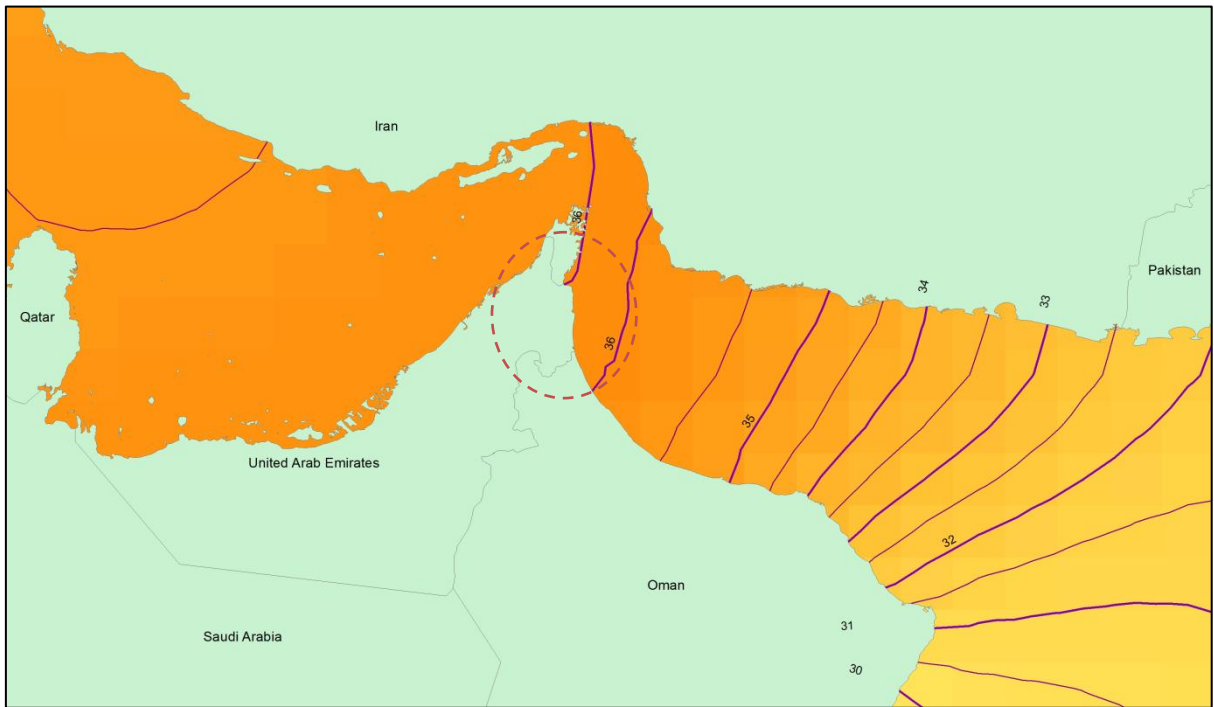
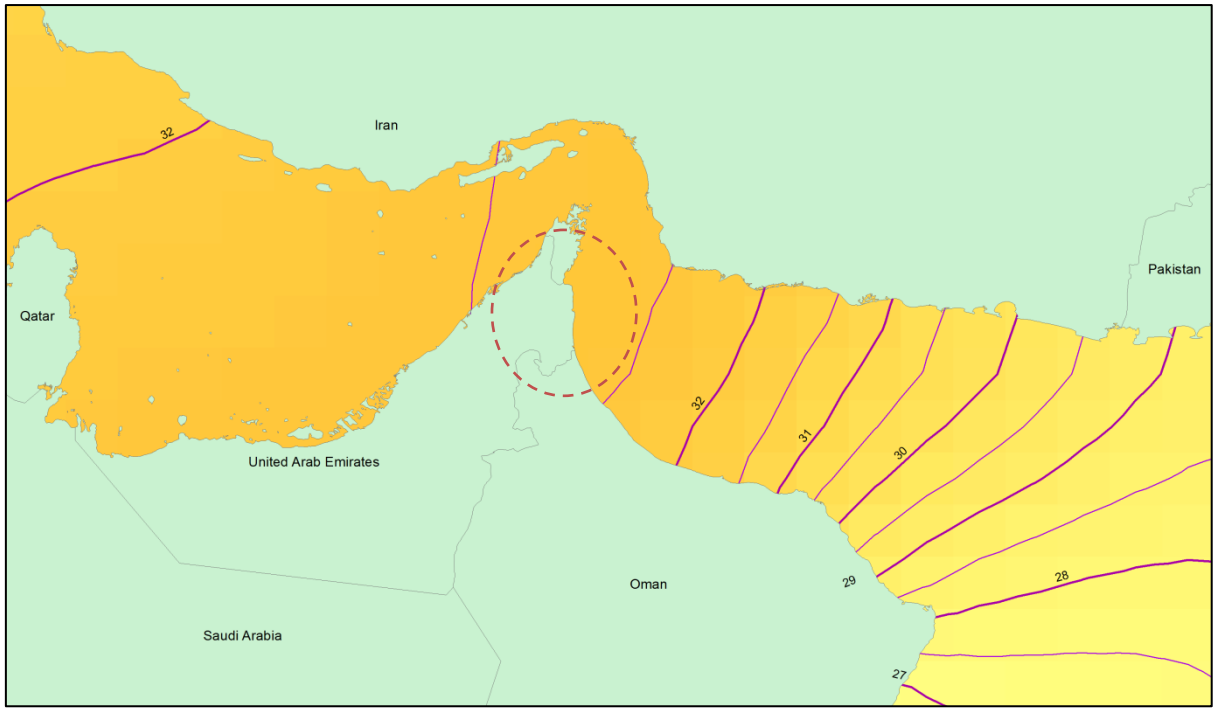


Figure 6-17 Comparison of SST for the Middle East region (Fujairah circled) for the month of July, baseline (top) vs 2070 (below) using A1FI-high, 21-GCM ensemble-global

Figure 6-17 shows that the July SST projection for 2070 exceeds 36°C, compared to 32°C in the baseline year of 1990. As noted earlier, SST powerfully influences the growth and health of coral reefs, so proper monitoring of the coral reefs in this region will be essential. Currently

many corals reefs survive along Fujairah's coastline, coping with the 32°C SST that occurs occasionally. It is very unlikely that the reefs will be able to cope with an SST of 36°C.

Bleaching of coral reefs (an important ecological and tourist resource in Fujairah) is more likely when SSTs exceed 29.5°C. This temperature however does not immediately kill the coral. Although the precise mechanisms are still unclear, other important aspects are involved in coral bleaching, including the length of the exposure (days vs. weeks), the speed of the increase (slowly warming vs. sudden jump in temperatures), reef health (exposure to other stress-factors like acidity, nutrients, sediments), the species of coral, and other external pressures (sediments from sandy beaches).

The results shown in Figure 6-17 emphasise the importance of projecting climate change and taking protective measures for Fujairah's coral reefs as a tourism resource, as change to the coral reefs not only impacts coastal erosion but other tourism resources like marine wildlife and related activities such as diving and fishing. Examples of protective measures include mapping the density of coral reefs and identifying the level of risk from increased SST, increasing awareness about the negative impacts of climate change on coral reefs for all stakeholders including tourists and government, supporting monitoring and research, and minimising negative anthropogenic activity on water quality (e.g., managing the discharge from desalination plants). Other possible protective measures are relieving or removing stress factors like sediments (from artificial beaches), use of explosives to remove parts of the reefs, and stopping the removal of mangroves, which now capture most of the sediments which would otherwise smother the reef.

6.3.4 Ocean acidification

Ocean acidification is the process whereby oceans become more acidic due to the absorption of CO₂ from the atmosphere. About one third of global CO₂ emissions end up in the oceans (Harrould-Kolieb and Savitz 2009). Although oceanic absorption slows down the increase in atmospheric CO₂ (and thus the process of global warming), it has a negative impact on marine ecosystems and on coral reefs in particular by reducing their ability to absorb calcium carbonate (DoneyBalch, et al. 2009; Kleypas and Yates 2009).

Figure 6-18 depicts rising CO₂ levels (from 380ppm in 2005 to 500ppm projected for 2050) that are predicted to increase ocean acidification and place reef systems under severe stress (Cao and Caldeira 2008). For instance, the 380ppm (2005) case shows clearly a bluish colour (3.25, corresponding to marginal to adequate Aragonite saturation levels for absorption by corals) on the Fujairah side of the Gulf (connecting with the Indian Ocean) which shifts to yellow (3.00, lower marginal Aragonite saturation levels) by 2030. Aragonite is a common carbonate mineral.

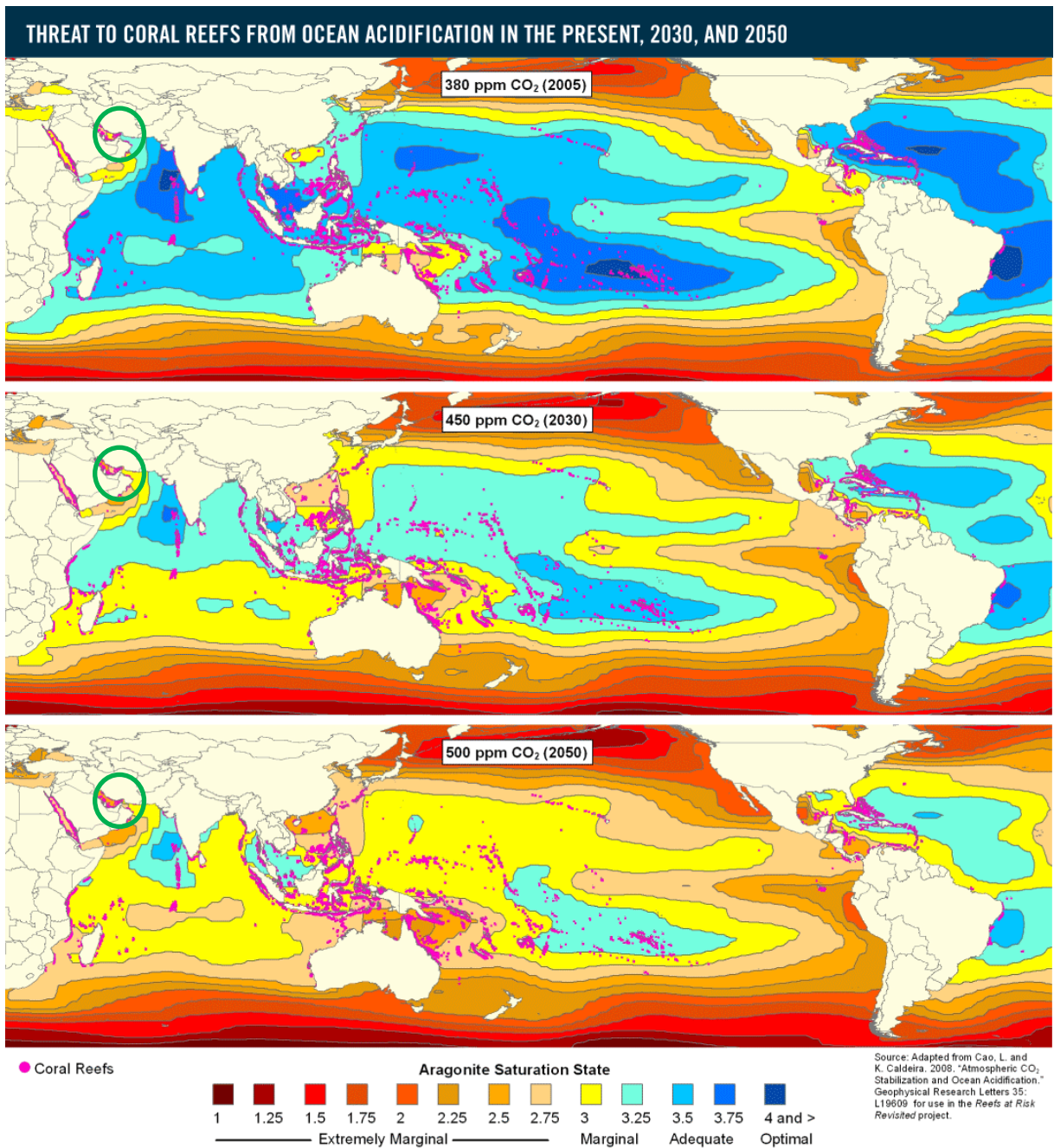


Figure 6-18 Measured (2005) and projected (2030, 2050) Aragonite saturation levels showing the effects of ocean acidification (the Fujairah region is circled) (Cao and Caldeira 2008)

6.3.5 Sea level rise

Local SLR is driven by global SLR resulting from both the melting of land ice (glaciers, ice caps etc) and from the thermal expansion of the upper water layers of oceans. It also depends on vertical land movement (VLM) (Mote et al. 2008). Figure 6-19 shows the ratio between the local and global thermal expansion component in the Fujairah region, obtained by using SimCLIM to combine the SLR patterns of 13 GCMs (see Table 6-1).

A value of 1.07 means that for every centimetre of global increase, the local increase is 1.07cm (7%). There are many reasons for local differences. For example, the temperature increase of the sea water is different in different places, as it is driven around by wind and other factors (Niiler, Maximenko and McWilliams 2003). Local VLM is impacted by anthropogenic factors, e.g., groundwater or oil extraction (Gornitz 2006; Lambeck et al. 2004). Predicting local SLR helps to determine the likely impacts on coastal tourism resources and also aids management response plans.

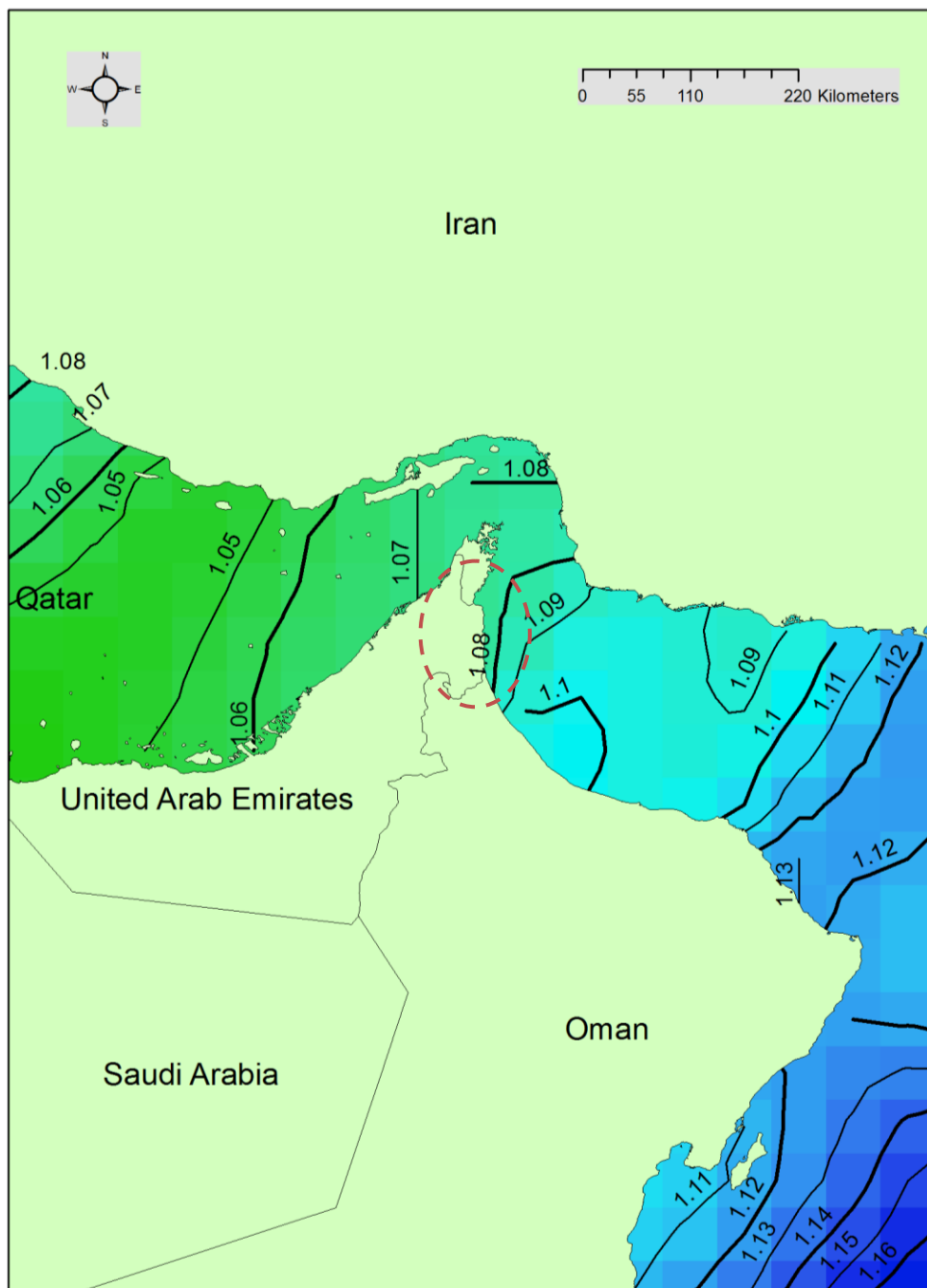


Figure 6-19 Ratio of local to global SLR (cm) (Fujairah circled)

With a global SLR of 45 cm expected by the year 2070 (under a ‘high’ climate sensitivity; see Figure 6-20), sea levels around Fujairah are expected to rise by 48cm by the year 2070. This value does not take VLM in account.

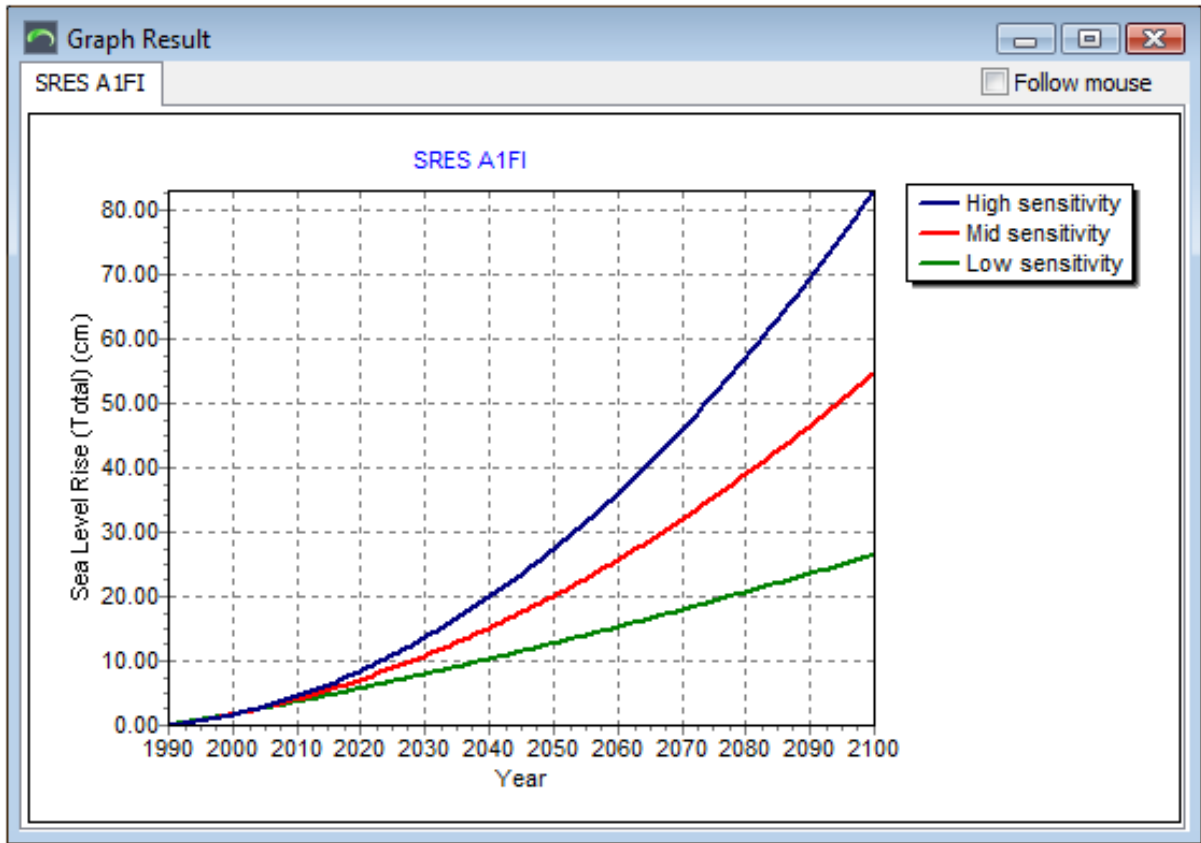


Figure 6-20 Global SLR under A1FI scenario (reproduction of IPCC AR4 using SimCLIM)

Local SLR, as experienced on land, also depends on the VLM. This is a process comparable in magnitude to SLR. VLM can be determined from tidal data, or from GPS measurements at a fixed location (Holgate 2007), but neither was available for the Emirate of Fujairah. The closest observation point is in Bahrain, where both tidal data and continuous GPS observations for the period 1979-2007 showed a VLM of 0.0 mm/yr (SONEL 2010). In fact, there is no reason to expect substantial VLM in this area: it is not earthquake prone, no groundwater extraction takes place, and no sediment builds up from rivers.

Using the ensemble of 13 GCMs together with the VLM value of 0.0 mm/year, the SLR under the worst case A1FI-high scenario was projected for Fujairah using SimCLIM and is represented in Figure 6-21.

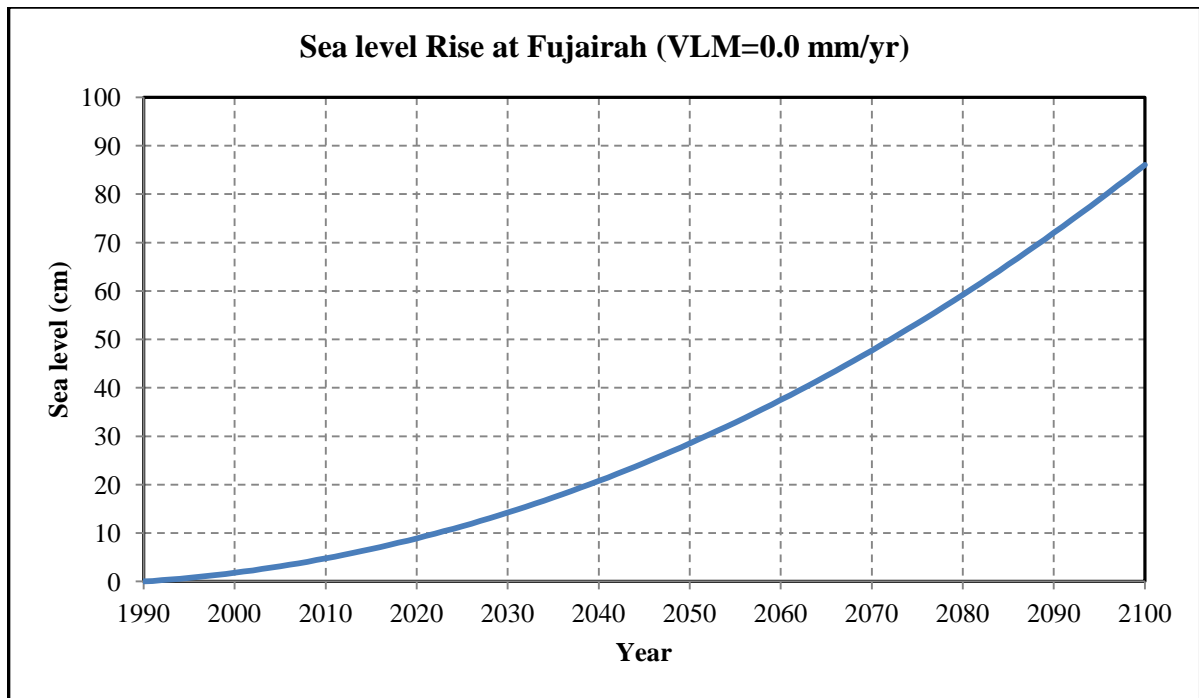


Figure 6-21 Projection of SLR at Fujairah, 1990-2100

With regard to the SLR projections given in Figure 6-21, the following points are noted:

- (a) The graph does not take into consideration possible catastrophic melting of the Greenland or Antarctic ice caps, which could add 5-7 metres to the global sea level (Parry et al. 2007).
- (b) Although certain countries project SLR up to 2200, projections in this study were undertaken to the year 2100 as SimCLIM follows the current (AR4) IPCC data and models (Burton 2012; Titus and Narayanan 1996).

Areas of Fujairah potentially at risk from SLR

To assess the areas within Fujairah that might be at risk from SLR, a flood model can combine the elevation data with sea level and storm surge models (see Chapter 2). While SimCLIM does not have a generic flood model (it is designed only for specific areas), it provides a DEM based on the global 30m × 30m dataset, which can be used to provide an approximate assessment of the flood risks due to SLR (see Figure 6-22).

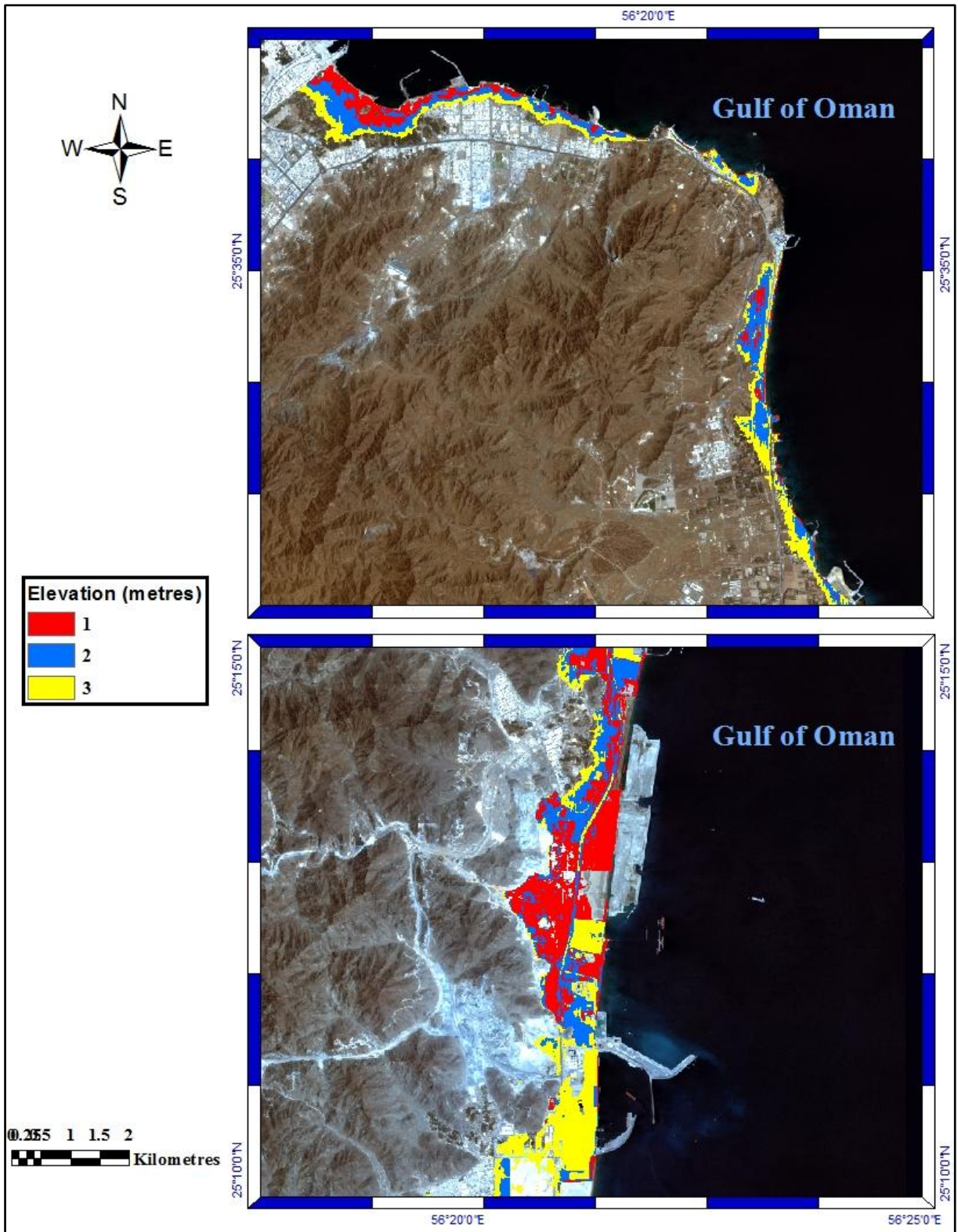


Figure 6-22 Map of Fujairah showing areas classified according to their elevation showing flood risks from SLR, Dikka City (top) and Fujairah City (below)

Figure 6-22 classifies regions of Fujairah according to three elevation ranges (above mean sea level): below one metre, between one and two metres, and above two metres – thus identifying the areas potentially at risk from a corresponding rise in sea level. It is evident from Figure 6-22 that existing tourism resources in the coastal zone of Fujairah are directly at risk from SLR. And as the areas shown are less than two metres above mean sea level, they are already at risk from flooding from storm surges. This risk increases while SLR is taking place.

Rising sea levels pose a threat to coastal tourism resources such as coastal recreational projects in Fujairah, the details of which are discussed in the next chapter.

6.3.6 Coastal Erosion

Coastal erosion is the loss of material along the shoreline that can lead to a landward movement of that shoreline. Many factors contribute to the existence and rate of shoreline erosion such as currents, human intervention, wind-direction and speed as well as SLR (Komar 2011).

Many models exist that describe coastal erosion, most requiring comprehensive datasets and extensive calibrations. As no reliable data were available for the Fujairah region, this section focuses on the potential coastal erosion in Fujairah due to SLR, estimated using the widely applied Bruun Rule (Ranasinghe and Stive 2009) (see Appendix D). Although the Bruun rule is frequently challenged, there is no alternative. The Bruun rule describes the change in the ‘equilibrium shoreline’ associated with a changing sea level. The equilibrium shoreline (ES) is the shoreline’s ‘natural’ position to which it tends to return; that is, if the current shoreline is further seawards, it will erode to the ES. For a given coastline profile, determined by slope, height of the dune, and depth and distance to shoreline of the seabed contributing to sediment exchange, an ES can be calculated. In the SimCLIM modification of the Bruun rule, the shoreline can also erode beyond the ES from storms, after which it will grow back to the ES. SLR changes the profile parameters, moving the ES landward.

The Bruun Rule is used frequently because of its simplicity and its ability to explain some of the typical behaviours of a sandy coastline. Thus, the Bruun Rule is not a tool for predictive modelling. Rather, it is a tool that can produce reasonable shoreline behaviour in response to sea level changes and is useful for asking ‘what if’ questions about coastal changes as a basis

for impact assessments, coastal planning and management (Callaghan and Roshanka 2009; Cooper and Pilkey 2004; FitzGerald et al. 2008).

The storms SimCLIM allows for in its Bruun rule implementation are defined with a mean and a standard deviation of the erosion perpendicular to the shoreline. For example, with a mean of 10m and a standard deviation of 5m, a storm on average will erode 10m of the shoreline, with a variation of +/- 5 m.

In order to demonstrate the Bruun Rule in the context of Fujairah, the *Al-Aqah* beach tourism resource was selected. Table 6-5 lists the ‘best guess’ parameter values for coastal erosion (as noted earlier, no local expertise or data on Fujairah’s shoreline system exists). These best guess values are based on general knowledge about sandy shorelines and some experimenting with values to assess their sensitivities.

Table 6-5 Bruun rule parameters used to estimate erosion due to storm surges and sea level rise at Al Aqah Beach, Fujairah

Parameter	Value
τ - Shoreline response time (the time it takes to reach equilibrium)	10 years
I - Closure distance (from how far seawards material can be exchanged)	200m
d - Depth of material exchange (the average depth the material comes from)	8m
h - Dune height (height of the dune at the shoreline)	5m
μ - Storm surge cut mean (average cut from a storm)	5m
σ - Storm surge cut standard deviation	5m

Using the parameters listed in Table 6-5, the outputs obtained using SimCLIM are as follows:

- (a) Coastal erosion projections without considering SLR (that is, considering random storms only) (Figure 6-23).

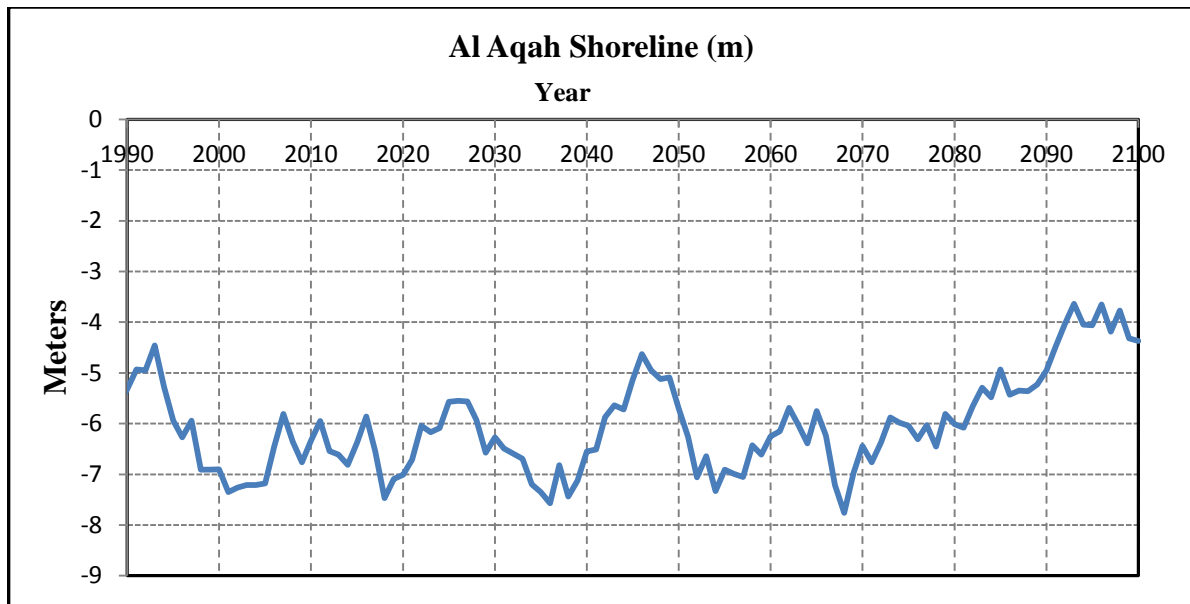


Figure 6-23 Coastal erosion projections for Fujairah’s Al-Aqah shoreline without considering the SLR (random storms only) with reference to equilibrium shoreline

Note that the figure shows where the horizontal shoreline is (not the height above mean sea level). It does not show an absolute position, but the movement over time relative to the equilibrium shoreline (which is at 0). Figure 6-23 shows the predicted change in the coastline at Al-Aqah over a period of 110 years (i.e., from 1990 to 2100), as a result of random storms. The figure shows that depending on the period chosen, different conclusions would be drawn about the changes in the coastline. For example, between 1990 (ca. -5m) and 2040 (ca. -7.5m) the beach loses about 2.5 m, while between 2070 (ca. -7.5m) and 2100 (ca. -4.5m) it gains more than 3m. This highlights the issue that too short periods of observation may lead to incorrect conclusions about local coastal dynamics.

- (b) Coastal erosion projections under climate change taking SLR into consideration (A1FI-high, 13-GCM ensemble-global, VLM = 0.0 mm/yr).

The simulation in Figure 6-24 was obtained using both SLR and random storms. It shows a loss of coastline at Al-Aqah of up to 14m by the year 2100 compared to 1990 – an erosion driven by SLR of approximately 85cm (see Figure 6-21). Figure 6-24 again highlights the inappropriateness of short observation periods: from 2010 (ca. -7.5m) to 2050 (ca. -7.5m) (40 years), no major change in the shoreline is seen despite SLR.

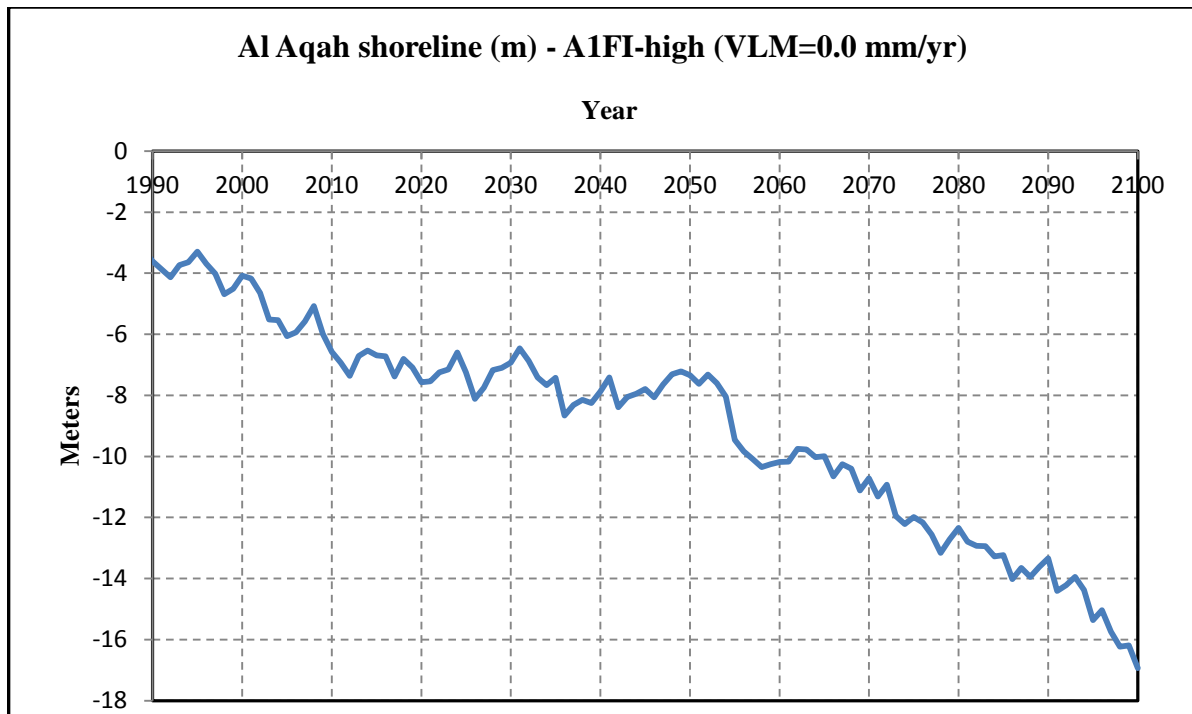


Figure 6-24 Coastal erosion projections for Fujairah’s Al-Aqah shoreline considering SLR as well as random storms with reference to the equilibrium shoreline in 1990

6.3.7 Wind speeds

Wind affects tourism resources – for example, through wind erosion of cultural heritage buildings such as old forts and mosques. Activities such as traditional boat racing can also be affected. Furthermore wind contributes to storm surges which in turn affect coastal erosion. For the projections of future wind speeds for Fujairah, an ensemble of all available GCMs (19) with wind information on a global resolution was used as no local wind patterns were available. Figure 6-25 shows the long-term normal of daily observations (1995-2011) of wind gusts for Fujairah airport. Figure 6-26 shows the percentage change in wind speeds for the Middle East region including Fujairah by 2070, compared to the 1990 baseline, for A1FI-high from a 19 GCM ensemble-global.

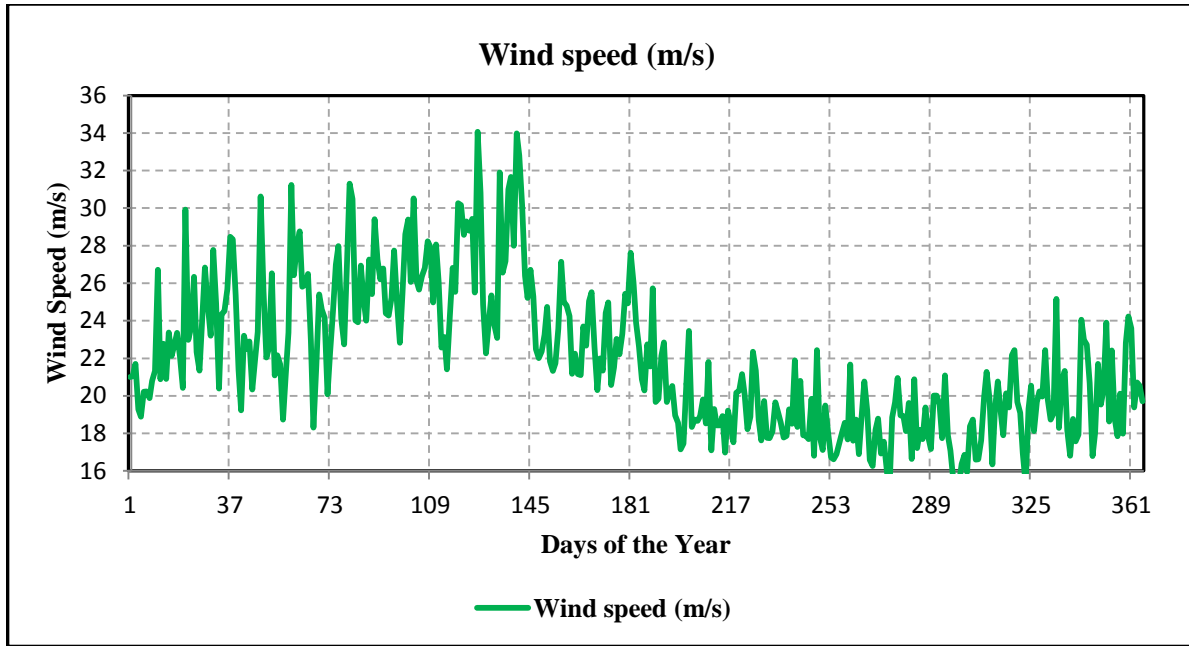


Figure 6-25 Long-term normal of daily wind gusts at Fujairah airport, 1995-2011 (derived from SimCLIM)

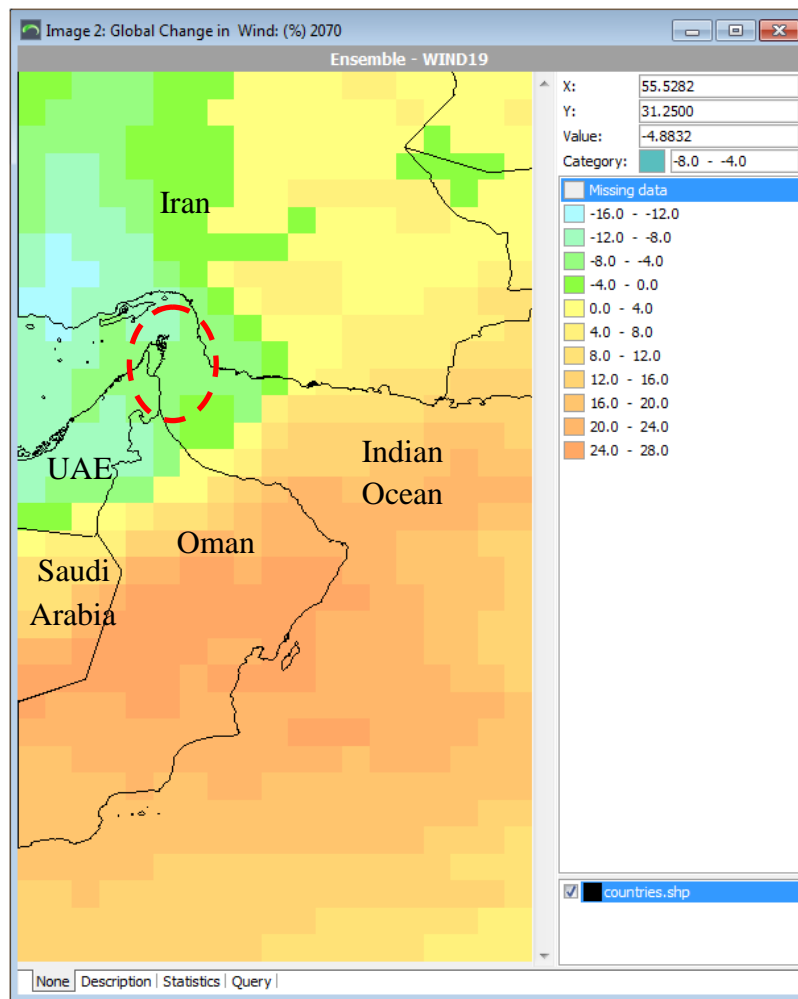


Figure 6-26 Percentage change in wind speeds for the Middle East region (Fujairah circled) by 2070, compared to the 1990 baseline, for A1FI-high from a 19-GCM ensemble-global

From the projection results shown in Figure 6-26, it can be seen that the wind-speeds in and around Fujairah decrease by 4-8 % by 2070 under the A1FI-high conditions compared to the baseline. This decrease in wind speeds could be considered favourable with respect to reducing the severity of storm surges, sandstorms and erosion of cultural resources. However, it may be unfavourable with regard to outdoor tourism activities such as sailing and wind surfing.

6.4 Overall climate changes in Fujairah

According to the climate projections made with SimCLIM (from the CMIP3/AR4 results), Fujairah's climate is changing both over the short and the long term. These changes need to be tracked by observing both the change and the rate of change of tourism resources. Table 6-6 summarises the possible changes in Fujairah's climate outlined in this chapter so far. Each of those changes will have a unique impact on Fujairah's tourism resources (to be identified in chapter 7).

It is worth mentioning that uncertainties may arise due to different data inputs used. In particular, multiple spatial resolutions were used, depending on many inputs such as grid resolution, the baseline climate and the climate change patterns, all provided by CLIMsystems Ltd, the producer of SimCLIM. The first resolution was determined by SimCLIM based on the available data, and the size of the area, SimCLIM can only deal with a certain number of columns and rows, thus the larger the area, the coarser the grid needs to be (in this research it was 1km x 1km). The second resolution is that of the baseline climate (i.e., at the year 1990). This was extracted from the Worldclim database, which has a fairly fine resolution. Some information was added to the extracted data, for example temperatures changes with elevation. The Worldclim dataset was extracted at the SimCLIM resolution (i.e., 1km x 1km). The last resolution was of the patterns. These come from the GCM, which are standardised (made the same for all models, which natively use different resolutions) on 0.5 x 0.5 degrees (roughly 50x50 km). These were then downscaled (bi-linearly interpolated, as no additional data were available to inform the downscaling process) to the SimCLIM resolution (1km x 1km). The boundary of Fujairah was included as a shape file (i.e., imported from GIS).

Table 6-6 Overall projections of climate change in Fujairah

Climate change effects	Climate projection in SimCLIM
Average air temperature	Increase in average air temperature of more than 5°C from the baseline (1990) to 2070
Maximum air temperature	Change in maximum temperature (averaged over June-August) of more than 5°C by 2070
Extreme high temperature (heatwaves)	Increased recurrence frequency of 7-days periods of very high temperature
Shift of seasons	Longer summers and shorter winters
Total annual precipitation	Precipitation is likely to reduce by between 5.8% and 11.3% by the year 2070
Water balance	Reduced water availability of 13-17% is projected by the year 2070 compared to the baseline of 1990
Extreme high precipitation (flash floods)	Shorter return period (RP) for extreme events
Extreme low precipitation (droughts)	A decrease in total annual rainfall likely means longer droughts
Sea surface temperature	The SST projection for July in 2070 exceeds 36°C (compared to 32°C in the 1990 baseline year)
Ocean acidification	Rising ocean acidification levels due to change in atmospheric CO ₂ from 380 ppm in 2005 to 500 ppm in 2050
Sea level rise	The sea level around Fujairah is expected to rise by up to 48cm by the year 2070
Areas potentially at risk from SLR	Future SLR puts some coastal areas under increased risk
Coastal erosion	A loss of coastline at Al-Aqah beach of up to 14m is projected by the year 2100 compared to 1990
Wind speeds	The wind speeds in and around Fujairah decrease by 4-8 % by 2070

6.5 Conclusion

This chapter discussed projected changes in the climate and weather conditions in the Emirate of Fujairah together with spatial variations in the middle and long term (i.e., 2030 and 2070 respectively). The spatial results were overlaid with the GIS-based distribution of tourism resources discussed in Chapter 5. The procedures and techniques adopted for these projections were also presented. The simulations were carried out using SimCLIM software (which replicates results from CMIP3/AR4); projections were based on the most extreme case, the A1FI emission scenario with a high level of climate sensitivity, as justified earlier in the chapter.

The climate change effects analysed in this chapter were air temperature (average and maximum temperature, heat waves, and shifts of seasons), SST, precipitation-related factors (total annual precipitation, water balance, flash floods, and droughts), ocean acidification, SLR, coastal erosion and wind speeds.

Average air temperatures in Fujairah were projected to increase by more than 5°C between the baseline year of 1990 and the year 2070. Also the recurrence frequency of an average maximum daily temperature of more than 45°C over a 7-day consecutive period may increase sevenfold by 2030 compared to the 1990 baseline year. Seasons in Fujairah may change, giving longer summers and shorter winters.

Mean SST in July was projected to exceed 36°C by the year 2070; this is expected to threaten the survival of Fujairah's coral reefs. Precipitation is expected to decrease by up to 11.3% from the 1990 baseline, while evapotranspiration will increase by 7%. The combination of reduced precipitation and increased evapotranspiration will decrease water availability in the region up to 18%. Despite the predicted reduction in water availability in Fujairah, the severity and frequency of flash flooding is likely to increase – it will rain less but when it rains, it will rain harder.

An analysis of drought was performed on the basis of the projected number of consecutive dry days. Fujairah's agricultural sector, including palm tree plantations, will be further affected by the increased aridity of the region.

Ocean acidification may worsen as a direct result of an increase in the atmospheric CO₂ concentration to 500 ppm by 2070. Also, the sea level is projected to rise, which could in turn worsen coastal erosion. Average wind speed was projected to decrease by 4 to 8% by 2070.

A full discussion of the impact of these climate change effects on tourism resources in Fujairah is presented in Chapter 7.

Chapter 7 Using a Management Tool to Determine Potential Impacts from Climate Change

7.1 Introduction

The previous chapter contained a comprehensive analysis of and projections for the climate change effects which are key to the tourism resources in Fujairah. In this chapter an analysis of the impacts of these effects on Fujairah's tourism resources is described and the results presented and discussed. This analysis is inherently geospatial, because climate change effects vary spatially while tourism resources are geographically distributed. The key question is "Which tourism resources in Fujairah will be impacted by the effects from climate change, and what will that impact look like?".

For each tourism resource identified in chapter 5, this chapter highlights the impacts from the climate change effects identified in chapter 6. The importance of each impact is assessed as well. The chapter begins by presenting and discussing ways to analyse impacts of climate change. Information on building a conceptual model for impact assessment, based on the DPSIR framework, is also presented.

7.2 Approaches to analysing impacts of climate change effects

The spatial distribution of climate change effects of increased temperature and reduced precipitation was overlaid with the key tourism resources in Fujairah, shown in Figure 7-1. It reveals that coastal resources are vulnerable to increased temperature in 2070. In addition mountain areas, especially in the eastern parts of Fujairah, are impacted mostly by decrease of precipitation in the projected year 2070.

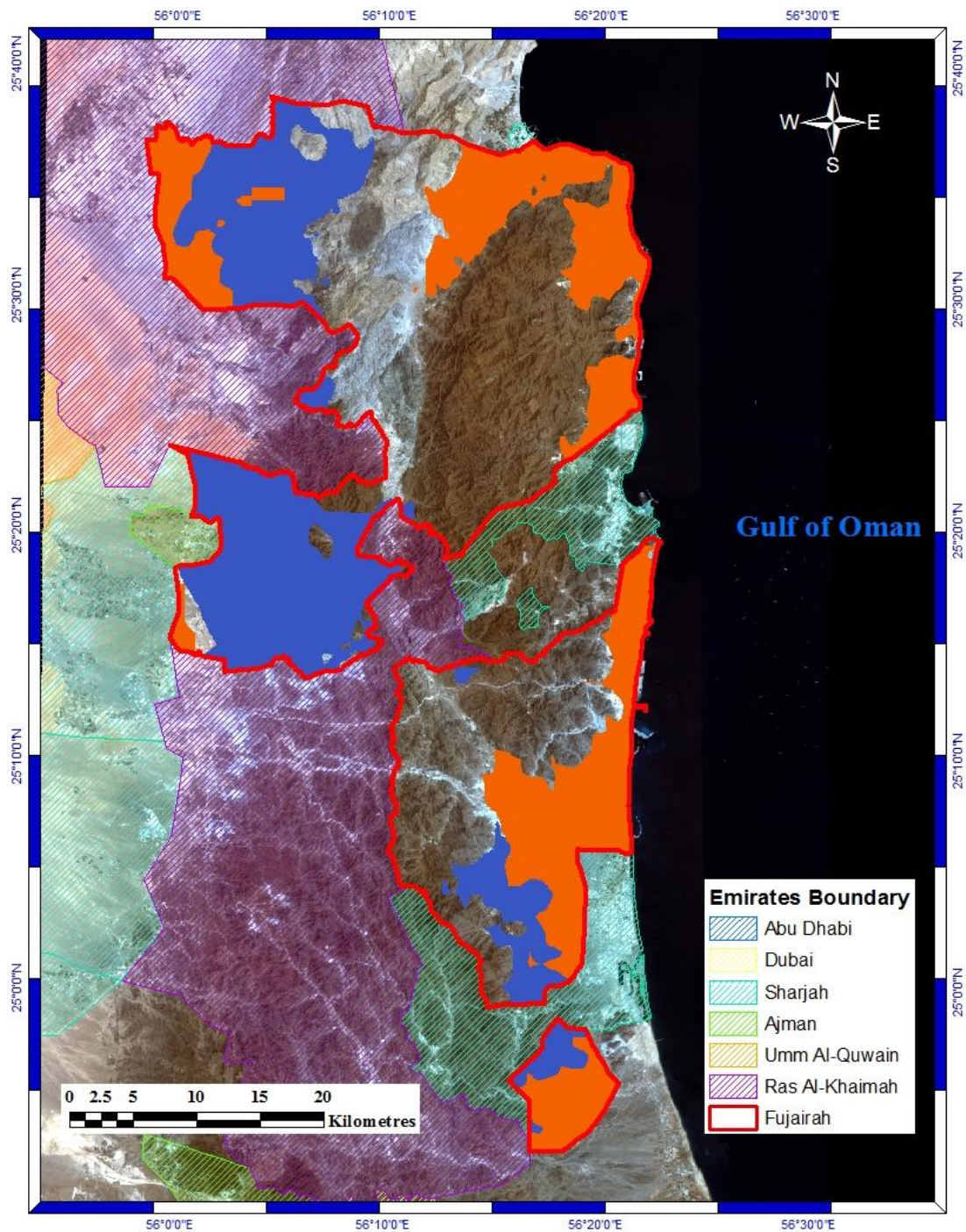


Figure 7-1 Spatial distribution of projected increased temperature (orange), and precipitation reduction (blue) in Fujairah, 2070

The two possible approaches to investigate the impacts of climate change effects are by identifying:

- (i) Climate change effects that impact on *an individual tourism resource*, are
- (ii) Impacts on all tourism resources for a *given climate change effect*.

The two different approaches are depicted in Figure 7-2.

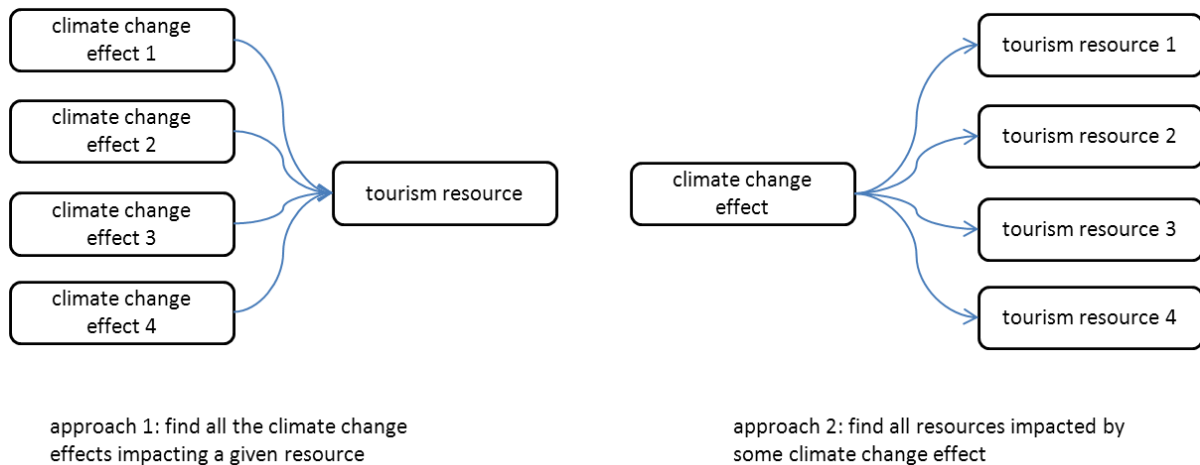


Figure 7-2 Approaches to analysing impacts of climate change effects on tourism resources in Fujairah

This chapter uses the first approach, as it is the more logical approach from the perspective of planning and management of tourism resources; a manager of a specific resource is interested to learn about all the possible impacts from climate change on that resource. Thus the result of the analysis is an overview of *how* and to what *extent* specific tourism resources in the Emirate of Fujairah are impacted by climate change effects.

Tourism resources and their interrelations can be viewed as a system (as in the ‘system dynamics theory’). This system is in a certain state that can be changed by external influences like changes in climate. Some of the impacts occur directly, while others are transferred from one part of the system (e.g., beach) to another (e.g., coral reefs), following cause-effect pathways. Building and understanding the multiple components, characteristics, relationships and changes is a non-trivial task, but the methodology of mind-mapping is a proven means of addressing it (Mento, Jones and Dirndorfer 2002; Winowiecki et al. 2011). As discussed in Chapter 3, software exists can help to model these mind-maps (a mind map is a diagram used to visually outline information). The mind map model would not only be used to identify the impacts but also to address their importance. This needs some outputs (quantitative or qualitative) for the changes that are spreading through the system. The Rapid Assessment Program (RAP) software (described in detail in section 2.9.3) is the only known software with this capability.

7.3 Building of a conceptual model for impact assessment

The Drivers-Pressures-State-Impacts-Responses (DPSIR) framework (detailed in Chapter 2) was used to define the conceptual model. This framework allowed formalisation of the *drivers*

(in this case the climate change effects), the *states* (the tourism resources), the *pressures* (the stress of the climate change effects on the tourism resources) and the *impacts* (the change in the tourism resources as a result of the pressures from the climate change effects). As mentioned in Chapter 3, RAP is a tool that integrates the DPSIR framework, and was used to create and analyse the conceptual model.

RAP is a software implementation of a methodology for rapid, integrated policy analysis which includes systems analysis. RAP provides a structured approach, allows for the building of a qualitative conceptual model and assists with the presentation of changes. Therefore RAP is ideally suited to assess the impacts of the drivers (climate change effects) on the states (tourism resources of Fujairah). The building of a model in RAP involves the following steps:

1. Stating the problem, including objectives
2. Defining the components that make up the problem (i.e., tourism resources)
3. Defining the characteristics of the components and the relationships between these characteristics
4. Indicating those characteristics (criteria) that directly link with the objectives (i.e., quality of tourism resources)
5. Specifying the exogenous changes that act on the system (i.e., the climate change effects).

The first step precedes the actual building of the conceptual model (steps 2 and 3). Once the model is built, it is implemented by applying steps 4 and 5.

All steps are explained in detail below.

7.3.1 Problem and goal definition

A clear definition of the problem reduces both the ‘problem space’ (what are the elements of the problem) and the ‘solution space’ (what could be part of a solution) – a first step in reducing the complexity of the conceptual model. The problem definition requires asking questions like “For whom it is a problem?” and “Why it is a problem?” Once this is done, the goals or objectives to be achieved by solving this problem are set (when is the problem deemed to be solved?), as well as overall goals relevant to the problem (i.e., specific sustainability objectives). RAP also requires that the temporal and spatial boundaries are set.

For the analysis of the impacts of climate change on Fujairah's tourism resources, the problem statement was defined as shown below (see also Figure 7-3).

- (a) **Description of the problem:** What are the impacts of changes in climate and its variability on tourism resources in Fujairah?
- (b) **List of project objectives:**
 - 1) To maintain or improve the quality of Fujairah's tourism resources impacted by climate change;
 - 2) To maintain or improve the quantity of Fujairah's tourism resources impacted by climate change.
- (c) **List of overall objectives:** Assess the sustainability of the Emirate of Fujairah's tourism industry by preserving the existing tourism resources.
- (d) **Boundaries, scales and preconditions (spatial and temporal):**

Spatial: The Emirate of Fujairah.

Temporal: Long term (2070) for average climate effects and short to mid-term (2030) for extreme weather events.

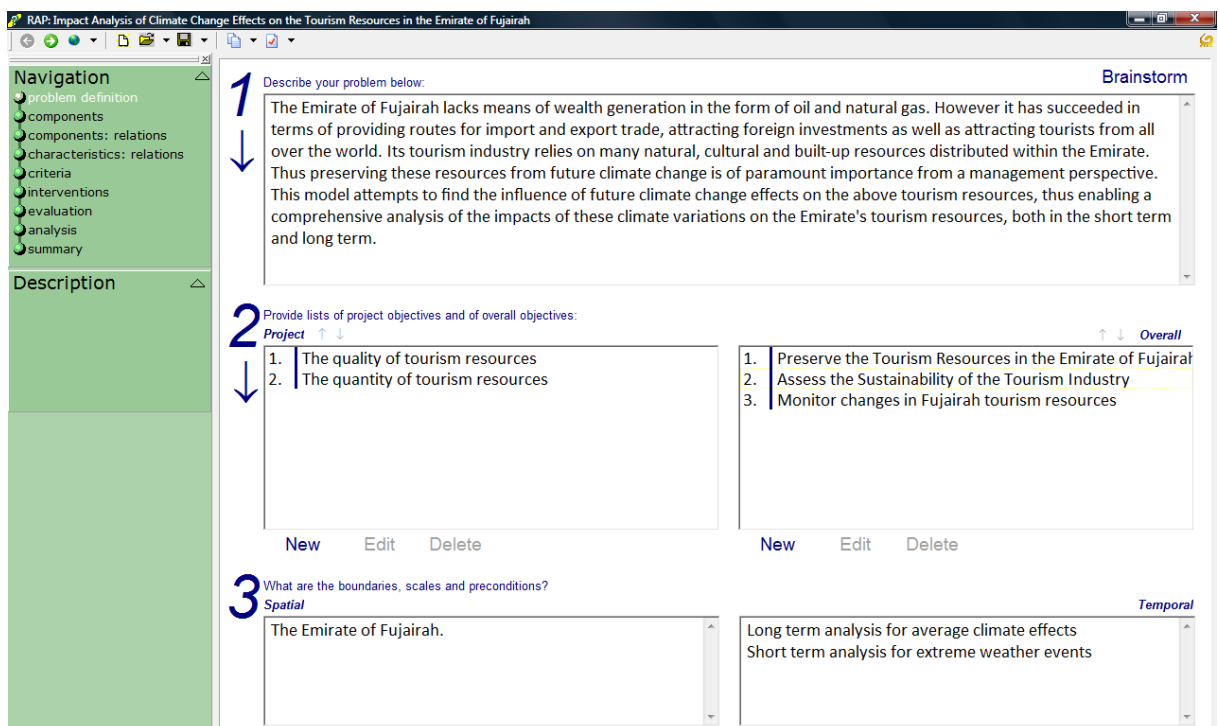


Figure 7-3 Screen capture of the problem statement definition in RAP

7.3.2 Model building (components, characteristics and relationships)

(i) Components

The next step in RAP was to set up the elements of a qualitative model. As it is not always immediately clear what level of abstraction is needed for the conceptual model, it should be noted that modifications of and additions to the model are possible throughout the whole mind-mapping process.

The process starts with a specification of the components related to the problem. Components are high-abstract entities that are important in the system (with respect to the problem) such as climate, weather, or ecosystems. The final set of defined *components*, including their *characteristics* and the projections (from section 6.4) of the climate change effects, are summarised in Tables 7-1 to 7-3.

In this study the components are those aspects that are relevant to the impacts of climate change on tourism resources in Fujairah. Thus some components correspond to climate change itself (average, extreme and ocean related climate change effects) and others to the tourism resources under consideration (island ecosystems). An effort was made to identify the not-so-obvious impacts on tourism resources. This led to the inclusion of the component labelled ‘Tourism Resource Accessibility’.

RAP focuses on the concept of transference of change, where changes in one part of a system cause changes in other parts of the system (i.e., changes in climate result in changes to tourism resources).

(ii) Characteristics of components

The components need to be further refined (characterised) in order to better define the system in relation to the problem. This process is aided by a graphical interface in RAP. The defined characteristics are visually placed within the components as they refine the component (‘given a component, how is this component characterised’). Characteristics in RAP must be entities that are able to increase or decrease, such as quality and quantity, so that RAP can analyse changes later on (van der Werff ten Bosch and Kouwenhoven 2004).

The components and characteristics not only have a linguistic connotation, but also a hierarchical relationship. Characteristics are the model variables in the conceptual model, entities that can change. Components can be seen as logical groupings of these characteristics, as some belong together more than others. Components in RAP only have a function in the

mind-mapping process, as part of stepwise development of the conceptual model, while the ‘logical grouping’ is as a result of that process.

No preconceived expectations were used to guide the building of the conceptual model. For example, the ‘wind’ climate change effect was included as a characteristic in building the model, although the impact on tourism resources from the projected decrease of wind speeds was expected to be minimal.

Tables 7-1 to 7-3 contain lists of model characteristics specified under each component, while Figure 7-4 depicts a graphical overview of them. Components were grouped according to different categories, for example the climate change component (yellow) includes average climate effects, extreme weather events and ocean related climate effects. Tourism resources were divided into four different categories: cultural tourism resources (dark green), built-up tourism resources (brown), tourism resource accessibility (grey) and natural tourism resources (purple).



Figure 7-4 Graphical overview of the components and their characteristics in RAP

Table 7-1 Components and characteristics related to Climate Change Effects defined in RAP

COMPONENT / Characteristic	Projection / Description
AVERAGE CLIMATE EFFECTS	The slow-changing ‘average weather’ effects considered over a long period (<i>under A1FI-high, by 2070, from an ensemble of all applicable GCMs, compared to baseline</i>)
Precipitation	Will drop by up to 11.3% by 2070
Seasons	Longer summer periods and shorter winter periods
Temperature	Average air temperature will increase on average across Fujairah by over 5°C by 2070, more than the global mean increase of 4.4°C
Water balance	The difference between the precipitation (which will decrease) and evapotranspiration (which will increase because of the rise in temperature) will rise, decreasing the overall water balance by up to 17%
Wind	Average wind speed was forecast to decrease by 4 – 8% by 2070
EXTREME WEATHER EVENTS	Rare but severe weather events (<i>under A1FI-high, by 2030, from an ensemble of all applicable GCMs, compared to baseline</i>).
Droughts	Droughts are characterised by consecutive days without rain. Currently a period of at drought of least 300 days occurs (on average) every five years. Due to the decrease in precipitation, it is expected that droughts will become both more frequent (same length) and more intense (longer periods)
Flash floods	For a given extreme rainfall event the return period becomes shorter (the event becomes more frequent), while extreme rainfall events become more severe
Heatwaves	A 7-day period of more than 45°C (on average) currently occurs every 30 years. This is projected to increase to once every six years on average
OCEAN RELATED CLIMATE EFFECTS	This corresponds to the aspects of the sea that will change due to climate change (<i>A1FI-high, 2070, ensemble of all applicable GCMs, compared to baseline</i>)
Acidity	Ocean acidification will rise because of the change in atmospheric CO ₂ levels from 380ppm (2005) to 500ppm (by 2050)
Sea Level Rise	Fujairah’s sea level, already 7% higher than the global mean, is projected to rise by 48cm by 2070
Sea Surface Temperature	The sea surface temperatures around Fujairah are projected to exceed 36°C

Table 7-2 Components and characteristics related to Fujairah’s natural tourism resources defined in RAP

COMPONENT / Characteristic	Description
SURFACE-WATER RELATED FEATURES	Important tourism resources related to surface waters
Wadis (valleys)	A special feature of Fujairah: small intermittent streams deeply embedded in the landscape
Waterfalls	Certain waterfalls are very important tourism resources; the availability of amounts of water sufficient to maintain flow is a major concern
ISLAND ECOSYSTEMS	Tourism resources in the form of small islands close to the coast
Distribution	How much of the island ecosystem exists
Ecosystem health	How well the islands’ environments are suited to the ecosystems they harbour
CORAL REEFS	Tourism resources in the form of coral reefs
Extent	The amount of coral reef present: not only the reefs that attract tourists, but all the parts that contribute to their survival
Quality	The quality of the coral reefs: growing well, stagnating, deteriorating, or dead
BEACHES	Sandy beaches visited by tourists for sunbathing, swimming and other activities
Comfort	Both the temperature of the air and the sea water determine how comfortable the beach is: too hot will reduce its quality
Width	How much beach-space is available to enjoy. This is impacted by coastal erosion (due to sea level rise), storm surges and changes in wind speeds
WETLANDS	Sabkhas (salt flats) and mangroves
Distribution	The ‘extent’ of the wetlands
Wetland-health	The ‘quality’ of the wetlands
COASTAL FRINGE	The areas around the coastline are sandy beaches, rocky foreshores and cliffs
Marine mammals	Animals like dolphins and turtles
FRESH WATER RESOURCES	Water resources that provide fresh water for domestic use
Quality	The quality of the resource (low salinity)
Quantity	The extent (spatial distribution) of the resources
MARINE ACTIVITIES	Marine activities that attract tourists (to watch or to participate in)
Fishing	Recreational fishing activities
Marine-club services	Quality of marine sports and leisure activities provided

Table 7-3 Components and characteristics related to cultural and built-up tourism resources and their accessibility defined in RAP

COMPONENT / Characteristic	Description
CULTURAL TOURISM RESOURCES	Archaeological heritage resources and events that are important from a traditional perspective
Forts, castles, ancient mosques	Tourism resources such as the Fujairah fort, Al-Bediya mosque and the Al-Hail castle which constantly attract tourists
Souks (Friday markets)	The attractiveness of souks is impacted by extreme rain and temperature as well as by droughts which will result in unavailability of local produce (fruit and vegetables)
Heritage village	Represents the traditional way of life of the residents in the Emirates and consists of traditional houses, with their cooking utensils and farming tools
BUILT-UP TOURISM RESOURCES	Constructed resources that have the potential to attract tourists
Public parks	Quality of the public parks
TOURISM RESOURCE ACCESSIBILITY	Ease of access to tourism resources (enabling their usage): includes roads, airports, ports and jetties
Ease of inside access	This refers to the accessibility of tourism resources such as museums and malls (impacted by extreme weather events such as flash floods)
Ease of open-air access	This refers to the accessibility of open-air resources such as local markets, heritage villages and fishing areas (mainly impacted by extreme rain and temperature)

(iii) Specifying the relationships between the characteristics

In the final part of the model building process, relationships between the various *characteristics* are specified. These relationships describe the pathways along which the change in one characteristic is transferred to another. The easiest way to find these relationships is to take each characteristic as a starting point. Assuming that a specific characteristic is going to increase, what other characteristics are going to change as a direct result of the increase of the first characteristic? (The indirect changes are always comprised of a series of direct changes.) A change can be instantaneous or delayed (but within the time-horizon that was specified in the problem definition step).

This specification process captures the relationship between drivers (the climate change effects) and states (the tourism resources), that is ‘how’ and ‘how strongly’ each and every climate change effect (driver) is perceived to influence the tourism resources (states). Importantly, the relationships are not limited between drivers (which refer to climate change effects) and states (which refer to tourism resources); sometimes a change in one state could cause a change in another state. For example, change in quality (e.g., bleaching) of coral reefs may cause a change in the quantity of fish caught.

When specifying the relationships between characteristics, the “polarity” of the relationship (increase or decrease) must be indicated (the increase in one characteristic is causing either an increase or a decrease in another characteristic) as well as the intensity of the change caused. Three levels of intensity are available: weak, medium and strong. Visually, RAP represents this through line thickness and colour, indicating intensity and polarity of change respectively.

For instance, ‘sea level rise’ is perceived to affect the ‘width of the beach’ (a characteristic of the natural tourism resource ‘beach’). The following provides the details of the relationship between the two:

- The *source* (from) is the SLR and the *target* (to) is the width (of the beach)
- The *type* of the relationship is ‘*negative*’: that is, a rise (*increase*) in SLR is expected to decrease the width of the beach (over the time-scale considered: the long term)
- The intensity (*value*) of the relationship is *strong*.

Figure 7-5 shows the process of configuring this relationship, while Figure 7-6 shows the graphical representation in RAP. The intensity of the relationship is represented in RAP by way of pluses (+) and minuses (-), whereby three pluses (+++) and three minuses (---) represent a strong increase or decrease, two pluses or minuses (++, --) a moderate increase or decrease, and one plus or minus (+, -) a weak increase or decrease.

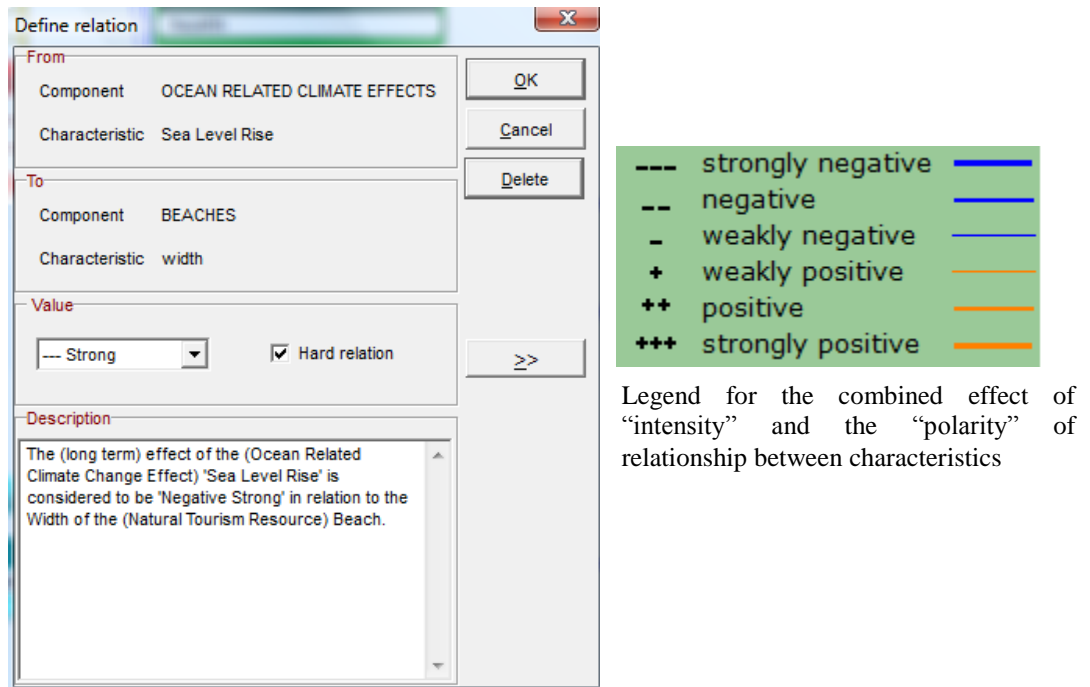


Figure 7-5 Configuring a relationship between two *characteristics* ('SLR' and 'width of the beach') in RAP

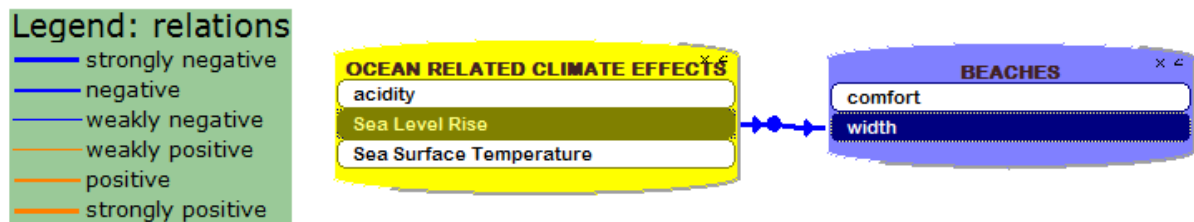


Figure 7-6 Graphical view of the relationship between SLR and the width of the beach represented in RAP (thick blue line = strong negative relationship: i.e., if SLR increases, the width of the beach decreases)

Figure 7-6 depicts the relationship between the SLR and the width of the beach. Of course, the change in the width of the beach is not only impacted by SLR but may also change with other characteristics. Likewise, a given climate change effect (SLR) could affect other characteristics in different ways and with varied strengths. An example of this is shown in Figure 7-7 (note the different line widths).

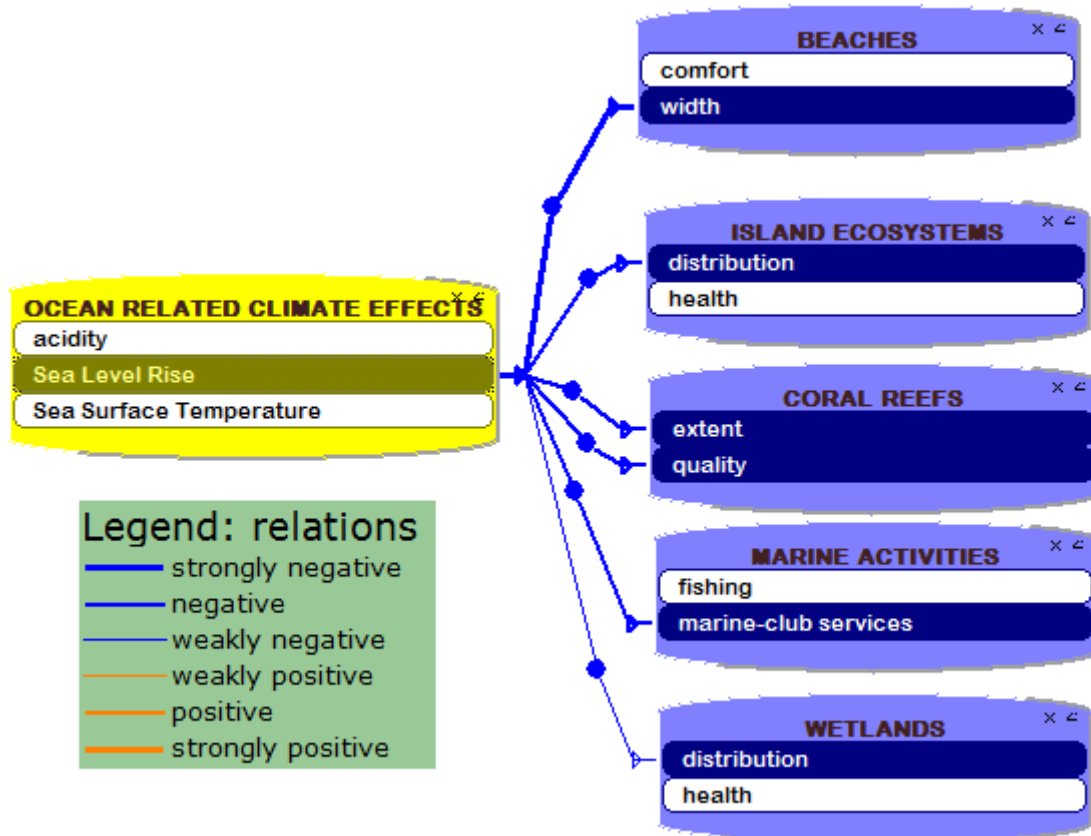


Figure 7-7 An example of how SLR impacts several aquatic tourism resources

Relationships between characteristics were defined using local expertise about Fujairah. As only direct relationships were needed, that simplified this task, as well as the review and verification of the resulting conceptual model (shown in Figures 7-8 and 7-9). In the table the first three letters of the component are abbreviated (e.g., EXT is for *extreme weather events* and AVE refers to *average climate effects*) followed by the characteristic.

Figure 7-9 emphasises that even this relatively simple system (for climate change effects and tourism resources) already has a multitude of relationships representing a complex cause-effect problem that can only be tackled with a tool like RAP.

Impact Analysis of Climate Change Effects	Legend: relations																										
	--- strongly negative -- negative - weakly negative + weakly positive ++ positive +++ strongly positive																										
	EXT flash floods	EXT heat waves	OCE acidity	OCE Sea Level Rise	OCE Sea Surface Temperature	BEA comfort	BEA width	ISL distribution	ISL health	COA marine mammals	COR extent	COR quality	WET distribution	WET health	FRE quality	FRE quantity	MAR fishing	MAR marine-club services	SUR Wadis (valleys)	SUR waterfalls	TOU ease of inside access	TOU ease of open-air access	CUL forts, castles and ancient mosques	CUL heritage village	CUL Souks (traditional markets)	BUJ public parks	
AVE precipitation																											
AVE seasons						-				-			++	+	++	++			++	++							+
AVE temperature						--			-					-	-	-											-
AVE water balance																+++				++							
AVE wind																											
EXT droughts																											
EXT flash floods																											
EXT heat waves						--			-																		
OCE acidity										-	--																
OCE Sea Level Rise							--	-			-	-															
OCE Sea Surface Temperature						-						--															
BEA comfort											++																
BEA width										+																	
ISL distribution																											
ISL health										++																	
COA marine mammals																											
COR extent							++																				
COR quality									+++	+++	++																
WET distribution																											
WET health																											
FRE quality																											
FRE quantity																											++

Figure 7-8 The Fujairah climate change vs. tourism resources system: relationships defined in RAP

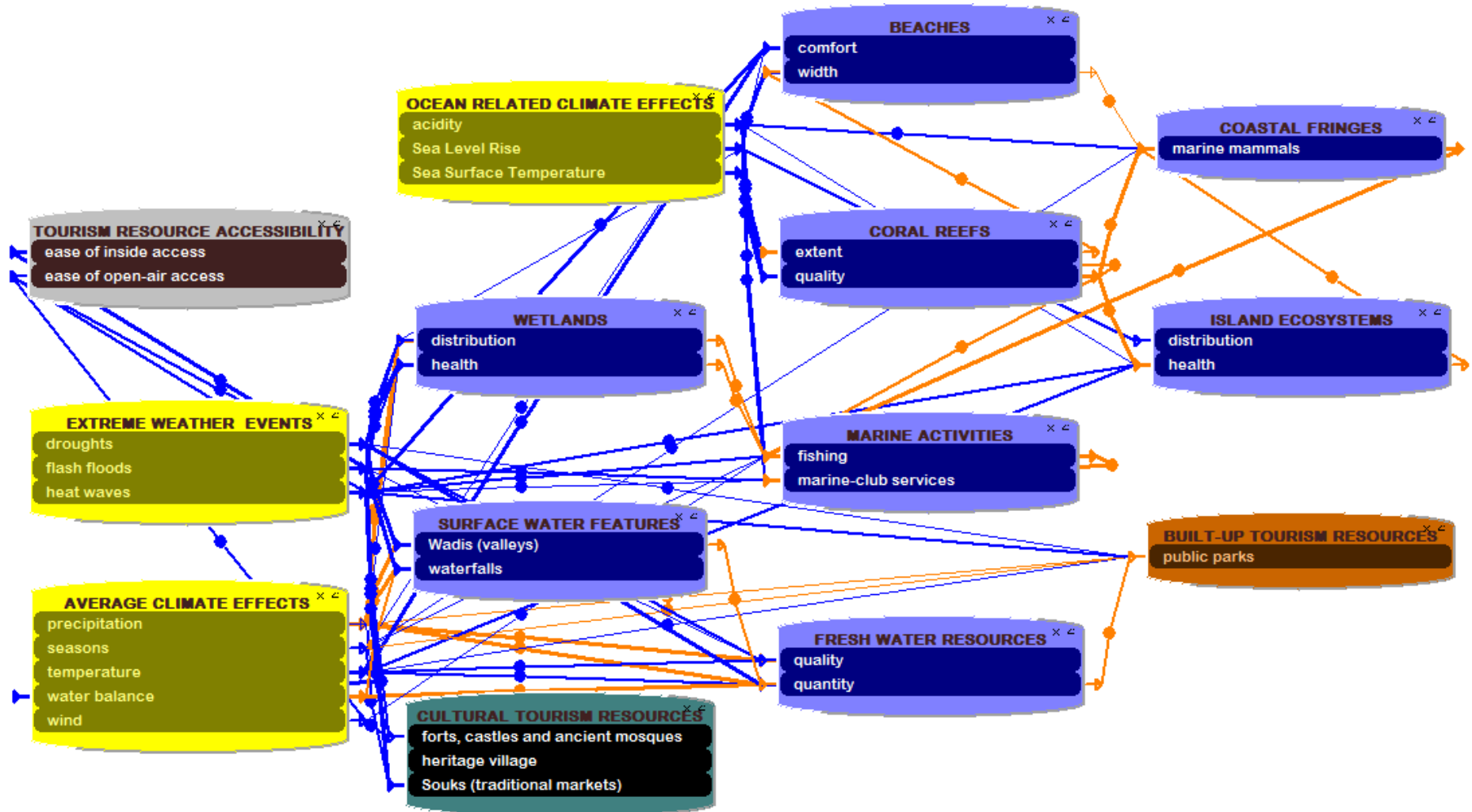


Figure 7-9 The final conceptual model of relationships between characteristics

7.3.3 Defining criteria

After its components, their characteristics and the relationships between these characteristics have been defined, the conceptual model can be applied. First, however, indicators (or criteria) need to be chosen to identify the achievement of the goals specified in the problem definition (section 7.2.1). Figure 7-10 shows how some characteristics of the tourism resources have been mapped on two objectives, (a) the qualitative aspects and (b) the quantitative aspects of the impacts on tourism resources. For example, the ‘comfort’ of the tourism resource *beach* is a ‘qualitative’ aspect while the ‘distribution’ of the *wetlands* is a ‘quantitative’ aspect.

The criteria correspond to selected characteristics in the model that best signal the effect of changes on the system. Thus the RAP model is also a useful tool for identifying indicators for state-of-the-environment reporting (Mason 2008). Usually, three types of indicators can be distinguished. They are linked to 1) the achievement of an objective, 2) the actual implementation of a measure, or 3) the status of the system (van der Werff ten Bosch and Kouwenhoven 2004). These types can overlap. The overall intention of this thesis is to present an approach for managers to use in monitoring the status of and change in their tourism resources, reflected by the type 1 and 3 criteria.

- 1. Qualitative Analysis of the Impact on Tourism Resources**
- BEACHES
 - ◆ comfort
 - ISLAND ECOSYSTEMS
 - ◆ health
 - CORAL REEFS
 - ◆ quality
 - WETLANDS
 - ◆ health
 - FRESH WATER RESOURCES
 - ◆ quality
 - MARINE ACTIVITIES
 - ◆ fishing
 - ◆ marine-club services
 - SURFACE WATER FEATURES
 - ◆ Wadis (valleys)
 - ◆ waterfalls
 - TOURISM RESOURCE ACCESSIBILITY
 - ◆ ease of open-air access
 - ◆ ease of inside access
 - CULTURAL TOURISM RESOURCES
 - ◆ forts, castles and ancient mosques
 - ◆ heritage village
 - ◆ Souks (traditional markets)
 - BUILT-UP TOURISM RESOURCES
 - ◆ public parks
- 2. Quantitative Analysis of the Impact on Tourism Resources**
- BEACHES
 - ◆ width
 - ISLAND ECOSYSTEMS
 - ◆ distribution
 - CORAL REEFS
 - ◆ extent
 - WETLANDS
 - ◆ distribution
 - FRESH WATER RESOURCES
 - ◆ quantity

Figure 7-10 Selection in RAP of characteristics as indicators (criteria) for each of the objectives

7.3.4 Defining the climate changes effects in RAP

In order to determine the *impacts* on tourism resources from climate change, as identified in Chapter 6, the changes in climate need to be defined in RAP so they can be applied to the conceptual model that was constructed in the previous paragraphs, in order to identify how these changes migrate through the system, via the defined relationships, changing characteristics (including the indicators) on their way. Being a generic tool, RAP recognises

two different types of changes: 1) internal interventions, which result from policies, and are implemented by the resource manager (i.e., to counteract climate change), and 2) external influences (exogenous changes) that happen outside the control of the resource manager (i.e., the effects from climate change). RAP then uses the concept of “cases”, combinations of zero or more internal interventions with external influences.

It is important to note that the aim of this chapter was to describe the impacts of predicted climate change effects on tourism resources; consequently, there are no internal interventions to consider (e.g., current government policy). Therefore, the cases defined within RAP only reflect the external influences, and include all climate change effects such as decrease in precipitation, increase in temperature, acidification of the ocean and SLR, as depicted in Figure 7-11.

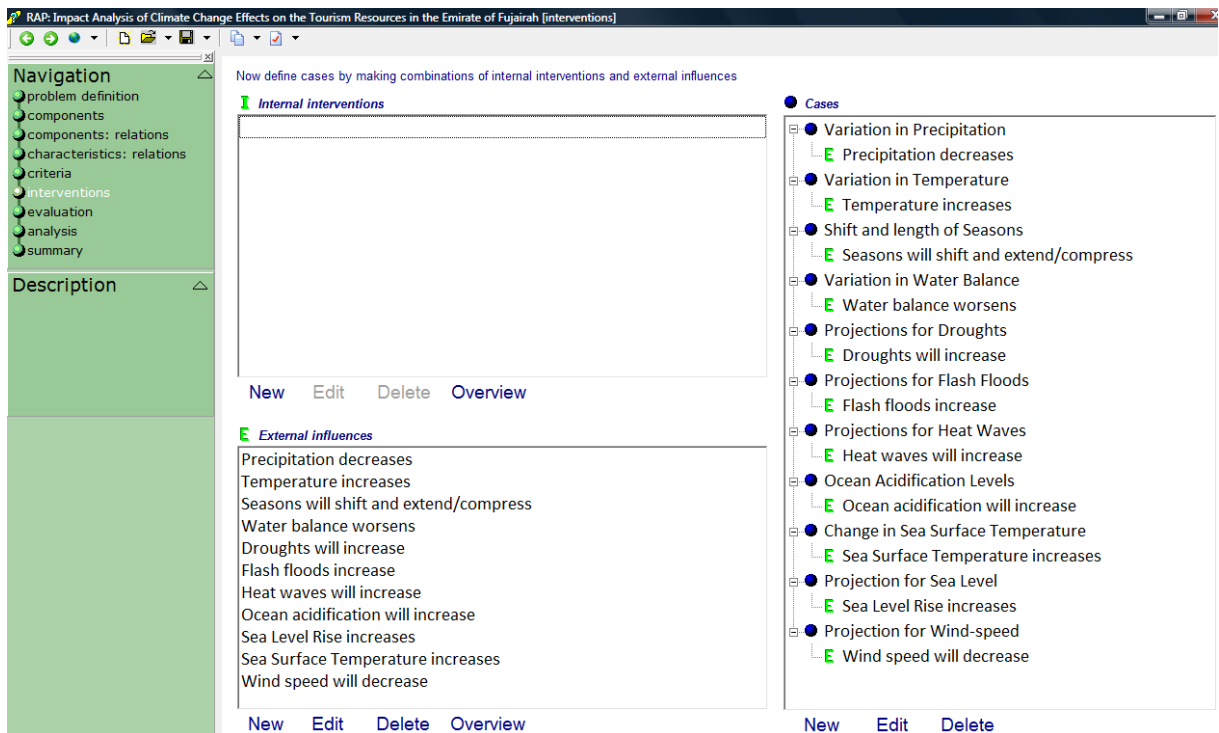


Figure 7-11 Definition of the external influences and cases in RAP

The climate change effects were all characterised as external influences using the definitions (a) – (k) detailed below and based on the results of Chapter 6. The translation of a quantified effect to a qualitative change required by RAP is determined by the importance of a given climate change effect compared to the other effects relating to tourism resources in Fujairah. For example, an increase in the average air temperature of 5°C can be considered a very significant or strong change (represented in RAP as +++). Also, an 11.3% decrease in rainfall

is only a loss of 15mm of rain for Fujairah, and therefore less important as the people of Fujairah have learned to cope with little rainfall. The magnitude (strength) and the direction (positive/negative) for an external influence, takes the form presented in Table 7-4.

Table 7-4 Possible magnitudes and directions of external influences in RAP

<i>Direction</i>	Positive: (increase)	Negative: (decrease)
<i>Strength</i>		
Strong	+++	---
Medium	++	--
Weak	+	-
No Effect	0	0

Using best judgement and recognising that some effects are stronger than others, while there is only a three level scale (weak, medium, strong), the climate change effects from Chapter 6 as defined for RAP in Section 7.2.2 can be summarised as follows:

- (a) **Temperature:** The average temperature in Fujairah is projected to increase by more than 5°C by the year 2070. In an environment where high temperatures are already causing issues, this effect was defined as ‘Strong’ (+++).
- (b) **Precipitation:** Precipitation will decrease by up to 11.3% by 2070. This was defined as a ‘Medium’ (--) effect.
- (c) **Shift in seasons:** Fujairah’s summer season will start earlier and end later. This lengthening was considered a ‘Medium’ (++) effect.
- (d) **Water balance:** The water balance will worsen (decrease by up to 18% by the year 2070) due to the increase in temperature, increasing the potential evapotranspiration, while precipitation will decrease. Given the negative balance in the region, the change was considered to be ‘Medium’ (--).
- (e) **Droughts:** Drought periods are expected to lengthen and droughts of a given intensity are expected to become more frequent. As the current (i.e., long-term average) length of droughts is long (10 months), the variation of the effect was considered to be ‘Medium’ (++) .
- (f) **Flash floods:** Although Fujairah’s total annual rainfall is projected to decrease with climate change, extreme rainfall events will become more intense for a given return period. As the extreme event itself is only relatively extreme (very small compared to extreme rainfall events in wet areas around the world), this change is only considered to be ‘Weak’ (+).

- (g) **Heatwaves:** The projected increase in heatwaves (both in terms of maximum temperature and duration) is the most dramatic effect of climate change in this part of the world. This effect was expressed as ‘Strong’ (+++).
- (h) **Ocean acidification:** Ocean acidification will continue as long as the international community does not take effective action in reducing CO₂ emissions. Once the critical level of 450ppm atmospheric CO₂ is reached (projected for 2030), the impacts on coral reefs become catastrophic. Given that the current emissions are exceeding the most pessimistic projections, this effect was defined as ‘Strong’ (+++).
- (i) **Sea level rise:** Although Fujairah’s expected SLR is 7% higher than the global mean and there is no off-setting vertical land movement, it is a slow process which allows for a delayed response; thus the effect was expressed as ‘Medium’ (++).
- (j) **Sea Surface Temperature (SST):** Because the SST is already high in this area, the ‘relative’ increase is less than in more moderate regions. Thus the effect was estimated to be ‘Medium’ (++).
- (k) **Wind speed:** The average wind speed in Fujairah by the year 2070 is projected to decrease by 4-8% when compared to the baseline. Thus the effect was considered ‘Weak’ (-).

7.3.5 The RAP evaluation process

After all the information from the previous steps was used to build the model, the RAP evaluation process commenced. By applying the changes (the effects from climate change) in each of the defined cases in the conceptual model, RAP calculates how these changes transfer through the cause-effect pathways as defined by the characteristics and the relations between them. A cause-effect pathway describes the chain of characteristics through which changes are passed. For instance a change is introduced into the system that increases A; A is positively related to B, so B is increased as well. Because of the change in B, C changes. A→B→C is the cause-effect pathway. Because many different pathways exist, RAP keeps track of the largest changes, both negative and positive. The results are presented in an outcome table, with the range-of-change per criterion for each of the cases as shown in Figure 7-12.

The length of the longest pathway to be considered can be set in RAP (called ‘order’, thus first, second, third (etc.) order effects can be evaluated), as well as an option to aggregate all changes up to and including that order. By setting a value for the highest order effect to

consider, only cause-effect pathways of that length (and shorter, if the “aggregate” function is used) are considered in the analysis.

To determine the effect of an introduced change (corresponding to a climate change effect), all the cause-effect pathways need to be followed and computed. This can be done in steps, each time looking at longer pathways. At some point, extending the pathways makes no difference to the model outputs. The system stabilises because changes are not amplified as they are passed through (a ‘++’ change cannot become a ‘+++’ change in the next step along the pathway). Sometime the intensity stays the same, but usually the changes fade out when passed on along the cause-effect pathways.

It should be noted that neither increases nor decreases in characteristics automatically translate to a ‘better’ or ‘worse’ situation (i.e., temperature increase is worse, precipitation increase is better). Therefore the user can ‘value’ the results obtained from RAP, i.e., specify whether an increase or a decrease is better.

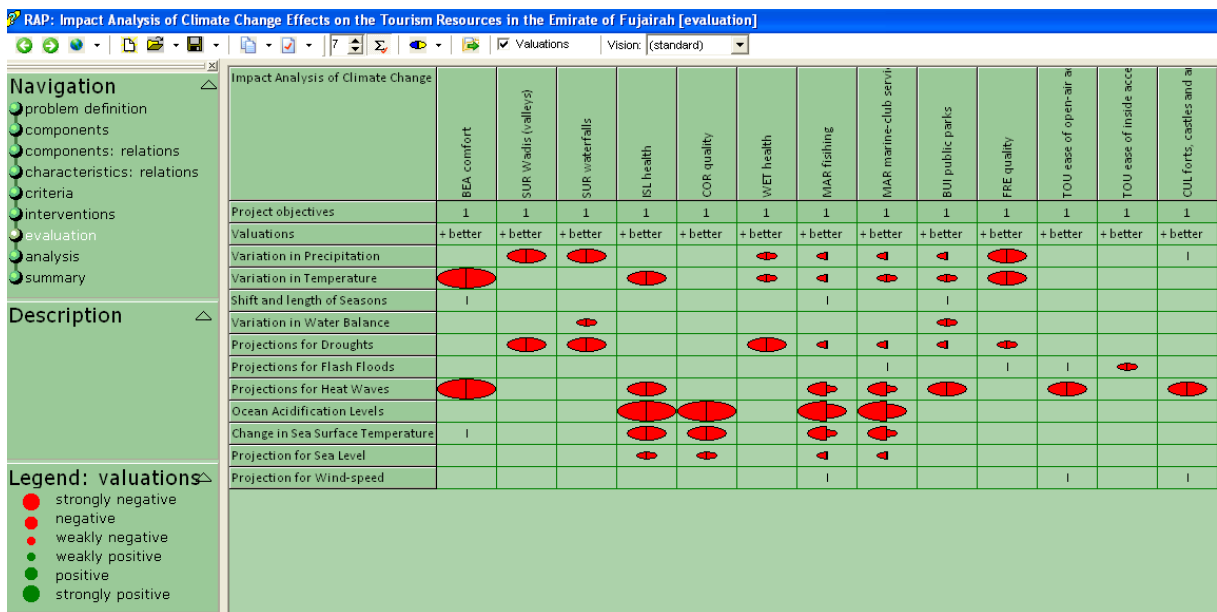


Figure 7-12 Impacts of climate change effects (case, left column) on tourism resources (criterion, top row)

Figure 7-12 shows part of the criteria table containing the valued changes aggregated to the 7th order (as indicated in the toolbar on top). The larger the ellipse, the greater the change. The ‘|’ in the table indicates that there is a cause-effect pathway between the changes introduced by the case (on the left hand side) and the criterion (on top) but, while the introduced change passes through this pathway from characteristic to characteristic, it fades away completely. By the time the pathway gets to the criterion, there is no resulting change in that criterion.

Section 7.3 contains an analysis of some of the properties of the conceptual model for Fujairah's tourism resources, and is followed by an analysis of the results in section 7.4.

7.4 Analysis of the conceptual model

RAP provides various tools to look at the properties of the DPSIR model (Kouwenhoven 2009) in order to gain confidence in its quality and performance:

- (i) A consistency check
- (ii) A cross-correlation matrix
- (iii) A shortest pathway functionality
- (iv) A back-tracking functionality
- (v) A driver-state impact visualisation functionality.

7.4.1 The consistency check

The consistency tool checks the relationships in the conceptual model for specific anomalies that might be unintended and then should be corrected: 1) isolated characteristics (without relationships with other characteristics, thus not having a function in the model), 2) characteristics with only outgoing relationships (which should coincide with the 'hooks' for the external influences), 3) characteristics with only incoming relationships (which normally coincide with some of the criteria), 4) feedback loops, and 5) contradictory cause-effect pathways up to the 2nd order. During the development of the model, the consistency check tool found some issues, but no inconsistencies were located in the final Fujairah conceptual model.

7.4.2 The cross-correlation matrix

The cross-correlation function calculates cross-correlations between the 'climate change effects' (*drivers*) and changes in the 'tourism resources' (*states*). These values are derived from the directions and strengths of the relation pathways that exist between the former and the latter. Cross-correlation values close to $-/+1$ indicate a strong relation while values close to 0 mean poor to no correlation. The higher the (absolute) correlation, the more a change in the driver will be reflected by a change in the state.

A screen capture of the cross-correlation matrix is shown in Figure 7-13.

Impact Analysis of Climate Change	OCE Sea Level Rise	OCE Sea Surface Temperature	BEA comfort	BEA width	ISL distribution	ISL health	COA marine mammals	COR extent	COR quality	WET distribution	WET health	FRE quality	FRE quantity	MAR fishing	MAR marine-club services	SUR Wadis (valleys)	SUR waterfalls	TOU ease of inside access	TOU ease of open-air access	CUL forts, castles and ancient mosques	CUL heritage village	CUL Souks (traditional markets)	BUJ public parks	
AVE precipitation										1.00	0.67	1.00	0.83	0.50	0.50	1.00	1.00						0.44	
AVE seasons			-0.33				-0.33								-0.33	-0.33							-0.67	0.33
AVE temperature			-1.00			-0.67	-0.33					-0.33	-0.67	-0.83	-0.17	-0.33								-0.44
AVE water balance													1.00				0.67							0.67
AVE wind															-0.33	-0.33								-0.67
EXT droughts										-0.67	-1.00	-0.67	-0.83	-0.50	-0.50	-1.00	-1.00							-0.67
EXT flash floods										-0.67	-0.67	-0.33		-0.33	-0.44				-1.00	-0.67				-1.00
EXT heat waves			-1.00			-0.67	-0.33								-0.50	-0.44								-0.67
OCE acidity						-0.67	-0.58	-0.67	-1.00						-0.61	-0.61					-0.67	-0.67		-1.00
OCE Sea Level Rise	1.00			-1.00	-0.67	-0.67	-0.44	-0.56	-0.67	-0.33					-0.33	-0.39								
OCE Sea Surface Temperature		1.00	-0.33			-1.00	-0.83	-0.67	-1.00						-0.78	-0.78								
BEA comfort			1.00																					
BEA width				1.00			0.33	0.67							0.33	0.33								
ISL distribution					1.00																			
ISL health						1.00	0.67								0.67	0.67								
COA marine mammals							1.00								1.00	1.00								
COR extent								1.00																
COR quality									1.00						0.78	0.78								
WET distribution										1.00					0.67	0.67								
WET health											1.00				0.67	0.67								
FRE quality												1.00												

Figure 7-13 Screen capture of cross-correlation values between climate change (*Drivers*, left column) and tourism resources (*States*, top row) for Fujairah

As shown, the cross-correlation between changes in *heatwaves* and changes in the *marine club services* is -0.44. This means that an increase in heatwaves will result in a decrease in *marine club services*. The cross-correlation between change in *coral quality* and changes in *fishing* is 0.78, meaning an increase in the quality of the coral reef would lead to more fishing. The table can be used as a first cut to identify the direction (+ or -) of the impact and the magnitude of the change. Empty cells indicate that no cause-effect pathways exist between the corresponding characteristics.

7.4.3 The shortest pathway functionality

RAP can show the length of the shortest cause-effect pathway between a given climate change effect (driver) and any of the tourism resources characteristics (state). The length is from one characteristic to another following the pathways that are defined in the conceptual model. When there are multiple pathways, the shortest is reported. Figure 7-14 contains a matrix of effects and resources, which allows identification of an expected influence. Thus at least four steps exist between the climate change effect *temperature* and the tourism resource *marine club services*. This is also the longest pathway, as well as the only pathway of that length. If a cell is empty, no pathway exists between the characteristics. The most immediate

level of influence (secondary, tertiary, causal effect) reported gives information on the complexity of the conceptual model. Those models that are easier to formulate, understand and verify are the ones that show low values, indicating that short pathways dominate. The conceptual model for Fujairah’s tourism resources impacted by climate change proved to be such a model.

Impact Analysis of Climate Change Effects	BEA comfort	BEA width	ISL distribution	ISL health	COA marine mammals	COR extent	COR quality	WET distribution	WET health	FRE quality	FRE quantity	MAR fishing	MAR marine-club services	SUR Wadis (valleys)	SUR waterfalls	TOU ease of inside access	TOU ease of open-air access	CUL forts, castles and ancient mosques	CUL heritage village	CUL Souks (traditional markets)	BUI public parks	
AVE precipitation								1	1	1	1	2	3	1	1			1			1	
AVE seasons	1				1							1	2								1	1
AVE temperature	1			1	2				1	1	1	3	4		2							1
AVE water balance											1				1							2
AVE wind												1	2				1	1				
EXT droughts								1	1	1	1	2	3	1	1						1	1
EXT flash floods								1	1	1		2	1			1	1				1	
EXT heat waves	1			1	2							1	1				1	1		1	1	
OCE acidity				1	1	2	1					1	2									
OCE Sea Level Rise		1	1	2	2	1	1	1				2	1									
OCE Sea Surface Temperature	1			2	2	2	1					2	3									
BEA comfort																						
BEA width					1	1						2	3									
ISL distribution																						
ISL health				1								2	3									
COA marine mammals												1	2									
COR extent																						
COR quality				1	1	1						1	2									
WET distribution												1	2									
WET health												1	2									
FRE quality																						
FRE quantity																						1

Figure 7-14 Lengths of the shortest causal pathways between climate change (*Drivers*, left column) and tourism resources (*States*, top row) with same colour = same length

7.4.4 The back-tracking functionality

As the name implies, this functionality in RAP makes it possible to back-track the change in a given tourism resource characteristic to the responsible climate change effect(s); it explains the ‘reasoning’ behind the results generated by RAP. An example of this is shown in Figure 7-15.

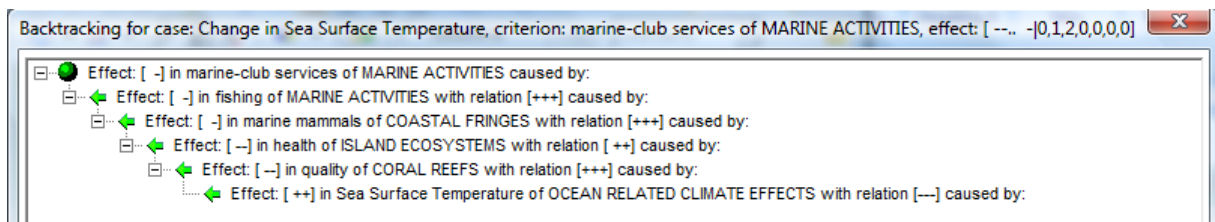


Figure 7-15 Screen-capture of the back tracking functionality

The example shows how a change in *sea surface temperature* (at the bottom) successively influences the tourism resources ‘quality of coral reefs’, ‘health of island ecosystems’, ‘marine mammals (in the coastal fringe)’, ‘fishing (as a marine activity)’ and finally ‘marine club services’ higher toward to the top. It also shows the intensity and direction of each influence. More specifically, a medium increase (++) in SST will cause a medium decrease (--) in the ‘quality of coral reefs’, leading to a medium decrease (--) in the ‘health of the island ecosystems’, which in turn will result in a weak decrease (-) in the number of ‘marine mammals’. A weak decrease in the number of ‘marine mammals’ is shown to weakly decrease (-) the ‘fishing’, and the causal chain ends with a weak decrease (-) in ‘marine club services’.

The back-tracking function is used to analyse the results in the output table (with cases and criteria, Figure 7-16). If a result is unexpected, the back-tracking function can help to understand how RAP calculated the outcome. Sometimes this points to a problem in the conceptual model which can then be corrected.

7.4.5 Analysis using the driver-state impact visualisation functionality

The impacts of climate change on tourism resources were obtained using the ‘evaluation’ functionality in RAP shown in Figure 7-16. The top row shows which outcomes are considered – that is, each of the tourism resource characteristics. The second row shows to which objective the outcomes are linked, for example, the ‘wadis’ *characteristics* under the *component* ‘surface water features’ is linked with the objective number 1 which is *the quality of tourism resources* as stated in section 7.2.1. The left column lists the impacts of climate change analysed for their effects. Effects are shown as ranges, in the form of left and right half-ellipses: the left half is the lower range, the right half is the upper range. Red indicates getting worse and green getting better. The size (small, medium, large) indicates the magnitude of the change (weak, medium, strong). The ranges are the results of the multiple pathways between climate change impacts and outcomes.

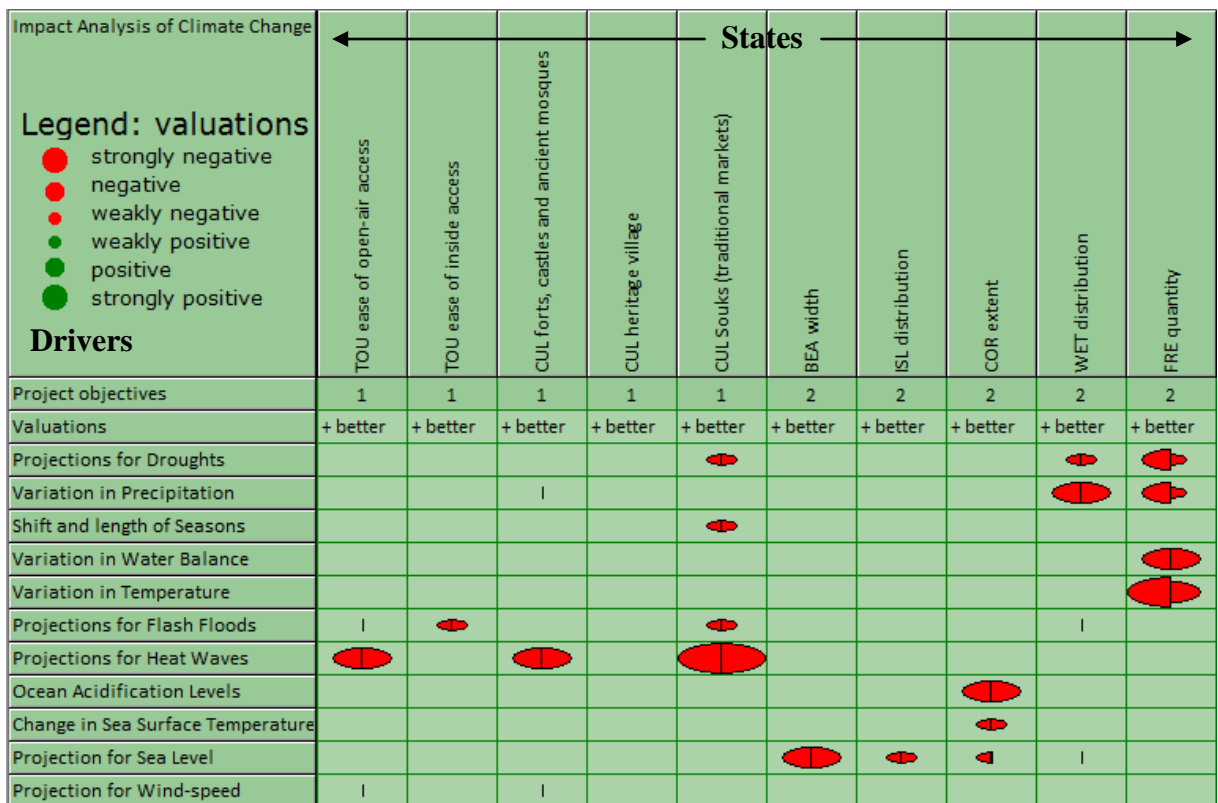
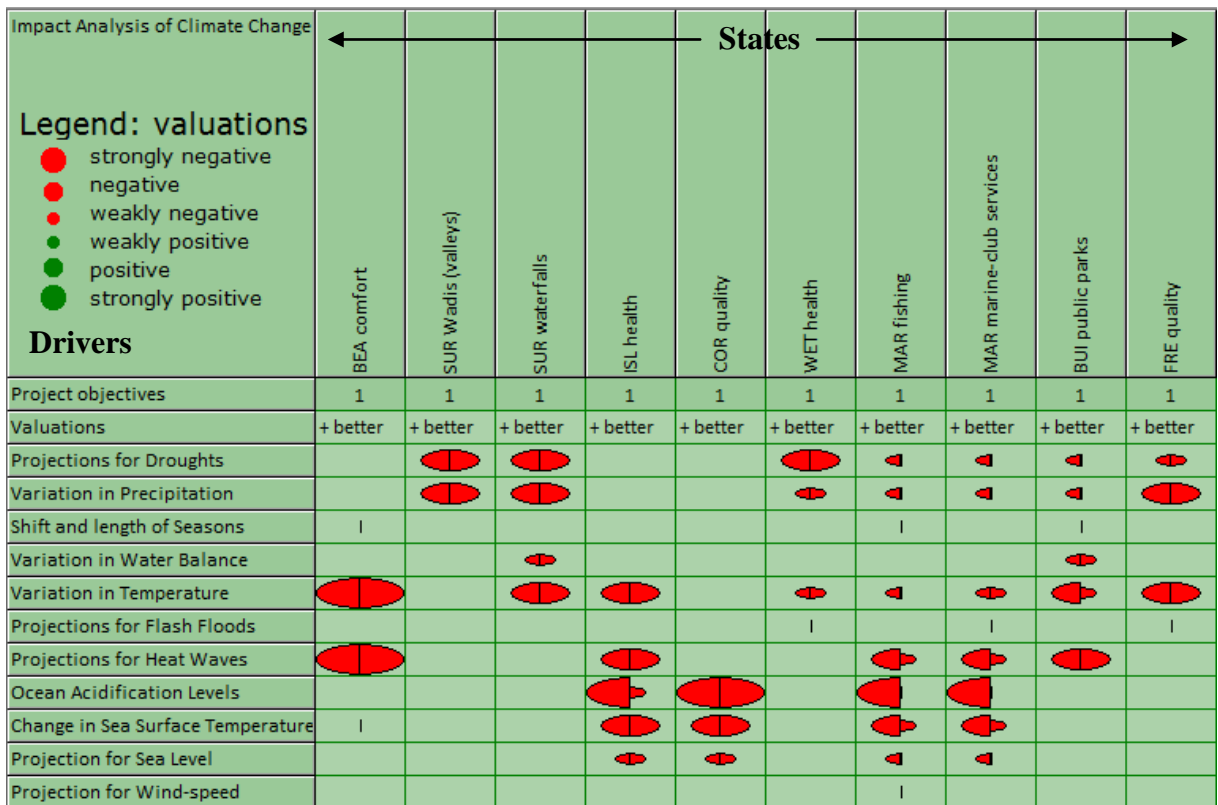


Figure 7-16 Overview of impacts from climate change effects on tourism resources in Fujairah

It should be noted that for every single tourism-resource-related characteristic the valuation decreases (signified by red result ellipses), indicating a worsening of the situation.

Some initial observations from Figure 7-16 are as follows:

- The decreased wind speed has negligible effects: its row is empty; all other climate change effects cause at least one impact
- The distribution of island ecosystem is impacted by only one climate change effect (sea level rise); all other resources have impacts from more than one climate change effect
- Comfort level on the beach is strongly impacted by temperature increase and heatwaves (maximum ellipse size)
- The only other climate change effects with strong impacts are ocean acidification, variation in temperature and heatwaves; all other remaining climate change effects have only moderate or weak impacts on tourism resources.

7.5 Potential impacts of climate change effects on Fujairah's tourism resources

As stated in Section 7.1, an analysis of the impacts on Fujairah's tourism resources from climate change effects can be presented in two ways:

- Analysing those climate change effects that impact a *given tourism resource*
- Analysing the impacts on tourism resources from a *given climate change effect*.

One of the main aims of this thesis is to outline a framework for monitoring that can assist with the management of tourism resources which are impacted by climate change. For this reason the approach was to analyse climate change effects that impact a specific tourism resource, as proposed in Figure 7-17. As it is likely that each tourism resource is managed independently from others, listing resources with all the climate change effects that impact on that resource simplifies the formulation of proper management actions for individual resources.

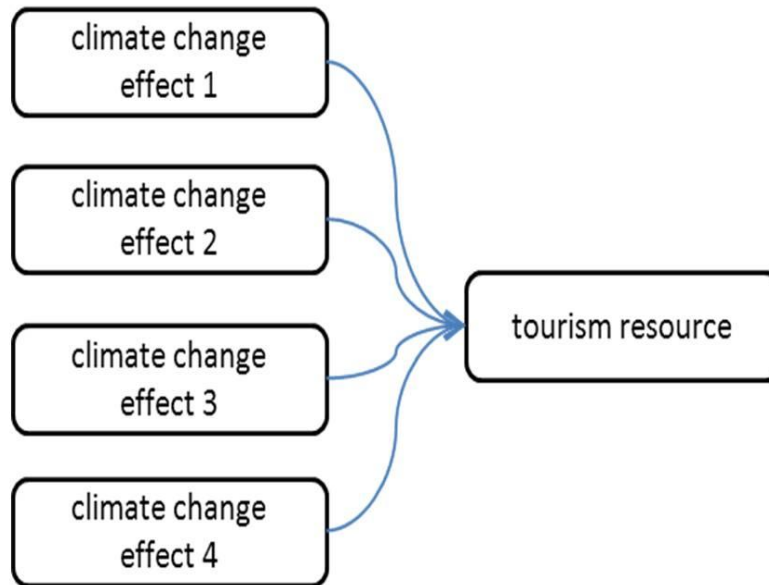


Figure 7-17 Analytical approach centred on tourism resources

The following analysis is an overview of how specific tourism resources in Fujairah are impacted by different climate change effects. The key tourism resources were analysed using the conceptual model built with RAP. Each model result is presented in a separate tabular overview; the top rows distinguish the quality and quantity aspect of the tourism resource while the left columns list the potential climate change effects. The top row of each table uses the first three letters of the *component*, followed by the name of the *characteristic*. For example, for the component *surface water related* the label is SUR followed by the characteristic *waterfall*. The impact on each tourism resources characteristic (negative or positive) and its magnitude is shown by colour and size of effect ellipses. When judging the presented outcomes, it is important to remember that the given impacts are relative to each other; when an effect is medium it means that some other effects are stronger, in other words there is no absolute judgement scale.

7.5.1 Surface-water-related features

Figure 7-18 shows the possible impact of different climate change effects on surface-water-related resources. The two main resources considered, wadis and waterfalls, receive a medium impact from the decrease in precipitation and more extensive droughts. In addition to that impact, waterfalls gets a further medium impact from the variation in temperature. There is also a small impact from the shift in the water balance on the waterfalls (but not on the wadis). Both water systems are totally dependent on the availability of water for at least a

small period of the year; they are directly linked to precipitation. The current variability in rainfall is greater than the slow and small change in precipitation from climate change; therefore, it is possible that a climate-change-induced reduction in water availability is already occurring. This means that this impact must be managed as soon as possible. Degradation of the quality and quantity of surface water will affect resources such as flora and fauna. Other surface water resources in Fujairah, such as hot springs, are likely to receive the same impact. These changes will negatively affect the sustainability of the tourism industry in Fujairah.

Impact Analysis of Climate Change Effects		
Legend: valuations	SUR waterfalls	SUR Wadis (valleys)
● strongly negative		
● negative		
● weakly negative		
● weakly positive		
● positive		
● strongly positive		
Project objectives	1	1
Valuations	+ better	+ better
Variation in Precipitation		
Variation in Temperature		
Shift and length of Seasons		
Variation in Water Balance		
Projections for Droughts		
Projections for Flash Floods		
Projections for Heat Waves		
Ocean Acidification Levels		
Change in Sea Surface Temperature		
Projection for Sea Level		
Projection for Wind-speed		

Figure 7-18 Impact on surface water related resources (Wadis and waterfalls)

7.5.2 Island ecosystems

Fujairah has several islands that attract tourists wanting to see birds or visit the coral reefs. The outcomes from the RAP model reveal that variation in temperature, heatwaves, ocean acidification, SLR and SST are anticipated to have a negative impact on Fujairah’s island ecosystems. Figure 7-19 suggests that the island areas will receive a small impact from SLR. This is because the process of SLR is very slow (only 3-4 cm over a 10-year period, as was

seen in section 6.3.5) and also because the islands have steep coastlines that result in small losses in area. The island ecosystems can tolerate a marginal shift in their boundaries, but the quality/health of the ecosystem is more quickly and strongly impacted by the change in climatic conditions. The strongest impact will come from ocean acidification, which may totally destroy the coral reefs (see below). Overall, the projected increases in air temperature, heatwaves and SST are likely to have a medium impact in these ecosystems. The main reason for this is that ecosystems in Fujairah are already experiencing high temperature conditions.

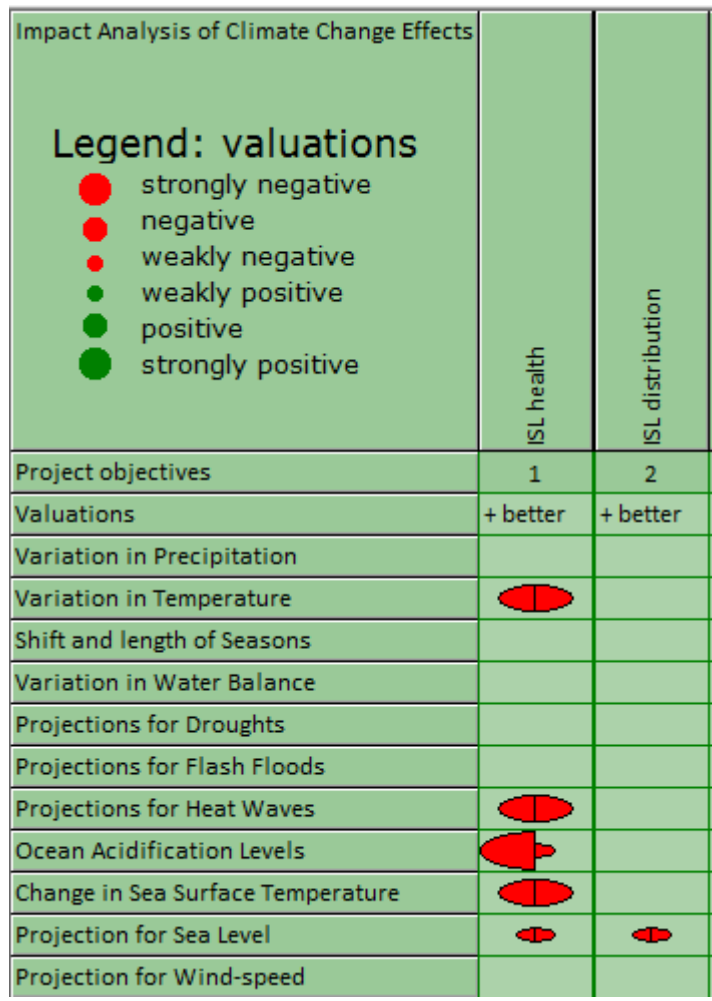


Figure 7-19 Impact on Island Ecosystems

7.5.3 Coral reefs

Coral reefs are one of Fujairah’s most important tourism resources. The impacts on reefs from a change in climatic conditions can be analysed by looking at changes in how healthy (i.e. quality) they are and how much area (extent) they cover. Research shows that climate change effects such as ocean acidification, SST increase and sea level changes threaten coral reefs (Burke et al. 2011; Hughes et al. 2003). Similarly, the outcomes presented below show that

coral reefs are impacted by those climate effects. The highest impact on the coral reefs (Figure 7-20) is from ocean acidification: this will have a strong impact on the quality of the reefs and a medium impact on their extent. Once atmospheric CO₂ rises above 450ppm (which will occur in about 20 years, given the current level of 395ppm and a yearly increase of 2-3ppm), more than 80% of the world’s coral reefs will be catastrophically damaged (Cao and Caldeira 2008). Acidification slows and eventually totally stops the growth of the reefs; in conjunction with SLR, this may cause the reef area to shrink. An increase in SST (which is already stressing the coral reefs) will impact the health (medium scale) and extent (small scale) of the reefs. The slow rise of sea level (3.1 mm/year being the current global average) (Grinsted, Moore and Jevrejeva 2010) by itself will have a small direct impact on coral reefs. If coral reefs disappear, many reef-dependent species will not survive.

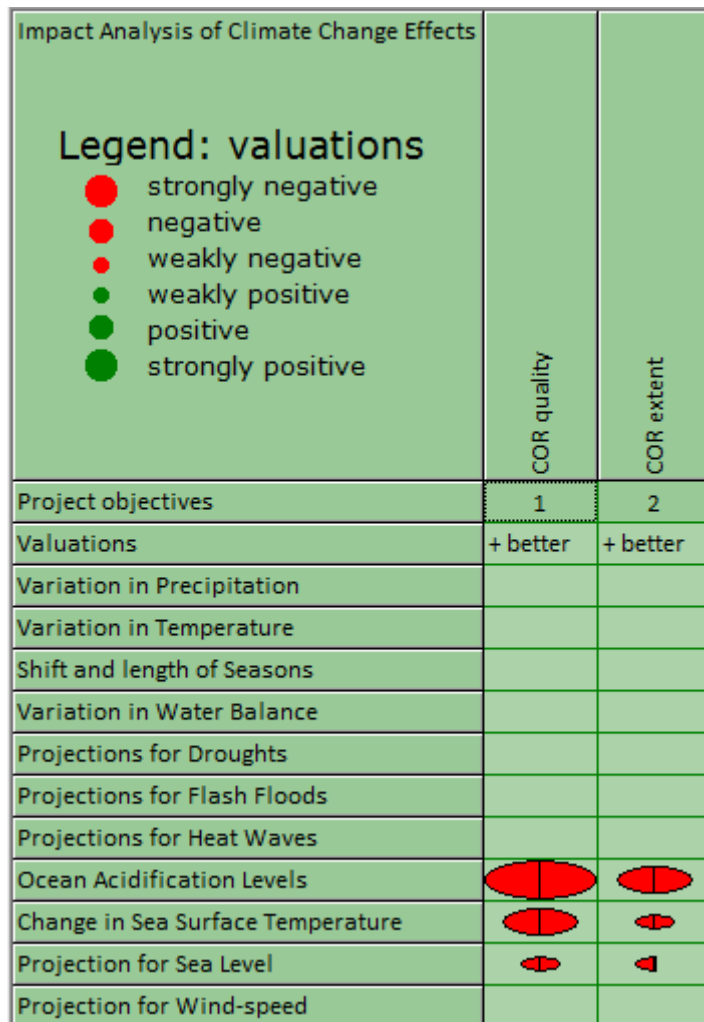


Figure 7-20 Impact of climate change on Fujairah’s coral reefs

7.5.4 Beaches

Two important aspects of beaches as tourism resources are analysed in this chapter, namely the quality of the beach in terms of physical characteristics (referred to here as *comfort*) and its quantity, that is, beach *width*. The comfort of the beaches (Figure 7-21) is strongly impacted by the increase in temperature and more extreme heatwaves. (Comfort is not to be confused with tourists' like or dislike of the beach, rather it refers to the temperature of the beach and sand and its environment.) In addition, causal pathways such as longer summer seasons and increased SSTs exist but lead to negligible impacts. The width of the beaches is directly impacted by SLR and indirectly through the loss of coral reefs (due to increased of ocean acidity, as described above). The degradation of coral reefs which supply sand to beaches and also dissipate wave energy is an important factor contributing to beach erosion (Waite et al. 2011).

Impact Analysis of Climate Change Effects		
Legend: valuations	BEA comfort	BEA width
	1	2
Project objectives	+ better	+ better
Variation in Precipitation		
Variation in Temperature		
Shift and length of Seasons		
Variation in Water Balance		
Projections for Droughts		
Projections for Flash Floods		
Projections for Heat Waves		
Ocean Acidification Levels		
Change in Sea Surface Temperature		
Projection for Sea Level		
Projection for Wind-speed		

Figure 7-21 Impact of climate change on Fujairah's beaches

7.5.5 Wetlands

The Ramsar Convention's definition of wetlands is:

Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m (Wheeler and Proctor 2000).

Fujairah has several areas which fit this definition, such as the Wurayah and Soda wetlands. In 2009, the former was announced as the first mountain protected area in the UAE due to the richness and international importance of its flora and fauna (Tourenq et al. 2009). In this section the *distribution* (extent) and *health* (quality) of wetlands are considered.

As Figure 7-22 shows, the *health* of Fujairah's wetlands is predicted to be impacted by extreme droughts on a medium level and weakly by the decrease in precipitation, while the *distribution* of wetlands will be weakly impacted by extreme droughts and suffer a medium impact from the decrease in precipitation. This is explained by the fact that the extent of a wetland location varies with the seasons (essentially due to the quantity of water available), and will experience a permanent decrease in (average) area from the slow decrease in annual precipitation (and less from the already long droughts). Wetland health is also weakly impacted by increased temperature. Further, there is negligible effect from flash floods on the *health* of wetlands. There is a causal pathway between SLR and the *distribution* of coastal wetlands, but the effect is negligible; wetlands will probably shift more inland with the rise of the sea.

Impact Analysis of Climate Change Effects	WET distribution	WET health
	2	1
Legend: valuations		
● strongly negative		
● negative		
● weakly negative		
● weakly positive		
● positive		
● strongly positive		
Project objectives	2	1
Valuations	+ better	+ better
Variation in Precipitation		
Variation in Temperature		
Shift and length of Seasons		
Variation in Water Balance		
Projections for Droughts		
Projections for Flash Floods		
Projections for Heat Waves		
Ocean Acidification Levels		
Change in Sea Surface Temperature		
Projection for Sea Level		
Projection for Wind-speed		

Figure 7-22 Impact of climate change on Fujairah’s wetlands

7.5.6 Coastal fringes

Fujairah’s coastline comprises sandy beaches, rocky foreshore and cliffs. Marine species like dolphins and turtles are found in the coastal zone. Both species are vulnerable to sea and air changes driven by climate change. Fujairah is known for its wonderful marine biodiversity, but some of its fauna (e.g., the green turtle) are endangered or becoming extinct.

Figure 7-23 shows that marine mammals in Fujairah’s coastal area are impacted by five different climate change effects. The most important is ocean acidification, which degrades coral reefs that are breeding and hatching areas and provide shelter and food. An increase in SST is the next most significant change, as SST is already high in this region. Temperature increase, heatwaves and SLR follow with weak effects. The projected longer summer season has a negligible impact.

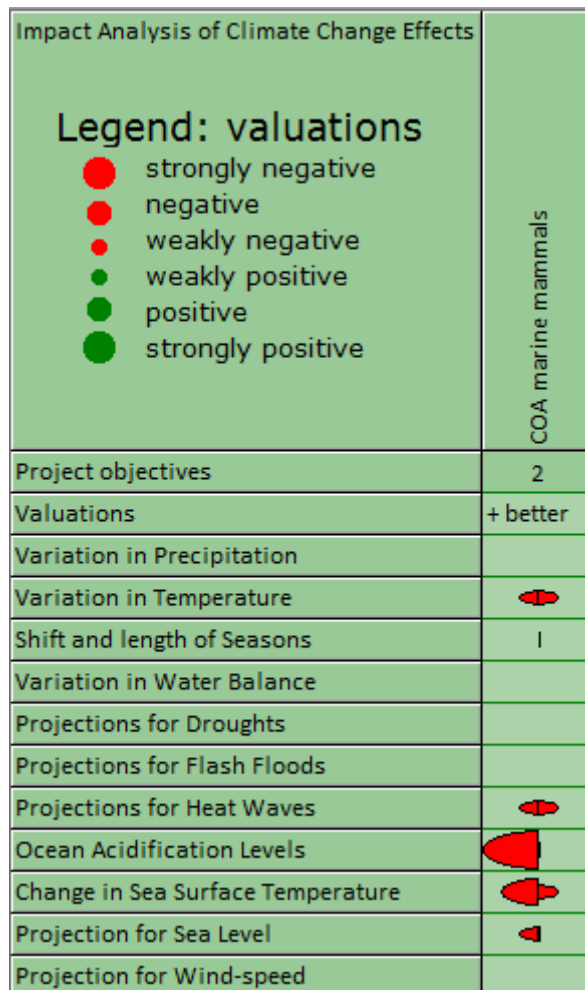


Figure 7-23 Impact of climate change on Fujairah’s coastal fringes

7.5.7 Fresh water resources

Fresh water for domestic use in Fujairah comes from desalination plants and groundwater (wells). The effects of climate change on the hydrological cycle directly and indirectly affect groundwater (Green et al. 2011). According to Figure 7-24, the projected impacts on fresh water resources are related to temperature (climate) and precipitation (climate and weather; extreme droughts). These will likely result in a medium negative impact on the quality of the water due to the decrease in precipitation as well as increased air temperature; it is expected that groundwater will become more salty as a result of sea water intrusion. More frequent and worse droughts will affect groundwater by changing the properties of the soil, delaying penetration of water and thus allowing sea water to mix with fresh water, with a weak negative impact as shown in the Figure (Shangguan and Zheng 2006). Furthermore, a medium to weak impact on the quantity of water was predicted to result from variation in precipitation and projected drought. The availability of fresh water was seen to suffer a strong to medium impact from an increase of air temperature. The change in the water balance has a medium

impact on the availability of fresh water. There is a causal link to flash floods in terms of quality, but with a negligible effect. The relationship between climate variables and groundwater is more complicated than with surface water (Holman 2006).














Impact Analysis of Climate Change Effects		
	FRE quantity	FRE quality
Legend: valuations		
 strongly negative		
 negative		
 weakly negative		
 weakly positive		
 positive		
 strongly positive		
Project objectives	2	1
Valuations	+ better	+ better
Variation in Precipitation		
Variation in Temperature		
Shift and length of Seasons		
Variation in Water Balance		
Projections for Droughts		
Projections for Flash Floods		1
Projections for Heat Waves		
Ocean Acidification Levels		
Change in Sea Surface Temperature		
Projection for Sea Level		
Projection for Wind-speed		

Figure 7-24 Impact of climate change on Fujairah’s fresh water resources

7.5.8 Marine activities

Fishing activities and the marine club services (Fig 7-25) are impacted by climate change in an almost identical fashion. These tourism resources will experience nine different impacts of climate change (including two negligible). The strongest impact is from ocean acidification, which impacts coral reefs and therefore fish resources. Second is the increase in SST, again affecting coral reefs, and then heatwaves impacting at a low to medium range. All other impacts are weak to negligible.

Impact Analysis of Climate Change Effects		
Legend: valuations		
	MAR fishing	MAR marine-club services
● strongly negative		
● negative		
● weakly negative		
● weakly positive		
● positive		
● strongly positive		
Project objectives	1	1
Valuations	+ better	+ better
Variation in Precipitation	◀	◀
Variation in Temperature	◀	◀
Shift and length of Seasons		
Variation in Water Balance		
Projections for Droughts	◀	◀
Projections for Flash Floods		
Projections for Heat Waves	▶	▶
Ocean Acidification Levels	▶	▶
Change in Sea Surface Temperature	▶	▶
Projection for Sea Level	◀	◀
Projection for Wind-speed		

Figure 7-25 Impact of climate change on Fujairah’s marine activities

7.5.9 Cultural tourism resources

Heatwaves have a medium impact on cultural resources such as forts, castles and ancient mosques (see Figure 7-26). As these resources were built more than 400 years ago, they are prone to cracking and erosion. The decrease in precipitation and decrease in wind speeds will have causal effects, but the impacts are negligible. Heritage villages, usually built from traditional materials and designed to withstand the aridity of the region, are not directly impacted by any of the expected climate change effects.

The traditional souks are strongly impacted by heatwaves and weakly impacted by the shift of seasons, flash floods and droughts. This is because the markets are an outdoor tourism resource and are also impacted by the availability of local produce.











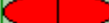
Impact Analysis of Climate Change Effects	CUL forts, castles and ancient mosques	CUL heritage village	CUL Souks (traditional markets)
Legend: valuations			
 strongly negative			
 negative			
 weakly negative			
 weakly positive			
 positive			
 strongly positive			
Project objectives	1	1	1
Valuations	+ better	+ better	+ better
Variation in Precipitation			
Variation in Temperature			
Shift and length of Seasons			
Variation in Water Balance			
Projections for Droughts			
Projections for Flash Floods			
Projections for Heat Waves			
Ocean Acidification Levels			
Change in Sea Surface Temperature			
Projection for Sea Level			
Projection for Wind-speed			

Figure 7-26 Impact of climate change on Fujairah’s Cultural Resources

7.5.10 Built-up tourism resources

Built-up tourism resources are either indoor, such as shopping malls, or outdoor, like public parks. The impacts of climate change on Fujairah’s public parks are mostly weak to negligible because they are actively managed and irrigated, so any climate change effect is likely to be mitigated. The bigger issue is from more extreme heatwaves (see Figure 7-27). Irrigation facilities might not be able to deal with longer periods of really high temperatures that threaten vegetation in the parks.

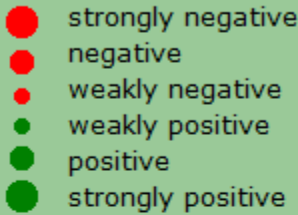





Impact Analysis of Climate Change Effects	
Legend: valuations 	
	BUJ public parks
Project objectives	1
Valuations	+ better
Variation in Precipitation	
Variation in Temperature	
Shift and length of Seasons	
Variation in Water Balance	
Projections for Droughts	
Projections for Flash Floods	
Projections for Heat Waves	
Ocean Acidification Levels	
Change in Sea Surface Temperature	
Projection for Sea Level	
Projection for Wind-speed	

Figure 7-27 Impact of climate change on Fujairah’s built-up resources

7.5.11 Tourism resource accessibility

Two types of access (Fig 7-28) to tourism resources were considered: access to open-air resources, which is moderately impacted by heatwaves (e.g., it is less attractive to go to the local market when there is a heatwave), and access to indoor resources (e.g., museums) which suffer from wind speed and flash floods (they make it harder to reach these resources).

Impact Analysis of Climate Change Effects		
Legend: valuations	TOU ease of open-air access	TOU ease of inside access
● strongly negative		
● negative		
● weakly negative		
● weakly positive		
● positive		
● strongly positive		
Project objectives	1	1
Valuations	+ better	+ better
Variation in Precipitation		
Variation in Temperature		
Shift and length of Seasons		
Variation in Water Balance		
Projections for Droughts		
Projections for Flash Floods		●
Projections for Heat Waves	●	
Ocean Acidification Levels		
Change in Sea Surface Temperature		
Projection for Sea Level		
Projection for Wind-speed		

Figure 7-28 Impact of climate change on Fujairah’s tourism resource accessibility

7.6 Summary

This chapter focused on analysing the potential impacts of future climate change, as projected using the SimCLIM tool in Chapter 6, on the tourism resources of Fujairah. Such an analysis is not a trivial task, as the causal links between the changes in the climate system and their impacts on the tourism resources are complex. In addition, this situation does not allow for experimentation; it is not possible to temporarily introduce climate change in Fujairah and observe its impacts on tourism resources. Thus the analysis of the potential impacts had to be performed solely through induction: first understanding the magnitude of the climate change effects, then assessing the potential relationship between weather/climate conditions and specific tourism resources, and finally combining the two. This had to be done in a robust, structured, verifiable, reproducible and defensible way.

The methodology used the DPSIR framework to construct a conceptual model in order to analyse the impacts of climate change on tourism resources. RAP software was used for this

purpose. This tool facilitates the building of conceptual models on the basis of the qualitative relationship between characteristics through a graphical interface. The steps carried out with RAP allowed for the identification of both the climate change effects that will influence a given tourism resource and the intensity of the likely impacts.

The results presented in this chapter show that tourism resources in Fujairah are being and will continue to be impacted by climate change effects in multiple ways. Increased temperatures and the continuing acidification of the ocean will impact tourism resources most severely. This can be attributed to high temperatures already being an issue for the region, while the vulnerability of coral reefs and their importance as a tourism resource explains the priority of ocean acidification.

These outcomes provide valuable insights for tourism management, enabling targeted monitoring of resources as well as the formulation of adaption strategies to manage the impacts of climate change effects and/or identification or creation of alternative tourism resources, thereby contributing towards a sustainable tourism industry in Fujairah.

A further discussion of the overall results is presented in the final chapter of this thesis. The next chapter contains possible approaches for monitoring temporal changes occurring to the tourism resources in Fujairah.

Chapter 8 A Pilot Study to Monitor Changes in Fujairah’s Tourism Resources

8.1 Introduction

Chapter 6 presented an overview of the likely effects of climate change, both for the relatively slow changes in average (temperature and rainfall) projected for 2070, and for the faster changes in the extremes projected for 2030. These effects should be considered in terms of increased risks; society already deals with weather and climate, and necessary measures are taken to lower the risks from its severity. Risk is a function of probability of a climate/weather effect, and the severity of its impact. Changing climate and weather change increase the probability and the magnitude of the impact, and measures need to be taken to bring the risks back to the accepted level. As the focus of this research is on tourism resources, Chapter 7 identified the impacts of climate change on tourism resources in Fujairah – which resources will be impacted, and the magnitude of the impact. This assessment was based on qualitative magnitudes of the climate change effects (weak, medium or strong), and knowledge of the local tourism resources. Direct impacts were considered as well as indirect impacts operating through other changes.

Monitoring changes in tourism resources could make decision-makers aware of the rates of change and their causes. This chapter introduces possible approaches for monitoring temporal changes occurring to tourism resources. It covers small and large-scale changes and the tools that can be used to measure the changes.

8.2 Monitoring uncertainties

The assessment of climate change impact on tourism resources involves many uncertainties. These uncertainties derive from multiple sources: for example, in the assumed emission scenarios and climate sensitivity, in the GCMs used for the projection of the change in climate, in the observations of local weather, in the qualification of the climate change effects, in the development of the qualitative model of tourism resources, their interrelationships and the way they are affected by climate and weather. The research dealt with these uncertainties by focusing on the largest possible ultimate effects and impacts. People tend to interpret uncertainty as “we do not know exactly what is going to happen at a certain point in time”. However, as climate change is continuing to accelerate and affects our environment, in this

case it can better be interpreted as “we do not know when something is going to happen”. Extreme high sea levels and extreme high temperatures will be reached at some point.

In some ways the inevitability of climate change impacts makes the tourism resources managers’ tasks easier. Decisions with a long-reaching effect (e.g., the building of a sea wall or a hotel) should take into account the potential extreme climate change effects and impacts, regardless of them being forecast to occur in 40 or 70 years. Other decisions are more sensitive to the timing and magnitude of the effects and impacts of climate change.

One way to deal with uncertainty is to gather more information. Managers of tourism resources should consider monitoring the following aspects:

- Climate change effects: Are the effects (as projected in Chapter 6) occurring at the projected magnitude and timing? (Or are they less or more severe, and happening slower or faster?)
- Climate change impacts: Are the impacts (as projected in Chapter 7) occurring at the projected magnitude? What is the probable timing of the impacts?
- Measures/responses taken to mitigate or adapt regarding the impacts: Are measures being implemented? Are the measures successful (this requires careful definition of ‘success’)? Are the measures causing unintended negative side effects?
- Non-projected effects and impacts: Monitoring should be broad enough to capture changes caused by climate change not identified by this research.

A process should be created that includes all aspects of monitoring:

- What should be monitored?
- How should it be monitored?
- When and how often should it be monitored?
- What is the monitoring methodology?
- What is the required precision?
- What are the expected results?
- What is the action to be taken when these results are not met?
- Who is responsible?
- How is quality control performed?
- How is the monitoring plan and approach evaluated?

8.3 Detection of changes in Fujairah's tourism resources

Many tourism resources in developing nations are historic in nature and are subject to environmental and human pressures that are not so pronounced in developed countries. In addition, developing country tourism resources are not so well understood or researched (Nuñez and Pauchard 2010; Oppermann 1993; Zhong et al. 2011), and baseline models for managing change have not been created. Consequently, among the proactive measures required, the most prominent one is the ability to monitor the changes (irrespective of the nature and scale) occurring to tourism resources over time. Such monitoring will assist in understanding the susceptibility and elasticity of a given resource (Rio and Nunes 2012). Finally, monitoring will aid with restoration planning and management.

The Emirate of Fujairah is yet to possess the technology required for monitoring, detecting and quantifying the changes in tourism resources due to climate change. The outer wall of a tourism resource such as an ancient mosque could erode by as little as 1-2 mm per year (Burbank 2002) or develop cracks due to climate change effects. However, the early detection of these changes is of paramount importance to prevent further degradation of the original structure. A discussion of the different types of tourism resources that are susceptible to climate change effects was provided in Chapter 5. Very few existing studies document changes that are likely to occur in tourism resources. In practice, it is hard to prove that any damage to tourism resources is caused by climate change because human activity may sometimes cause the same effects. However, the rate of natural deterioration is exacerbated by climate change. It is, however, characteristics of tourism resources that can determine which climate conditions may have direct impact on them, therefore changes in particular climatic conditions plausibly result in more pressure on those resources.

For example, in Iran (a developing country), many cultural resources and in particular historical buildings are deteriorating due to fluctuations in temperature, moisture and seasonal variations (Ganje, Hezbkhah and Maashkar 2011). The destruction is directly due to the effects of atmospheric pollution and changes in climatic conditions may worsen the effects. The methods used to document change on Iran's historic tourism resources were frequent inspection and maintenance. The observation method usually makes substantial assumptions about whether the observed changes are due to internal climate variability or land-use change, especially in small areas (Hegerl and Zwiers 2011). In addition, a closely related technique that discriminates between slow changes in climate and shorter timescale variability to

identify in observations a pattern of surface temperature change associated with long timescales was used and tested (Schneider and Held 2001).

8.3.1 Expected change in tourism resources

Cultural tourism resources such as historic buildings are vulnerable to normal weather effects such as erosion from rain. Climate change puts additional stress on Fujairah's ancient forts and castles. The Fujairah Fort, for example, is constructed from natural materials harvested from the immediate environment, including rocks, wadi boulders, mud bricks, clay, date palm materials and hardwood. The annual change expected is very small, measureable in millimetres to centimetres. Thus a very sensitive detector is needed to detect changes in the Fujairah Fort, and must be non-invasive to avoid damaging the building.

Natural tourism resources are also vulnerable to change, and these changes frequently cascade from one resource to another. Surface water in Fujairah's reservoirs, for example, is forecast to decrease in coming decades. As described in chapter 6, in every five-year period Fujairah experiences at least 300 days without rain. Water shortages can be estimated by calculating the water volume in dams or by spatial analysis using map algebra. Fujairah beaches, which attract many international and local visitors, are similarly vulnerable to change. Beaches naturally advance and recede according to the Bruun Rule (see section 6.3.6); however, SLR and other climate change effects make beaches more susceptible to erosion. In Turkey, Kuleli et al. (2011) studied shoreline change on coastal Ramsar wetlands and observed wetland change of more than 765 m with an erosion rate of 20.7 m/yr in one site. Their method was based on multi-temporal Landsat satellite images. In Fujairah however, a loss of coastline at Al-Aqah beach of up to 14 m is projected by the year 2100 compared to 1990 (average 0.13 m/yr), as calculated in section 6.3.6. Obviously, monitoring Al-Aqah beach will require a higher satellite image resolution than used by Kuleli et al. (2011), because Landsat has a spatial resolution of 30 m, insufficient for monitoring Fujairah beaches. For example, the IKONOS satellite can provide images with one metre resolution.

8.3.2 Detection limits

The limitations on our ability to detect change in tourism resources as a result of climate change impact derive from several sources. There are limitations in the sensitivity of the instruments being used, the availability of tools required to do the work as well as their cost, the knowledge of the phenomena being monitored, and limitation of temporal scale to determine the change rate.

Measuring instruments have limits on their capability in terms of accuracy and limits of detection. Highly sensitive technology that can detect a small change has associated limitations, such as being unable to detect changes at a distance. Ground-based instruments can miss surface data such as roofs and hidden line of sight locations, and air-base monitoring produces errors in vertical measurements.

The unavailability of the right tools can inhibit change detection. Authorities in developing countries may have difficulty in finding funds to acquire the necessary high-resolution instruments, but need to do so if their income-producing tourism resources are to be managed sustainably.

Human activities can interfere with the monitoring of climate-change-induced events such as drought or shore line erosion. For example, in developing countries where water is already scarce, agricultural irrigation might cause water shortages. Coastal engineering projects may cause changes to shorelines.

Finally, other factors limiting change detection are time constraints; it is not possible to undertake change detection without at least two scans over time. This is an important limitation, as longer intervals between scans are needed to detect small changes. Moreover, scan intervals may vary for different tourism resources and even for different parts of the same resources, further complicating monitoring. For example, to detect change in cultural resources such as historic buildings constructed from mud bricks and date palm, surfaces that face the prevailing wind may erode millimetres or centimetres per year faster than those on the lee side.

8.3.3 Technologies available to monitor change

Detecting and tracking micro (one metre or less) and macro (larger than one metre) changes occurring to tourism resources over extended periods of time constitutes a major part of the strategy to preserve them in the long term. Technologies capable of use for change detection are unmanned aerial vehicles (UAV), total stations, light detection and ranging (LiDAR), terrestrial laser scanning (TLS), vehicle-based laser scanning (VLS), and terrestrial photogrammetry, as well as aerial and satellite images. These technologies can be used solely or combined with each other for improved results.

The agricultural sector contributes directly and indirectly to the tourism industry through providing food and maintaining green scenery and attractive trees. In order to monitor change

in the agricultural sector in Spain, Ruiz (2011) used UAV coupled with TLS to characterise individual trees within forested and agricultural ecosystems. The TLS was used to investigate the impact of vegetation architectural parameters on the quantitative estimation of physiological indicators of stress (i.e. evapotranspiration, and leaf chlorophyll content) using UAV (Ruiz 2011). The use of UAV may help in reducing risk in environments dangerous to human life through remote data acquisition (Everaerts 2008). TLS can give high resolution data in a short period of time relative to manual collection.

TLS and LiDAR (or ALS) were used at Tanah Rata and Habu in the Cameron Highlands of Malaysia to study the behaviour of landslides (Wan Aziz et al. 2012). This study proved the ability of TLS and ALS to obtain reliable 3D slope information over unstable areas. Many other researchers have relied upon TLS for determination of surface change as small as several centimetres (Chang et al. 2008; Milev and Gruendig 2008; Schäfer et al. 2004).

Ground-based TLS cannot be used for monitoring a large area; aerial images or LiDAR are more appropriate. The resolution of an aerial image is usually higher than that of LiDAR data (Nakagawa and Shibasaki 2003). Using aerial images for observing change in tourism resources such as beaches and surface water resources is the fastest and most accurate way to obtain data. It is worth mentioning that the UAE has recently started to rely more on aerial spatial data gathered from various satellites and in 2009 launched its own satellite, called Dubai Sat-1 (Al Rais, Al Suwaidi and Ghedira 2009). Satellite data applications including infrastructure development, urban planning and environment monitoring and protection are currently possible in the UAE.

Fujairah's tourism resources are continuously subjected to degradation and change due to natural factors such as variations in weather and the climate, sandstorms and atmospheric pollution – especially resources that are fragile or sensitive in nature (Hall 2011; Price 1997). For example, sandstorms are a frequent phenomenon in the UAE (Miller 2004) and are responsible for continuous degradation of historic buildings (Armesto-González et al. 2010). These resources also undergo large-scale changes due to sudden catastrophic weather or the long-term accumulation of slower climate change effects. Hence, it is essential that these sites of importance are regularly monitored and managed to maintain their importance as major tourism attractions. Detecting and tracking micro and macro changes occurring to these resources over extended periods of time constitutes a major part of the strategy to preserve them in the long term.

8.4 TLS-based micro change detection for Fujairah’s tourism resources

After careful comparison with other techniques such as total stations, terrestrial photogrammetry and airborne LiDAR, the TLS technology was selected to test the capability of monitoring micro change in some of Fujairah’s tourism sites.

With the approval of the FTAA, the TLS technology was employed on several archaeological, heritage and natural tourism resources in Fujairah during January 2012. The objective was to identify and explore the applicability of TLS technology for the long-term monitoring of the emirate’s tourism resources with respect to climate change effects as well as to establish a baseline. This field work is the first of its kind for the FTAA, and will provide it with a standard to compare against any further monitoring to determine if drastic changes are occurring. Ongoing monitoring will help the emirate to preserve its natural, cultural and built-up resources over the long term.

8.4.1 Detailed description of TLS

As stated in section 2.6.2.3, TLS has been successfully applied in the documentation of historic buildings, archaeological features and natural features all over the world and is expected to become the future standard tool for high-resolution 3D documentation (Brenner, Dold and Ripperda 2008; Lermaa et al. 2010). It is suitable for swiftly collecting reliable, high-resolution data and can save hundreds of person-hours of effort. The scanned data can also be used for restoration planning and creating virtual reality models. 3D TLS is being applied in areas such as architecture (e.g., facade scans (Moorthy et al. 2011)), project visualisations (e.g., complex buildings such as mosques and heritage buildings (Armesto-González et al. 2010)), infrastructure (e.g., views of complicated structures such as bridges and tunnels (Lubowiecka et al. 2009)), and volume and deformation measurements, as well as archaeological preservation (Bremer and Sass 2012).

During recent years laser scanning technology has evolved significantly (Riveiro et al. 2011). TLS, with a mid-range of measurement up to 100m approximately, usually implies a higher accuracy of measurement. Table 8-1 presents a summary of some characteristics of currently available mid-range TLS scanner systems.

Table 8-1 Mid-range TLS scanners and their characteristics

Manufacturer	Model	Nominal accuracy	Range (m)	Maximum acquisition rate (m)
Zoller + Fröhlich	ZF5010	2 mm @ 100 m	187	1016,000
Leica	HDS6200	9 mm @ 50 m	0.4–79	1016,727
Faro	FOCUS 3D	2 mm @ 25 m	0.6–120	976,000
Trimble	CX 3D	2 mm @ 100 m	80	54,000

Source: Riveiro et al. (2011)

The Trimble CX 3D Laser Scanner was used for the pilot study in this research. It is an advanced 3D laser measurement system with a highly accurate data capture process and an easy-to-use interface. This laser sensor exploits the ‘time of flight’ and ‘phase shift’ principles; it has a nominal accuracy of 1.25 mm at 30 m in normal illumination and reflectivity conditions (Trimble 2011). It is also a mobile and light weight (11.8kg) instrument that allows for easy movement on a project. Other system specifications include a 360° x 300° field of view and real-time integrated colour video. Finally this scanner has a high scanning speed of 54,000 points per second, making updating easy.

TLS instruments emit a large number of laser pulses in the desired directions; these are reflected back to the scanner and marked as points. The set of points generated this way is known as a point cloud, and can contain millions of points with 3D x,y,z coordinates which simulate the surface of the target object. An illustration of the Trimble CX 3D Laser Scanner in use in Fujairah is shown in Figure 8-1.



Figure 8-1 Trimble CX 3D Laser Scanner set up inside Bithna Fort, Fujairah

TLS scanners have a high-quality integrated camera system so that as the rotating laser captures points it also captures photos, which can be used in data processing for points of reference and visualisation, communication, or even for the final representation of the resultant 3D model (Guarnieria, Remondinob and Vettorea 2006). Also the data can be captured without people or equipment being in contact with the site; this is a distinct advantage when scanning historic sites that could be easily damaged, or when scanning tall structures. TLS is also becoming more feasible as a data collection method for applications in industrial and construction fields (Al-Neshawy et al. 2010). The ability of a laser scanner to capture large amounts of data quickly and with a fine resolution means that the real world can be accurately modelled (Bornaz and Rinaudo 2004).

TLS was used as a means of monitoring changes and detecting rock-falls in Spain, and its high spatial resolution capability proved very valuable for identifying small short-term changes (Abellán et al. 2010). This is a further confirmation of the suitability of TLS for tourism resources monitoring. Other recent research confirms the suitability of TLS for

deformation measurement (Montserrat and Crosetto 2008; Tapete et al. 2013) and structural monitoring (González-Aguilera, Gómez-Lahoz and Sánchez 2008; Park et al. 2007).

8.4.2 Selection of tourism resource sites

After an initial reconnaissance mission to Fujairah, five sites of international tourism significance were selected; they comprise a mixture of natural and cultural tourism resources. These sites were selected as they represent a broad range of the type of tourism resources available in Fujairah. These sites were:

(i) The Al-Aqah beach

Al-Aqah is a village nestled between the Hajar Mountains and the Indian Ocean. The coral reefs just offshore are home to rare and exotic fish species, making it an ideal spot for scuba diving and snorkelling; advanced divers can explore the nearby shipwreck. The area is home to many seaside resorts, including Le Méridien Al Aqah Beach Resort, Fujairah Rotana Resort and Spa and Miramar Al-Aqah Beach Resort. Stretches of sandy beach add to the experience of tourists (see Figure 8-2). Scuba diving, snorkelling trips, water sports and deep sea fishing are other examples of activities possible at the Al-Aqah beach.

For beach monitoring and observing morphology changes, LiDAR at yearly intervals would work best. However, as explained by Lindenbergh et al. (2011), beach change is not a regular process and is strongly correlated with meteorological conditions. They performed a series of terrestrial laser scans of a beach to measure notice the effects of strong wind and storms on a beach, and detected rates of elevation changes below 1mm per hour.

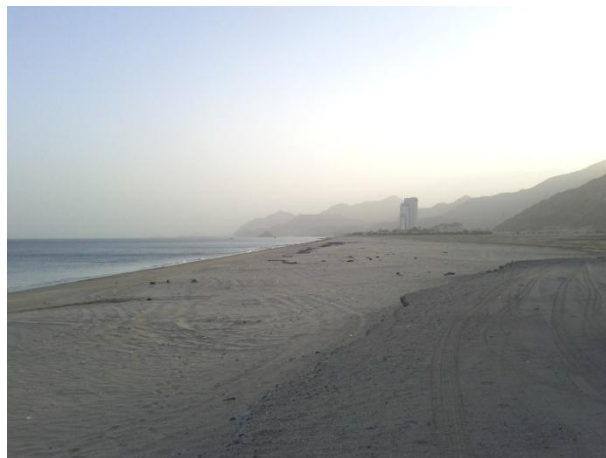


Figure 8-2 Al-Aqah beach

(ii) The Wurayah Waterfall

Wadi Wurayah is located 10 km southwest of the village of Bidiyah. The total catchment area of the Wadi Wurayah basin is 129 km² and the maximum elevation is 956 m above mean sea level. This means that the Wadi benefits from orographic rainfall occurring in both winter and summer months and sustains perennial surface water flows in the form of contact springs, pools, flash floods and waterfalls (Tourenq et al. 2009). The beauty of the waterfall is enhanced by the surrounding scenery, which encompasses Hajar Mountains and diverse Arabian species of flora and fauna. Figure 8-3 gives a view of the Wurayah waterfall. TLS can be used to monitor water level over time.



Figure 8-3 Wurayah waterfall and the pool below it

(iii) The Al-Bidiya Mosque

Al-Bidiya (also spelt Bidiyah) mosque dates from the second half of the 17th century (Ziolkowski 2007). It is the oldest functioning place of worship in the UAE and still in use. The mosque is built of stone and mud, making it vulnerable to normal weather and the extremes that may occur due to climate change (see Figure 8-4).



Figure 8-4 Front side of Al-Bidiya Mosque

(iv) The Bithnah Fort

Bithnah (sometime spelt Bithna) fort was built to command the route in and out of Fujairah and is positioned in Wadi Ham about 13.5km northwest of the city of Fujairah (Ziolkowski and Al-Sharqi 2009). The main building materials used within the fort's construction are mountain rocks, smooth wadi boulders, mud bricks, date palm (*Phoenix dactylifera*) material and hardwood (see Figure 8-5). The original fortification dates from the second millennium BC and additions were made in the late pre-Islamic period (Ziolkowski and Al-Sharqi 2009).



Figure 8-5 Corner view of Bithnah Fort

(v) Fujairah Fort

Fujairah Fort is located on a hill at the edge of date gardens about three kilometres from the coast and was completed in 1670. It was badly damaged in the early 20th century. It has served as a defensive building and a home for the ruling family. Fujairah Fort is a mud brick structure with three major sections, several halls, one square tower and two round towers. The fort has been renovated and restored many times throughout its history. For centuries it was the only stone building along the Fujairah coast. Figure 8-6 illustrates Fujairah Fort.



Figure 8-6 Fujairah Fort

The locations of the five sites listed above are shown in Figure 8-7.

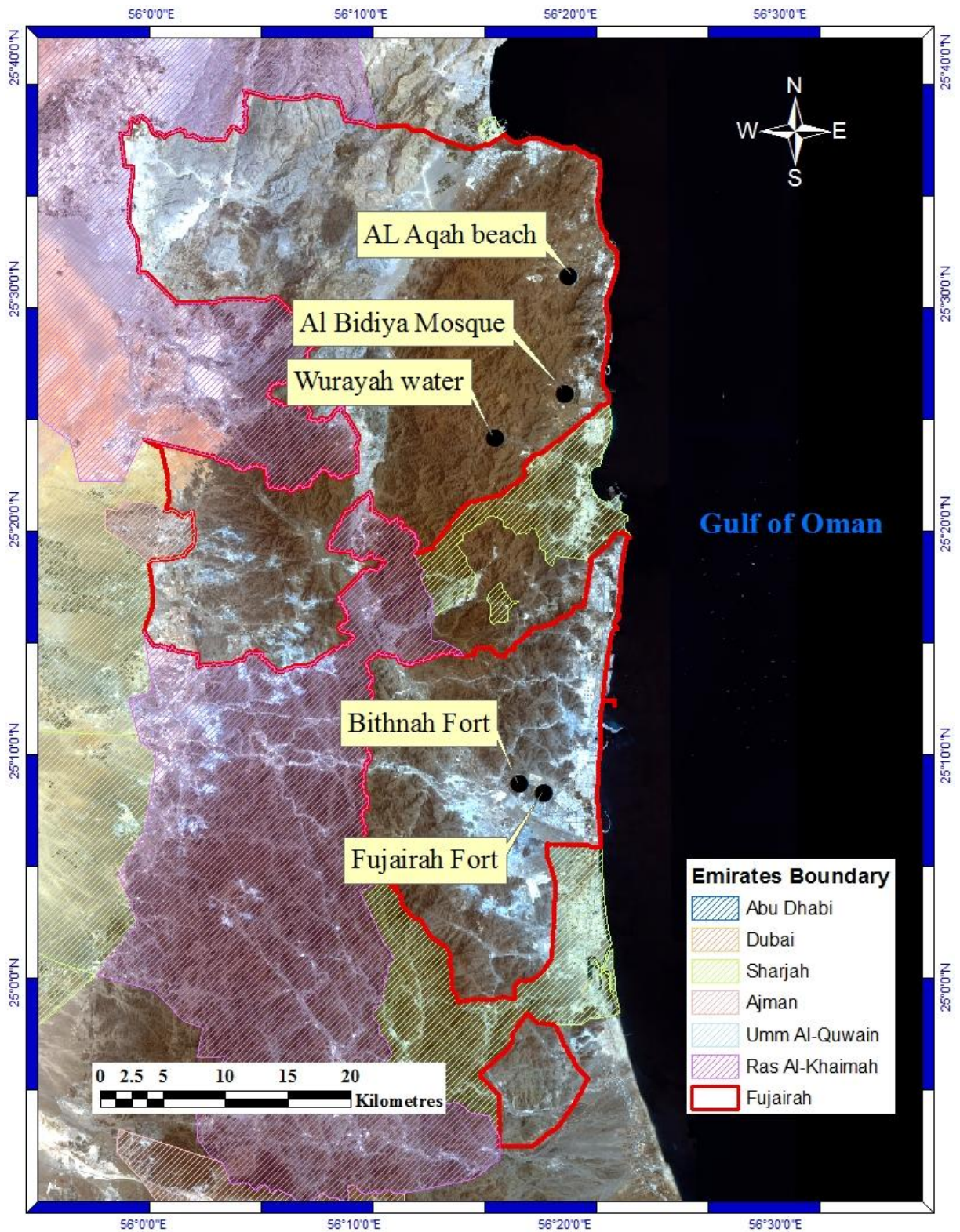


Figure 8-7 Map showing Fujairah and pilot study sites

8.4.3 Fieldwork procedure

TLS technology was used to collect 3D data for each of the five sites with a view to re-observing in the future to model change detection via comparison. The process of developing 3D point cloud models using TLS is presented below. For the purpose of detecting change in the tourism resources, the TLS survey of each site was undertaken in three stages: pre-scanning, scanning and post-scanning. The survey of Fujairah Fort is described in detail as an example of the process adopted for all five sites.

1. **Pre-scanning.** This stage comprises the preparation and positioning of the TLS equipment. The associated equipment includes tripods, targets, tribrachs, target poles, and a laptop computer.

(a) Selecting the scan resolution

Deciding on the scan resolution required for each of the selected sites was the first step during the pre-scanning stage. The resolution, during this research, was set to about 1cm over 30m in order to be able to map minute details.

(b) Choice of station locations

This involves deciding the locations of stations required to obtain different ‘views’ of the object/structure under consideration after a reconnaissance of the site. This is done to identify the locations of the stations to obtain the best possible views of the resource. The data scans obtained from such ‘views’ (stations) are combined to generate the final 3D point cloud of the resource. To accommodate a full external view for the Fujairah Fort, seven stations were necessary. The number of stations required for each site is shown in Table 8-2 and the plan of station setups is given in Figure 8-8.

Table 8-2 Scan parameters for the selected sites

Site	Type of scan	No. of views (stations)	No. of Control Targets
Al-Aqah Beach (northern end)	External	1	4
The Wurayah Waterfall	External	1	4
Al-Bidiya Mosque	External	6	6
Bithna Fort (situated in a valley)	External	6	12
	Internal	1	4
Fujairah Fort (located on a seaside hill)	External	6	19
	Internal	1	0

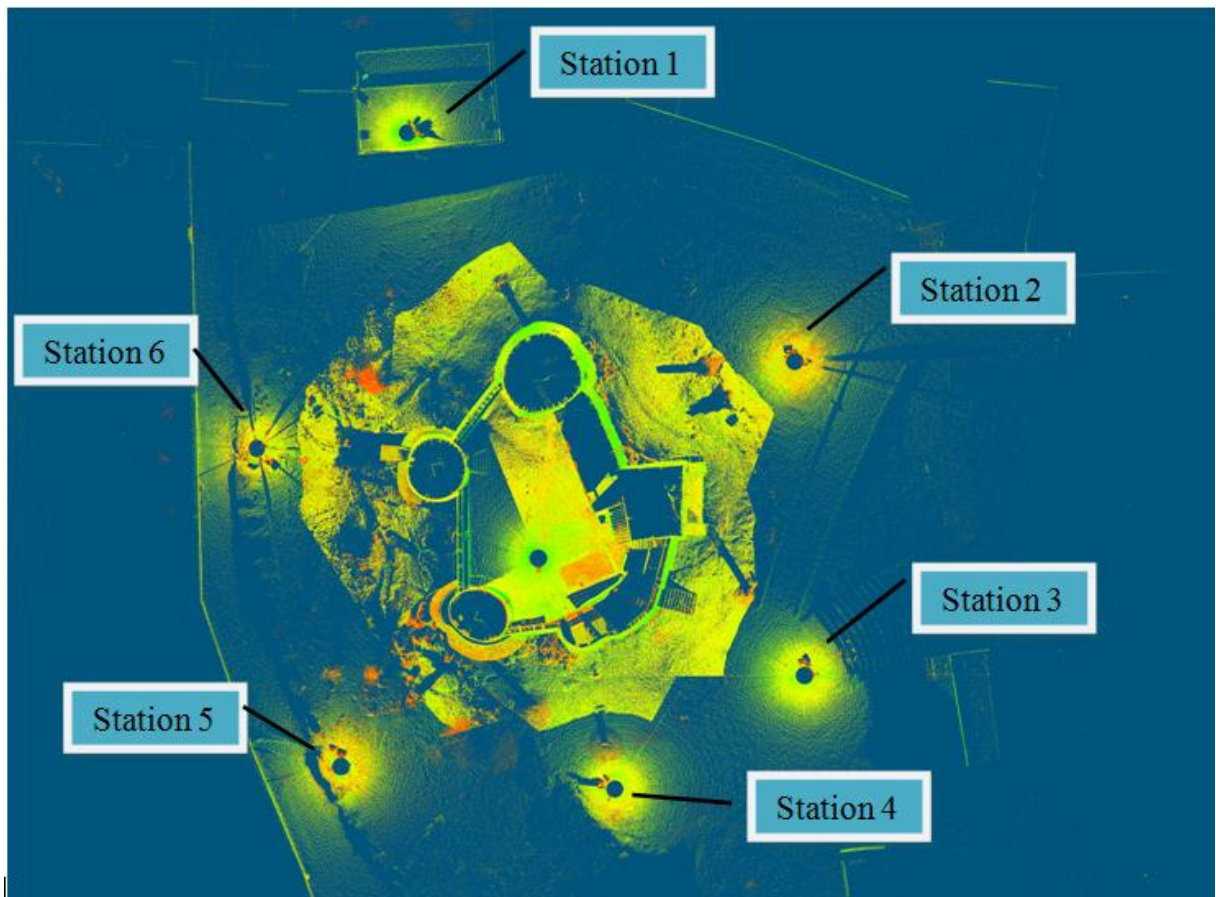


Figure 8-8 Plan of station setup for 3D modelling of Fujairah Fort

(c) Positioning the control targets

The construction of a 3D model from the scans at different stations requires the registration of all of the point clouds obtained. To facilitate this registration, several clearly visible markings,

or control targets, are set up at various positions on or near each structure. The positioning of these control targets with respect to each station location is decided upon during the reconnaissance stage. Figure 8-9 shows an example of such a control target used during scanning Fujairah Fort.



Figure 8-9 An example of control target used at Al Bithnah

(d) Geo-reference

The local coordinate system used during the scanning process was transformed into the (WGS-84) coordinate system. Therefore, the 3D point cloud model generated from TLS is geo-referenced onto a global datum. For the purposes of temporal change detection due to climate change effects, it is not imperative that the above process be carried out; however, this transformation has the auxiliary benefit of allowing the scanned tourism resources to be incorporated into digital software (such as Google Earth). The GPS data required for the geo-referencing of the Fujairah sites was obtained by using two Trimble Geo receivers (GPS) simultaneously at each site.

2. Scanning

The scanning process involved setting-up the tripod, the scanner and the data tablet (containing the Trimble software) so that the control targets corresponding to each of the station locations was visible. For each such location, the TLS scanner was placed at a distance of approximately 20-30m from the structure to be scanned, as shown in Figure 8-10.



Figure 8-10 Positioning and preparation of the TLS equipment for scanning at Al Bithnah fort

The Trimble CX Scanner operates by emitting multiple laser beams of light which are reflected by a surface on which they fall (electronic distance measurement technology). These beams are reflected back to the scanner which can then determine, based on time-of-flight, the distance to a point given by a specific coordinate. The result of scanning is a point-cloud corresponding to the ‘view’ selected. The set of cloud point data obtained from two different stations (‘views’) of the Fujairah Fort is shown in Figure 8-11, the total number of points scanned at Fujairah Fort was 11,036,000. The number of scanned points for all the sites is given in Table 8-3. These point cloud data form the basis for change monitoring of these tourism resources.

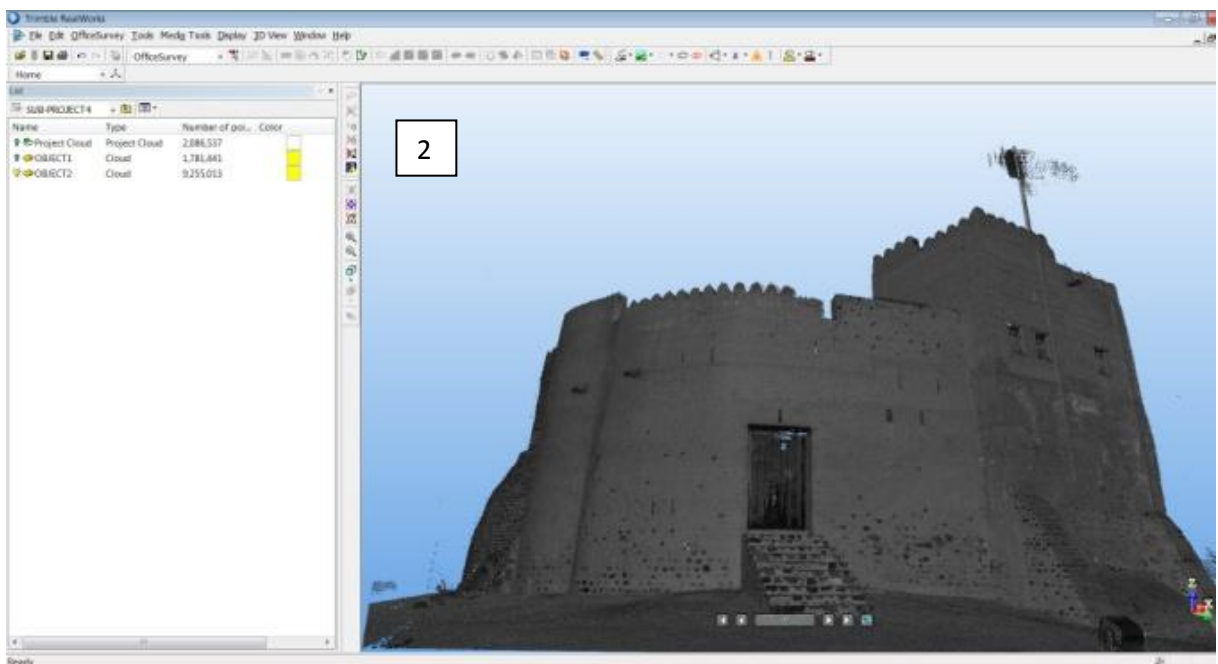
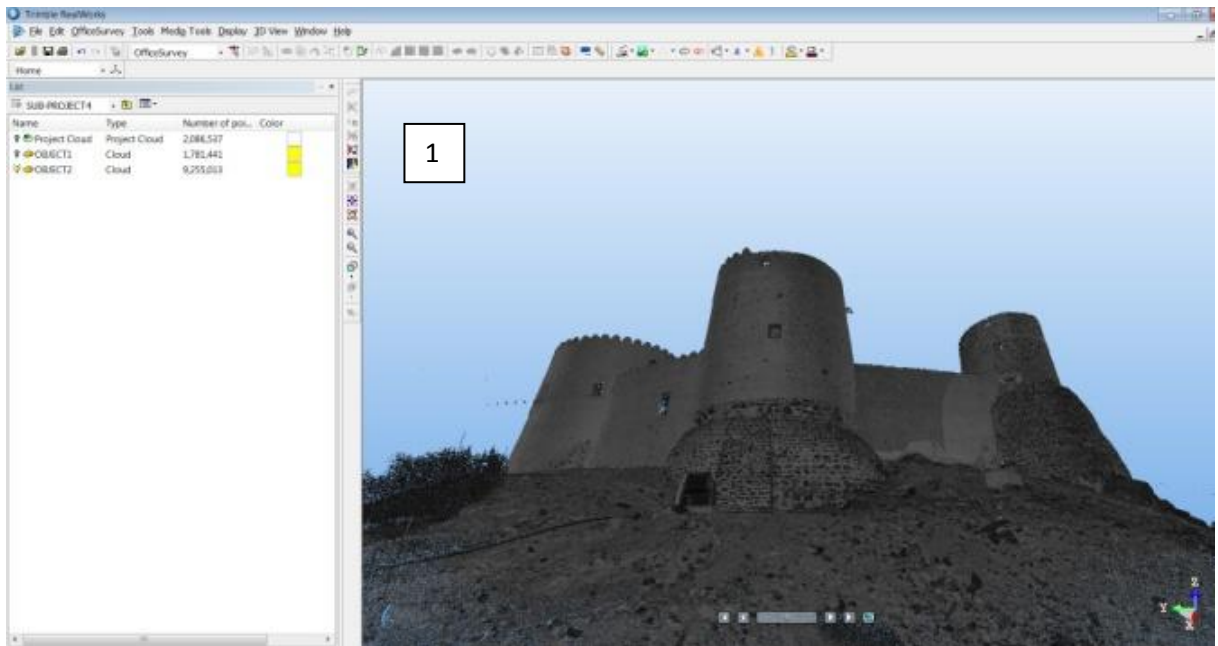


Figure 8-11 Cloud point data obtained from two different ‘views’ of the Fujairah Fort

3. Post-scanning

This stage involved transferring the cloud-point data from the data logger to the software RealWorks Advanced Version 7 (see Figure 8-12) and manipulating these to construct 3D point-cloud models.

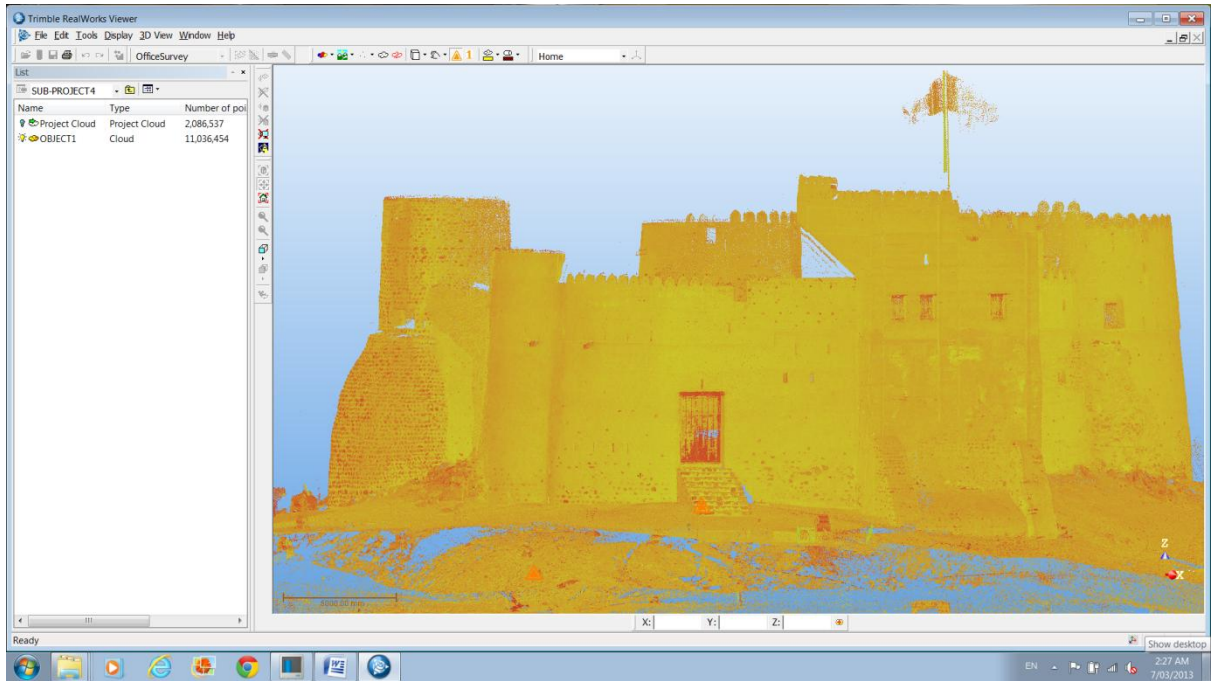


Figure 8-12 Manipulation of the cloud point data in the RealWorks software

(a) Registering/Alignment: This process consists of the alignment of point-cloud data obtained from multiple views, using the control targets in order to create the 3D model of the structure scanned and is called ‘target-target’ registration. The result of this process in the current study is shown in Figure 8-13. After the registration process, the temporal changes can be found with a comparison technique, for example using image subtraction, as explained below.

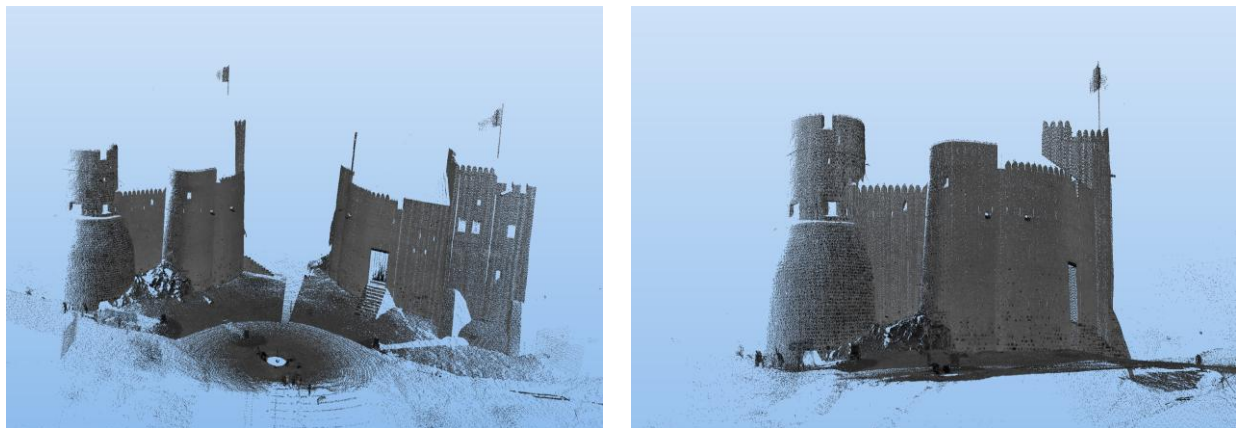


Figure 8-13 Registering/alignment of the point clouds obtained from different views

A screen capture of a complete 3D model constructed using TLS point cloud data from the Fujairah Fort, using the RealWorks software, is shown in Figure 8-14.

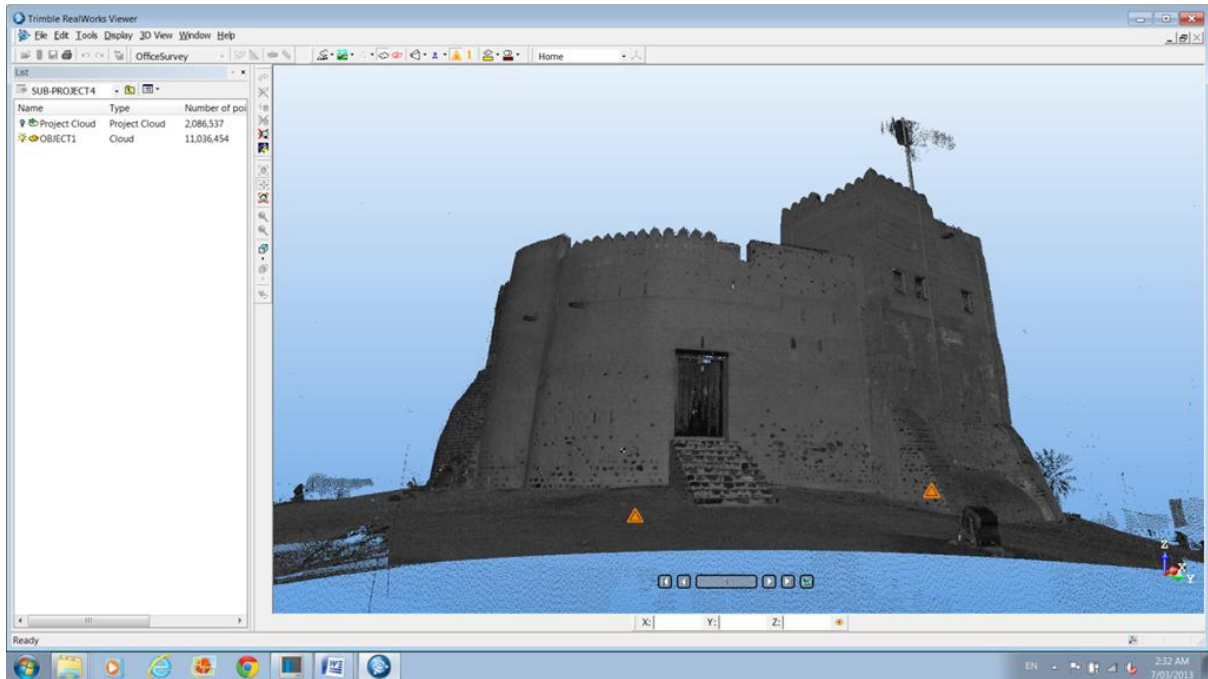


Figure 8-14 3D model of the Fujairah Fort constructed using TLS point-cloud data

(b) Data editing (noise removal)

Editing involves the refinement of the raw data in order to exclude unwanted background points in the scanned point-clouds. This is achieved using the segmentation tool. The process of segmentation corresponds to partitioning the 3D model of the object for the purpose of reducing the complexity of the change detection process. This partitioning is usually prioritised based on the nature of the resource under consideration. For example, the eastern part of the Fujairah Fort faces the sea and is subjected to relatively high amounts of erosion due to wind effects, which could justify prioritising the analysis of change detection for that segment.

The result of this process performed using the functionalities in the RealWorks software is illustrated in Figure 8-15.

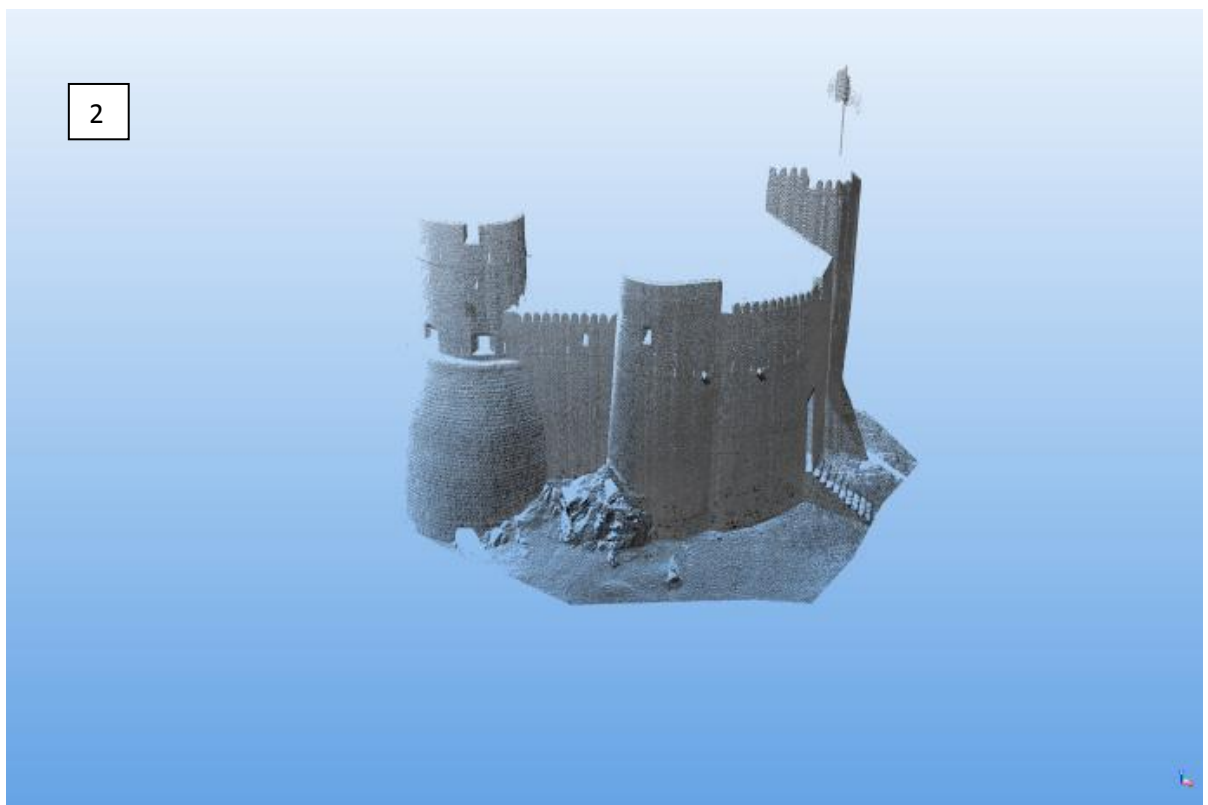
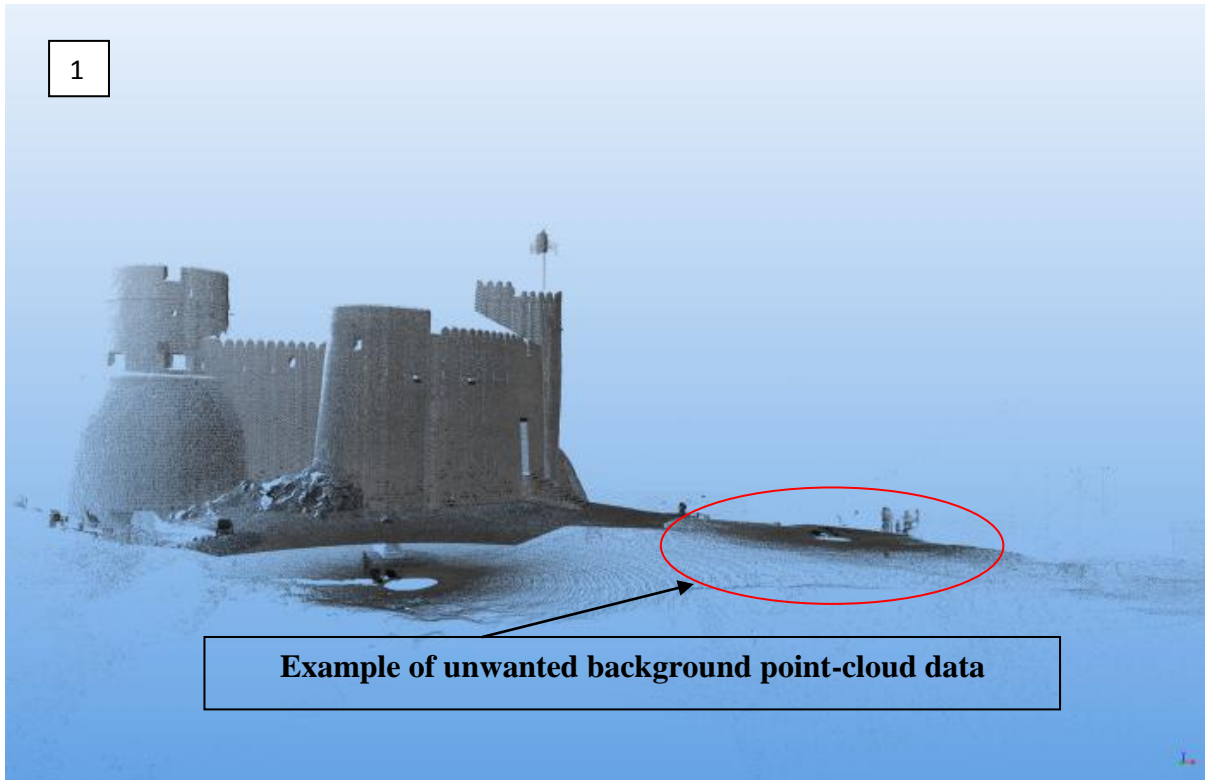


Figure 8-15 Refinement of the registered 3D cloud-points to exclude unwanted background data (shown in view 1, at top, but excluded from view 2)

The total numbers of points scanned are shown in Table 8-3. The 3D models developed for the selected sites using the TLS scan data are illustrated in Figures 8-16 to 8-20, respectively.

Table 8-3 Details of the TLS based 3D models developed for the selected sites

No.	Site name	Total number cloud points	Anticipated Impact
1.	The Al-Aqah Beach	3,005,000	Beach erosion, SLR, storm surge
2.	The Wurayah Waterfall	2,082,000	Water depletion, high temperature
3.	The Al-Bidiya Mosque	28,690,000	Wind erosion, storms, heat
4.	The Bithna Fort	10,622,760	Wind erosion, flood, storms, heat
5.	The Fujairah Fort	11,036,000	Wind erosion, storms, heat

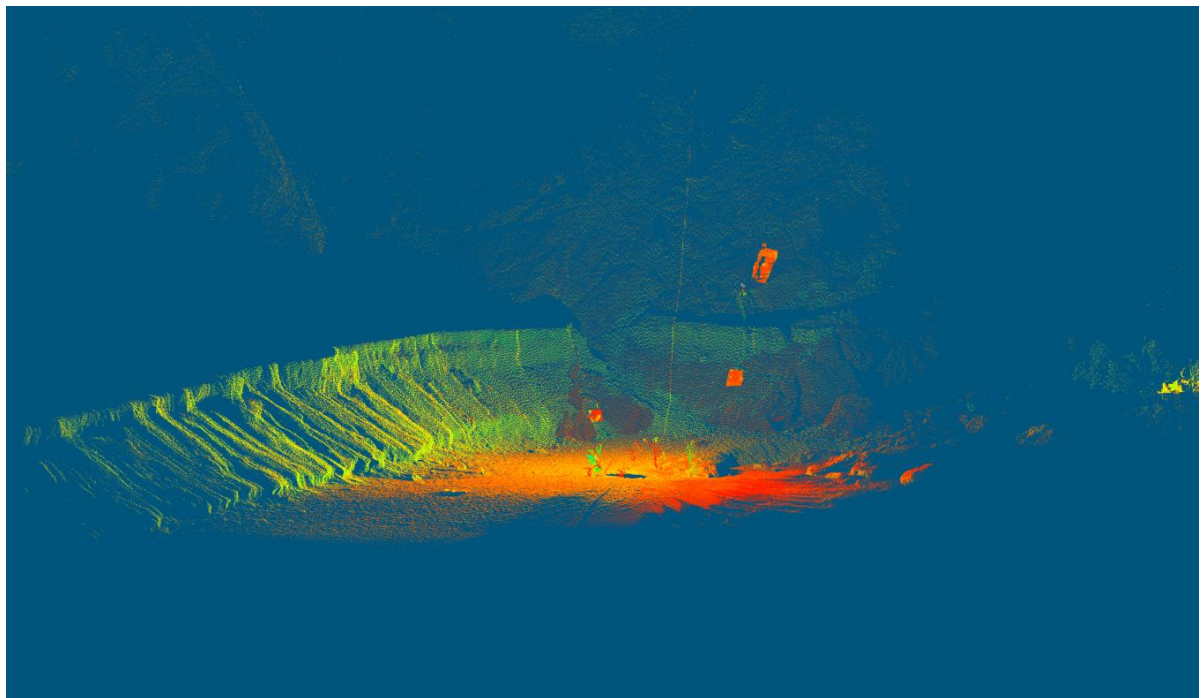


Figure 8-16 3D point cloud model for Al-Aqah Beach

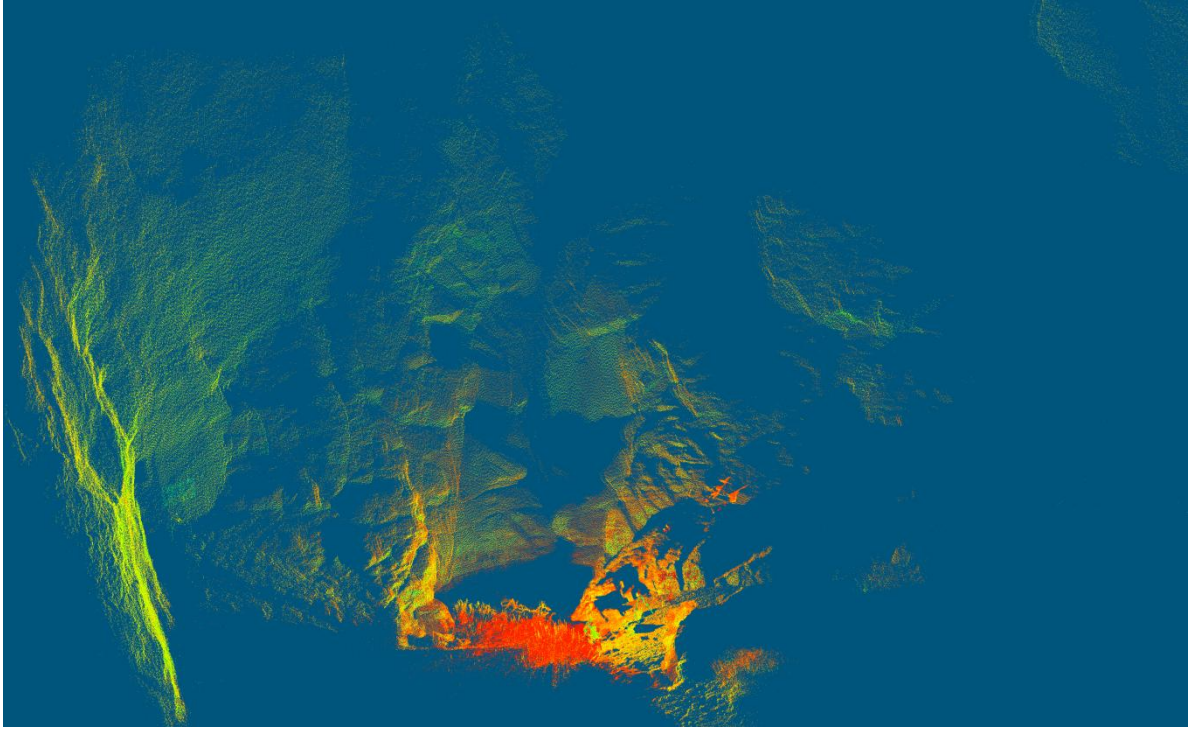


Figure 8-17 3D point cloud model for Wurayah waterfall

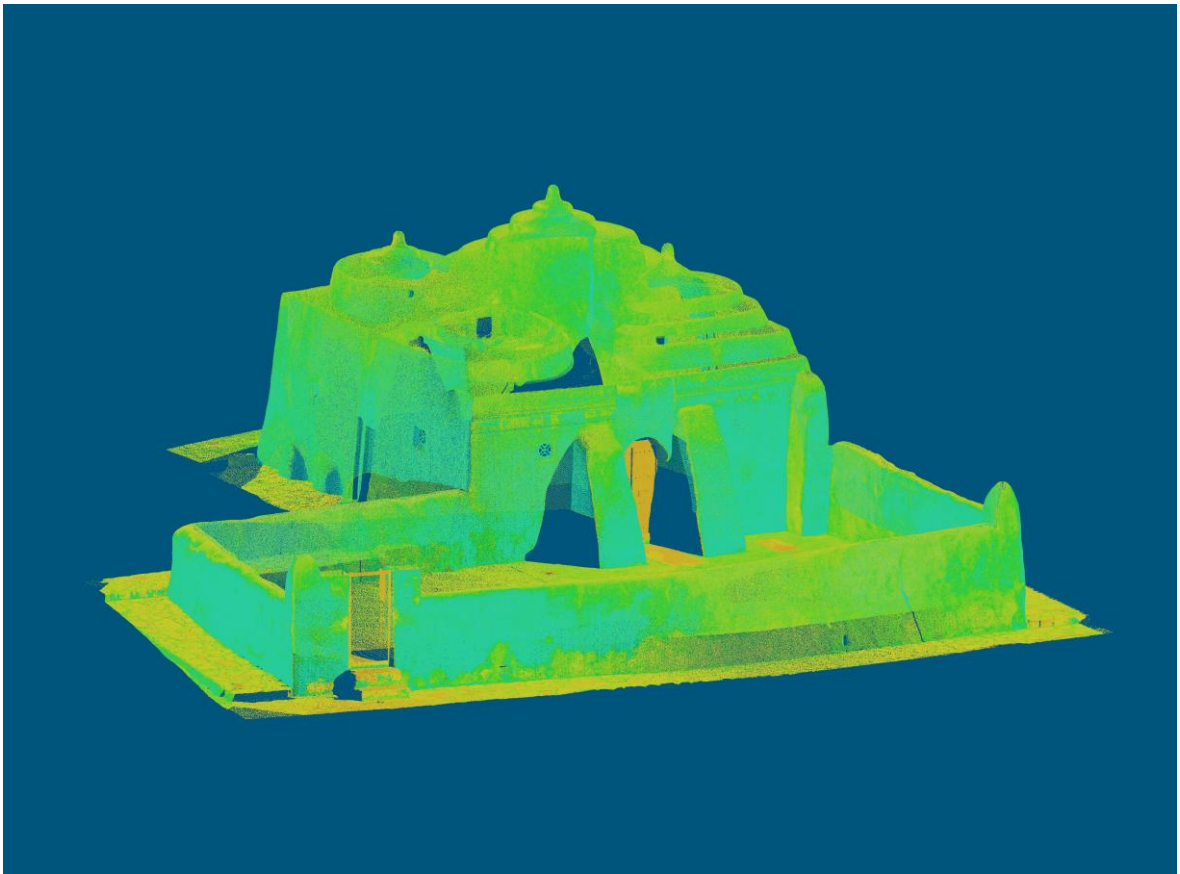


Figure 8-18 3D point cloud model for Al-Bidiya Mosque

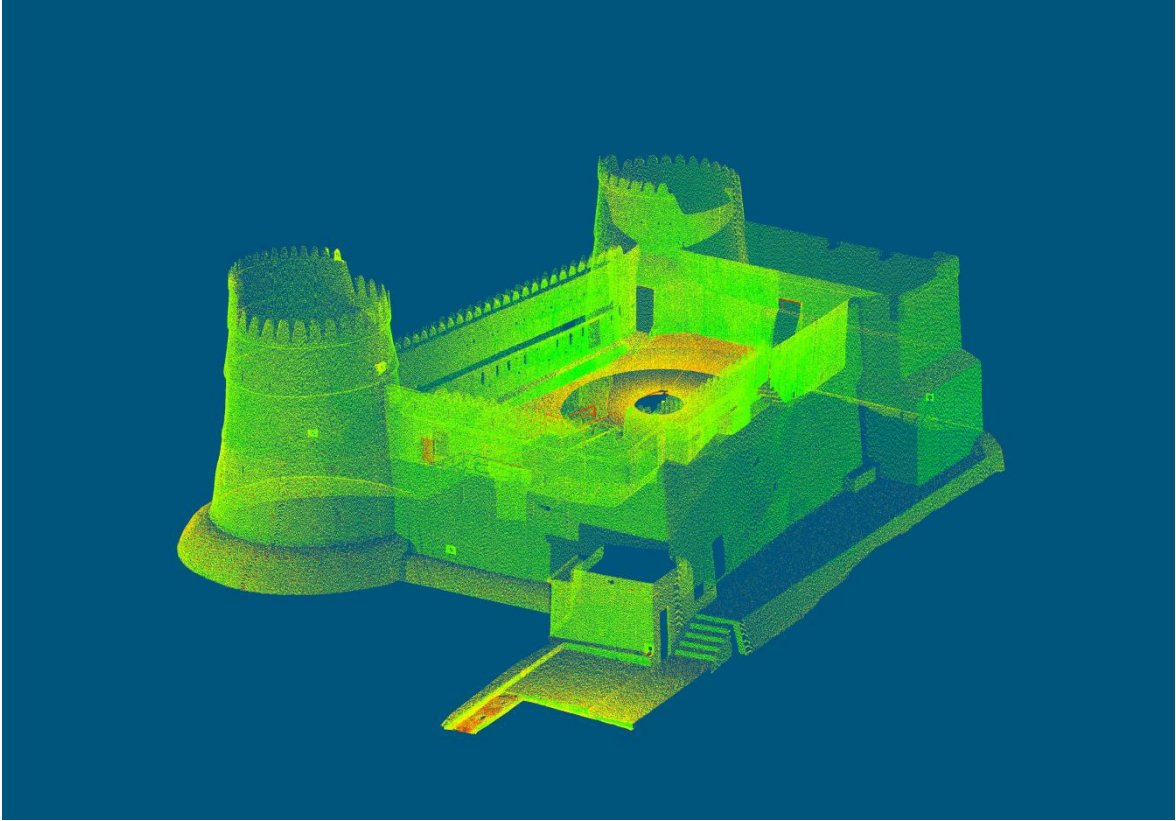


Figure 8-19 3D point cloud model for Bithna Fort

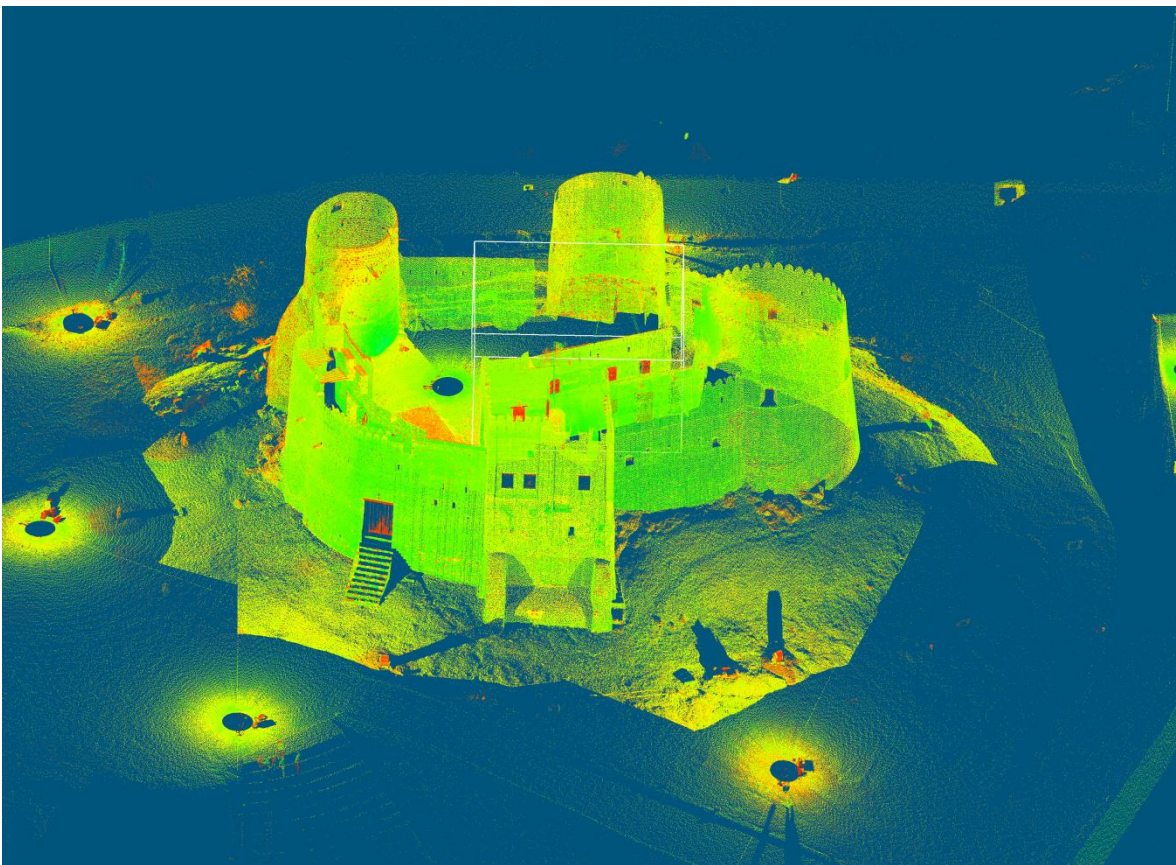


Figure 8-20 3D point clouds model for Fujairah Fort

8.5 Quantification and estimation of micro change for Fujairah’s tourism resources using TLS

The temporal analysis of tourism resources requires the monitoring of changes for such resources over extended time periods. These can be identified quantitatively from the 3D point-cloud data obtained from successive TLS surveys. For example, the TLS scan data could be generated every 3-5 years for all sites of interest and a change detection algorithm could be used to quantify or estimate the temporal impacts on these resources due to climate change effects. These impacts may be the erosion of structures, formation of cracks or any other form of impact discussed in Chapter 7. The analysis of temporal effects on multiple points of a resource will also capture relative spatial variations which may be of interest during the course of reconstruction and preservation.

Note that the time periods to be selected for future scans of the tourism resources will depend on the nature of the resource, the date of construction, the construction materials and the anticipated negative impact of changes.

8.5.1 Simulation of change detection using TLS

The Real Works software was used to simulate micro scale change to tourism resources in Fujairah. This is shown in Figure 8-21 where the simulation was carried out in relation to part of the Fujairah Fort.

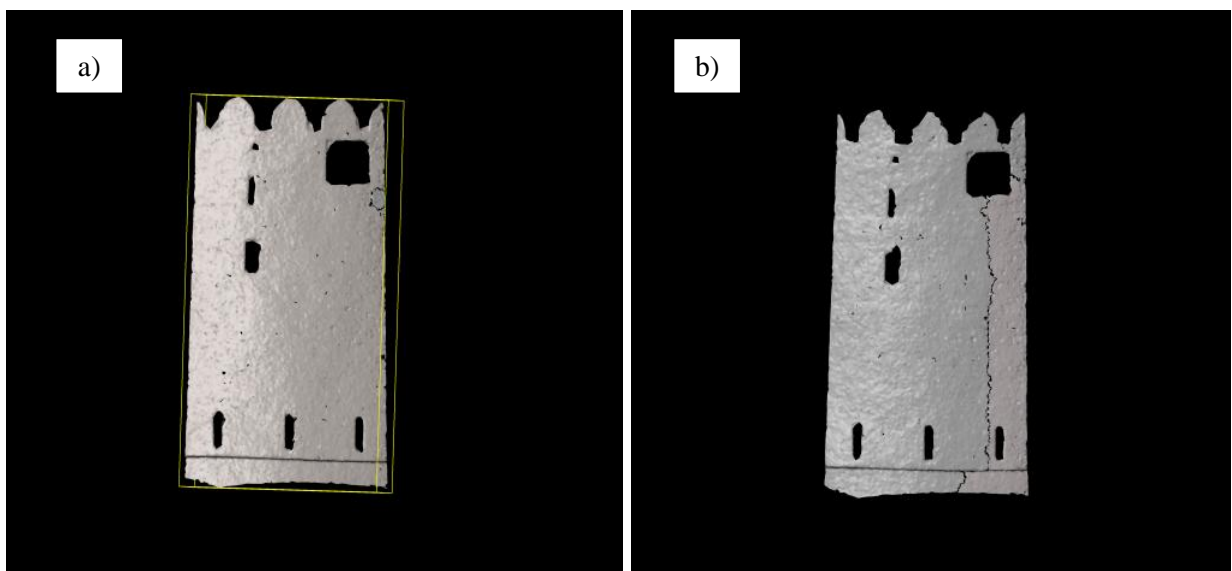


Figure 8-21 Simulation of micro change occurring to the Fujairah Fort (a) before (b) after

A simulation was carried out using the Real Works software to illustrate how micro scale change might be detected at important tourism resources in Fujairah. A simulation was conducted as currently only one baseline dataset is available; however, when future scans are conducted, this approach can also be followed. This simulation was undertaken on a section of the Fujairah Fort, in which it is believed damage has occurred in numerous crenellations along the top of the tower. This damage is probably be the result of weathering by temperature and wind.

This simulation procedure (in RealWorks) is based on identifying the change between surface models generated from different point clouds recorded at different periods of time. The software is able to accurately identify areas where significant change has occurred between these surfaces. The accuracy of the software depends on the resolution of the scanned point clouds. A higher density of points and a greater resolution will allow the detection of finer change.

The results of the simulation are illustrated in Figure 8-21 above. In part (a), the crenellations are shown in their prior (undamaged) condition (after restoration). In part (b), the change in shape of the crenellations is evident and illustrates the damage done over time. From this information it would be possible to quantify how much damage has occurred and also how much restoration would be required to return them to their original condition.

8.5.2 Macro change detection of resources using spatial data

A combination of satellite imagery and aerial photography (processed within the GIS environment) was used to explain the process of detection of macro change in Fujairah's tourism resources. These technologies were chosen due to the availability of satellite and aerial data for Fujairah. The following sections discuss how this approach could be used to temporally detect macro spatial changes in Fujairah's tourism resources. IKONOS satellite images and orthophotographs (rectified aerial photographs) of Al-Aqah beach (Figure 8-22) were used to demonstrate this process.

Macro change detection using GIS is a process that measures how the attributes of a particular area have changed between two or more time periods. Change detection often involves comparing aerial photographs or satellite imagery of the area taken at different times. This process, as applicable to macro change detection in tourism resources, is detailed next for Al-Aqah beach.

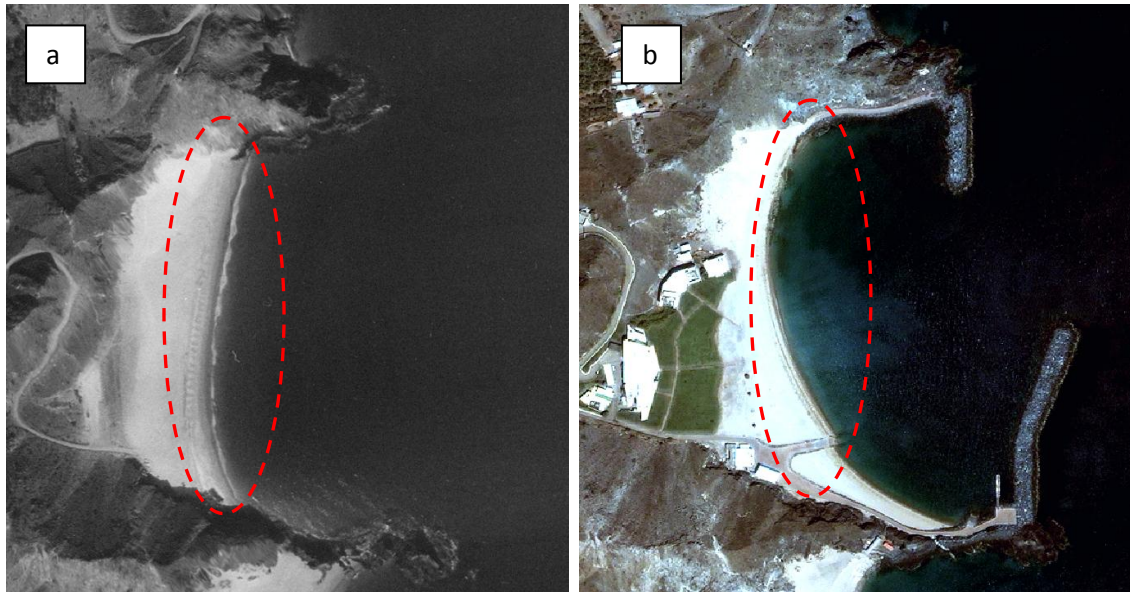


Figure 8-22 Depiction of macro changes in Al-Aqah beach using (a) an aerial image taken in 1995 (left) (b) an IKONOS satellite image taken in 2010 (right)

Coastal erosion is one of the main climate change concerns in relation to beaches. In the case of macro landscape features such as beaches, change detection is best performed using aerial/satellite imagery. Figure 8-22 shows the erosion of Al-Aqah beach between 1995 and 2010. The same concept of macro change detection can be extended for future purposes as well.

8.6 Summary

This chapter introduced the possible approaches for monitoring changes occurring in tourism resources in Fujairah. Sometimes effects are very small, thus relying on human observation is impractical; more sophisticated technologies and high-resolution data must be employed. A TLS-based technique for micro change detection was chosen and applied to selected key sites in Fujairah. This involved using TLS to create baseline 3D models for the purpose of change detection via comparison with future scan data. (Note that this TLS-based change detection model was employed in the Emirate of Fujairah as a proof of concept and has not yet been officially adopted.)

As well as detecting changes in tourism resources due to climate change effects which are inherently slow in nature, the TLS-based change detection method can be extended to situations in which a human-induced or natural catastrophe causes significant damage to a resource. The approach introduced in this chapter can aid any documentation process in relation to the tourism resources of the Emirate.

In this chapter, it was demonstrated how aerial/satellite imagery could be used for detecting macro changes occurring over an extended period of time. This results underline that a strategy for monitoring both micro and macro changes occurring to major tourism resources in Fujairah is vital, not only from a long-term perspective but also from a short-term or ‘as and when required’ basis.

Chapter 9 Implementing the established framework in other developing countries

9.1 Introduction

Chapters five to eight illustrated how Fujairah's tourism resources could be identified and monitored. This will enable Fujairah to develop a sophisticated and responsive resources management approach.

Chapter 8 provided an overview of how changes in tourism resources can be monitored in Fujairah. The steps involved in this process were: Understanding the importance of tourism resources and documenting them using a spatial approach (chapter five); Projecting the future climate in a particular area such as the Emirate of Fujairah using SimCLIM (chapter six); Analysing the links between the effects of climate change and impacts on tourism resources; Finding the potential impacts on tourism resources using RAP software (chapter seven); and using GIS techniques to overlay maps containing the effects of climate change and Fujairah tourism resources.

An overview of the monitoring process is presented in this chapter. These steps provide the necessary information for the management of priorities, enabling care to be directed to those resources that are impacted most strongly and immediately. This research did not attempt to prescribe any suggestions for management, that is, the changes that should be implemented to minimise or eliminate negative impacts.

This chapter shows how the steps can be used as a generic framework that can be implemented by other developing nations. It starts with a review of the importance of tourism for developing countries, then highlights the risks posed by climate change to tourism resources. Next, the chapter combines all stages to build a framework that can be used for monitoring and managing tourism resources. The implementation of this framework was then tested using Turkey as a case study.

9.2 Tourism resources in developing countries

Tourism resources in developed countries differ from those in developing countries, both in terms of characteristics and in diversity. In addition, the facilities that support tourism resources (e.g., transport and communications, water supply and sanitation, public security, and health services) are readily available in developed countries (thereby increasing the value

of tourism for their economies) but not in developing countries. It is not the aim of this research to analyse the differences in the tourism resources of developed and developing countries, but rather to highlight the changes that are likely to result from the impacts of climate change and how to manage/monitor these changes. Tourism resources in developing countries are more susceptible to the effects of climate change, and therefore need careful monitoring.

Developing countries have assets that are of enormous value to global tourism. Many developing countries boast unique wildlife and art, warm climates, music and culture, magnificent natural landscapes, and World Heritage sites (UNWTO 2006). Tourism generates income that assists the conservation of these cultural and natural assets.

9.3 Climate change and tourism in developing countries

Developing countries are increasingly realising the value of tourism as a source of income. This industry relies heavily on the quality and quantity of resources that attract tourists. The fastest-growing sector of tourism is nature-based tourism, involving excursions to national parks and wilderness areas, and occurs in many developing countries where a large portion of the world's biodiversity is concentrated (Christ 2003; Kuenzi and McNeely 2008).

The relationship between tourism and weather is strong. Thus climate change is a risk to the sustainability of this industry, as the effects of climate change will impact negatively on the resources upon which the tourism industry relies. Climate change poses a major risk to tourism resources worldwide in multiple ways: bleaching and disappearance of coral reefs; destruction of mangroves and coastal wetlands; general coastal erosion and degradation; loss of alpine glaciers, snow cover and meadows; shift of animal and plant ranges; extinction of species; and flooding of low-lying islands and coastal areas (Kuenzi and McNeely 2008; Reid et al. 2008). In addition, the fact that tourism is weather- and climate-sensitive means climate defines the length and quality of tourist seasons and plays a major role in destination choices (Gössling, Hall and Scott 2009).

9.4 A framework for monitoring tourism resources under climate change

The flowchart below (Figure 9-1) summarises the framework developed from this thesis that could be used for monitoring and managing tourism resources in developing countries.

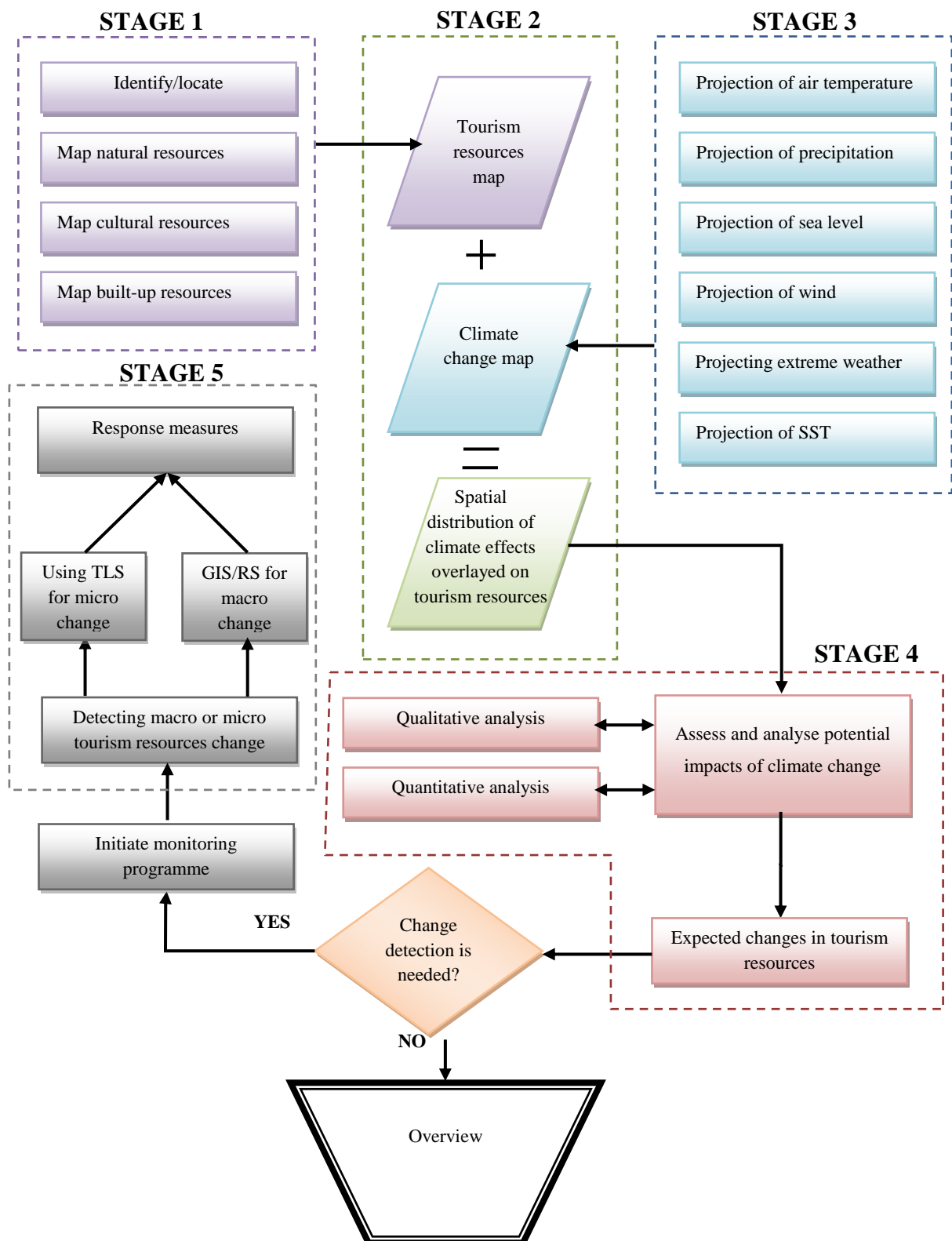


Figure 9-1 The monitoring and management framework

Figure 9-1 illustrates the process of managing tourism resources in developing countries vulnerable to climate change impacts. The framework has five main stages. Two of these stages involve the actual preparation for the process, that is, the mapping of tourism resources

and projecting climate change effects, while the third stage involves assessing the outcomes from the projections. The fourth stage involves making a decision about the need to monitor changes. The last stage consists of the monitoring program and its recommended tools, which depend on the scale of change expected (micro or macro).

Mapping the tourism resources of a developing country is the first step. In this stage a country is required to examine its tourism industry from different perspectives. Focusing on the tourism sector may provide benefits in the form of employment, sustaining the environment, social activity and financial gain. This will eventually lead to an assessment of the tourism resources available. In order to highlight tourism resources it is necessary to categorise them into different classes. In this thesis, tourism resources were divided into three types: natural, cultural and built-up resources. The tourism map should contain all current and potential tourism resources in the country or sub-area. In this research GIS was found to be the most suitable tool for identifying the locations of tourism resources, as it is able to 'layer' different types of tourism resources and overlay them to produce a map.

Once the tourism resources map emerges the climate change effects can be predicted and mapped (stage two). The effects of climate change vary from country to country depending on their geographical location, topography, position relative to the coast and characteristics. These effects must be projected into the future. The quality of the projections relies heavily on the quality of the available data; the more local historic data is available, the better the results. Many developing countries lack comprehensive local observation data, which reduces the accuracy of climate change projections that must use global data with low spatial resolution. However, any available local data, even for a short timeframe (e.g., 10 or 15 years) are useful. Local observed data can be used through the *perturbation method* (also called the change factor method – see Appendix C). This enables change factors from future climate scenarios to be applied to the historic observed data to form a new time series that represents the future climate conditions. Climate data are inherently spatial and thus can be mapped. Climate change affects sea level, sea surface temperature (SST), air temperature, precipitation, wind and extreme weather events, which can then be plotted as a digital map. Many tools that allow projection of climate change effects are listed in the *Compendium on methods and tools to evaluate impacts of, vulnerability and adaptation to climate change* (UNFCCC 2008). SimCLIM is one of those tools, and has been acclaimed as one of the best for use in multiple sectors to describe baseline climates, examine current climate variability and extremes,

generate climate and sea-level change scenarios and conduct sensitivity analyses. Another feature of SimCLIM is that it includes a customised GIS with layers showing the spatial distribution of climate change effects in a given study area. Thus a plot of climate change can be produced and overlaid with the tourism resources to produce a map or series of maps that give information about which tourism resources are located within each climate change effect zone and are vulnerable to impact from that effect.

The third stage involves assessing and analysing the potential impacts of climate change on the selected tourism resources. This step involves examining the quantity and quality of tourism resources so the expected changes in tourism resources can be described. The changes give a general idea of the impacts that might occur. These impacts are not usually direct but the result of other changes that are transferred from one change to the next, following cause-effect pathways. Characterising and understanding these multiple changes is a non-trivial task. Mind mapping, using the RAP software, can then be used to assess the vulnerability of natural, cultural and built-up tourism resources to the expected changes in climate.

Stage four requires the decision-makers (in this case, tourism managers) to decide whether there is a need to detect change in tourism resources. The expected change for some tourism resources might be of the micro scale, so the tourism manager may prefer to postpone the change detection process. However, some tourism resources may be very vulnerable, such as historic buildings, and might require monitoring for weathering effects that maybe only a few millimetres per year, but become significant over decades.

The final stage involves on-going monitoring of macro or micro scale changes. Many tools are available to detect macro change. For the tourism resource examined in this research, requiring detection of changes at the kilometre scale, remote sensing combined with GIS proved useful; changes can be detected by using satellite images from different times for the same area (i.e., using map algebra). For micro scale changes at the sub-metre level, TLS was found to be a useful tool.

Based on this framework, responses can be planned using results unique to each country, including adaptation or mitigation measures that include legislation, restoration program and other measures based on the type of the tourism resources.

9.5 Implementation of the framework

The problem must be clearly defined. Understanding the problem enables the clarification of objectives. These objectives reflect the goals of the tourism managers who are seeking to protect their tourism resources from any risk posed by climate change. The tourism resources of each country also need to be defined and identified.

To map the tourism resources in stage one, existing databases should be assessed and updated. Some developing countries (e.g., Thailand) have geodatabases which are outdated or incomplete, so updating is an option. If no geodatabase exists, then one from a developed country can be used as an example of best practice. The types of tourism resources available, will determine the map that needs to be produced.

In the next section, the Republic of Turkey is used as a case study for implementing the developed framework.

9.6 Case study: Republic of Turkey

The tourism industry in Turkey has expanded rapidly over the past three decades. Turkey is now among the top 10 tourist destinations in the world in terms of incoming tourists and tourism receipts (UNWTO 2011). Although many developing countries are seen by tourists as pristine, natural paradises, they are also perceived as poor, insecure, and underdeveloped (Echtner 2002). Turkey has positioned itself as a tourist destination by promoting its 'sea, sun and sand' attractions (Okumus et al. 2012). About 58% of tourists visiting Turkey choose it for beaches vacations while only about 6% choose Turkey for cultural tourism alone (Tursab 2011).

Cultural tourism in Turkey takes its strength from the country's rich history as well as its authenticity (Richards and Wilson 2006). According to Okumus et al. (2012) Turkey has not yet fully utilised all of its cultural resources to position itself as a leading cultural destination. Cultural zones such as Phryg, Troy, Aphrodisia and Sogut can be promoted for cultural tourism. In addition, Istanbul was announced as the European Capital of Culture for 2010 because it has a unique geographical location (the only city in the world to straddle two continents) and a cultural heritage reaching back thousands of years into human history (Estanbul 2010).

9.6.1 Stage one: mapping tourism resources

In order to map natural and cultural tourism resources in Turkey a database is required. Aydinoglu and Yomralioglu (2007) mentioned the necessity of building a Tourism Management Information System; this used GIS technology which can facilitate managing and automating tourism data for the planning, development and marketing of tourism activity (Aydinoglu and Yomralioglu 2007). An example of such a database is shown in Figure 9-2 and the basic production process for tourism maps in Figure 9-3.



Figure 9-2 An example of datasets for a Tourism Management Information System (Aydinoglu and Yomralioglu 2007)

Note: The word ‘Hydrography’ is incorrectly spelt in the diagram

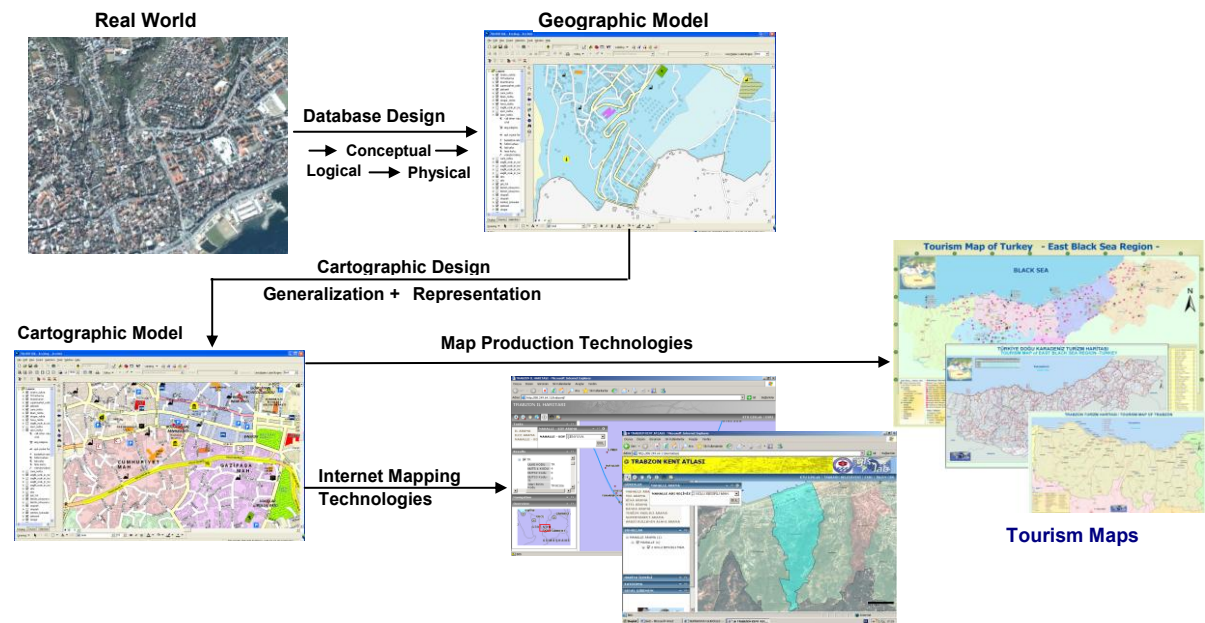


Figure 9-3 Basic production process for tourism maps (Aydinoglu and Yomralioglu 2007)

Turkey has many resources that have the potential to be tourist destinations. Some of these tourism resources (e.g., cultural tourism resources) are still to be added to the tourism map. Stage one of the framework consists of the completion of the mapping of the different types of tourism resources in Turkey.

9.6.2 Stage two: projecting climate change effects

Turkey submitted its first national communication report (Initial NC or INC report) on climate change to the UNFCCC secretariat in 2007. About 40 developing countries have already produced their second report, while some developed countries have submitted their sixth report. The INC report is vital for researchers as it lists the issues facing the country under climate change. According to the report, climate projections for Turkey include changes in precipitation intensity, frequency and duration, and rise in temperature and sea levels.

Projected precipitation for the period 2071-2100 in Turkey shows different results for various regions. It is likely that precipitation will decrease along the Aegean and Mediterranean coasts and increase along the Black Sea coast (Turkey Ministry of Environment and Forestry 2007). The Ministry of Environment and Forestry identified increased coastal erosion, flooding and inundation along the Turkish shoreline as problems of national significance. The Ministry also predicted that surface water resources will decrease in volume by nearly 20% by the year 2030 and by 35% and 50% by the years 2050 and 2100 respectively. Average annual mean

temperature increase for the entire country is estimated to be around 2-3°C by 2100, but some areas might experience increases of up to 6°C (e.g., the Aegean region) (Blue Plan 2008).

Using SimCLIM, it is possible to project average annual mean, maximum and minimum temperatures for Turkey using global data (i.e., to produce example maps of the projected climate change effects for stage two in the developed framework). Figure 9-4 shows averaged annual maximum temperature (°C) for Turkey and surrounding countries using the A1FI-high scenario, from a 21-GCM ensemble for the year 2070. Figure 9-5 shows the projected averaged annual minimum temperature.

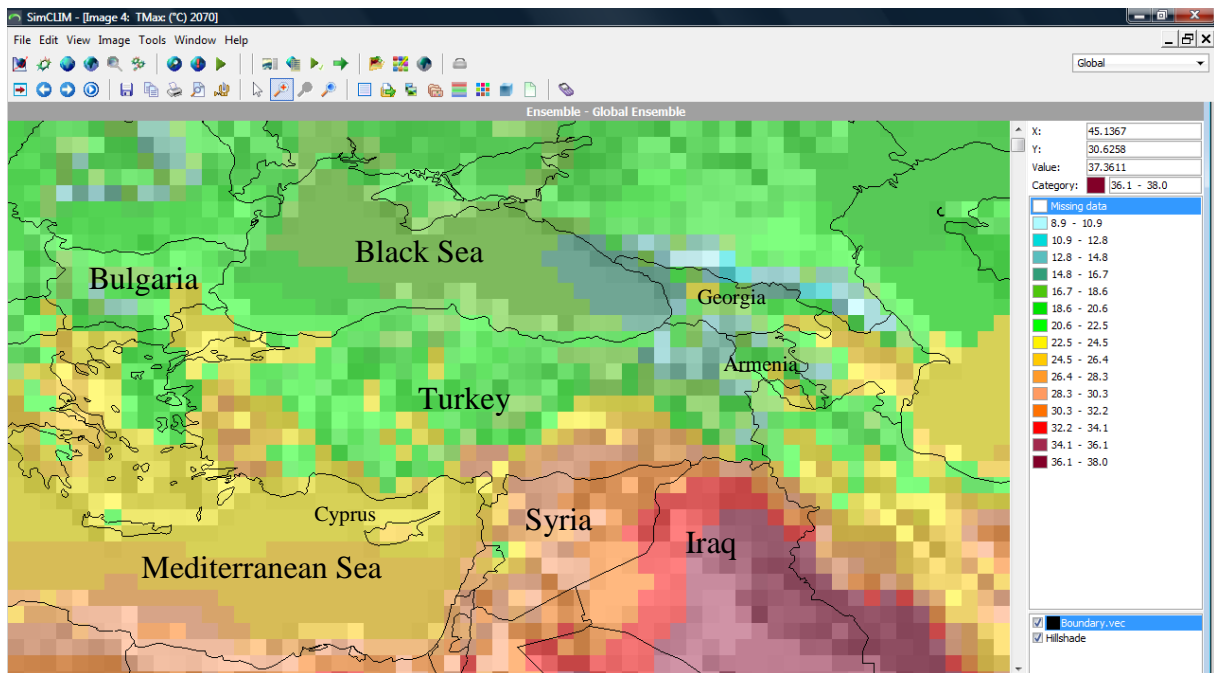


Figure 9-4 Projected averaged annual maximum temperature (°C) for Turkey and surrounding countries, 2070

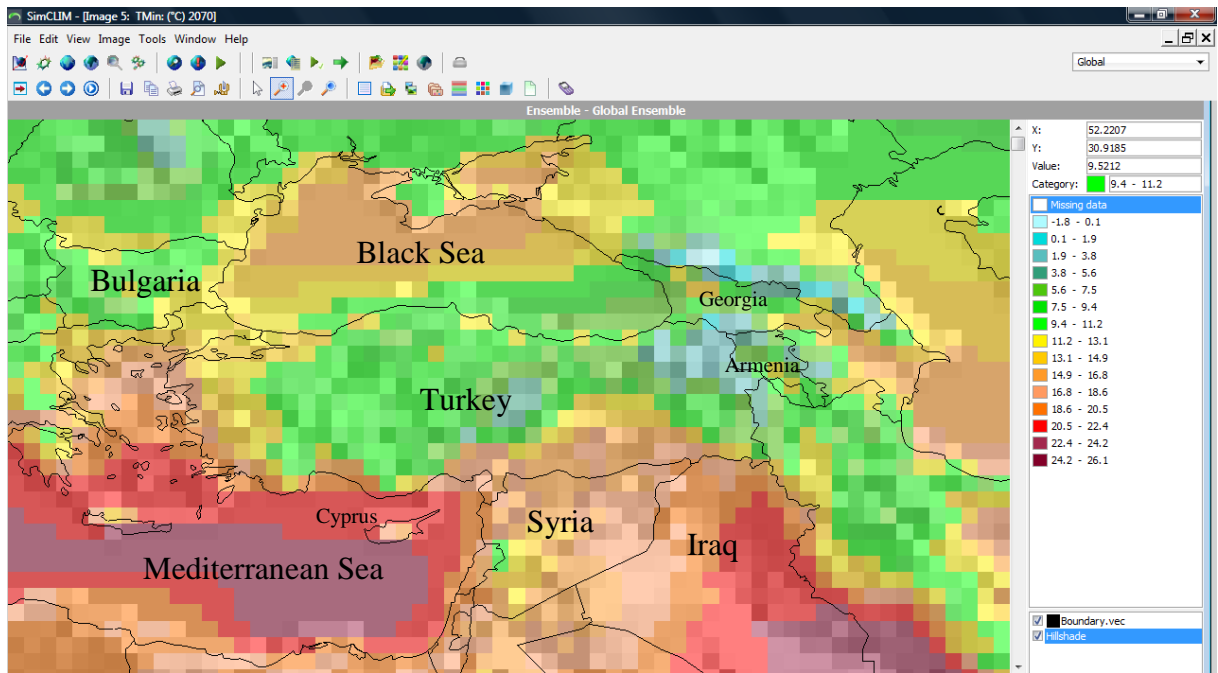


Figure 9-5 Projected averaged annual minimum temperature (°C) for Turkey and surrounding countries, 2070

SimCLIM-projected increases in average annual maximum temperature for areas across Turkey are depicted in table 9-1. Location points in the north, south, east and west of Turkey are selected as representative of their area to show predicted temperature increases by 2070 compared with 1990. The SimCLIM projections show that these areas are expected to experience an increase in mean monthly maximum temperature of 5-6°C, matching official projections (Turkey Ministry of Environment and Forestry 2007).

Table 9-1 Average monthly maximum temperatures in Turkey projected for 2070 compared with the 1990 baseline

Location (Latitude and longitude)	Baseline 1990 value in °C	Projected 2070 value in °C
X = 36.003540 Y = 38.470726	14.8	20.0
X = 34.862897 Y = 38.002373	16.6	21.6
X = 43.321766 Y = 39.026897	14.3	20.0
X = 35.827904 Y = 41.046677	17.4	22.2

9.6.3 Stage three: identifying climate change impacts

After producing maps of tourism resources for Turkey as well as maps showing projected climate change effects, these can be overlaid in GIS to derive the spatial distribution of climate effects on tourism resources. This step was not performed as part of the case study

due to the unavailability of sufficient tourism resources data for Turkey in GIS format. In stage 3, RAP is utilised to analyse the potential impacts of climate change on the tourism resources. Factoring in the quantity and quality of tourism resources allows the potential impacts of climate change to be assessed. As stated in chapter 7, building a model in RAP involves a series of steps to define:

1. The problem statement
2. The components
3. The relationships between the components
4. The characteristics and the relationships between the characteristics
5. The criteria
6. The exogenous changes (i.e., climate change).

The problem statement might be:

Tourism resources in Turkey are significant and the country is becoming a prime tourist destination. To sustain Turkey's tourism industry, its tourism resources must be managed sustainably. This requires managing risks relating to the deterioration of tourism resources, including the risks posed by climate change. The most important aspect of management with respect to climate change is to monitor the impacts of change on tourism resources. Historic and heritage resources are non-renewable, thus early change detection is vital to respond promptly (Figure 9-6).

Four *components* are highlighted: climate change projections, extreme weather events, natural tourism resources and cultural tourism resources. Under each of these *components*, several *characteristics* are defined for demonstration purposes. These *characteristics* and the *relationships* between them are illustrated in Figure 9-7. For example, there is a strong negative relationship between the *characteristic* 'decrease in precipitation' under the 'climate change projection' *component* and *characteristic* 'forests' under the 'natural tourism resources' *component*. These forests, which account for 27% of the total land area of the country, are of importance to the tourism industry in Turkey not only as a source of timber and other products and services needed by tourism but also for the natural attractions they contain (Kuvan 2005). In addition, historic sites in Turkey are likely to be eroded by climate change effects such as wind and temperature (Vlcko et al. 2009).

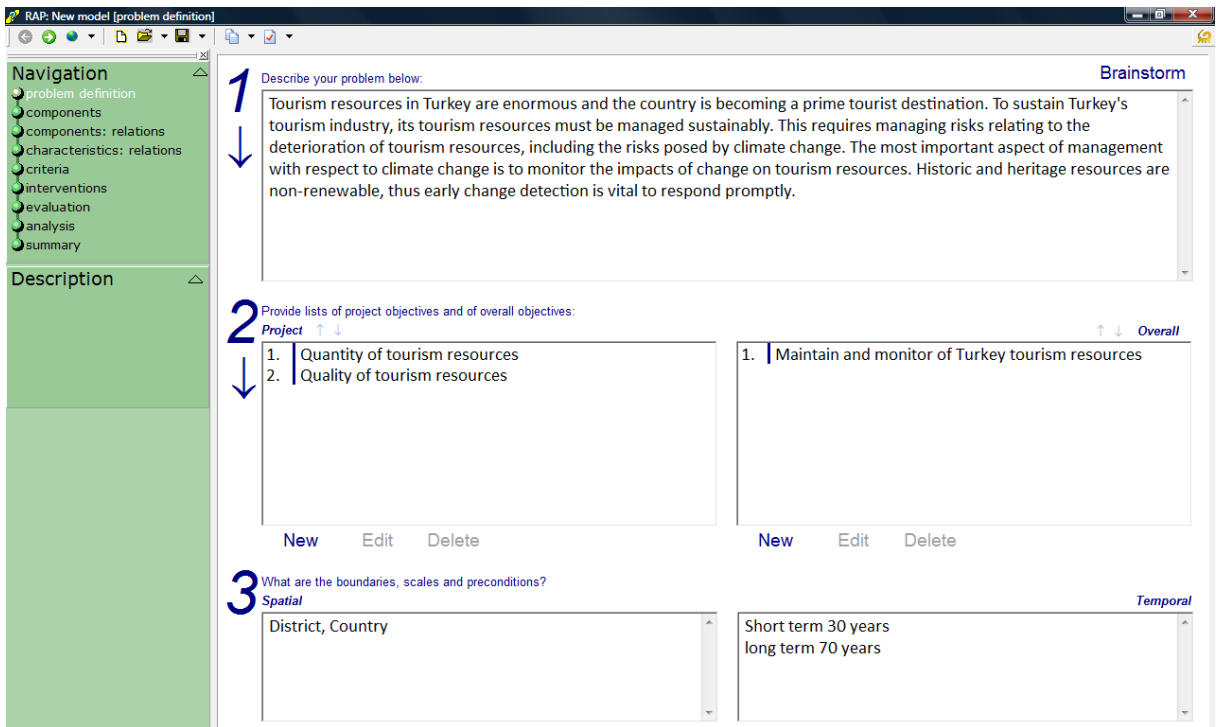


Figure 9-6 RAP model showing problem definition for Turkey

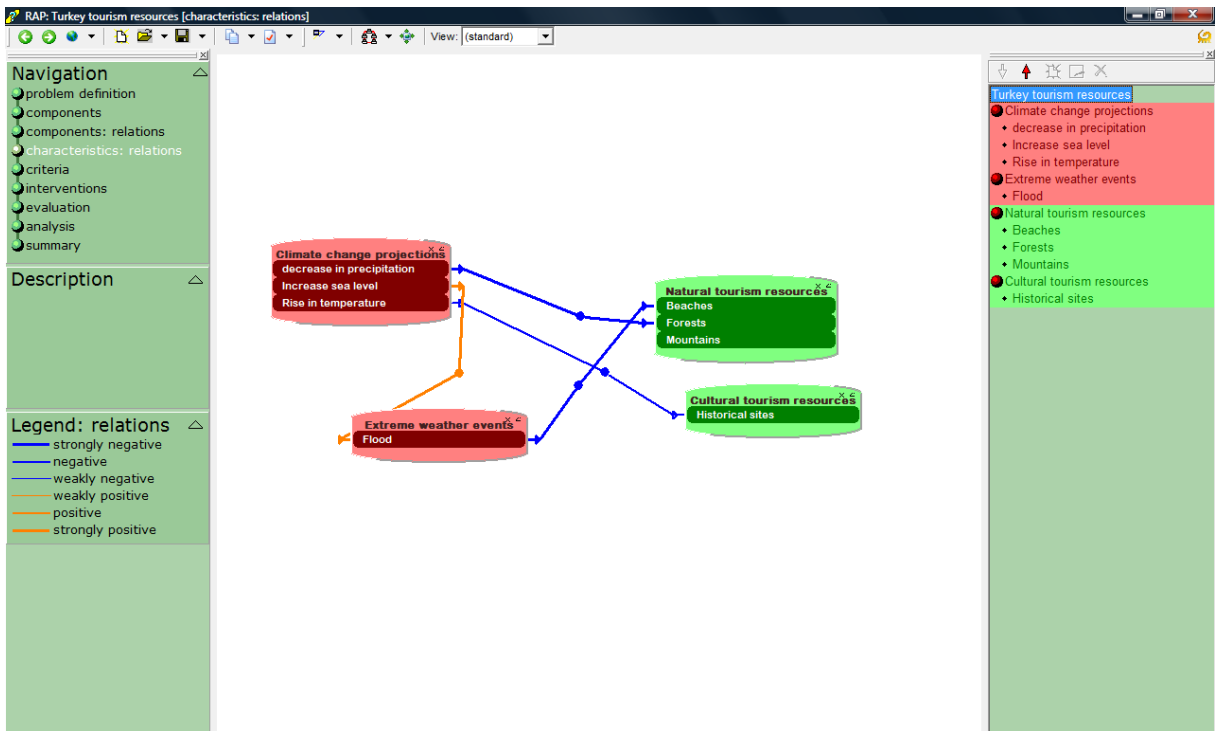


Figure 9-7 RAP model showing the relationship between characteristics

9.6.4 Stage four: deciding on change detection

The expected change in Turkey's tourism resources due to climate change, such as small-scale depletion of water resources and forests as well as large-scale erosion of heritage and historic sites, calls for a monitoring program to detect changes in tourism resources. The land used land cover change (LULCC) program is being implemented by the government.

9.6.5 Stage five: monitoring change in tourism resources

Should Turkey's tourism managers choose to monitor tourism resources, they need to select the appropriate tools for the task. Two types of change will occur: micro and macro-scale. Various techniques are available to assess change for each scale. Alphan (2003) and Alparslan (2002) used remote sensing and GIS with multi-temporal high-resolution satellite data to monitor aspects such as vegetation cover and soil degradation (an example of macro change). To detect micro-scale change, Altuntas et al. (2010) used TLS to scan Turkey's *Alaaddin Palace* (see Figure 9-8).



Figure 9-8 *Alaaddin Palace, Konya, in Turkey* (Altuntas et al. 2010)

A 3D point-cloud of *Alaaddin Palace* is shown in Figure 9-9. The building was scanned with about 3.5 mm point spaces collecting 8,440,464 points (Altuntas et al. 2010). Tourism managers will benefit from the generation of 3D point-clouds for all heritage sites in Turkey, as this will help in monitoring change in these resources.

This case study demonstrated the suitability of the framework as an approach for identifying and monitoring changes in tourism resources due to the impacts of climate change. The framework can assist developing countries to maintain their tourism resources through targeted risk management.

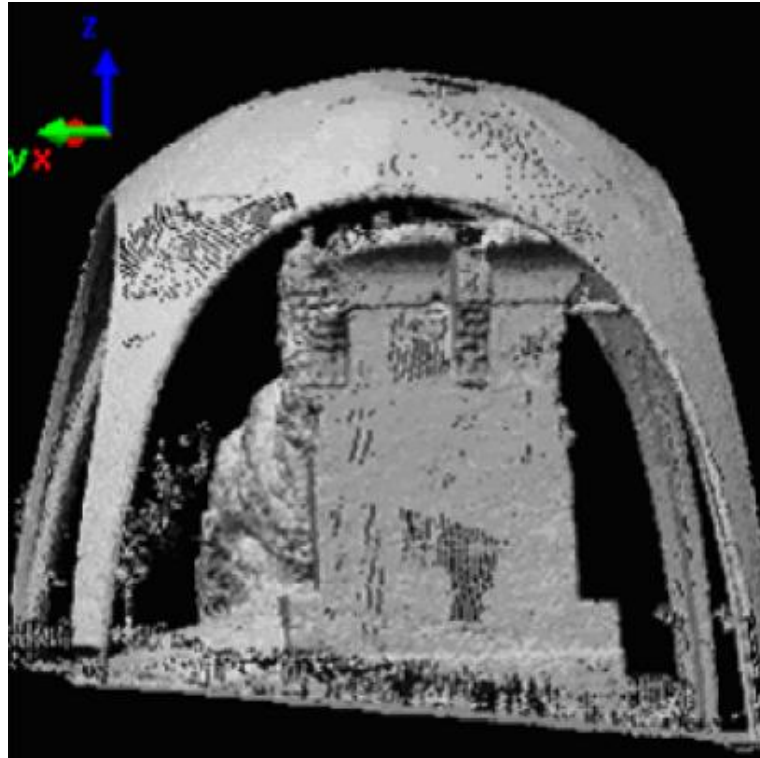


Figure 9-9 Point cloud visualisation of the *Alaaddin Palace* (Altuntas et al. 2010)

9.7 Adaptability of the framework to other tourism resources

The tourism resources considered in the framework include natural, cultural and built-up resources. This range of classifications of tourism resources makes the framework highly adaptable. The essential elements of the approach remain: to identify the resources to be considered, locate them spatially, match resources locations with climate change effects, identify impacts, decide on monitoring. Other resources such as agricultural or mining resources could be analysed in the same way.

The approach consists of logical stages with descriptions of the various tools and methods that could be used in each stage. The outputs of each stage feed into the next until the required information about the changes occurring in the tourism resources is reached and the appropriate response measures can be formulated. Furthermore, the framework can cope with the expected changes, ranging from micro to macro-scale, that might occur in tourism resources. Micro-scale changes, in particular, can be efficiently detected using high-sensitivity survey tools such as TLS. Finally, the tools described at each stage in the framework are easy to use and do not require extensive training in order to be applied.

9.8 Summary

The chapter began with a recapitulation of the five framework stages developed in the previous chapters: identifying and locating tourism resources using GIS; projecting climate change effects using SimCLIM software; utilising the RAP software to assess and analyse the potential impacts of climate change on those tourism resources; and deciding if monitoring of change in tourism resources can be performed using TLS technology for micro-scale or using satellite images for macro-scale changes.

The framework can be used in a generic way by different developing countries. Tourism managers can benefit from the outputs of this framework by using them to initiate appropriate responses and measures to manage their tourism resources.

This chapter showed the applicability of the developed approach to tourism resources within developing countries other than Fujairah. Turkey, a country well known for its richness of different types of tourism resources, was chosen as a case study for the framework.

Chapter 10 Conclusions and Future Directions

10.1 Introduction

This thesis presented the results of research focused on assessing the impacts of future climate change effects on tourism resources in developing countries. The research culminated in the development of an approach which can be used by decision-makers (i.e., tourism managers) to monitor their resources to enable proactive management. The thesis is based on the research questions formulated in line with the aim and objectives stated in Chapter 1.

Tourism was shown to be an important sector in developing countries. It was emphasised that this rapidly growing economic sector is heavily dependent upon climate, making it vulnerable to the impacts of climate change. The research was motivated by the fact that tourism resources in developing countries are threatened by climate change effects. The chapter provided a definition of tourism resources in the context of developing countries, as well as a preliminary explanation of climate change and tourism resources. The first research question ‘*What is a tourism resource?*’ was addressed in this chapter.

The literature on tourism resources and climate change was reviewed in Chapter 2. This included descriptions of various tools for climate change projection, for impact analysis and assessment, as well as for micro- and macro-scale change detection and their relative merits and disadvantages. This chapter addressed the research question ‘*What are the tools available for future climate change projections, impact assessment and impact analysis and change detection?*’

The methodology used in this research was detailed in Chapter 3. It included approaches for the creation of a comprehensive geodatabase of tourism resources in Fujairah and justifications for selecting SimCLIM as the climate change projection tool, RAP as the impact analysis and assessment tool and the use of TLS and GIS in the pilot study for micro- and macro-scale change detection, respectively. This chapter addressed the research question ‘*What are the most appropriate tools and techniques for future climate change projections, impact assessment and analysis, and change detection, in this research?*’ In addition, the chapter justified selection of the Emirate of Fujairah as a case study, one that is representative of other developing countries. This chapter addressed the research question ‘*How well do Fujairah’s tourism resource typify the tourism resources in developing countries?*’

Chapter 4 gave a detailed description of the Emirate of Fujairah including its geographical and geological features, socio-economic features, land use and climate. This chapter served as useful background for the following chapters.

In Chapter 5 the different types of tourism resources in Fujairah, such as natural, cultural and built-up, were described. A comprehensive geodatabase was developed in order to identify and map Fujairah's important tourism resources. It was shown that this mapping process, coupled with the spatially distributed climate change effects and impact analysis of the tourism resources, can assist in the management of climate change impacts on tourism resources. Thus the research questions: '*What are the different types of tourism resources that exist in Fujairah?*' and '*How can a comprehensive geodatabase assist in identifying change in tourism resources?*' were addressed in this chapter.

Chapter 6 detailed the methods, parameters, datasets and information associated with climate change projections and described how projections for the 2030 and 2070 years were made for Fujairah using SimCLIM. These projections were made for the most important climate change variables such as temperature, precipitation, SLR, ocean acidification, and took into account extreme weather events such as droughts and heatwaves. Thus the research questions '*What datasets and information are important in projecting future climate change?*' and '*How will climate change affect Fujairah over the middle term and long term?*' were addressed during this chapter.

Chapter 7 was the key chapter, as it presented an approach for assessing the impacts of climate change effects on Fujairah's tourism resources using RAP. A conceptual model incorporating the relationships between tourism resources and climate change effects was built and the potential impacts of projected climate change effects on several types of Fujairah's tourism resources were assessed. Thus the research question '*Which tourism resources in Fujairah might be impacted by climate change?*' was addressed in this chapter.

Chapter 8 focused on methods for monitoring the change occurring due to climate change effects in Fujairah's tourism resources. A pilot study was detailed that included both micro-scale change detection using TLS and macro-scale change detection using GIS techniques. Therefore, the research question '*How can changes in tourism resources be monitored?*' was addressed in chapter 8.

Finally, chapter 9 presented a methodological framework. The developed framework was generalised in order to be useful for other developing countries. The framework was tested using tourism resources in Turkey, hence demonstrated its broad applicability. The developed framework was shown to be a simple tool that can be used by tourism managers. Thus, in chapter 9 the last question '*Who might be using the results of this research and how will they benefit from it?*' was addressed. Thus, research objectives were met and answered.

The remainder of this chapter concludes this thesis by discussing the constraints and limitations encountered, the key findings and the benefits of this research, and finally some directions for future research.

10.2 Constraints and Limitations

This research resulted in several important outcomes related to monitoring change in tourism resources due to the projected impacts of climate change effects. Nevertheless, it was restricted by certain limitations and constraints beyond the control of the researcher. The limitations identified during the course of this research were as follows:

- (i) Projections for potential impacts on tourism resources due to climate change effects do not account for possible catastrophic events. Climate change projections are uncertain due to assumptions made in scenario selection (A1FI), climate sensitivity, and the GCM/ensemble selected.
- (ii) The case study involved limited observed data; meteorological data for the Emirate of Fujairah was only available from 1995 onwards and for just two locations. There is a lack of local data for extreme event analysis and downscaling for local temperature, precipitation and wind patterns, and for downscaling of SST and SLR patterns. No methodologies exist to deal with this problem, nor do detailed local data from elsewhere (other than Fujairah) exist to validate and verify such methodologies.
- (iii) In relation to projecting coastal erosion, the Bruun Rule parameters had to be based upon *best guess* values (based on generic coastline characteristics) as measured values were not available.
- (iv) The identification of climate change impacts on tourism resources was based on the analysis of a conceptual model (DPSIR) created using the RAP tool. The validity and completeness of the impact analysis depend on how well the conceptual model represents the real situation. However, the conceptual model was created from a particular perspective – that of the researcher. It would have been possible to use RAP

to create different versions of the conceptual model (to mimic a variety of perspectives) and compare their outcomes, but this was beyond the scope of the thesis. Nevertheless, it is unlikely that different models would lead to very different conclusions on how climate change impacts the tourism resources in Fujairah, as the Fujairah projections are aligned with those for other regions.

- (v) The possibility of the phenomenon of GHG-producing tourism-related activities (such as transport) exacerbating climate change, as raised in Chapter 1, was not included in the scope of this thesis.
- (vi) The negative impact of tourist behaviour on tourism resources (e.g., polluting and damaging the resources) was not considered (in spite of these impacts being observed during the fieldwork).
- (vii) Individual preferences of tourists were not taken into account when identifying the importance of tourism resources as they can easily shift; they were considered to be outside the scope of this thesis.
- (viii) Due to the time constraints of a PhD, only a single scan was performed to detect micro-scale change in selected tourism resources; no previous scans exist for comparison. Thus a simulation was conducted in this research for demonstration purposes.
- (ix) The monitoring techniques described herein relate only to physical resources, whereas some cultural resources (like festivals or sporting events) are essentially non-tangible and therefore impossible to monitor using these methods.

10.3 Discussion of Key Findings

Important tourism resources in Fujairah were identified and mapped by constructing a comprehensive geo-database. This geodatabase is expected to be used by the Fujairah authorities for tourism management purposes. By analysing the geo-database, it was found that the majority of Fujairah's tourism resources are located between the coastline and the inner mountains in a coastal zone ranging up to 15 km in width. Analysis also showed that the total number of tourist accommodation facilities in Fujairah increased considerably between 1995 and 2010. Other built-up resources such as shopping malls and parks also increased considerably during the same period.

Using the climate projection tool SimCLIM, projections for several climate variables such as temperature, precipitation, sea level, ocean acidification, and extreme weather events were

made for Fujairah. The average air temperature was projected to increase by more than 5°C over the baseline year 1990 by the year 2070; this is higher than the projected global average temperature increase of 3°C for the same period. There will be a shift in seasons, with longer summers and shorter winter periods. By 2070, precipitation in Fujairah will have decreased by up to 11.3%, while evapotranspiration will increase by 7%. The combination of these factors will further decrease water availability in the region, and the frequency of droughts will increase. Yet, while the total annual precipitation will decrease, the severity and frequency of flash floods will increase; it will rain less, but when it rains the intensity of these events will be higher.

The wind speeds in and around Fujairah may decrease by 4-8% by 2070. Ocean acidification was projected to rise compared to baseline while the SSTs in July will exceed 36°C by the year 2070 (compared to 32°C in the baseline year). This underlines the importance of taking protective measures for Fujairah's (and other developing countries') coral reef tourism resources, as changes to coral reefs not only impact coastal erosion but other tourism resources like marine wildlife and related tourist activities such as diving. Examples of protective measures may include mapping the density of coral reefs and identifying their level of risk from an increase in SST. These activities will enable the raising of awareness of all stakeholders about the negative impacts of climate change on coral reefs, leading to support for monitoring programmes and research and ways of minimising negative anthropogenic impacts on water quality (e.g., directing the discharge from desalination plants away from reefs).

Tourism resources in Fujairah will be impacted by climate change effects in a multitude of ways. Ocean acidification and the climate change effects of temperature will impact several tourism resources more strongly than other effects. The projected rise in temperature will impact the quality of most tourism resources (because outdoor activities will be less comfortable), while increased ocean acidity levels will impact resources close to the coastal fringe: coral reefs, marine mammals, island ecosystems and the coast itself through erosion.

Based on the above climate change projections, the potential impacts on the quality and quantity of Fujairah's tourism resources were assessed. Several technologies for physical change detection that could be used to monitor changes occurring to the Emirate's tourism resources were presented and discussed.

The research findings presented in this thesis are expected to aid tourism decision-makers in Fujairah and other developing countries. They provide valuable insights into ways to measure the probable effects of climate change and their impacts on tourism resources, enabling the implementation of adaptive and proactive responses to minimise damage and ensuring a sustainable tourism industry. Effective monitoring of tourism resources is vital to detect physical deterioration of resources. A complicating issue is that it is hard to distinguish between anthropogenic negative impacts on tourism resources (from tourist behaviour) and impacts from climate change only.

10.4 Future Directions

Future research could involve the use of monitoring techniques such as TLS for micro change detection (limited to scanning five resources only in this research) to obtain scans for all appropriate tourism resources within Fujairah, thus developing a comprehensive database of TLS scan data for all suitable tourism resources. Databases containing 3D models of all major physical tourism resources would be valuable to any developing country, especially those that already experience natural hazards like earthquakes or floods. Using LIDAR or UAV in conjunction with TLS would further enhance these outcomes.

Research on the impacts of the phenomenon of tourism-related activities that exacerbate climate change (excluded from this research) would be useful. The ongoing global increase in tourism and air travel means more fossil fuel consumption and resulting GHG emissions.

The work described in this thesis could be extended by projecting the economic losses due to (unmitigated) climate change effects impacting tourism resources. This might include taking account of tourist preferences. Random samples of tourists could be surveyed about their probable responses to the conditions created by climate change and their expectations of comfort. A method called ‘discrete choice modelling’ that offers participants multiple scenarios (vignettes) to gauge their responses can be used in this type of research (Greene 2008).

Geodatabases could be expanded to include detailed statistical descriptions such as the number of tourists visiting each site over different time periods over the day and over the year, which will help tourism managers to comprehend site-specific characteristics. Such an approach, apart from supporting the management of each site, will help to assess anthropogenic impacts on tourism resources in addition to natural climatic effects. For

instance, measuring the impacts on tourism resources from visitation (e.g., trampling and graffiti) could be useful for decision-making.

Finally, there is value in policy-oriented research into the development of a strategy for tourism resources that counters and combats the negative impacts of climate change. The Fujairahan tourism authorities are in the process of reviewing their current strategic plan and developing a new one.

10.5 Contribution and closing comments

The research described in this thesis focused on how future climate change will impact tourism resources in developing countries, taking Fujairah as a case study, and how the changes occurring in those resources can be monitored. It developed a framework for monitoring the impacts of climate change which provides a platform for thinking about mitigation methods. The results of this research are expected to aid the FTAA and other authorities in the Emirate of Fujairah, and similar bodies within other developing countries, to reduce the impacts of projected climate change effects on their tourism resources.

This thesis describes the first study of its type conducted in the Arabian Gulf countries, many of which are rich in oil resources yet remain developing countries. It was a challenging task to integrate the different aspects of the research, such as remote sensing and GIS, climate change projections and scenarios, systematic impact assessment from climate change, and the field survey using TLS. The core outcome of this thesis, the monitoring framework, is a significant contribution to the field of management and maintenance of tourism resources. The adaptability of the developed framework to be used for monitoring different types of tourism resources adds to its advantages.

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Appendix A: Global CO₂ Concentration

10-1 Global CO₂ concentration from 1990 to 2100, adopted from global warming database in SimCLIM

Year	Low sensitivity (ppm)	Mid sensitivity (ppm)	High sensitivity (ppm)	Year	Low sensitivity (ppm)	Mid sensitivity (ppm)	High sensitivity (ppm)
1990	353.63	353.63	353.63	2028	445.52	447.62	450.08
1991	355.16	355.16	355.16	2029	449.63	451.86	454.49
1992	356.67	356.67	356.67	2030	453.83	456.21	459.02
1993	358.18	358.18	358.18	2031	458.15	460.68	463.66
1994	359.71	359.71	359.71	2032	462.58	465.26	468.43
1995	361.25	361.25	361.25	2033	467.13	469.97	473.33
1996	362.81	362.81	362.81	2034	471.79	474.8	478.37
1997	364.39	364.39	364.39	2035	476.57	479.75	483.54
1998	365.99	365.99	365.99	2036	481.46	484.82	488.84
1999	367.61	367.61	367.61	2037	486.47	490.02	494.27
2000	369.24	369.24	369.24	2038	491.59	495.35	499.85
2001	370.94	370.95	370.97	2039	496.83	500.8	505.56
2002	372.7	372.75	372.81	2040	502.19	506.38	511.41
2003	374.53	374.62	374.71	2041	507.67	512.09	517.41
2004	376.41	376.54	376.68	2042	513.29	517.94	523.57
2005	378.35	378.52	378.71	2043	519.03	523.93	529.87
2006	380.34	380.55	380.79	2044	524.9	530.06	536.33
2007	382.38	382.65	382.94	2045	530.9	536.34	542.95
2008	384.48	384.8	385.15	2046	537.03	542.75	549.73
2009	386.63	387	387.42	2047	543.29	549.31	556.67
2010	388.84	389.27	389.75	2048	549.69	556.01	563.77
2011	391.13	391.61	392.17	2049	556.22	562.86	571.03
2012	393.52	394.07	394.7	2050	562.87	569.86	578.46
2013	396.02	396.64	397.35	2051	569.61	576.95	586
2014	398.63	399.32	400.11	2052	576.39	584.09	593.62
2015	401.34	402.1	402.98	2053	583.21	591.29	601.31
2016	404.15	404.99	405.95	2054	590.07	598.54	609.08
2017	407.05	407.98	409.04	2055	596.98	605.86	616.94
2018	410.05	411.06	412.22	2056	603.94	613.24	624.88
2019	413.14	414.24	415.51	2057	610.95	620.69	632.91
2020	416.32	417.51	418.89	2058	618.01	628.2	641.03
2021	419.6	420.89	422.39	2059	625.13	635.79	649.25
2022	422.99	424.38	426	2060	632.3	643.45	657.57
2023	426.48	427.98	429.73	2061	639.52	651.18	665.98
2024	430.08	431.7	433.57	2062	646.8	658.97	674.48
2025	433.79	435.52	437.53	2063	654.12	666.83	683.07
2026	437.6	439.44	441.6	2064	661.49	674.75	691.75
2027	441.51	443.48	445.79	2065	668.92	682.75	700.53

2066	676.4	690.82	709.41	2084	820.02	847.9	886.13
2067	683.93	698.95	718.39	2085	828.25	857.03	896.63
2068	691.52	707.16	727.47	2086	836.47	866.17	907.17
2069	699.17	715.45	736.66	2087	844.68	875.31	917.75
2070	706.88	723.82	745.95	2088	852.88	884.46	928.35
2071	714.65	732.25	755.34	2089	861.07	893.62	938.99
2072	722.47	740.76	764.83	2090	869.26	902.79	949.6
2073	730.34	749.33	774.42	2091	877.45	911.97	960.17
2074	738.26	757.98	784.11	2092	885.64	921.16	970.7
2075	746.23	766.69	793.9	2093	893.83	930.36	981.19
2076	754.27	775.48	803.79	2094	902.02	939.53	991.63
2077	762.35	784.34	813.78	2095	910.22	948.65	1002.03
2078	770.5	793.28	823.89	2096	918.41	957.72	1012.38
2079	778.71	802.29	834.09	2097	926.59	966.74	1022.69
2080	786.97	811.39	844.41	2098	934.72	975.71	1032.94
2081	795.26	820.52	854.8	2099	942.8	984.62	1043.14
2082	803.53	829.64	865.21	2100	950.83	993.49	1053.29
2083	811.78	838.77	875.66				

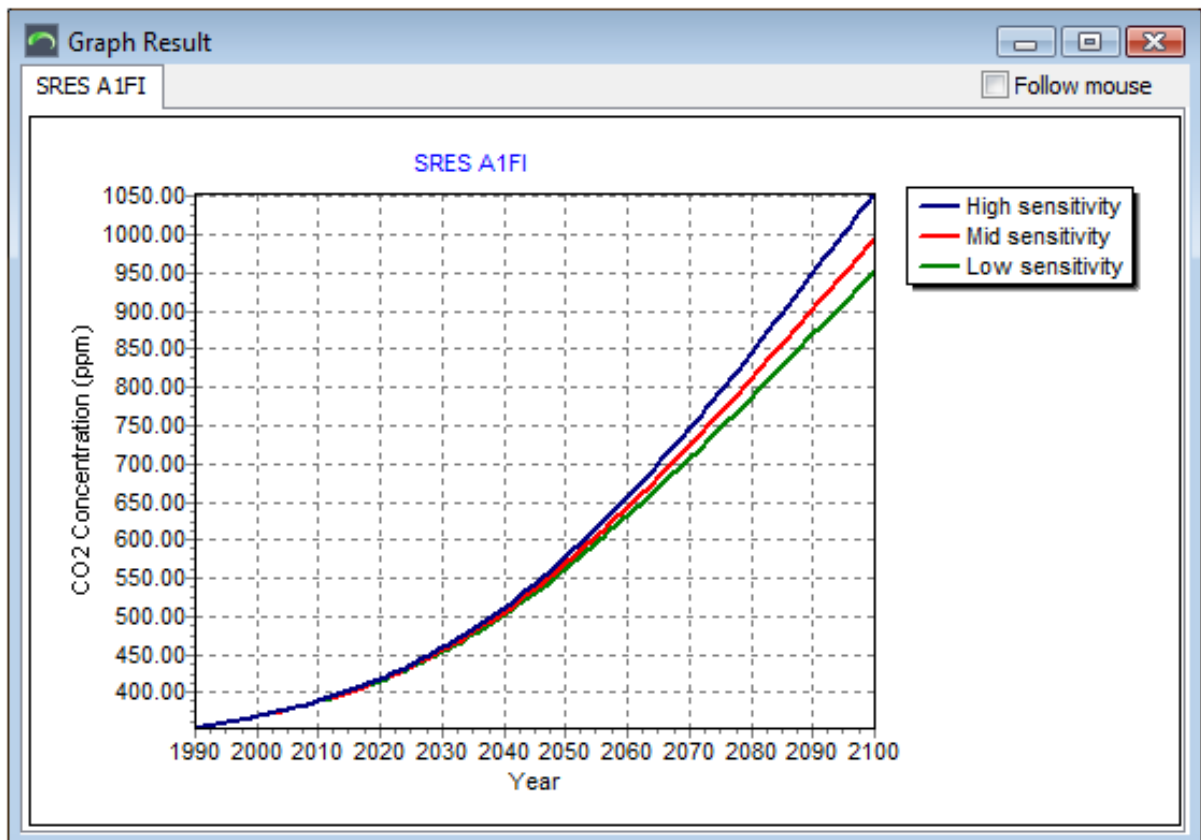


Figure 10-1 Global CO₂ concentration (ppm) under SRES A1FI emission scenario

Appendix B: GCM Models

All GCM models available in *SimCLIM* from the IPCC (National Climate Change Adaptation Research Facility 2011b).

Table 1 GCMs used in SimCLIM precipitation and temperature patterns.

No	Originating Group(s), Country	Model	SimClim name	Horizontal grid spacing(km)
1	Bjerknes Centre for Climate Research, Norway	BCCR	BCCRBCM2	~175
2	Canadian Climate Centre, Canada	CCCMA T47	CCCMA-31	~250
3	Meteo-France, France	CNRM	CNRM-CM3	~175
4	CSIRO, Australia	CSIRO-MK3.0	CSIRO-30	~175
5	CSIRO, Australia	CSIRO-MK3.5	CSIRO-35	~175
6	Geophysical Fluid Dynamics Lab, USA	GFDL 2.0	GFDLCM20	~200
7	Geophysical Fluid Dynamics Lab, USA	GFDL 2.1	GFDLCM21	~200
8	NASA/Goddard Institute for Space Studies, USA	GISS-E-H	GISS—EH	~400
9	NASA/Goddard Institute for Space Studies, USA	GISS-E-R	GISS—ER	~400
10	LASG/Institute of Atmospheric Physics, China	FGOALS	FGOALS1G	~300
11	Institute of Numerical Mathematics, Russia	INMCM	INMCM-30	~400
12	Institute Pierre Simon Laplace, France	IPSL	IPSL-CM40	~275
13	Centre for Climate Research, Japan	MIROC-H	MIROC-HI	~100
14	Centre for Climate Research, Japan	MIROC-M	MIROCME D	~250
15	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, Germany/Korea	MIUB-ECHO-G	ECHO---G	~400
15	Max Planck Institute for meteorology	MPI-	MPIECH-5	~175

	DKRZ, Germany	ECHAM5		
17	Meteorological Research Institute, Japan	MRI	MRI-232A	~250
18	National Center for Atmospheric Research, USA	NCAR-CCSM	CCSM—30	~125
19	National Center for Atmospheric Research, USA	NCAR-PCM1	NCARPCM1	~250
20	Hadley Centre, UK	HADCM3	UKHADCM3	~275
21	Hadley Centre, UK	HADGEM1	UKHADGEM	~125

Table 2 GCMs used in SimCLIM sea level change patterns.

No.	Originating Group(s), Country	Model	SimCLIM name	Original spatial resolution
1	Canadian Climate Centre, Canada	CCCMA T47	CCCMA-31	96*192
2	CSIRO, Australia	CSIRO-MK3.0	CSIRO-30	~175
3	Geophysical Fluid Dynamics Lab, USA	GFDL 2.1	GFDLCM21	200*360
4	NASA/Goddard Institute for Space Studies, USA	GISS-E-H	GISS—EH	180*360
5	NASA/Goddard Institute for Space Studies, USA	GISS-E-R	GISS—ER	46*72
6	NASA/Goddard Institute for Space Studies, USA	GISS-AOM	GISS_AOM	60*90
7	Centre for Climate Research, Japan	MIROC-H	MIROC-HI	320*320
8	Centre for Climate Research, Japan	MIROC-M	MIROCMED	192*256
9	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, Germany/Korea	MIUB-ECHO-G	ECHO---G	117*128
10	Max Planck Institute for meteorology DKRZ, Germany	MPI-ECHAM5	MPIECH-5	180*360
11	Meteorological Research Institute,	MRI	MRI-232A	111*144

	Japan			
12	National Center for Atmospheric Research, USA	NCAR-CCSM	CCSM—30	395*320
13	Hadley Centre, UK	HADCM3	UKHADCM3	144*288

Table 3 GCMs used in SimCLIM extreme precipitation analysis.

No.	Originating Group(s), Country	Model	SimCLIM name	Horizontal grid spacing(km)
1	Bjerknes Centre for Climate Research, Norway	BCCR	BCCRBCM2	~175
2	Canadian Climate Centre, Canada	CCCMA T47	CCCMA-31	~250
3	Meteo-France, France	CNRM	CNRM-CM3	~175
4	CSIRO, Australia	CSIRO-MK3.5	CSIRO-35	~175
5	Geophysical Fluid Dynamics Lab, USA	GFDL 2.0	GFDLCM20	~200
6	Geophysical Fluid Dynamics Lab, USA	GFDL 2.1	GFDLCM21	~200
7	Institute Pierre Simon Laplace, France	IPSL	IPSL-CM40	~275
8	Centre for Climate Research, Japan	MIROC-M	MIROCMED	~250
9	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, Germany/Korea	MIUB-ECHO-G	ECHO---G	~400
10	Max Planck Institute for meteorology DKRZ, Germany	MPI-ECHAM5	MPIECH-5	~175
11	Meteorological Research Institute, Japan	MRI	MRI-232A	~250
12	National Center for Atmospheric Research, USA	NCAR-CCSM	CCSM—30	~125

Appendix C: Perturbation Method

SimCLIM uses the *perturbation method*, also known as the *change factor method*; this is described below, as is the CMIP3 database from which the data were extracted.

Perturbation method

The perturbation method involves adding the change factors of monthly mean changes for future scenarios to the historic observed daily or monthly data to form a new time series that represents future climate conditions. The perturbed time series data can be used for future climate change impact assessment. For example, if a mean temperature in January is projected to increase by 1.2°C by 2050 (A1B). This 1.2°C change factor is added to each day in January for every year in the observed time series. Similarly, if precipitation in January is projected to increase by 10% by 2050 (A1B), then this 10% change factor is added to each day in January for every year in the observed time series. Statistically, this time series become representative of 2050 (A1B) in terms of climatology and variability.

CMIP3 database of climate simulations (Meehl et al. 2007)

The dataset of experiments from 21 models from research groups around the world was obtained from Coupled Model Intercomparison Project 3 (CMIP3) database (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php). CMIP3 was a major advance in the evaluation of climate models and the generation of climate projections. The availability of a new set of systematic model experiments from the CMIP3 database represents a major advance both for the evaluation of models and the generation of climate projections. The database includes more than 21 models and more simulations of emission scenarios using each model. The model output is freely available to the research community, and this has resulted in unprecedented levels of evaluation and analysis. The models in the CMIP3 database represent the current state-of-the-art in climate modelling, with generally more sophisticated representations of physical and dynamical processes, and finer spatial resolution. The CMIP3 database provides monthly mean temperature and precipitation data for all 21 models. Some models have single simulations for the 20th and 21st centuries, while others have multiple simulations (ensembles). For models with multiple simulations, ensemble-mean changes in climate have been computed. The simulations of 20th century climate, driven by observed changes in greenhouse gases and aerosols, were used as the baseline.

Appendix D: Bruun Rule (Kenny et al. 2000)

The concept behind the 2-dimensional "Bruun Rule" model is explained in the United States Country Studies Program Handbook (Benioff, Guill and Lee 1996). In effect, in the Bruun Rule the equilibrium profile of a beach and dune system is readjusted for a change in sea level. A rise in sea level will cause erosion and re-establishment of the equilibrium position of the shoreline further inland, as follows (Kenny et al. 2000):

$C_{eq} = z \cdot l / (h + d)$ where:

C_{eq} is the equilibrium change in shoreline position (in metres)

z is the rise in sea level (in metres)

l is the closure distance (the distance offshore to which materials are transported and "lost", in metres)

h is the height in metres of the dune at the site

d is the water depth in metres at closure distance ($1/(d+h)$ thus gives slope)

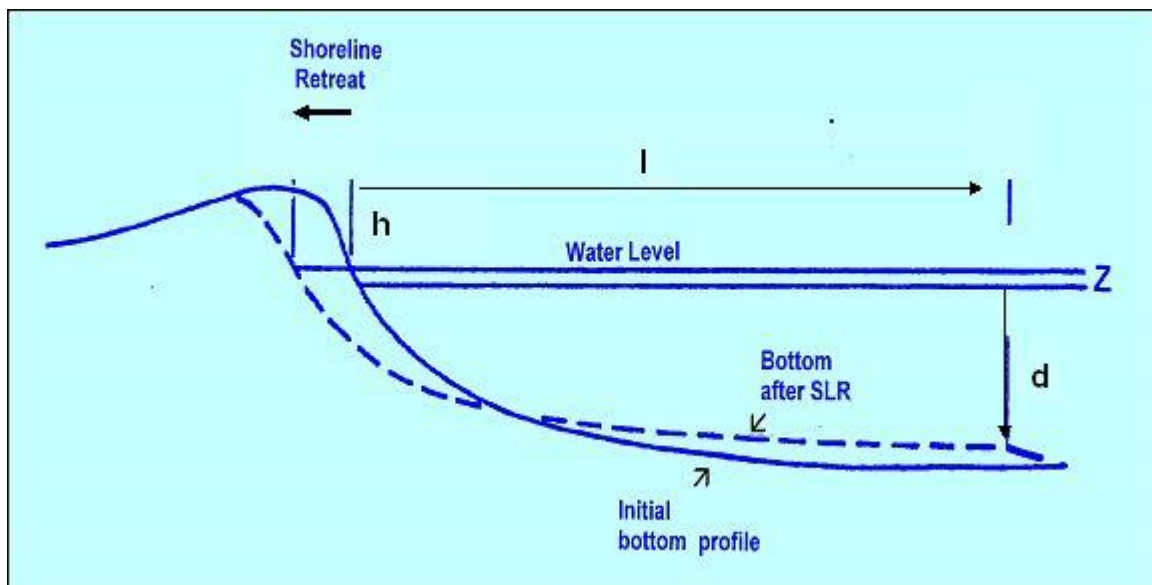


Figure 1: Principles of the Bruun Rule

There are two important drawbacks to using this simple model to examine shoreline change under a trend of rising sea level. First, it gives only the "equilibrium" (or steady-state) change. In reality, coastal systems do not adjust instantaneously; rather, there is apt to be some time lag in the response. Second, in reality shoreline retreat, as evidenced by historical

data on beach profiles, is apt to occur in fits and starts over time, not as a steady, year-by-year incremental change. This uneven response of the shoreline is partly a function of the chance occurrence of severe stormy seasons, which often cause erosion (in contrast, a season of very few, or mild, storms may allow the natural system to replenish the sediment supply and the shoreline to advance).

For these reasons, the Bruun Rule was modified slightly to add a response time and a stochastic "storminess" factor as follows:

$$dC/dt = (C_{eq} - C)/\tau + S \text{ where:}$$

t is time (years)

C is the shoreline position (metres) relative to that of $t=0$

C_{eq} is the equilibrium value of **C**

τ is the shoreline response time (years)

S is a stochastically-generated storm erosion factor

In other words, the yearly change in shoreline is a function of the difference between where the shoreline should be (according to the Bruun Rule) in that year and where it actually is (as a consequence of what has occurred in previous years), as well as the effect of storms. The greater the difference, the greater the potential for erosion in that year, subject to the rapidity with which the system can respond.

The model is forced by changes in sea level (projections selected by the user) and by the randomly selected "storms". The model runs year by year and the results are displayed graphically.