Climate Change Vulnerability and Adaptation Assessment of the Maldives Land and Beaches

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Summary

In the face of predicted climate change and sea level rise, land is amongst the most scarce and vulnerable resource in the Maldives. There have been considerable calls for research into the perceived impacts of climate change on land and beaches, and adaptation measures. This paper is intended as a contribution to the research process by exploring the current status of research into the field, especially on Maldives. The paper presents the status of beaches and land, identifies their key climate change vulnerabilities and impacts based on the latest scientific findings and explores potential adaptation measures available. In addition, priority actions required in light of the latest findings are highlighted.

1. Introduction

The Maldives is considered one of the most vulnerable countries to the predicted global climate change and its long-term survival has been questioned with the latest climate change predictions. Although the debate on climate change, especially sea level rise is far from over, the presence of a probability has necessitated Maldives to consider climate change impacts and adaptation measures in all aspects of its future development. The National Adaptation Programme of Action (NAPA) under the Integrated Climate Change Strategy (ICCS) is an attempt to develop a countrywide programme that encompasses immediate and urgent adaptation activities that address current and anticipated adverse effects of climate change. The goal of NAPA formulation is to provide a framework to guide the coordination and implementation of adaptation initiatives and to develop a specific priority programme of action. The NAPA formulation process involves identification of key vulnerabilities and adaptation measures through a series of technical studies in areas which lack them.

In this respect, vulnerability to land and beaches of Maldives has been identified as one of the most critical impacts and an area which requires substantial scientific research (MHAHE, 1999, 2001, 2003, 2004). This paper has been prepared as a contribution to the research and the NAPA formulation process. The main objective is to provide a summary of latest findings in the field, especially on Maldives and identify adaptation measures based on them.

The paper is divided into four main sections. The first section provides a summary status of land and beaches in Maldives. The second section assesses the predicted impacts of climate change on Maldives based on the latest scientific findings. The third section explores potential adaptation measures and the final section highlights areas of urgent intervention.

2. Status of Land and Beaches

2.1. Land

2.1.1. Land Scarcity and Utilisation

Land is considered one of the scarcest resources in Maldives comprising a mere 1% amongst the expansive 21,436 sq km of reef. There are reportedly 1190 islands, of which 203 are inhabited and 87 are resort islands. The official land area of Maldives is generally cited as 298 sq km or 300 sq km (MIA, 2006, MPND, 2004), approximating to about 1000 persons per sq km in 2006. The actual land area may even be smaller than the official figure, as highlighted by two recent studies: Hanson (1995) reported the vegetated land area as 185 sq km[1] and Shaig (2006) reported the upper limit of land area, inclusive of beach and newly reclaimed land as 235 sq km[2]. The rest of the land area data provided in this study is based on the latter calculation.

Land scarcity is more apparent if island utilisation across Maldives is analysed. Six types of island use could be identified: 1) human settlements; 2) infrastructure islands (such as airports, waste disposal, oil storage); 3) economic islands (such as tourism, agriculture, fisheries); 4) stewardship or *varuvaa;* 5) recreation islands; and 6) administrative islands (eg. defence). Table 1 summarises the distribution of land and island utilisation across administrative atolls. It may seem that Maldives would have plenty of land to spare with 1190 islands and only 375 of these islands currently being utilised. On the contrary, the 375 islands represent approximately 75% and the 203 inhabited islands alone represent 59% of total land area. The reason is simple. As shown in table 2, most unutilised islands are small and contribute little to total land area, while 90% of larger islands (over 50 ha) with a bigger share of total land area is currently being utilised[3].

[1] Hanson based his calculations on 1969 aerial photographs and involved manual digitising. His findings were reportedly rejected by the Government due to inaccuracies in aerial photographs and exclusion of beach areas and newly reclaimed land.
[2] Calculations based on latest satellite images from NASA (Landsat 30 m resolution), Digital Globe (2.6-15 m resolution) and aerial photographs from MPND (1998-2006). The accuracy of calculations are estimated at +/- 3 sq km. Since the inclusion of beach area is subject to debate, a safer estimate of land area was reported between 205 sq km and 215 sq km.
[3] Exclude islands simply leased on varuvaa, unless a major economic investment has been made.

Atoll Name	No. of Islands [1]	Land Area (Sqkm)[2]	No. of Inhab. islands[3]	Inhab. Island Area	% of inhab. land area[4]	Economic & Admin Land (sqkm)[5]	% of all inhab. land[6]
Haa Alifu Atoll	41	18.75	16	14.44	77%	1.81	87%
Haa Dhaalu Atoll	33	23.03	16	18.16	79%	2.84	91%
Shaviyani Atoll	52	18.60	16	10.91	59%	0.49	61%
Noonu Atoll	74	17.69	13	8.45	48%	0.62	51%
Raa Atoll	87	12.65	15	6.22	49%	0.88	56%
Baa Atoll	60	10.34	13	4.92	48%	1.29	60%
Lhaviyani Atoll	46	7.29	5	1.84	25%	1.90	51%
Kaafu Atoll	95	15.03	12	9.03	60%	5.70	98%
Alifu Alifu Atoll	26	4.49	8	3.45	77%	0.88	97%
Alifu Dhaalu Atoll	61	5.48	10	3.16	58%	1.86	92%
Vaavu Atoll	18	1.06	5	0.59	56%	0.12	67%
Meemu Atoll	30	4.30	9	3.18	74%	0.19	78%
Faafu Atoll	32	2.30	5	1.67	73%	0.23	82%
Dhaalu Atoll	49	4.83	8	2.00	41%	0.15	45%
Thaa Atoll	84	8.74	13	4.26	49%	2.84	81%
Laamu Atoll	130	25.27	12	16.96	67%	3.49	81%
Gaafu Alifu Atoll	76	12.11	10	5.38	44%	1.16	54%
Gaafu Dhaalu Atoll	152	21.43	10	7.07	33%	4.97	56%
Gnaviyani Atoll	1	4.99	1	5.01	100%	0.00	100%
Seenu Atoll	35	14.56	6	9.63	66%	4.45	97%
TOTAL	**1182**	**232.96**	**203.00**	**136.34**	**59%**	**35.88**	**74%**

Table 1: Distribution of land across administrative atolls (Adapted from Shaig (2006))

Island Size Range	Total No. of Islands	Land Area (sqkm)	No. of Utilised islands	Land Area of utilised islands	% of utilised islands	% of total area utilised
1-25ha	949	56.53	177	18.75	18.7%	33.2%
25-50ha	124	44.69	84	30.97	67.7%	69.3%
50-100ha	66	45.15	55	38.31	83.3%	84.9%
100-250ha	33	47.67	32	47.45	97.0%	99.5%
250-500ha	7	20.35	7	20.35	100.0%	100.0%
500+ha	3	16.40	3	16.40	100.0%	100.0%

Table 2: Land utilisation based on island size (Adapted from Shaig (2006))

Apart from the island size, geographic conditions such as accessibility and soil conditions also effect island utilisation. The soil in Maldivian islands is generally alkaline and contains substantial quantities of parent material, coral rock and sand. As a result only around 10% of land is suitable for agriculture (WHO, 1996). Similarly, if an island is relatively inaccessible due to shallow reef, they may not be suitable for most economic activities.

[1] Includes all natural islands including permanent sand banks and reclaimed islands
[2] Refers to Island area and includes enclosed wetland areas
[3] Includes Male', Hulhumale' and Viligilli as separate islands
[4] Considers whole island to be used for settlement even if the settlement foot print is localised.
[5] Temporarily inhabited economic, infrastructure and administrative islands (incl. resorts, airports etc..)
[6] Percent of land occupied permanently or temporarily [7].

The demand for land is expected to increase in the future with population and economic pressure, and all islands with a useful size may be utilised in the near future. Islands containing sensitive and unique environments may soon be competing to stay pristine in the face of rising demand. Subsequently, pressures on environment may increase rapidly if proper land and environmental management practices aren't established. As human activities are known to expose islands to future climate change, majority of land in Maldives may already be exposed.

2.1.2. Pressures on Land

The main pressure on land is from the increase in population, which has grown 3.7 times over the past century from 72,000 persons to 270,101 (MPND, 2002). In 2006 population was expected to pass the 300,000 mark (MPND, 2006). While the over all population growth rate has declined consistently since 1990's from 3.4 to 1.6 in 2006 (MPND, 2002), the demand for land has increased considerably, perhaps owing to trend of preference for nuclear families. In the outer atolls alone plot allocations have increase 57% between 1995 and 2004[1] .

At present 24 islands do not have additional land for new housing (see table 3) and a large number of islands are approaching their capacity (see table 4).

1	Sh	Feevah	9	A.A	Bodufolhudhoo	17	Thaa	Guraidhoo
2	Sh	Komandoo	10	A. Dh	Kuburudhoo	18	Thaa	Thimarafushi
3	Noonu	Miladhoo	11	A. Dh	Fenfushi	19	Laamu	Maavah
4	Noonu	Holhudhoo	12	Vaavu	Rakeedhoo	20	GA	Dhaandhoo
5	Lh	Maafilaafushi	13	Meemu	Dhiggaru	21	G Dh	Madeveli
6	Kaafu	Maafushi	14	Faafu	Feeali	22	G Dh	Gadhdhoo
7	Kaafu	Male'	15	Dhaalu	Meedhoo	23	S	Hithadhoo
8	A.A	Rasdhoo	16	Dhaalu	Hulhudheli	24	S	Feydhoo

Table 3: List of islands with no additional land for housing in 2004 (based on VPA II data)

1	HA	Berinmadhoo	14	Kaafu	Huraa	27	Dhaalu	Vaanee
2	HA	Hathifushi	15	Kaafu	Himmafushi	28	Thaa	Vilufushi
3	Sh	Noomaraa	16	Kaafu	Gulhi	29	Thaa	Madifushi
4	Noonu	Hebadhoo	17	Kaafu	Guraidhoo	30	Thaa	Hirilandhoo
5	Noonu	Velidhoo	18	A.A	Ukulhas	31	Thaa	Gaadhiffushi
6	Raa	Rasmaadhoo	19	A.A	Mathiveri	32	Thaa	Kibidhoo
7	Baa	Eydhafushi	20	A. Dh	Mahibadhoo	33	Laamu	Kalhaidhoo
8	Baa	Thulhaadhoo	21	A. Dh	Dhagethi	34	Laamu	Maamendhoo
9	Lh	Hinnavaru	22	Vaavu	Felidhoo	35	GA	Kolamaafushi
10	Lh	Kurendhoo	23	Vaavu	Keyodhoo	36	GA	Viligili
11	Kaafu	Gaafuru	24	Meemu	Naalaafushi	37	G Dh	Fares
12	Kaafu	Dhiffushi	25	Meemu	Maduvvari	38	S	Maradhoo_Feydhoo
13	Kaafu	Thulusdhoo	26	Faafu	Biledhdhoo			

Table 4: List of islands expected to have housing land depleted in the near future[2] (based on VPA II data and Population Forecasts from MPND)

[1] Based on Census 2000 analytical report (MPND, 2002) and VPA II (MPND & UNDP, 2004).
[2] Based on islands with less than 50 plots left in 2004

The overall result of increasing population and depleting land resources is over crowding in a number of islands. Male' and its satellite islands have continued to grow at unprecedented levels with the population tripling during the past 25 years from 29,522 in 1977 to 104,403 in 2006. The population growth rate in Male' has increased from 3.5% in 2000 to 5.73% in 2006 and shows no sign of slowing down especially with the potential vacuum created by additional land in neighbouring Hulhumale' Island. It should be noted that there was a negative growth rate of -0.37% in the outer atolls in 2006, reflecting the influx of migrants to Male' Region. Male' island now has a density of 460 persons per hectare or 48,150 persons per sq km. Apart from Male', a number of islands in the outer atolls experience overcrowding. In 2006, 21 islands were found to have a density higher than 50 persons per hectare (see table 5).

No.	Atoll	Island Name	Land Area	Population 2006[1]	Density[2]
1	Kaafu	Male'	199.10	91,484	459
2	Kaafu	K.Viliglii	31.38	6,824	217
3	Lh	Hinnavaru	23.49	3,015	128
4	Sh	Komandoo	13.59	1,318	97
5	Raa	Ugufaaru[3]	37.35	2,989	80
6	Kaafu	Gulhi	8.46	674	80
7	A. Dh	Mahibadhoo	22.41	1,782	80
8	Meemu	Dhiggaru	11.79	911	77
9	Baa	Thulhaadhoo	24.14	1,757	73
10	Dhaalu	Meedhoo	12.60	915	73
11	Raa	Maduvvari	22.95	1,568	68
12	Baa	Eydhafushi	35.28	2,394	68
13	Lh	Naifaru	53.90	3,577	66
14	Noonu	Holhudhoo	23.94	1,526	64
15	Kaafu	Guraidhoo	21.24	1,219	57
16	GA	Dhaandhoo	20.25	1,113	55
17	Thaa	Thimarafushi	23.13	1230	53
18	Lh	Kurendhoo	23.04	1,213	53
19	Faafu	Feeali	13.95	734	53
20	Thaa	Madifushi	16.29	837	51
21	G Dh	Gadhdhoo	28.80	1,439	50

Table 5: Islands with a population density higher than 50 persons per hectare[4]

It is hard to define a maximum 'carrying capacity' of an island, but it is clear that some islands are moving beyond a socially sustainable population. It could be argued that capacity depends on the limitations on technology and capacity for humans to adapt, irrespective of the amount of congestion. If a nominal carrying capacity approach is used, 34 islands have already reached their 'minimum' capacity and an additional 17 islands (see tables 6 and 7) are expected to reach their capacity by 2015 (adapted from Shaig (2006)). It would mean that more than 50% of population are currently living in varying levels of congestion and the proportion could further rise to 60% by the year 2015.

[1] Based on Census Preliminary results (MPND, 2006)
[2] Population per hectare
[3] Contains temporarily displaced population from Kandholhudhoo, following Tsunami of 2004.
[4] It should be noted that, densities have changed in outer islands considerably due to land reclamation and out migration to Male'.

1	HA	Hathifushi	13	Kaafu	Gulhi	25	Dhaalu	Gemendhoo
2	HA	Dhidhdhoo	14	Kaafu	Guraidhoo	26	Thaa	Vilufushi
3	Sh	Komandoo	15	Kaafu	Male'	27	Thaa	Madifushi
4	Noonu	Holhudhoo	16	Kaafu	Viligilli	28	Thaa	Guraidhoo
5	Raa	Maduvvari	17	A.A	Bodufolhudhoo	29	Thaa	Thimarafushi
6	Baa	Kendhoo	18	A. Dh	Kuburudhoo	30	GA	Dhaandhoo
7	Baa	Eydhafushi	19	A. Dh	Mahibadhoo	31	G Dh	Gadhdhoo
8	Baa	Thulhaadhoo	20	Vaavu	Rakeedhoo	32	G Dh	Thinadhoo
9	Lh	Hinnavaru	21	Meemu	Dhiggaru	33	S	Maradhoo
10	Lh	Naifaru	22	Meemu	Maduvvari	34	S	Feydhoo
11	Lh	Kurendhoo	23	Faafu	Feeali			
12	Kaafu	Gaafaru	24	Dhaalu	Meedhoo			

Table 6: List of islands which have reached their minimum carrying capacity (Adapted from Shaig (2006))

1	HA	Hoarafushi	7	Baa	Hithaadhoo	13	Laamu	Maavah
2	HA	Ihavandhoo	8	Kaafu	Dhiffushi	14	Laamu	Maamendhoo
3	Noonu	Miladhoo	9	A.A	Rasdhoo	15	GA	Viligili
4	Noonu	Velidhoo	10	Vaavu	Keyodhoo	16	GA	Dhevvadhoo
5	Raa	Alifushi	11	Meemu	Naalaafushi	17	G Dh	Madeveli
6	Raa	Meedhoo	12	Thaa	Gaadhiffushi			

Table 7: List of islands forecasted to reach their minimum carrying capacity by 2015 (Adapted from Shaig (2006))

Population growth and subsequent congestion leads to a host of other pressures on land. Deforestation for housing construction, encroachment of beach area and removal of crucial coastal vegetation, improper waste disposal especially on coastal areas, ground water contamination due to improper sewerage systems and disposal methods, ground water degradation due to over extraction, marine water contamination, air and noise pollution and coral reef degradation are some of the problems well documented in environmental reports (MHAHE, 1999, 2001, 2003, 2004). Additionally need for larger and better coastal infrastructure such as harbours and reef entrances, and the need to reclaim land to ease land shortages results in inconceivable damages to the island environment as a whole (based on Kench et. al (2003) and Maragos (1993)).

2.1.3. Land Reclamation

It is estimated that more than 150 islands and about 9-11 sq km of land has been reclaimed in the Maldives (Shaig, 2006). At present, land reclamation is the main method to relieve land shortages. Table 8 shows some of the major land reclamation projects carried out in the last 30 years.

Past reclamation projects could be categorised in to 6 groups based on their rationales: 1) population pressure; 2) infrastructure development; 3) dredge material disposal; 4) mitigating coastal erosion; 5) economic benefits; and 6) recreation. Almost all major reclamation projects in inhabited islands (except in ADh. Maamigili) were to relieve land shortages. The most prominent project being Hulhumale' where an island almost the size of Male' was reclaimed from scratch. Additionally, small areas of most inhabited islands have been reclaimed as a method for dredge material disposal from access infrastructure development projects. Such reclamations are often associated with rationales such as recreation land development or erosion mitigation. Reclamation for economic benefits has become increasingly popular in the last few years with few tourist resorts opting to increase their land. (e.g. Fun Island, One and Only Reethirah and Dhonveli Beach Resort and Spa). Reclamation for infrastructure development is less common and mostly done for airport and port development (e.g. Hulhule, Maamigli and Kulhudhuffushi) and waste disposal (Thilafushi).

Island	Atoll	Area Reclaimed (ha)[1]	% of island reclaimed	Rationale
Hulumale'	Male'	189	100%	Population Pressure
Male'	Male'	82	41%	Population Pressure
Maamigili	A. Dh	80	51%	Economic and infrastructure
Hulhule	Male'	76	58%	Infrastructure
Thinadhoo	G Dh	66	60%	Population Pressure
Hithadhoo	S	53	10%	Population Pressure
Thilafushi	Male'	49	100%	Infrastructure
Naifaru	Lh	37	68%	Population Pressure
Thulhaadhoo	Baa	14	66%	Population Pressure
Hinnavaru	Lh	12	54%	Population Pressure

Table 8: Islands with major land reclamation (Adapted from Shaig (2006))

While land reclamation is considered a necessity to alleviate land shortages, the procedures and methods used in implementing land reclamation projects have exposed islands to environmental and climate change pressures (Shaig (2006)). A process to assess and mitigate the environmental impacts of such project exists through formal EIA requirements, but is hardly efficiently implemented. Amongst over 90 inhabited islands reclaimed only 3 islands have had a formal EIA[2]. Environmental impacts on other inhabited islands were ignored or visually assessed based on a single field visit by an Environment Ministry’s official. EIA requirements for major economic activities are more tightly observed. Resort development is perhaps the only seriously managed area. Unfortunately, some of the largest reclamation projects in tourism industry (for example, One and Only Reethirah and Donvelibeach Resort and Spa)), were initially implemented without developing an EIA.

2.1.4. Vulnerabilities of Land to Climate Change & Severe Weather Events

a. Geological and Geographic Vulnerabilities

The main geological factors which make the coral islands of Maldives vulnerable to climate change and episodic flooding are its unconsolidated nature and extreme low elevation (Collin D. Woodroffe, 1989). If the predicted climate change and associated sea level rise take place, large parts of Maldives are at risk of inundation. With an average height of just 1.5m above sea level the islands of Maldives are considered least defensible (Gommes, Guerny, Nachtergaele, & Brinkman, 1998).

[1] Estimated values derived from comparing 1969 and 2001-2006 satellite and aerial photos.
[2] Source Ministry of Planning and National Development and MEEW

Coral islands are morphologically unstable, changing in their size, shape, elevation and position on reef platforms in response to short-term and seasonal adjustments in wind, wave and current patterns ((Flood., 1986); (Ali, 2000)) and medium to long-term shifts in sea level (Leatherman, 1997). Consequentially, islands require considerable room to adjust future climate changes as sediments can be reworked to the island surface or alongshore to promote island migration on reef platforms ((P.S. Kench & Cowell, 2001, 2002). The natural process unfortunately proposes major challenges in inhabited islands as their infrastructure and settlement may not be able withstand the changes natural processes and increased beach erosion.

Regular flooding has been a feature in natural history of Maldives (see for example (Luthfy, 1994; Maniku, 1983, 1990). Over the last 6 years more than 90 islands (45% of all islands) have been flooded at least once and 37 islands have been inundated regularly or at least once a year (Shaig, 2006). During the severe weather event of May 2004 alone, at least 71 islands (36% of all inhabited islands) were flooded. Ocean induced severe weather events are usually the result of localised storms in the Maldives region (RMSI, 2005), but the flooding events of 1987 proved that swells generated from distant storms also has the potential to cause flooding in Maldives (Goda, 1988; Harangozo, 1992). There has not been enough regular data collection to identify a trend in the flooding incidents, but may become possible in the near future.

Coral islands have a precarious hydrological system. In the event of sea level rise and during times of ocean induced flooding, saltwater infiltrates the water lens and could make the water lens saline (Pernetta & Sestini, 1989), depriving the island of fresh water required for its inhabitants and terrestrial environment.

Geographic location and geomorphologic features may make some islands of more vulnerable to climate change than others, at least in the medium-term. Shaig (2006) reported statistical relationships between past ocean induced severe weather events, severe erosion and geographic features (specifically island location within the archipelago or atoll, specific geomorphologic characteristics such as island shape, orientation and size of reef). Points of importance in the findings include the comparatively high exposure and incidence of southern half of Maldives to flooding; overwhelmingly high vulnerability of smaller islands; relative less vulnerability of islands within the atoll lagoon as opposed to the rim; relative less vulnerability of smooth shaped islands (oval to circular) compared to irregular shapes; and the exposure of island with large reef flats.

b. Human Induced Geological Vulnerabilities

As noted earlier, there is a widely held belief in the field of geomorphology that coral islands left in their natural state will adapt to changes in sea level and severe weather events through their own defence mechanisms. (see for example, Stoddart & Steers, (1973) Woodroffe, (1993), P.S. Kench & Cowell, (2001; 2002)). As far as inhabited islands of Maldives are concerned, most of them may no longer be considered in their natural state. The following human activities are widely believed to have increased the vulnerability of inhabited islands.

i. Construction of coastal structures around coral islands are known to have major implications on its coastal processes and future natural adaptation capabilities (Maragos, 1993). Studies on Maldives have revealed improperly designed and constructed coastal structures have had a major impact in exacerbation of coastal erosion (P.S. Kench et al., 2003; Readshaw, 1994) and possibly to the increase in vulnerability to climate change (Pernetta & Sestini, 1989). Unfortunately, by 2008 all islands are expected to have access infrastructure developed on them[1] based on current 'high risk' designs.

ii. Land reclamation projects implemented without proper concern for the geomorphologic forces operating in a reef flat or a particular part of the atoll may increase the vulnerability of an island to sea level rise and ocean induced severe weather events. Shaig (2006) reported a direct relationship between flooding incidence and major land reclamation projects. The current designs do not consider the island formation process or their existing natural defence mechanisms against changing oceanographic conditions. More evidence is now available on coral islands and their adaptation, which suggest the current land reclamation designs and thinking have serious flaws in planning for a predicted climate change. It is known that, there are topographic variations especially on an ocean ward side of islands in Maldives and this probably is in response to the climate, wave and current conditions of an island (Collin D. Woodroffe, 1989). From studies done elsewhere (P.S. Kench & Cowell, 2001, 2002) it is apparent that the topography of the ocean ward side is critical to develop and maintain natural defense systems of an island. Furthermore, islands are developed in a certain location since it is the point where equilibrium in natural forces could be achieved (Paul S. Kench, 1997). Ignoring such patterns and reclaiming the ocean ward side of the island at flat elevation would naturally increase the susceptibility to flooding.

iii. Removal of coastal vegetation and encroachment of human settlements to beach areas, often due to land shortage and congestion, acts to reduce the natural holding capacity of beaches and facilitate erosion. Vegetation can be removed for housing development or simply to create a better view. Undergrowth in the coastal vegetation is usually stripped clear for aesthetic reasons.

iv. At present, there are questions over the ability of coral reefs to adapt in relation to sea level rise and assist in island stability (Yamano, 2000). Destruction of coral reefs, especially on the ocean ward side, usually through coral mining or during land reclamation projects changes the wave and current regime on the reef flat and may reduce the capacity of islands to develop natural defences. Consequentially, an island may be exposed to increased coastal erosion and future sea level rise.

v. Sand mining, while considerably reduced due to strict environmental regulations, has potentially contributed to shrink the sediment budget of islands, potentially exposing such islands to erosion and sea level rise (Brown & Dunn, 1988). Sand mining,

[1] National Access Improvement Programme 2004-2007.

although illegal, is still practiced in some larger islands, especially Fuvahmulah and L.Gan.

vi. Over-extraction of ground water in coral islands leads to rapid deterioration of fresh water lens (V. S. Singh & Gupta, 1999). In face of rising sea level and episodic flooding, ground water may be more susceptible to further rapid deterioration in islands with population congestion and over-exploitation.

c. Infrastructure and human settlement vulnerabilities

Human settlements are increasingly becoming exposed to potential severe weather induced flooding and sea level rise, due congestion and increasing proximity to sea. It is reported that more than 73 percent of the inhabited islands have buildings less than 100 feet away from the shoreline and more than 55 percent of the islands have buildings less than 50 feet from the shoreline (MHAHE, 2004). Most islands have poor structures which may not withstand severe flooding (UNEP, 2005). Furthermore, houses are constructed without any elevation and could easily cause flooding inside housing units causing considerable economic loss to inhabitants. While a trend in flooding and their intensity across Maldives cannot be identified due to data limitations, the extent of economic loss per incident is certainly on the rise[1]. This is an indication of the increase in number of houses exposed to flooding.

It is estimated that coastal access infrastructure valued at more than US $200 million is currently located across the coastline of Maldives. Much of this infrastructure, especially in inhabited islands, has not been built to withstand severe weather events or future sea level rise. There were more than 75 harbours constructed across the inhabited islands by 2005, based on predominantly poor design and construction material. In 2004, the Government announced a programme to provide access infrastructure to all the inhabited islands by the end of 2007, using the same design. Hence, the likehood of damage to coastal infrastructure during a severe weather event would be much higher from 2008 onwards. It should be noted that a large proportion of the 75 harbours were damaged during the Indian Ocean Tsunami of 2004.

2.2. Beaches

There is an estimated 11-13 sq km of beach along an approximately 1,900-2300 km of coastline in Maldives[2]. Beaches are the most dynamic geomorphologic feature of a coral island. The unconsolidated nature of beaches, together with reversal of monsoon from NE to SW, tends to create a naturally dynamic and unstable environment (P. S. Kench & Brander, 2006). As a result erosion and accretion becomes a regular island building process. Beaches are also one of the most precious economic and recreational assets of Maldives.

[1] Based on newspaper reports of incidents over the past 10 years.
[2] Based on satellite images. Calculation of actual beach area is almost impossible due to difficulties in measuring the boundary of a beach (i.e. low tide, high tide line, median tide line or ‘island foot print’).

2.2.1. *Beach Erosion*

In 2004, 97% of inhabited islands in Maldives experienced coastal erosion and 64% of them had severe erosion (see figure 1). The problem is not specific to inhabited islands as a large number of tourist resorts have also reported ongoing erosion (MHAHE, 2004). As noted earlier, erosion and accretion is a natural process but concerns over erosion arise when coastal infrastructure and properties in inhabited islands get affected. Erosion patterns of inhabited islands have been further complicated due to human intervention in coastal areas. In an evaluation of coastal engineering issues in the Maldives (Readshaw, 1994), reported that causes of erosion are manifold and includes: loss of sediment in reef; increased exposure to the incident wave climate due to historical mining of house reef; changes in near shore current patterns, either due to natural causes or man made changes, such as construction of coastal infrastructure; changes in the natural sediment balance; and up drift impoundment of sand behind coastal structures built without pre-filling. Similarly, Kench et.al (2003) reported direct links with exacerbation of coastal erosion in inhabited islands and improper design of coastal structures.

Despite the evidence against current practice and designs of coastal infrastructure, no practical solution has so far been found. As noted earlier a programme to develop coastal infrastructure in all inhabited islands by 2008 would mean considerable coastal modifications and hence, the probability of a reduction in number of islands with severe coastal erosion is grim.

The question now is not about how to prevent erosion, but how to minimise their impacts. It is highly likely that radical actions such as erection of sea walls and land reclamation would become common practice in the future in order to minimise exacerbation of erosion.

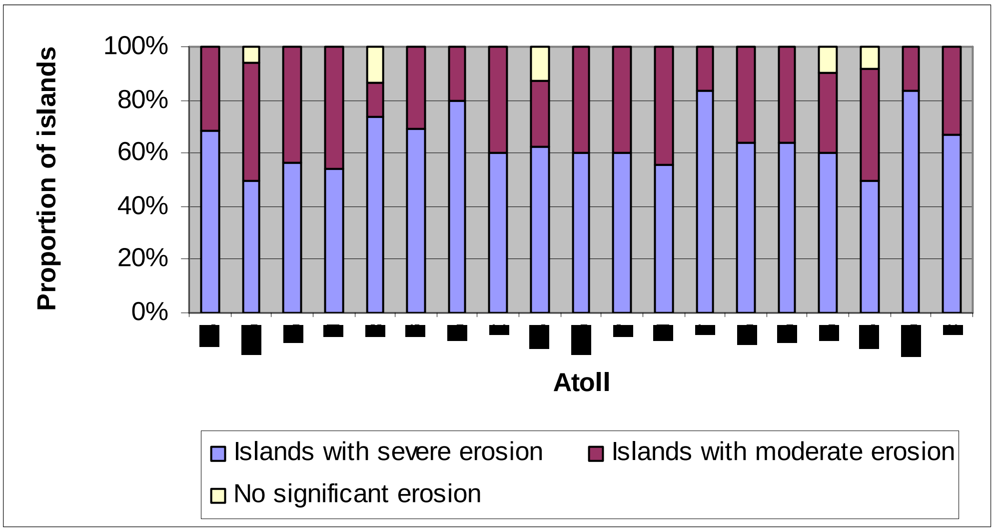

Figure 1: Extent of erosion in Inhabited Islands across Maldives (Based VPAII and MoEEW data)

2.2.2. *Other Pressures on Beaches*

Apart from the well established relationship between beach erosion and improper coastal infrastructure in Maldives, there are a number of other pressures on beaches which may combine to deteriorate beach conditions across Maldives. Firstly, removal of coastal vegetation and encroachment of settlement to beach areas reduces the natural defensive capabilities of islands to wave action and exposes the settlement to erosion. There is a guideline for inhabited islands that advocates a minimum of 100ft between the nearest building and beach. As figure 2 shows, this guideline is rarely implemented or possibly impractical in the face of land shortages.

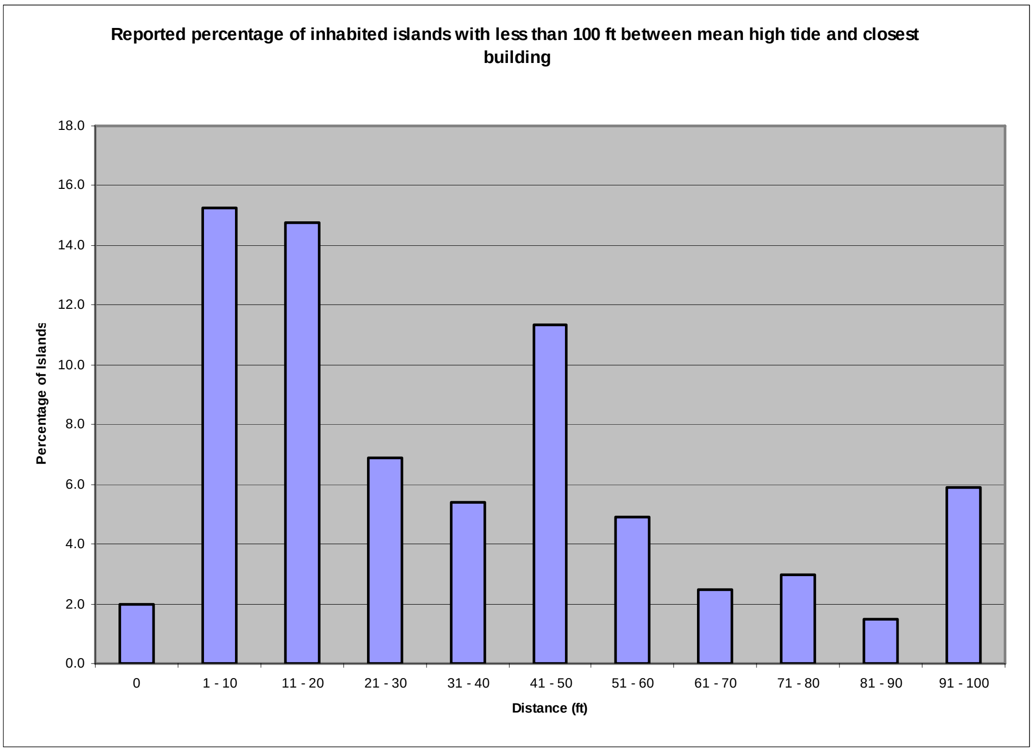

Figure 2: Distance between building and beach in habited islands (Adopted from MHAHE (2004))

3. Impacts of Climate Change on Land and Beaches

3.1. Status of Climate Change Debate on Maldives

During the past few years there has been considerable interest in using Maldives as a testing ground for potential impacts on small island states from Global Climate Change. Perhaps this interest was created by the media, which portrayed 'catastrophic disappearance' of small island states like Maldives, Kiribati and Tuvalu. The debate although still inconclusive, has major implications on Maldives.

In arguably the best evidence supporting the sea level rise in Maldives region, Singh et. al, (2001) reported that sea level has risen 5.8 and 8.5 mm y–1 (depending on season) over the past few years along the Maldives coast. This finding has been backed by a study in neighbouring Chagos where a short series of sea level data indicated a rise of 5.5 mm per year (Sheppard, 2002). These calculations are higher than the average annual rate of 5.0 mm forecasted by IPCC (2001), but IPCC does predict a likely acceleration as time passes. The study however is inconclusive as time series data used were short (Morner, Tooley, & Possnert, 2004) and studies related to tectonic activities of the area and subsidence/uplift may be needed to understand abnormal rise and to confirm whether the rise is eustatic (Khan et al., 2002).

In comparison Morner (Morner, 2004; Morner et al., 2004) argued that sea level has fallen in Maldives over the past millennia and more recently during the last 30-50 years. They argued that Maldives experienced a sea level 0.6m higher than the present level in last millennia and have further fallen since the 1970's. He also refuted Singh et. al, (2001) report on sea level rise and claimed that the actual rise was a negligible 0.9mm if better time series data were utilised. Morner (1994) went to the extent of claiming that Maldives is now 'free from condemnation to sea level rise'. While his findings certainly require consideration in climate change analysis, the methodology used in the study is not suitable for a comprehensive conclusion.

A more conservative analysis was conducted by Kench et. al (2005) and Woodroffe (1993). After analysing the formation of islands based on the relationship with sea level rise, both Kench et al., and Woodroffe suggested that the reef islands formed and maintained its stability in the face of up to a 2.5m rise in sea level, during their formation between 5500 and 4000 yr B.P. Based on these findings, Kench et. al (2005) suggested that the midrange projection of 0.48 m of sea-level rise by the year 2100 (Church et al., 2001) is unlikely to physically destabilize the reef islands of Maldives. Hence, according to Kench et. al 'contrary to most established commentaries on the precarious nature of atoll islands Maldivian islands have existed for 5000 yr, are morphologically resilient rather than fragile systems, and are expected to persist under current scenarios of future climate change and sea-level rise'.

These recent findings do favour a better prospect for Maldives. However, the findings need to be accepted with caution, since these studies were predominantly done on uninhabited islands. The inhabited islands of Maldives are highly modified and their natural adaptation to any future climate change is yet to be determined. Until then, a cautious approach is required in planning for climate change.

3.2. Worst Case Scenario

If the predicted climate change becomes a reality with the maximum changes while sea level continues to rise as predicted and the geological forces fail to adapt to sea level rise, Maldives most likely would cease to exist as a nation within the next 150-200 years. Frequent inundations of land and damage to island hydrology could make the islands virtually uninhabitable.

3.3. Geological Impacts

There are two scenarios for geological impacts. First, if the sea level continues to rise as projected and the coral reefs keep up with the rising sea level and survive the rise in Sea

Surface Temperatures, then the negative geological impacts are expected to be negligible, based on the natural history of Maldives (based on findings by Kench et. al (2005), Woodroffe (1993)). Second, if the sea level continues to rise as projected and the coral reefs fail to keep-up, then their could be substantial changes to the land and beaches in Maldives (based on (Yamano, 2000)). The question whether the natural islands could adjust to the latter scenario may not be answered convincingly based on current research. However, it is clear that the highly, modified environments of inhabited islands stands to incur substantial damage (even during the potential long term geological adjustments), due to loss of land through erosion and increased inundations, and salt water intrusion into water lens.

Impacts on inhabited islands may be significant in both scenarios, if islands have inland wetland areas. Since wetland areas in coral islands are linked to the tide and sea level, an increase in sea level may result in increase in size of such areas and a subsequent reduction in land (Collin D. Woodroffe, 1989). Islands most at risk are Gn.Fuvahmulah, Sh.Maakandoodhoo, S.Hithadhoo, S.Hulhumeedhoo and Hdh.Kulhudhuffushi.

3.4. Economic Impacts

Beaches are used as an economic product and along with coral reefs form the basis of tourism industry. Most of the resort islands are small unconsolidated islands which are most at risk in the event of sea level rise. Even at present, considerable costs are being incurred on resort islands due to continued coastal erosion. Hence, gradual economic loss may accrue to the entire Maldivian economy due the continued loss of one the main economic products. Beach replenishment may be a temporary remedy for the beach loss, but would still be a major financial burden in the face of increase in erosion intensity.

Similarly reduction in ground water quality due to potential saltwater intrusion may destroy the small agricultural industry and increase food insecurity. It could incur major economic and social costs in the future.

Coastal infrastructure, which is the most essential requirement for an island’s social and economic development, may be hardest hit following the sea level rise. Since majority coastal infrastructure are built based on poor designs and low cost material, their capacity to with stand increased sea level and storm intensity is limited. On the other hand, funds to build more solid structures are unavailable due to the sheer number of islands to be protected.

3.5. Social Impacts

Increase in sea level and intensity of storms are expected to expose more population and property to severe weather events especially with the increased congestion and encroachment of beach areas in settlements. Furthermore, past construction material used for housing in Maldives may not be adequate to withstand the increase in intensity of flooding in most islands.

4. Adaptation measures

The probability of climate change and sea level rise derived from a majority consensus amongst the scientific community, warrants action from small island states like Maldives for the sake of their future. The options available for adaptation in Maldives are limited. IPCC (1990) describes three methods for adaptation to sea level rise: accommodate, retreat and protection. Unfortunately, the only option available for Maldives is protection, which may also be beyond its financial and economic capacity. There is a case to consider whether sea level is rising today or is predicted to rise, a question which still has no consensus. Fortunately, contrary to what has been portrayed in the media, climate change and sea level rise in particular is not a single catastrophic event but rather a gradual process that may take aver 75-100 years to reach a catastrophic level. In this sense there is enough time to consider gradual introduction of adaptation measures, with perhaps improved technological and cost-effective solutions. This section provides some of the potential adaptation measures that could be used to counter the vulnerabilities and impacts on land and beaches highlighted in this study.

i. There is a case to consider 'no action' and to allow natural forces to adjust and develop defences in the islands. As the natural history of Maldives provides evidence of past sea level rise and natural adaptation, it may perhaps be a better option to minimise human intervention today. However, there remain questions over the capacity of highly modified coastal environments of inhabited islands to adapt and capacity of coral reefs to keep up with sea level rise amidst global warming.

ii. The most obvious adaptation measure available for Maldives is coastal protection through massive sea walls around the islands. Capital Male' is the only island presently protected in this manner. However, the anticipated costs of coastal protection are extremely high. The initial cost estimates in 1998 projected US$ 1.5 billion for 50 of the inhabited islands (Gayoom, 1998) or US$ 6 billion[1] for 200 inhabited islands (MHAHE, 2001). These costs were based on the concrete 'tetra-pod' designs and specifications used for Male', which are considered a rather expensive option. More conservative calculations based on boulders and accurate coastline measurements estimate US$1.8 billion for 200 inhabited islands[2] if the entire island is protected and US$1.1 billion if the present settlement areas only are considered (Shaig, 2006). Nevertheless, it would be a major undertaking for any government to protect all islands with the limited public finances and competing social and economic investment requirements. Fortunately, this investment need not be made within a short-period as impacts of sea level rise will be gradual and in the future more cost-effective technological solutions may become available.

iii. Another 'hard engineered' solution against sea level rise is elevating the island. The costs of elevating a metre in all inhabited islands in 2006 would be between US$500-1000 million. However, the practicality of such an activity and the environmental impacts, including the change to island's natural topography, impact on terrestrial environment and marine environment are so far beyond comprehension. Such a project may appear more

[1] Estimate based on more accurate coastline measurements put the costs at US$ 7 billion (Shaig, 2006)
[2] IPCC (1990) reported US$1.9 billion for 200 islands.

feasible if elevating island rims only are considered. Then again, the resulting artificial 'saucer shape' topography may have far reaching effects on island hydrography.

iv. Perhaps a better alternative would be a combination of 'no action' and 'soft engineering' solutions. Since the inhabited islands have already been modified to possibly negate the natural process, solutions to facilitate and enhance the natural processes may prove to be effective. For example it is known that most reefs surrounding inhabited islands are damaged and that one of the requirements for survival of islands during sea level rise is to ensure that reefs keep up with the rise. Such reefs could be rehabilitated using artificial reefs as has been already been experimented in Maldives (Clark & Edwards, 1995; Clark & Edwards, 1999). Similarly, the process of shoreline stabilisation and adjustment, according to the prevailing wave conditions are known for Maldives and coral islands in general. (P. S. Kench & Brander, 2006; P.S. Kench & Cowell, 2001, 2002; C. D. Woodroffe, 1993). The island of Fuvahmulah is a classic example of such natural adjustments where a ridge higher than 4.0m was observed on the stormiest side of the island (CDE, 2006). The already modified shorelines of inhabited islands could be enhanced periodically according to this principle. Similarly, new modifications such as land reclamation could take into account the natural processes and alter the designs to facilitate the natural processes. The downside of this option is the lack of current research on the effectiveness on such natural process enhancement activities. Given the time available for adaptation measures, studies on this option could prove be a more efficient and cost-effective method for sea level rise adaptation in Maldives.

v. Most of the vulnerabilities of land and beach have been a direct result of improper human activities in the past, highlighting the potential flaws and limitations in the current environmental regulation and management. Major coastal modifications such as land reclamation and coastal infrastructure development need to be properly assessed and impacts mitigated, especially in the inhabited islands. Environmental regulations and laws need to be applied consistently to inhabited islands as has been done to other major economic activities. In the face of climate change, it is the inhabited islands that have more at stake due to its human settlements. Environmental planning needs to be strengthened and included in the current land use planning process. Such planning should advocate minimising impacts on natural adaptation processes of islands and help to facilitate the natural processes where they have been damaged. This may include proper assessment of land reclamation projects and future coastal infrastructure projects. Additionally, the environmental agenda needs to be further promoted in the outer atolls and in the sectoral decision making processes.

vi. Population and Development Consolidation (PDC) Policy is a policy aimed at promoting consolidation of population from smaller settlements to larger islands. The main objectives of the policy are economic and social: achieving economies scale, reducing diseconomies of scale in public service provision and providing quality social infrastructure for Maldivian population. PDC policy has the potential to reduce the number of vulnerable populations exposed to sea level rise and severe weather events by reducing the cost of protection and adaptation measures through minimising the number of vulnerable inhabited islands. Shaig (2006) reported that cost of coastal protection could be reduced from US$1.8 billion to US$488 million[1] and the cost of access infrastructure could be reduced from US$355 million to US$262 million. Significant reductions in public expenditure on protection measures would mean a better implementation possibility even in the short-term. The impacts of 2004 tsunami have shown that such an approach may be necessary even in the immediate future. Consideration of environmental vulnerability factors along with economic factors in determining islands for consolidation would provide a more focused approach in achieving both economic and social welfare goals. Currently environmental criteria are used for selection of 'host islands', but not for the islands considered for consolidation. A methodology to derive vulnerability indicators and incorporate vulnerability factors into the island selection process of PDC policy has been presented in Shaig (2006). PDC policy certainly would not be free of environmental impacts (AGRIFOR Consult, 2006), but certainly would ensure the impacts a spread at manageable level. In short, strengthening PDC policy with environmental considerations may prove to be an essential step in the adaptation to future climate change and severe weather events in Maldives.

vii. Research on impacts of climate changes and natural processes in the island of Maldives, especially natural adaptation processes, impacts of improper structures in inhabited islands and status of sea level rise in Maldives needs to be promoted and conducted urgently. It could be argued that the present method of promoting environmental research through a national environmental research centre has not so far yielded the desired benefits, perhaps due to administrative or personnel limitations. Alternative approaches need to be considered to find a practical solution to the lack of research. Some additional options include financing postgraduate research students to study topics of urgent requirement in overseas institutions and promoting a culture of environmental research in Maldives through environmental research conferences. It is a well known fact that a number of significant academic contributions by Maldivian research students go unnoticed due to the lack of a forum in Maldives to disseminate the knowledge.

5. Priority Actions

i. Policies aimed at climate change adaptation in outer atolls needs to be fully integrated and aligned with PDC policy. PDC policy has the potential to overcome the financial and economic limitations in reducing the vulnerability of Maldives population. In this respect,

(a.) Environmental criteria (with enough weights) need to be incorporated in determining islands considered for consolidation and Host Islands. Such criteria should consider among others: 1) emphasize prioritisation of consolidation process based on past and present vulnerability to severe weather events, severe erosion and future natural disasters, 2) avoid selection of sensitive environments as host islands, 3) emphasize consolidation of high density islands with no prospect for relief in land shortages, and 4) consider land reclamation as negative criterion.

[1] Based on population consolidation of up to 133 islands.

(b.) Land use planning process of host islands need to be strengthened with environmental criteria. Such criteria should emphasize the minimal impact on key geomorphologic processes in islands and periodic restoration of such features where damaged.

ii. In light of new evidence emphasising the natural adaptability of Maldivian islands to climate change, natural process enhancement should be given priority in environmental planning and awareness campaigns. These would include among others;

(a.) Measures to incorporate better environmental considerations in land reclamation and coastal infrastructure development. Reclamation designs should resemble adaptation to natural processes (such as high ridges where appropriate), avoidance of reclaiming oceanward side of an island wherever possible and avoidance of artificial shapes. Dredging on oceanward reef flat should be avoided for either harbour development or as land reclamation fill material source.

(b.) Land use planning should consider introduction of critical environmental zones that need to be maintained and avoided in the development of human settlements.

iii. There is an urgent need to enhance environmental regulations to minimise the gap between environmental policy and legal implementation. Special focus needs to be given to public infrastructure projects in inhabited islands which seem to bypass the environmental regulations. Land reclamation and access infrastructure development are two of the most destructive activities carried out in Maldives but are virtually excluded from the environmental assessment regulation. The legal frameworks need to be further strengthened to control the design and implementation process of damaging activities such land reclamation on the reef and wetland areas within islands.

iv. Environmental research needs to be strengthened and promoted. Alternative methods of research promotion such as sponsorship of postgraduate research students and promotion of research culture through activities like research conferences needs to be given urgent priority.

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