# VULNERABILITY TO CLIMATE CHANGE

# 4

Being a low-lying, small island state, the Maldives is very vulnerable to the impacts of climate change and associated sea level rise. Even though the Maldives contributes 0.001% to global emissions of GHGs (see Table 2-5), it is in fact one of the most vulnerable countries to climate change and sea level rise. The coastal settings of the Maldives make it vulnerable to natural disasters associated with sea level rise and the changes in the temperatures and rainfall patterns. Climate change will also impact the social and economic development of the country, as most of the economic activities are heavily dependent on the coastal ecosystem. Also, the entire population and the infrastructure of Maldives are very close to mean sea level. It is anticipated that climate change will have negative impacts on the economy and the Maldivian society; the society will be more prone to multiple stresses.

The main concern for the Maldives would be sea level rise. The rise in sea level would lead to, or exacerbate, land loss from beach erosion and inundation and also damage human settlements and vital infrastructure. Maldives would also be very vulnerable to impacts of rising air and sea surface temperatures and changes in rainfall patterns.

Identified below are some of the priority vulnerabilities of the Maldives to climate change:

- Land loss and beach erosion
- Infrastructure damage
- Damage to coral reefs
- Impacts on the economy
- Food security
- Water resources
- Human health

### *Climate change scenarios*

*IPCC emission scenarios, IS92a and IS92e were used to develop the scenarios using MAGICC and SCENGEN for the year 2025, 2050 and 2100.*

*The models used here predict that by the end of this century the temperature may have increased by between 2.0 °C and 3.8 °C and sea level may rise between 48 cm to 95 cm. The models were not able to indicate reliably how the rainfall pattern might change in the region as the models gave very distinct results for precipitation.*

*Overall, local long term climate recordings for the Maldives show that there is an increase in atmospheric temperatures and sea level while a decrease in rainfall is observed.*

| Year | 2025 | | | 2050 | | | 2100 | | |
|---|---|---|---|---|---|---|---|---|---|
| Model/ Scenario | Temperature (°C) | Rainfall (%) | Sea Level (cm) | Temperature (°C) | Rainfall (%) | Sea Level (cm) | Temperature (°C) | Rainfall (%) | Sea Level (cm) |
| CSIRO-Mk2 IS92a(mid) | 0.4 | 1.6 | - | 0.9 | 3.0 | - | 2.0 | 5.9 | - |
| CSIRO-Mk2 IS92e(high) | 0.6 | 2.5 | - | 1.4 | 3.6 | - | 2.8 | 8.1 | - |
| HaDCM2 IS92a(mid) | 0.7 | 12.1 | 9.3 | 1.4 | 23.0 | 19.9 | 2.6 | 44.3 | 48.9 |
| HaDCM2 IS92e(high) | 1.0 | 18.9 | 19.7 | 1.7 | 38.6 | 39.7 | 3.8 | 77.4 | 94.1 |

*Table 4-1: Climate change scenarios*

***The Vulnerability and adaptation (V&A) assessment process***

*The GEF Climate Change Enabling Activity is mainly a capacity building project. Therefore, under the guidance of the International Advisory Board (IAB) of the project it was decided that a national team should undertake the V&A assessment. This was a preferred option as the Maldives lacks detailed studies required for such an assessment. It was decided that a V&A team would be established and trained to facilitate the future assessments. The Maldives National V&A Team, which included 23 members from 13 government sectors, were trained on V&A assessment.*

*Trainings Activities:*
*April 2000 – special V&A training conducted by a 4 member team from International Global Change Institute, University of Waikato, New Zealand; University of South Pacific, Fiji and Ecowise Environmental, Australia.*

*August 2000 - training on the use of Geographic Information Systems (GIS) conducted by the Asian Institute of Technology, Thailand.*

*Method:*
*The team was grouped into sectoral groups to focus on assessing the vulnerability of particular sectors based on the anticipated climate change impacts on the Maldives. The V&A team worked over a five-month period to produce various sectoral reports. These reports were based on previous studies done in Maldives and field data collected in seven study islands. The islands were chosen to show the various circumstances and vulnerabilities found in the Maldives.*

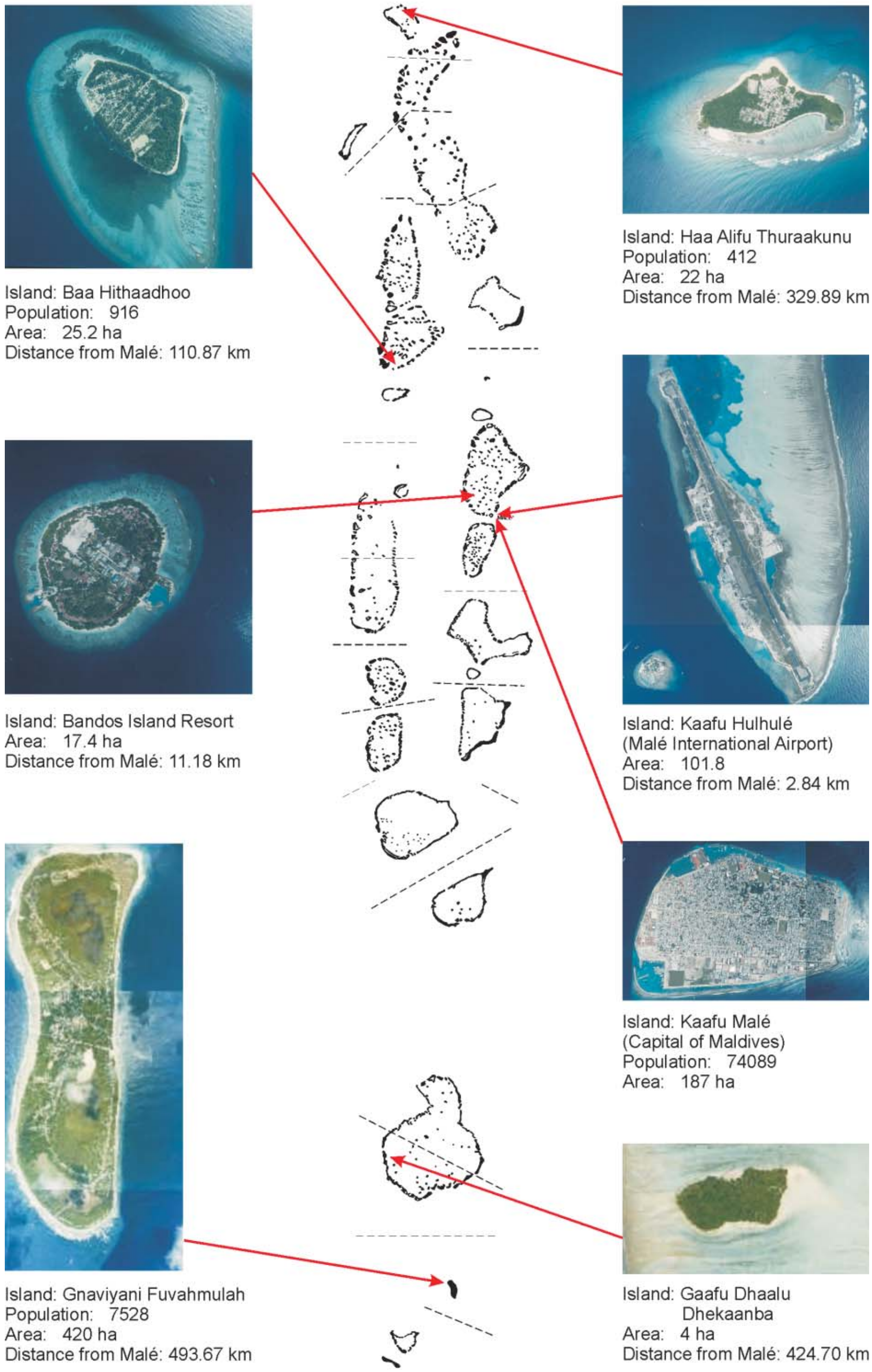
*Study Sectors:*

1. *Coastal Changes*
2. *Human Settlements and Infrastructure*
3. *Marine Ecosystems*
4. *Tourism*
5. *Fisheries*
6. *Food and Agriculture*
7. *Hydrology and Water Resources*
8. *Human Health*

*Study Islands:*

1. *Malé – the capital*
2. *Hulhulé - International Airport Island*
3. *Bandos Island Resort - resort island*
4. *Thuraakunu (Haa Alif Atoll) - inhabited islands in the north*
5. *Hithaadhoo (Baa Atoll) – inhabited island in the central region*
6. *Fuvahmulah (Gnaviyani Atoll) – inhabited island in the south*
7. *Dhekaanba (Gaaf Dhaal Atoll) - uninhabited island*

*Box 4-1: V&A Assessment Process*




*Map: 4-1: Aerial photographs and location maps of the islands selected for V&A Assessment*

| | Malé | Hulhulé | Bandos | Thuraakunu | Hithaadhoo | Fuvahmulah | Dhekaanba |
|---|---|---|---|---|---|---|---|
| Sectorial Group | (Capital) | (International Airport) | (Resort) | (Inhabited) | (Inhabited) | (Inhabited) | (Uninhabited) |
| Coastal Changes | √ | √ | √ | √ | √ | √ | √ |
| Human Settlements and Infrastructure | √ | √ | √ | √ | √ | √ | √ |
| Marine Ecosystems | - | - | - | - | - | - | - |
| Food and Agriculture | - | - | √ | √ | √ | √ | - |
| Tourism | - | √ | - | - | - | - | - |
| Fisheries | - | - | - | √ | √ | √ | - |
| Hydrology and Water Resources | √ | √ | √ | √ | √ | √ | √ |
| Human Health | √ | - | - | √ | √ | √ | - |

*Table 4-2:Sectoral studies done in the V&A study islands*

## 4.1 Land loss and beach erosion

Sea level rise will have grave consequences for the Maldives. The islands of the Maldives are among the most susceptible to inundation from water rising from the ground, as well as overtopping dune ridges. Being made of coral limestone, the islands of the Maldives are also among the least defensible against sea level rise in the world.

Over 80% of the land area of the Maldives is less than 1 m above mean sea level (MHAHE, 1999). No islands have an elevation greater than 3 m. The population is scattered over 199 islands, many of which are very small, less than 1 $km^2$. Although 37.3% of the population is found on 5 most populated islands, the rest representing almost 62.7% of the population, are scattered over 194 islands (MPHRE, 1996).

The islands of the Maldives are also extremely vulnerable to beach erosion. The shapes and size of these small islands are characterised by strong tidal and current patterns. The beach systems found on these islands are highly dynamic and have directional shifts within the shoreline in accordance with the prevailing seasonal conditions. An estimated 50% of all inhabited islands and 45% of tourist resorts at present suffer from varying degrees of beach erosion (ERC, 2001).

Predicted climate change will aggravate the already serious problem of beach erosion and threaten homes and economic activities. It is expected that a 1 m rise in sea level would cause the loss of the entire land area of Maldives. Even a few centimetres rise in sea level could have devastating implications for the Maldives.

Following the storm event of April 1987, the Government of Maldives has sought an engineering solution for the capital Malé, where over 25% of the population resides. The 1.2 km long breakwater constructed on the southern side of Malé cost US$ 14 million. The protective seawall on the western, eastern and southern perimeter of Malé cost US$ 30 million. The estimated cost for the northern side seawall that is under construction at present is US$ 14 million. These figures combined put the total cost of protecting Malé at US$ 58 million (MCPW, 2001).

These engineered structures have been designed for a wave of wave height, 2 metres above mean sea level and a period of 14 seconds (JICA, 1987). This solution was sought by the government in order to protect homes, businesses and lives in a crisis situation under present climatic conditions and so does not consider climate change and accelerated sea level rise. It needs to be studied further if the present seawall around Malé can withstand future predicted impact of climate change and accelerated sea level rise.

Such expensive solutions are technically feasible, but are of little use when neither funding nor adequate human resources are available. The cost of protecting 50 of the 200 inhabited islands of the Maldives with artificial structures was estimated to be over US$ 1.5 billion (Gayoom, 1998: p54)

### *Case study 1: Land loss and beach erosion*

#### *Objective:*

*To assess the vulnerability of islands selected for V&A assessment, with varying characteristics, to land loss and beach erosion by measuring their elevation above sea level.*

#### *Methodology:*

*Standard levelling technique was used to measure the beach profiles and transects across the study islands. The number of profiles taken for each island varied from about 10-40 depending on the size of the island. These levelling surveys provided information on their vulnerability to a rise in sea level.*

*The water level at a staff point was measured at a given time interval and the mean sea level for these water levels were estimated by taking into account the tidal predictions and the difference in time from when the mean sea level was recorded.*

#### *Observations/preliminary findings:*

*All of the islands surveyed had elevations of less than 1m above mean sea level, except for Fuvahmulah, which has a slightly higher elevation than the rest of the islands. Figures 4.1a-c below gives the traverse across some of the study islands and these show the effects of sea level rise on these islands.*

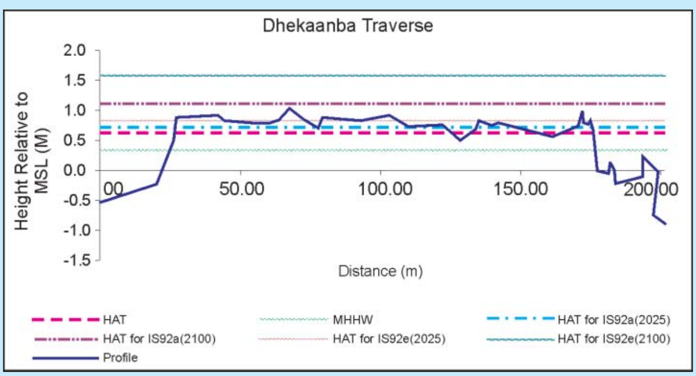



*Figure 4.1a: Transaction of Dhekaanba*

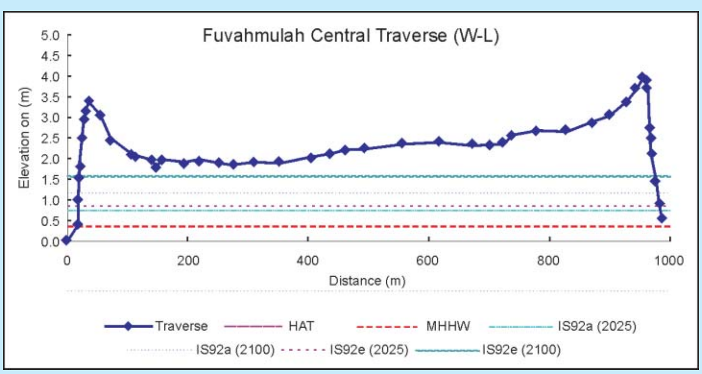



*Figure 4.1b: Transaction of Fuvahmulah*

*Box 4.3: V&A case study 1*

*Box 4.3: V&A case study 1 continued*

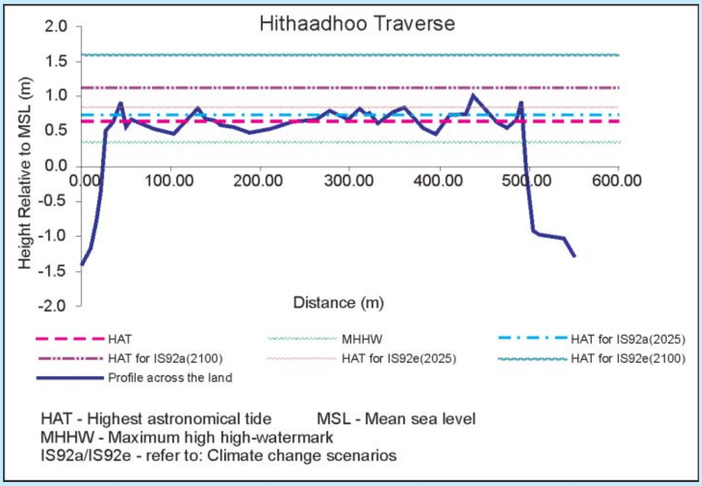



*Figure 4.1c: Transaction of Hithaadhoo*

***Difficulties encountered:***

*Due to errors, it was not possible to use all the profiles for analysis. Given the short study period it was not possible to run any sea level recorders. There were no baseline data on these islands to which the field data could be compared with. The little information available for comparison were the aerial photographs taken in the 1960's. Furthermore, the field data collected under the study does not represent the conditions at the sites throughout the year, but only gives a snapshot at the time the data were collected.*

***Study islands:***

- *Gaaf Dhaalu Dhekaanba*
- *Gnaviyani Fuvahmulah*
- *Baa Hithaadhoo*

## Impacts on Malé

Malé has experienced enormous change to its shoreline. The island's lagoon and reef flat have been reclaimed and the land has been extended almost up to the reef. The total reclaimed area of Malé is about 45% more the land in 1969. The increase in the population of Malé and the demand for housing led to the reclamation of Malé. Reclamation was initiated by the private sector and later this was done under the supervision of the government. Reclamation of land up to the reef has made the island more vulnerable to wave attacks, as the wave dissipation zone and reef flat do not exist anymore.

***Case Study 2: Impacts of sea level rise on Malé***

***Objective:***

*To show the impact of various predicted sea level scenarios on Malé, in terms of area that would be inundated.*

***Methodology:***

*Digital Terrain Model (DTM) of Malé was constructed in a Geographical Information System (GIS) by interpolation of elevation data collected using a Differential Global Positioning System (DGPS). Elevation contours were derived and converted into regions. 1995 National Census enumeration districts (ED) of Malé were digitised and converted into polygon areas. Average elevation derived from the contours was assigned to each ED (see Figure 4.2a). For each of the sea level scenarios highest astronomical tide level was added and all EDs below this height level were identified as inundation areas for the particular scenario.*

***Observations/preliminary findings:***

*The model constructed for the case study reveals the following:*

- *2025 (high) scenario – 15% of Malé inundated (see Figure 4.2b)*
- *2050 (low) scenario – no change (see Figure 4.2b)*
- *2050 (high) scenario – 31% of Malé inundated (see Figure 4.2c)*
- *2100 (low) scenario – 50% of Malé inundated (see Figure 4.2d)*
- *2100 (high) scenario – inundated completely (see Figure 4.2e)*

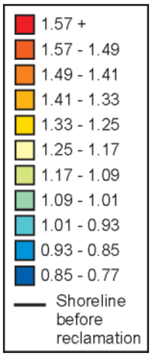
***Difficulties encountered:***

*Malé being over crowed with buildings proved difficult when collecting elevation data using GPS as the signal gets distorted at certain locations due to heavy tree coverage and dense buildings.*

***Study islands:***

- *Kaafu Malé*

*Box 4.4: V&A case study 2 (based on study by Manik, 2001)*



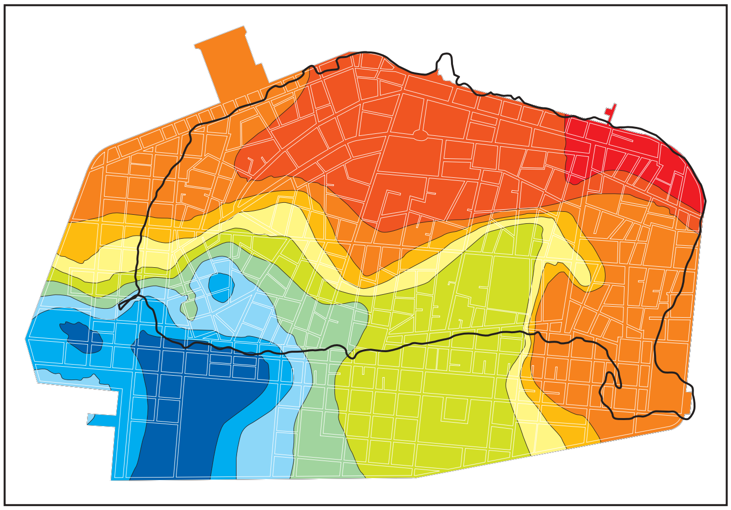



*Figure 4.2a: Elevation contour map and street map of Malé overlaid*

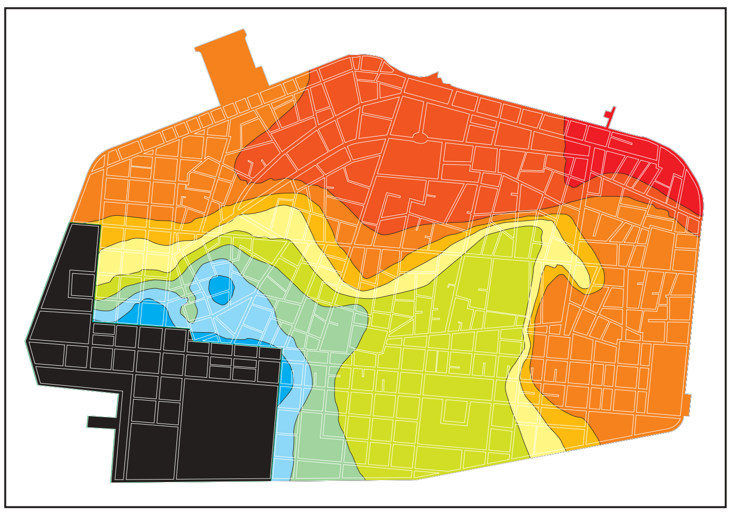


*Figure 4.2b: Map showing areas that would be inundated in 2025 (high) scenario. That is 0.84m (19.7cm + 64cm*). The same map is also applicable to year 2050 (low) scenario. That is 0.84m (19.9cm + 64cm*)*

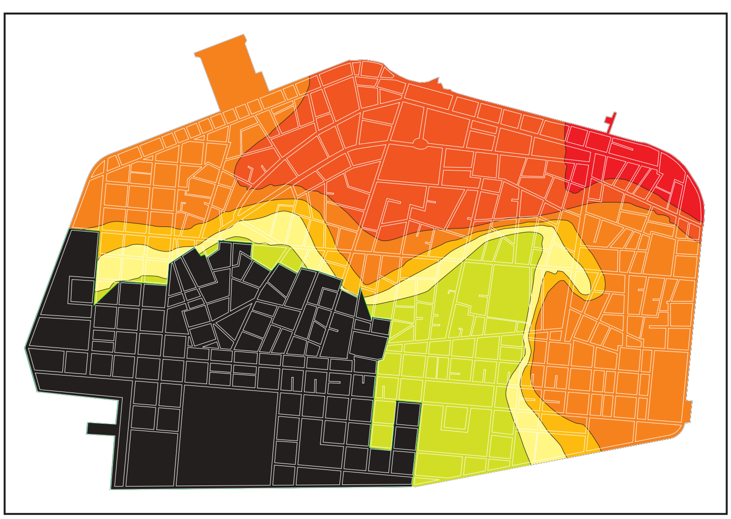


*Figure 4.2c: Map showing areas that would be inundated in 2050 (high) scenario. That is 1.04m (39.7cm + 64cm*)*

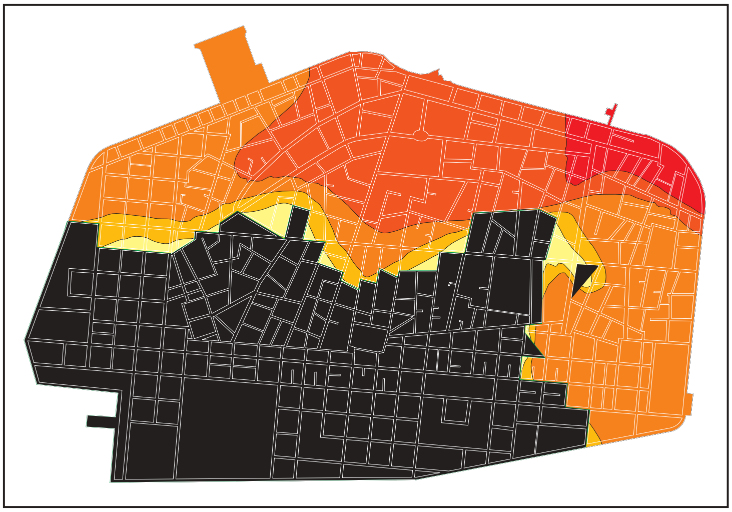


*Figure 4.2d: Map showing areas that would be inundated in 2100 (low) scenario. That is 1.13m (48.9cm + 64cm*)*

*Figure 4.2e: Map showing areas that would be inundated in 2100 (high) scenario. That is 1.58m (94.1cm + 64cm*)*

**Highest astronomical tide for Maldives (Woodroffe, 1989)*

## 4.2 Infrastructure damage

All of the human settlement, industry and vital infrastructure of the Maldives lie very close to the shoreline, within 0.8 – 2 m of mean sea level.

Being so close to the shoreline, these infrastructures are very vulnerable to change in climate and accelerated rise in sea level. The islands of the Maldives will disappear if the rate of sea level rise exceeds the rate of coral growth and sand generation. Even now some islands are seriously affected, with loss not only of shoreline but also of houses, schools and other infrastructure, compelling the government to initiate urgent coastal protection measures.

One of the most vulnerable structures in the Maldives is the Malé International Airport on Hulhulé island. This is the only international airport in Maldives and the gateway to the Maldives for tourists and the world. Other important vulnerable structures include investments on resort islands, which are discussed in detail in section 4.4.1 of this chapter.

***Case study 3: Infrastructure damage to Malé International Airport***

***Objective:***

*To assess the vulnerability of major infrastructure of the Malé International Airport, to damage from extreme climatic events and sea level rise.*

***Methodology:***

*The methodology involved survey of coastal area and shore, analysis of patterns of use of the runway, desktop review of existing literature on value of capital investment and of losses caused by past extreme weather events.*

***Observations / preliminary findings:***

*At the Malé International Airport no point appeared more than about 1.7 m above highest high water level. The height of the runway is 1.2 m above mean sea level and thus has only about 0.5m clearance at highest high water level. The edge of the turning apron and shoulders are lapped by the sea at high water in several places and on the northeast end, which is comparatively sheltered, the retaining wall consists of loose piled coral blocks.*

*The total investment in the airport by the Maldives Airports Company to date is estimated at almost US$ 57 million and the insurance premium for the year 2000 was about US$ 0.4 million (MAC, 2001). This does not include other investments, such as the recently opened Hulhulé Island Hotel, Maldives Inflight Catering Services and other investments by local businesses. Therefore, a total investment of more than US$ 57.4 million is in need of protection from effects of climate change and associated rise of sea level.*

*During the high waves incidence of 10-12 April 1987, the southern end of the runway was partly flooded and much coral debris was washed onto the runway. Extensive damage was done to the approach landing lights on the southern end of the runway and other service lights near the turning points on the southern end. The protective breakwater and containment wall on the southern and eastern side of the runway were either fully destroyed or extensively damaged. On the western side, the breakwater protecting the harbour suffered severe damage and the fuel jetty was also damaged. Almost 4000 m of containment wall and breakwater required renewal. This incident caused an estimated physical damage of over US$ 4.5 million.*

*Due to flight cancellations and diversions inestimable damages were also caused to the tourism industry questioning the security and reliability of the international airport to support the tourism industry.*

*Upgrading the sea defence of such a long, thin island will be a considerable, but essential undertaking. It had been estimated that just to secure sea defences up to the year 2000 would require a minimum of US$ 2-3 million (Edwards, 1989).*

***Difficulties encountered:***

*Due to the busy flights operating schedule of the airport, access to all parts of the airport were not possible, as a result the GPS survey was restricted to measuring elevations of the shoreline of the island. Hence, a Digital Terrain Model (DTM) of the Airport was not possible, which would have been invaluable in producing sea level rise impact models. To carryout a through GPS survey of the island would require the Airport to suspend its operations for a day, which would incur a substantial cost.*

***Study islands:***

- *Malé International Airport (Hulhulé island)*

*Box 4.5: V&A case study 3*

## 4.3 Damage to coral reefs

Coral reefs have shaped the lifestyle of the people of the Maldives since its habitation and the modern economy depends on the health of the reefs. Two major economic driving forces, the tourism and fishery industries depend heavily on the reef resources. Due to the low elevation of the islands, they are vulnerable to extreme storm events. The protection provided by the coral reefs has reduced the storm damage, coastal erosion and flooding by extreme storm events. Today, a key concern of Maldivians is how the reefs will respond to the predicted accelerated sea level rise.

Corals from reefs have been used as climatic indicators to study the changes to the climate in the past. Similarly, due to the potential vulnerability of the reefs to high temperature, they may be the first to show signs of ecological stress from global warming (IPCC, 1998). Detecting this change requires extensive monitoring for biological and physiological changes throughout coral reef regions of the world.

The most critical impact on coral reefs is likely to be due to the increase in sea surface temperature as observed by the series of coral bleaching and mortality events in the Maldives associated to the elevated sea surface temperature in the Indian Ocean. Coral bleaching has been observed in the Maldives in 1977, 1983, 1987, 1991, 1995, 1997 and 1998. The 1998 event was the most severe causing unprecedented damage to coral reefs in the central tourism region of the Maldives, with more than 90% of corals wholly or partially bleached (Naeem *et al*, 1998; Riyaz *et al*, 1998; Ali & Manik, 1989).

If the observed global trend in temperature rise continues, there will be an increased probability of a recurrence of the phenomenon observed in 1998 on the coral reefs of the Maldives in coming years. The latest climate model released from the Hadley Climate Centre predicts a seawater temperature increase of 2°C within 50 years due to global warming (Wilkinson *et al* 1999). If these predictions are correct, and all other factors remain equal, then the immediate future of coral reef systems is threatened unless global warming is reversed or corals naturally adopt.

***Case study 4: Damage to coral reefs***

***Objective:***

*To gather existing data on the impact on the coral reefs of selected islands of an extreme rise in mean sea surface temperature that took place in 1998. This is especially important as Maldives consists of 8,920 Sq Km of reef area, which represents 3.14% of the total reef area of the world (Spalding et al, 2001).*

***Methodology:***

*Data was gathered from studies of a range of islands representing diverse sectors or areas and including local inhabited islands, tourist resorts and the international airport.*

*Data from the sites that were surveyed prior to bleaching allowed direct comparison of the data for several sites. The Marine Research Centre in the Maldives has also been actively monitoring sites for the Global Reef Check Programme, University of California at Los Angeles, that compare pre and post bleaching live coral cover at the survey sites.*

***Observations / preliminary findings:***

*During the northeast monsoon, the mean monthly sea surface temperature rises from a low during January/December to high in April/May. In the central atolls, the average seasonal rise is about 1.3 °C and the mean monthly sea surface temperatures rarely exceed 30 °C. During the southwest monsoon the temperature slowly declines. In 1998, the monthly mean sea surface temperature was 1.2 - 4.0 $^{0}$C above average during the warmest months (March - June).*

*The post bleaching survey in 1998 showed a significant reduction in live coral cover at all study sites to include the entire stretch of Maldives from north to south. As shown in Table 4 -3, the average live coral cover decreased from 42% to 2% for the sites surveyed.*

***Difficulties encountered:***

*Little or no baseline data specific to these sites exist. The baseline data used in this section has been collected elsewhere in the country, which may include the fishery and agricultural sectors, tourist resorts and the international airport.*

***Study islands:***

- *Kaafu atoll – Bandos and other sites*
- *Vaavu atoll - Patch Reef, Fotheyo, Wattaru*
- *Ari atoll: various sites*
- *Meemu atoll: Thuvaru, Maduvvaree*
- *Haa Alif atoll – various sites*
- *Haa Dhaal atoll – various sites*
- *Addu atoll – various sites*
- *Huvadhu atoll – various sites*

*Box 4.6: V&A case study 4*

| Percent live coral cover | | | | |
|---|---|---|---|---|
| | Pre-bleaching | | Post-bleaching | |
| Survey sites | MRC/ERC (various reports) | MRC Reef Check August 1997 | GCRMN August-October 1998 | MRC Reef Check 1998 |
| Bandos (Malé Atoll) | 37.3 ± 11.0 | - | 4.1 ± 5.7 | - |
| Other sites (Malé Atoll) | 40.2 ± 8.0 | - | 1.3 ± 0.7 | - |
| Patch reef (Vaavu Atoll) | | | | |
| 3 meters | - | 57.5 ± 11.7 | 1.3 ± 1.0 | 0.0 ± 0.0 |
| 10 meters | - | - | - | 2.5 ± 3.2 |
| Fotheyo (Vaavu Atoll) | - | - | 4.6 ± 2.4 | - |
| Wattaru (Vaavu Atoll) | - | - | 2.7 ± 2.2 | - |
| Various sites (Ari Atoll) | - | - | 1.1 ± 0.8 | - |
| Thuvaru (Meemu Atoll) | | | | |
| 3 meters | - | 28.1 ± 17.9 | - | 0.0 ± 0.0 |
| 10 meters | - | 40.0 ± 8.6 | - | 1.3 ± 4.0 |
| Maduvvaree (Meemu Atoll) | | | | |
| 3 meters | - | 53.8 ± 17.6 | - | 5.0 ± 7.3 |
| 10 meters | - | 33.8 ± 9.5 | - | 3.8 ± 2.3 |
| Central Atolls | 42.0 ± 4.0 | | 2.0 ± 0.6 | |

*Table 4-3: Post and pre bleaching survey results for the 1998 mass bleaching event*

| Atoll / Area | 1998 | 1999 | 2000 |
|---|---|---|---|
| Haa alif, Haa Dhaal | 1.0 ±0.75 | 1.62 ± 2.18 | 0.95 ± 1.37 |
| Ari atoll | 1.0 ±1.36 | 0.33 ± 0.41 | 3.85 ± 1.67 |
| Male' atoll | 2.6 ±2.71 | 3.04 ± 2.67 | 3.91 ± 2.89 |
| Vaavu atoll | 2.9 ±1.82 | 2.37 ± 1.29 | 2.63 ± 2.32 |
| Addu, Huvadhu atoll | 3.1 ±2.21 | 2.28 ± 1.92 | 3.10 ± 1.90 |

*Table 4-4: Coral cover at the survey sites after bleaching in 1998 (National Reef Monitoring Programme, MRC)*

## 4.4 Impacts on the economy

### 4.4.1 Impacts on tourism

The tourism industry in the Maldives is almost entirely dependent on physical and geographic factors, such as good weather and activities associated with sea and coral reefs. The predicted climate change would have very serious implications on the nation's main economic sector; tourism. The main impacts of climate change and associated sea level rise to the tourism industry, and in particular to the tourist resort islands of the Maldives are:

- Impacts on marine dive sites due to reef degradation as a result of elevated sea surface temperature.
- Decrease in value of the tourism product due to changes to the beach as a result of increase in sea level and wave action.
- Damage to tourist infrastructure due to coastal erosion and innundation.
- Changes to the image of the Maldives as a tourist destina tion due to alteration of climate and weather patterns.

### Impacts on reefs and tourist dive sites

The coral reefs of the Maldives are one of the most highly ranked reefs of the world and Maldives is a world-renowned diving destination. It is estimated that about 25% to 35% of tourists visit the Maldives primarily for its excellent diving opportunities, while snorkellers at any one time on a resort can be averaged at 75% to 80% (Westmacott, 1996). It is not only Maldives, but also the world that is going to lose one of its favourite diving destinations if climate change trends continue.

An estimate by Anderson (1997) suggests the annual number of dives made by visiting tourists at more than half a million; each dive earning roughly US$ 35. From the Maldivian perspective, US$ 17.5 million a year earned through diving is a considerable amount since about 20% of tourism earnings contribute to the nation's GDP (Table 1-17).

The species diversity of Maldivian reefs also contributes a valuable asset to the country's economy. A survey conducted in 1992 estimated that the money spent by divers on shark dives alone amounted to some US$ 2.3 million a year. It was found that as a result of coral reef damage to a popular shark dive site, "Fish Head", in 1995 and 1996, the shark population was reduced, as was the number of divers visiting the site, resulting in a loss of revenue of US$ 500,000 a year (Anderson, 1997). This indicates that the loss of tourism value due to coral reef degradation is profound in the Maldivian economy.

### Impacts on beaches

The white sandy beaches of the Maldives are an important attraction for tourists. It has been identified that 70% of tourists visit the Maldives primarily for beach holidays. Erosion of these beaches is rapidly becoming an urgent problem in many resort islands. An estimated 45% of tourist resorts at present suffer from varying degrees of coastal erosion (ERC, 2001). Higher rates of erosion and coastal land loss are expected as a consequence of the projected rise in sea level.

### Impacts on tourism infrastructure and support facilities

Resorts in the Maldives as dictated by tourism regulations, are developed on uninhabited, small, low-lying, coralline islands. Most of the tourist bungalows and tourist facilities are located around the island with an average setback of about 5m from the vegetation line. Some of the water based resort concepts have their tourist facilities over the lagoon on stilts. Other support facilities are located in the middle or separated on one end of the island. The location of these facilities alone renders them highly vulnerable to predicted future sea level rise due to the low elevation and the narrowness of the islands.

The current resort islands represent a considerable capital investment averaging US$ 41,964 per tourist bed. An average investment for a tourist resort with 200 beds is over US$ 13 million and for a modern 700 bed resort US$ 43.5 million (MoT, 2001). Therefore, loss of beaches and infrastructure due to accelerated sea level rise will devastate the Maldivian economy.

Over 99% of the tourists arrive into the Maldives by air and Malé International Airport is the only entry point to the country by air. Any damage to the international airport by climate change and sea level rise, will cause extreme loss to the tourism sector *(Refer Section 4.2)*.

***Case study 5: Impacts on tourism (Bandos Island Resort)***

***Objective:***

*To assess the impact of reef die-off, beach erosion and airport closure on a well established resort in the Maldives.*

***Methodology:***

*Bandos Island Resort, which is the second resort developed at the beginning of the tourism industry in the Maldives, was selected for the case study because of its uninterrupted operation since its inception; due to its key location within Malé Atoll and due to the extensive developments that has taken place in the past years.*

*The case study was conducted through desktop reviews of existing reports and interviews with the management.*

***Observations / preliminary findings:***

***Impacts on reefs***
*Bandos Island Resort earns about US$ 1 million through reef related activities such as diving and snorkelling. The coral bleaching event of 1998 had caused a 30% drop in the revenues of the resort.*

***Impacts on beaches***
*According to reports from Bandos Island Resort, a considerable amount of beach had been eroded over the past 20 years. Building of sea walls around the resort had been the immediate response to the erosion problem. It costs about US$ 60,000 a year to maintain these structures.*

***Impacts on the international airport***
*Bandos Island resort has thus far been very lucky as the brief interruptions to the running of the international airport had not affected the resort.*

*Box 4.7: V&A case study 5*

*Box 4.7: V&A case study 5 continued...*

***Difficulties encountered:***

*No baseline data was available on the status of the beach of the island.*

***Study islands:***

- *Bandos Island Resort*

## 4.4.2 Impacts on fisheries

An understanding of the changes in the distribution and abundance of the tuna around the Maldives requires an understanding of the variations in the oceanographic conditions in the central Indian Ocean. There are spatial variations in the abundance and distribution of tuna in relation to the atoll chain, as well as associated seamounts. Oceanographic conditions vary along the length and so does the distribution of tuna. Upwellings associated with seamounts encourage productivity (Boehlert, 1987). The best-known seamounts in the Maldives are *Dheraha* in Laamu Atoll and *Satoraha* in the one and a half degree channel between Laamu and Gaafu Alifu Atolls. It is well known that these seamounts support high and regular tuna catches. The spatial variations of seamounts, tuna migration and interactions need to be studied in order to better understand the industry's vulnerability to climate change.

| Event | Skipjack Catch | Yellow fin Catch |
|---|---|---|
| El Niño | Low | High |
| La Niña | High | Low |

*Table 4-4: Variation of tuna catch during ENSO events*

The Maldives tuna fishery is affected by the seasonal monsoon and their associated currents (Stéquert & Marsac, 1989). Maldivian tuna catches are also affected by El Niño Southern Oscillation (ENSO) events. During the El Niño years of 1972-73, 1976, 1982-83, 1987 and 1992-94, the skipjack catches and the catch rates were noticeably decreased, while the yellowfin and other tuna species increased. During La Niña years, the skipjack catch rates increased while those of the other major tuna species decreased.

Over longer (decadal) time scales, cyclical shifts occur in the oceanographic climate regime with associated shifts in biological productivity and species composition. The Maldivian tuna catches show signs of being affected by decadal scale variation and the skipjack catches tend to go up while those of yellowfin catches go down.

The oceanographic processes that promote these decadal scale variations in tuna abundance in the Maldivian waters are not yet known. Also the stock structure of the skipjack and yellowfin in the Indian Ocean is not well known. More research needs to be undertaken in order to find any direct affects of climate change onto the fishery sector.

## 4.5 Food security

### 4.5.1 Agriculture

Clearly sea level rise, accompanied by saltwater intrusion of groundwater, will pose a threat to the little agriculture practised by rural farmers in the Maldives. Already there are problems with freshwater aquifers on several islands including Malé, where most of the mango trees have died. Saltwater intrusion of groundwater will affect deeper-rooted trees with low salt tolerance on the island. Particularly affected will be trees such as mango, banana and breadfruit.

The crop perhaps most vulnerable to rising sea levels, taro is grown in the southern atolls. This is grown in taro pits dug in and near the wetlands, about 40 cm above mean sea level. However, these pits are already below the highest tidal levels. Flooding of pits by seawater already occurs in Fuvahmulah as the storm water drainage systems in the pits are accidentally opened at high spring tides.

### Heavy import dependency

At present, almost all food requirements, medicines and goods, except fresh fish and coconut, are imported from other countries; perishable foods by air and non-perishable by sea transport. As mentioned in Chapter 1, most of our main food items such as rice, wheat flour and sugar are imported from countries such as India, Thailand and even as far off as Germany. Thus the vulnerability of Maldives to climate change extend to the agricultural vulnerability in other countries. The predicted climate change for South and South East Asia has indicated a reduction of rice production (Sinha, 1991). The Maldives is vulnerable to the changes in productivity of agricultural lands beyond our borders and will have to compete on the international market for access to the food products produced elsewhere.

### 4.5.2 Food storage and distribution

Imported rice and other food items are stored in Malé and distributed through out the country by the local, small business entrepreneurs using small boats and seaplanes.

The country's traditional food distribution system is largely via boat from the storage facilities in Malé to islands through the *ad hoc* transport system which is operating in the country. The transport system from Malé to the other islands is via small boats called *dhonis*. The quantity that can be transported across on one trip is therefore very small. The frequency of food supplies in particular islands depends on the transport vessels, the distance from Malé and the demand for replenishment. Islands with their own travelling vessels have a more frequent supply of food, whereas those islands with limited travel vessels have to depend on nearby islands for their food supplies.

Most of the islands in the country have no proper storage facilities for rice and other food items other than in the small warehouses of the small businesses.

According to the poverty assessment study (MPND & UNDP, 1998), food was in short supply in a number of islands due to the difficulty in transporting the food from Malé to the islands. The period of short supply ranges from 1 to 30 days in different regions of the country.

In 1990, due to the high winds and storm the transport system in the country got disrupted and many islands in the country faced a shortage of food for 10 days in June. The air lifting of emergency supply of food to the affected regions cost more than US$ 120,000. Thus, it is clear that the predicted climate change would have enormous problems for food security in the Maldives.

***Case study 6: Food security***

***Objective:***

*To access the vulnerability of the food security of selected islands to a breakdown in food distribution system due to extreme weather events.*

***Methodology:***

*The V&A Team circulated questionnaires to the inhabited islands to gather information on food security and distribution issues on these islands.*

***Observations / preliminary findings:***

*The results are shown below.*

| | | Food Supply | | Food Storage | | |
|---|---|---|---|---|---|---|
| Islands | Agriculture | Obtained from | Frequency | Local | Public | Food Shortage |
| Ha.Thuraakunu | Little | Male' | Twice monthly | Households/Shops | No | - |
| Baa.Hithadhoo | - | Male' | Weekly | Households | No | - |
| Gn.Fuvahmulah | Yes | Male'/S. Gan | Monthly | Households/Shops | Yes | Yes |

*Table 4-5: Case study for food security*

***Agriculture***

*Of the three inhabited islands visited in rural areas, Fuvahmulah is one island where agriculture contributes very much to the local economy. The main crop grown in Fuvahmulah is taro. Mango and other local fruits are also grown on this island.*

***Food storage and distribution***

*For all of the study islands, food items are obtained from Malé and are supplied from weekly to monthly depending on the storage capacity of the island and the distance from Malé. Fuvahmulah is larger compared to the other study islands and has the most number of shops, while Hithaadhoo with a much lower population, has only a few shops. Only the island of Fuvahmulah has a public storage facility where food items are stored in the warehouses of State Trading Organization.*

*According to the island office of Fuvahmulah, there had been two episodes of food shortage due to extreme weather conditions. In terms of travel by sea, Fuvahmulah is the furthest from the capital. The government had to provide emergency supplies during the one week food shortage in 1982. Another episodic event occurred in 1993 when emergency supplies were brought from the nearby atoll, Addu.*

***Difficulties encountered:***

*Lack of time to carry out a detailed survey to find out the storage capacity in each study island.*

***Study islands:***

- *Haa Alifu Thuraakunu*
- *Gnaviyani Fuvahmulah*
- *Baa Hithaadhoo*

*Box 4.8: V&A case study 6*

## 4.6 Water resources

Future changes in climate and sea level will have impacts on the water resources. To the Maldivian community, the effect on water resources would mean changes to freshwater availability.

The climate and hydrology, sea level movement and human activities influence the groundwater in the islands of the Maldives. Inundation of land and associated saltwater intrusion due to the predicted sea level rise would reduce the size of the freshwater lenses and thus reduce the available fresh groundwater of these islands. The groundwater is also very vulnerable to pollution by solid waste and other pollutants.

Unsustainable withdrawal of water from the water lens has depleted the freshwater lens in a few of the densely populated islands in Maldives. It is estimated that 9% of the population has no access to safe drinking water (MPND & UNDP, 1998).

Changes to the temporal and spatial patterns of rainfall as a result of climate change are believed to have impacts on the water resources of the islands like the Maldives (Falkland, 1997). The precipitation scenarios generated by different climate models predicted, with low confidence, the precipitation will increase for the Maldives. A change of temporal rainfall pattern may have an impact on the amount of rainwater harvested if the precipitation occurs as frequent short bursts and there is no chance to clean roof catchments. The change of temporal pattern and amount of rainfall to the country may cause more frequent flooding when the islands receive heavy rainfall to the freshwater lakes found in some islands.

The Centre for Clouds, Chemistry and Climate (C4) showed that the region is severely affected by transboundary air pollution (C4, 2000). The level of air pollutants found has raised concern about the impact on the rainwater quality collected from the roof catchments. This needs to be further analysed to quantify the extent of transboundary air pollution on the water resources of the Maldives. Currently, Maldives does not have the capacity to test the quality of rainwater in this region.

Desalinated water has become the major source of water for the capital, Malé. The present technology used for desalination is highly energy intensive and depends on diesel for the production of water. Thus the production costs of water depends on the market oil price. In the year 2000, the production of water with current desalination technology was very vulnerable to the oil price in the world market. Desalinated water is used by 28% of the country's population now (MWSA, 2001) and this carries a significant risk to water security and sustainable development in the Maldives.

Although desalination is a prospective alternative to groundwater and rainwater, more efficient technology that can be used for desalination needs to be explored. STELCO, the Maldivian electricity company uses waste heat from energy generation to produce desalinated water for use within the company. This operation started in 1991 and has a daily production capacity of 200 $m^3$ (STELCO, 2001). Such options need to be assessed for use by the whole of the nation.

***Case study 7: Water resources***

***Objective:***

*To assess the vulnerability of selected islands to shortage of freshwater resources due to saltwater intrusion or shifts in rainfall patterns.*

***Methodology:***

*The islands chosen for the assessments were of different sizes, population densities and had differing economic activities. For this assessment, water demand and supply of different water resources were determined in the field through interviews and further information was drawn from existing studies. The quality of the groundwater was assessed using salinity, ammonia and pH as the indicators. The freshwater lens of the island was tested from wells.*

***Observations / preliminary findings:***

*Salinity measurements showed that the groundwater is very fresh on all of the study islands except Malé and Hulhulé. However elevated levels of ammonia and pH were seen in some regions of the study islands, indicating pollution by sewage (WHO, 1995).*

*The following table gives the water consumption and water storage figures for the inhabited islands under study.*

*Box 4.9: V&A case study 7*

| | Bandos | Dhekaanba | Fuvahmulah | Hithaadhoo | Hulhulé | Malé | Thuraakunu |
|---|---|---|---|---|---|---|---|
| Population | - | - | 7,004 | 936 | - | 74,089 | 449 |
| No. of houses | - | - | 1,049 | 146 | - | 6,758 | 55 |
| Percentage of rainwater usage | - | - | 33 | 40 | - | - | 55 |
| Percentage of groundwater usage | - | - | 67 | 60 | - | - | 45 |
| Sewers / septic tanks | Sewers | - | Septic tanks | Septic tanks | Both | Sewers | Septic tanks |
| Desalination | Yes | - | No | No | Yes | Yes | No |
| Groundwater salinity | No | No | No | No | Yes | Yes | No |
| Is ground water polluted? | No | No | Some areas | Some areas | Yes | Yes | Some areas |

*Table 4-6: Case study for water resources*

*The case study island of Fuvahmulah gets flooded with each heavy rainfall. The water in the freshwater lakes in the island burst from the banks and floods a large part of the island extending to the residential areas. The predicted change of temporal pattern and amount of rainfall to the country may cause more frequent flooding when the islands receive heavy rainfall to the freshwater lakes.*

*In addition to the public rainwater storage facility, the study results also showed that there were rainwater storage facilities in some of the private homes. Of the surveyed 37 houses, 12 have their own rainwater tanks with an average storage capacity of 5.7 m3.*

*From interviews with the people of Thuraakunu it was found that the private and public rainwater tanks run out in the dry season during the northeast monsoon. Sometimes the tanks ran out for weeks before being filled with rainwater in the rainy season. In the dry season, groundwater is used for all purposes and, due to the high extraction rate, the groundwater turns saline in some parts of the island.*

*The groundwater of Hulhulé Island is mostly used for flushing. Desalination plants using reverse osmosis technology are used as the main water resource on the island. It was found that the wells that are in use were relatively saline compare to the few wells that were not in use. The high salinity levels observed were due to over-pumping.*

*The Malé Water and Sewerage Company has provided running water to the people of Malé since early 1980's. The MWSC has seven desalination plants with a daily total production capacity of 3,800 $m^3$ fresh water and a rainwater storage capacity of 4,800 $m^3$. Six years ago, it was estimated that 4000 private rainwater tanks have a total storage capacity of 14,000 $m^3$ (DANIDA, 1995).*

*Box 4.9: V&A case study 7*

*These private rainwater tanks are not sufficient to meet the water demand at households in the dry periods.*

***Difficulties encountered:***

*Ground water was sampled at the surface due to unavailability of equipment to carry out an in depth study of the water lens of the study island.*

***Study Islands:***

- *Haa Alifu Thuraakunu*
- *Gnaviyani Fuvahmulah*
- *Kaafu Malé*
- *Kaafu Hulhulé (airport)*

*Box 4.9: V&A case study 7 continued...*

## 4.7 Human health

Changes in climate affect human health in various ways. Changes in air temperature, rainfall patterns, humidity and sea level rise are the main factors that indirectly affect health through vectors and or the transmission of diseases through water and air. The more direct impacts would be due to extreme weather events and thermal stress.

Heat stress related health problems are identified as very much affected by climate change. Looking at the climate change scenarios, it can be estimated that air temperatures in Maldives may rise by 2 - 3.8 °C by the year 2100 (see Table 4.1). No studies have been conducted yet to find the effects of heat stress on the health of the Maldivian population. The population affected would mainly be the young and the elderly. As the population pyramid in Chapter 1 shows, the Maldives consists of a very young population.

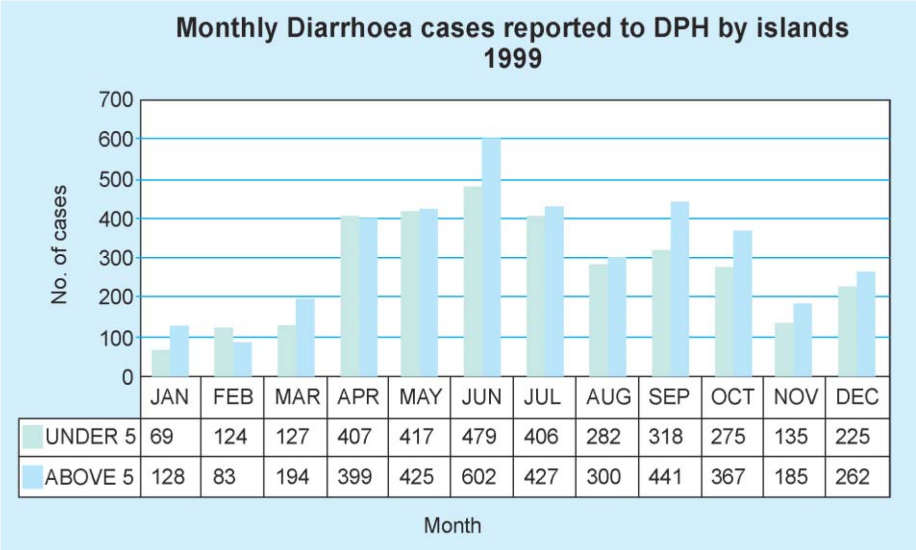
Another direct impact on health would be physical injury due to extreme weather events. Although there have been historically recorded storm events, not many records have been kept of physical injuries or spread of epidemics. To date, no studies have been conducted in the Maldives to find the relationship between extreme weather events and physical injury and the spread of epidemics.

The major impact of increases in extreme weather events for the rural islands of the Maldives would be to limit access to health facilities and other services. The available facilities at the island level are very limited and the nearest facilities would be at the Regional Hospitals or the Atoll Health Centres. The main mode of transport to these facilities is by boat and during severe weather storms it is virtually impossible to travel to these health care centres. Therefore it is important to improve the health care facilities available at the island level.

Indirect health effects of climate change includes secondary effects caused by changes in ecology and social systems. Transmission of some infectious disease patterns, such as malaria is extremely sensitive to climate change. But changes in climate as predicted by climate models may cause a comeback of malaria to the Maldives.

Flooding incidents are on the increase, and this may cause more outbreaks of waterborne diseases. Certain islands, like Fuvahmulah, due to the shape of the island are more susceptible to flooding caused by heavy rains. This, combined with the poor sanitation systems in most islands, make these islands easy prey to waterborne diseases. If sanitation conditions are not improved, this would be a major problem in the future.

Figure 4-3 below shows that the monthly cases of diarrhoea reported from the outer islands increase during the rainy season.




| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UNDER 5 | 69 | 124 | 127 | 407 | 417 | 479 | 406 | 282 | 318 | 275 | 135 | 225 |
| ABOVE 5 | 128 | 83 | 194 | 399 | 425 | 602 | 427 | 300 | 441 | 367 | 185 | 262 |

*Figure 4-3: Reported diarrhoea cases for 1999*

Table 4-8 below gives the specific death rates for Maldives from 1995 to 1998. The major causes of death are old age, diseases of the circulatory system, unknown causes and respiratory diseases. Recorded mortality due to vector borne diseases remained nil throughout the period.

Although Table 4-8 shows no mortalities due to vector borne diseases, dengue fever and dengue hemorrhagic fever have been identified as major health problems in the Maldives. The first epidemic was reported in 1979 and later in 1983. In 1988, a major outbreak occurred with 2,054 reported cases and 9 children below the age of 10 died of dengue and dengue hemorrhagic fever. In 1998 and 1999, reported cases of dengue and dengue hemorrhagic fever have been increasing. The majority of the cases occurred from March to June 1999 during the southeast monsoon when heavy rainfall occurred (Shaheem & Afeef, 1999; DANIDA, 1991; MoH, 1998). No studies have yet been done to determine the causes of the outbreak or to understand the possible links with climatic factors.

**Cause Specific Death Rate (percent) 1995 - 1998**

| Cause / condition of death | 1995 | 1997 | 1998 |
|---|---|---|---|
| Undiagnosed death at old age | 20.10 | 22.04 | 21.05 |
| Diseases of circulatory system | 18.10 | 22.38 | 20.96 |
| Not stated | 15.90 | 12.43 | 15.98 |
| Respiratory diseases | 6.40 | 9.02 | 8.30 |
| Blood and blood forming organs and disorders of immune mechanism | 5.80 | 3.57 | 2.53 |
| Conditions relating to prenatal period | 4.40 | 7.15 | 4.37 |
| Parasitic infections | 3.70 | 4.00 | 3.58 |
| Diseases of digestive system | 3.00 | 2.55 | 3.06 |
| External cause of morbidity and mortality | 3.00 | 2.98 | 2.71 |
| Clinical signs, symptoms not elsewhere classified | 2.60 | 0.34 | 0.17 |
| Diarrhoea and gastroenteritis | 2.50 | 0.43 | 0.17 |
| Diseases of nervous system | 2.00 | 1.70 | 4.10 |
| Tuberculosis | 2.00 | 1.28 | 0.87 |
| Endocrine, nutritional and metabolic diseases | 1.90 | 0.94 | 0.96 |
| Diseases of genito urinary system | 1.80 | 1.96 | 3.41 |
| Septicemia | 1.50 | 1.19 | 0.79 |
| Neoplasm | 1.50 | 3.66 | 4.10 |
| Pregnancy, childbirth and puerperium | 1.30 | 1.02 | 0.70 |
| Vaccine preventable diseases | 1.00 | 0.26 | 0.35 |
| Congenital and chromosomal abnormalities | 0.40 | 0.51 | 1.05 |
| Mental and behaviour diseases | 0.30 | 0.17 | 0.26 |
| Meningococcal infection | 0.20 | 0.17 | 0.00 |
| Vector borne diseases | 0.00 | 0.00 | 0.00 |
| Diseases of skin and subcutaneous tissue | - | 0.00 | 0.26 |
| Diseases of the musuloskeletal and connective tissue | - | 0.26 | 0.26 |

*Table 4-8: Cause specific mortality (MoH 1996, MoH, 2000)*

It is not easy to assess the impacts of climate change on human health in the Maldives. Even with the present data management methods, it is difficult to use existing health records to research into the effects of climate change.

***Case study 8: Human health***

***Objective:***

*To assess the impacts of climate change on human health, for the islands selected for V&A assessment.*

***Methodology:***

*Health records of three inhabited islands were studied. In addition, interviews were conducted with health officials and elderly people of the islands.*

***Observations / preliminary findings:***

*To facilitate any climate related studies on the health sector, a more accurate data management system needs to be set up.*

***Difficulties encountered:***

*Efforts to establish any links to health patterns and changes in climate were very unsuccessful, the main reason being the lack of proper record maintenance. If a person from these islands had a serious illness they would go to either the regional hospitals or to Malé the capital. Records of these people would be entered as from Malé with no indication of their original location. These records would also not be included in the island records. This would be true for all other islands of the Maldives.*

***Study islands:***

- *Haa Alifu Thuraakunu*
- *Gnaviyani Fuvahmulah*
- *Baa Hithaadhoo*

*Box 4.10: V&A case study 8*