UNITED NATIONS DEVELOPMENT PROGRAMME

Developing a Disaster Risk Profile for Maldives

UNDP
MALDIVES

Submitted by:

RMSI
Delivering a world of solutions

Volume 1 & 2

May 2006

United Nations Development Programme
Maldives

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Volume 1: Main Report

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May 2006

FOREWORD

The Indian Ocean tsunami of 2004 has been a test of resilience for the people of Maldives. Long regarded as "safe" from such large scale disasters, the country was for the first time made aware of its vulnerability to high impact, 'region-wide' events like the tsunami. This recognition has urged measures to pragmatically integrate disaster risk reduction and risk management perspectives into the government's planning and policy agenda.

In retrospect, it is apparent that there was an acute need for a comprehensive examination of where the risks from multiple hazards are concentrated in Maldives and also, who are most affected by them. To fully address this now, UNDP in close cooperation with the national authorities has commissioned this study on *Developing* a *Disaster Risk Profile* for *Maldives*.

This study provides a comprehensive risk analysis of Maldives with description of various hazards, vulnerabilities and potential damage and loss scenarios. The analysis provides the most complete hazard mapping exercise of the country till date and it is based on geographical evidence, historical data and projections of future hazards. It likewise assesses the complete range of vulnerabilities to multiple hazard events, which will inform coping and adaptive strategies for communities at risk.

This study is positioned to provide key findings which will influence development planning in the Maldives, and support the Government in reducing disaster risks. To enable such policy planning for the national development programme, this study's risk profiling will also play a critical role in deciding which islands can be designated as "safe islands". The findings of this study have obvious implications for a wide range of Ministries to effectively incorporate risk and vulnerability reduction in their plans, strategies and national programmes.

This report will also be a useful reference for disaster risk reduction and management practitioners, and agencies/organizations involved in disaster management for the country. The UN System through UNDP's Disaster Risk Management Programme will continue to seek ways to strengthen policy planning through such and other comprehensive assessments.

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ACKNOWLEDGEMENTS

At the outset, the study team would like to express its gratitude to UNDP Maldives for providing us an opportunity to undertake this interesting study. The team would like to acknowledge and sincerely thank the Government of Maldives, particularly officials from the Ministry of Planning and National Development, National Security Service, National Disaster Management Center, Ministry of Atolls Development, Ministry of Fisheries, Agriculture and Marine Resources, Ministry of Environment and Construction, Ministry of Tourism, Ministry of Education, Ministry of Health and Department of Meteorology, who have supported this study and contributed in a substantive way towards its completion.

We express our special gratitude to Mr. Man Thapa, Disaster Management Specialist, and Ms. Rita Missal, Recovery Officer, in UNDP who guided the direction of this study at different stages and helped in coordination with various ministries and departments of the Government of Maldives. We also extend our special gratitude to Ms. Zaha Waheed and Mr. Hassan Manik, National Disaster Management Center, and Mr. Adam Moosa, Director, Ministry of Atolls Development for the excellent cooperation to conduct field study in various islands and atolls.

We acknowledge the guidance provided by Mr. Kamal Kishore, Regional Disaster Reduction Advisor, Bureau for Crisis Prevention and Recovery, S & SW Asia and Mr. Pablo Torrealba, Risk Reduction Specialist, Regional Center, UNDP Bangkok. We are also thankful for the cooperation and help extended to the mission in logistics for the field surveys by Fathmath Thasneem, National Program Officer, UNDP. Special thanks to Ms. Shefali Juneja and Ms. Debanjali Chakraborti, Bureau for Crisis Prevention and Recovery, S & SW Asia for editorial support.

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GLOSSARY

Annual rate of occurrence

Average number of occurrences per year. Different from the *probability* of at least one event occurring in a year.

Attenuation

The reduction in ground motion with distance from an earthquake. The ground motions resulting from an earthquake decay as they travel away from the fault. An attenuation equation is used to estimate this decay, based on the magnitude of the earthquake as well as the distance and depth of the source.

Bathymetry

The lateral geographical variation of ocean depth.

Base map

A map of any kind showing outlines necessary for adequate geographic reference, on which additional or specialized information is plotted for a particular purpose; a map depicting background reference information such as landforms, roads, landmarks, and political boundaries, on which other thematic information can be superimposed. A base map is used for locational reference and often includes a geodetic control network as a part of its structure.

Central pressure

The lowest instantaneous atmospheric pressure at the center of a storm or a depression.

Community

A political entity that has the authority to adopt and enforce laws and ordinances for the area under its jurisdiction. In most cases, the community is an incorporated town, city, township, village, or unincorporated area of a county. However, each State defines its own political subdivisions and forms of government.

Coping capacity

The means by which people or organizations use available resources and abilities to face adverse consequences that could lead to a disaster. In general, this involves managing resources, both in normal times as well as during crisis or adverse conditions. The strengthening of coping capacities usually builds resilience to withstand the effects of natural and human- induced hazards (ISDR).

Damage ratio

The repair cost of a location represented as a percentage of the value at that location.

Deterministic model

A model that assesses the impact of a hazard by investigating the severity of a single possible outcome.

Disaster risk management

The systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards.

Earthquake magnitude

A scale defined by scientists to quantify the dimension of an earthquake. There are a number of different magnitude scales including local magnitude (ML), surface wave magnitude (Ms), and body-wave magnitude (mb). Each scale measures how fast the ground moves at some distance from the earthquake for a specific frequency band. Since they do not look at the entire frequency range of an event, the different magnitude scales will produce similar, but possibly different magnitudes. This difference becomes more pronounced for large events (>6.5). For this reason, it is very important to note which magnitude scale has been quoted for a given earthquake. Seismologists have recently developed a new scale, moment magnitude (Mw), which is calculated from the total energy released by an earthquake. The media often reports magnitudes using the open-ended Richter scale developed earlier for a specific seismograph that is no longer in use. Richter magnitudes usually refer to local magnitudes but should be viewed with caution unless additional information is provided.

Economic loss

The total monetary cost incurred, whether insured or not, because of a shock ; total losses from a disaster that include direct and indirect losses as well as insured losses and those paid by all other sources (such as property owners and the public sector).

Elements at risk

Population, buildings, civil engineering works, economic activities, public services, utilities and infrastructure etc. that are at risk in a given area.

Epicenter

The surface of the earth directly above the hypocenter of an earthquake (the hypocenter or focus is the point at which the fracture of the earth's crust begins, thus triggering an earthquake). The epicenter is represented by latitude and longitude coordinates for risk modeling purposes.

Event set

The set of discrete events used in probabilistic risk modeling to simulate a range of possible outcomes.

Exceedance Probability (EP)

See "exceeding probability".

Exceeding Probability

Also known as "exceedance probability" or "EP", it is the probability of exceeding specified loss thresholds. In risk analysis, this probability relationship is commonly represented as a curve (the EP curve) which defines the probability of various levels of potential loss for a defined structure or portfolio of assets at risk of loss from natural hazards.

Exposed elements

Persons, resources, production, infrastructure, goods and services which may be directly affected by a physical phenomenon due to their location in its area of influence (CEPREDENAC-UNDP, 2003).

Exposure

The total value or replacement cost of assets (such as structures) that are at risk of a disaster

Fault

A break on the earth's crust along which horizontal or vertical movements occur. Sudden movements along a fault produce earthquakes, while slow movements produce seismic creep.

Food insecurity

It exists when all people at all times do not have the physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life (FAO, World Food Summit 1996). It is also defined as the risk of irreversible physical or mental impairment due to insufficient intake of macronutrients or micronutrients (Barrett, 1999).

Hazard

A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, damage to property, social and economic disruption and environmental degradation.

Intensity

A measure of the physical strength of a hazard such as an earthquake or a drought. Common scales for intensity include the MMI scale for earthquakes and the SPI or PDSI for drought.

Inventories

Formerly called stocks, these consist of materials and supplies which are stored for use during production, work-in progress, finished goods and goods for re-sale.

Mitigation

Structural and non-structural measures undertaken to limit the adverse impact of natural and technological hazards as well as environmental degradation.

Modified Mercalli Intensity (MMI)

It is a subjective scale used to describe the observed local shaking intensity and related effects of an earthquake. This scale ranges from I (barely felt) to XII (total destruction), with slight damage beginning at VI. In general, the MMI decreases with distance from the fault, except in regions with poor soils. Intensity is different from magnitude, which is a measure of the energy released at the source of the earthquake

Morbidity

A departure from a state of physical or mental well-being, resulting from disease or injury- frequently used only if the affected individual is aware of the condition. Awareness itself connotes a degree of measurable impact. Frequently there is another criterion that some action has been taken such as restriction of activity, loss of work, seeking of medical advice, etc.

Peak Ground Acceleration (PGA)

The maximum value of ground motion acceleration as displayed on an accelerogram.; a measurement of the maximum pulse of ground shaking at a location.

Peak gust

The maximum three-second sustained wind gust at 10 meters (30 feet) above the ground. Since the peak gust is sustained for a relatively brief period of time, it is substantially higher than a one-minute wind speed.

Probable Maximum Loss (PML)

It is a general concept applied in the insurance industry for defining high loss scenarios that should be considered when underwriting insurance risk. The exact probability or return period associated with a PML can vary based on the company's policies and objectives

Probabilistic model

A model that assesses the impact of a hazard and assigns probabilities to a whole range of possible outcomes.

Probability

See annual rate of occurrence.

Probability of exceeding

The probability that the actual loss level will exceed a particular threshold.

Probability of non-exceeding

The probability that the actual loss level will not exceed a particular threshold.

Regression

The study of the dependence of one variable (the dependent variable), on one or more other variables (the explanatory variables), with a goal of estimating and/or predicting the mean or average value of the former in terms of the known or fixed values of the latter.

Resilience

The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.

Return period

The expected length of time between recurrences of two events with similar characteristics. The return period can refer to hazards such as hurricanes or earthquakes, or it can refer to specific levels of loss (e.g. a US$100 million loss in this territory has a return period of 50 years).

Richter scale

The original magnitude scale developed by Charles Richter in 1935. Usually referred to as local magnitude, this scale is still often used by scientists for events less than M7.0. The term is often misused in the media to refer to earthquake magnitudes measured using other scales. See "earthquake magnitude" for more explanation of earthquake measurement scales.

Risk

The probability of harmful consequences, or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human induced hazards and vulnerable conditions. Conventionally risk is expressed by the equation

$$\text{Risk} = \text{Hazards} \times \text{Vulnerability/Capacity}$$

(UN/ISDR, 2004).

Shoaling Factor

When sea waves reach the coast, the changes that occur in wave length, speed, and energy are known as the shoaling effect. This effect is quantified in terms of a Shoaling Factor which is proportional to the ratio of wave height in shallow waters to wave height in deep waters.

Site

Same as 'location'. When defining exposure data, a site may represent multiple buildings in close proximity that are of similar construction and have a single deductible amount

Social capital

The existence of a certain set of informal values or norms shared among members of a group that permit cooperation among them. Social capital describes the pattern and intensity of networks among people and the shared values that arise from those networks. While definitions of social capital vary, the main aspects are citizenship, neighborliness, trust and shared values, community involvement, volunteering, social networks and civic participation.

Social vulnerability

Moser and Holland (1998) defined it as insecurity of well-being of individuals, households or communities in the face of a changing environment. Adger and Kelly (2000) conclude that vulnerability is "the ability or inability of individuals and social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being."

Subduction zone

The tectonic plate boundary where two plates converge, and the denser plate slides underneath the less dense one. Also known as a Benioff zone.

Terrain

The surface features of an area of land; it can have an effect on many hazards, such as localized windspeed during storms and landslide susceptibility during earthquakes.

Validation

The process by which probabilistic models and assumptions are reviewed and compared with empirical data (such as historically observed losses or insurance claims) to confirm that the model approach and assumptions generate reasonable estimates of potential loss.

Vulnerability

The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (UN/ISDR, 2004).

Vulnerability curve

A set of relationships that defines how structural damage varies with exposure to differing levels of hazard (such as ground motion or windspeed).

ABBREVIATIONS

ADB	Asian Development Bank
CBO	Community Based Organization
CDF	Cumulative Distribution Function
CVA	Community Vulnerability Assessment
DRM	Disaster Risk Management
EP	Exceedance Probability
EVD	Extreme Value Distribution
GCM	Global Climate Models
GDP	Gross Domestic Product
GHG	Green House Gases
GIS	Geographic Information System
HVI	Human Vulnerability Index
IDC	Island Development Committee
IMD	India Meteorological Department
IWDC	Island Women Development Committee
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
MDR	Mean Damage Ratio
MMI	Modified Mercalli Intensity
NCDC	National Climatic Data Center
NGDC	National Geophysical Data Center
NGO	Non Government Organisation
NIO	North Indian Ocean
NOAA	National Oceanic and Atmospheric Administration
PGA	Peak Ground Acceleration
PML	Probable Maximum Loss
PMP	Probable Maximum Precipitation
PRA	Participatory Rapid Assessment
PVA	Participatory Vulnerability Analysis
RCM	Regional Climate Model
RMSI	Risk Management Solution Inc.
RSMC	Regional Specialized Meteorological Center
SD	Standard Deviation
SEEDS	Sustainable Environment and Ecological Development Society
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
VCA	Vulnerability Capacity Analysis
VPA	Vulnerability and Poverty Assessment

EXECUTIVE SUMMARY

The disaster risk scenario for Maldives can be described as moderate in general. Despite this, Maldives is among the most severely affected countries hit by the Asian tsunami on December 26th, 2004. Maldives experiences moderate risk conditions due to a low probability of hazard occurrence and high vulnerability from exposure due to geographical, topographical and socio-economic factors. It is crucial to address this context of Maldives' high level of vulnerability in order to avoid the present scale of losses and damages in the future. Such an objective requires a detailed risk assessment which will map out *where* the risks from multiple hazards are concentrated in Maldives, *who* is affected and *how*.

In this context, the United Nations Development Programme (UNDP) in Maldives has initiated this study to develop a disaster risk profile for Maldives under a broader Disaster Risk Management Programme. RMSI, an Indian company with expertise in information technology and engaged in providing risk modeling and geospatial solutions, has been involved to undertake the study. To enrich the section on assessment of social vulnerability, RMSI in turn involved SEEDS, an Indian Non-Government Organization engaged in community based disaster management.

1. Objectives

The study was conducted with the following objectives:

i. To determine the probability of hazards across different regions of Maldives based on geological evidence, historical data and projections derived from theoretical analysis. This analysis will help map out the overall hazard context of Maldives and its corresponding vulnerability due to topographical, environmental and socio-economic factors.

ii. To assess the complete range of vulnerabilities in Maldives with reference to multiple hazard events. This analysis will assess the range of vulnerabilities experienced after the tsunami and extrapolate how these experiences, narrated in retrospect, have informed lessons learned in coping and developing adaptive strategies for the future. Such learning will be captured at the local and national levels.

iii. To influence inter-sectoral disaster risk management (DRM) strategies towards recognizing the dynamic form of vulnerabilities which are differentially experienced across regions, communities and time periods. Factoring such an understanding into the institutional measures taken for disaster preparedness, planning and risk mitigation activities will be crucial in contributing towards a sustainable system of recovery.

2. Methodology

The two main components of risk assessment comprise: (i) multi-hazard assessment and (ii) vulnerability assessment. The natural hazards that can have an impact on Maldives in the future are tsunami, storm, earthquake and sea-level rise. 'Storm' here includes wind, rainfall and surge hazards. Vulnerability assessments have been undertaken to incorporate physical and social aspects separately.

As the first step, a digital base map of Maldives comprising island boundaries and their attribute information has been created. 1037 islands have been captured using remote sensing images. Their attribute information includes names of islands, names of atolls, island types etc. The base map is fundamental to any geospatial analysis such as Geographic Information System (GIS).

Tsunami, storm and earthquake have been modeled using probabilistic techniques and their probable maximum intensities have been determined. Usually building codes recommend a hazard intensity that has a 10 per cent chance of exceeding in 50 years (normally considered as the life span of a building), which corresponds to a return period of 475 years. The same has been considered as a probable maximum intensity in the present study and has been used to create a hazard zone map. Zones have been ranked between 1-5, indicating very low, low, moderate, high and very high hazard risks respectively. The base map has been superimposed on each of the hazard maps in a GIS environment and hazard zones have been assigned to each island. For sea level rise, projections given by UNFCCC have been considered. The map below (Figure 1) demonstrates a sample hazard map of tsunami.

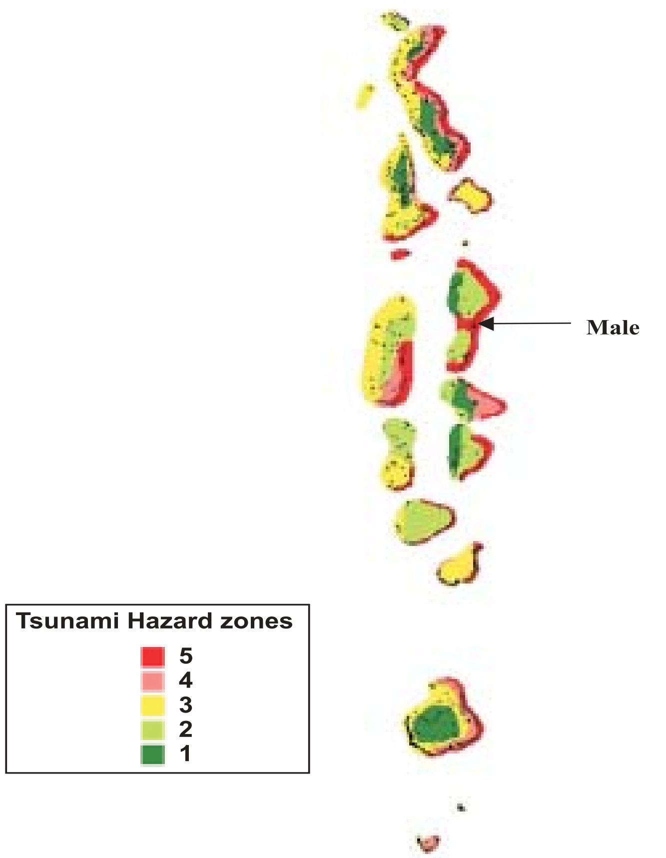


Figure 1: Tsunami Hazard Zones

Field visits have been conducted to collect primary as well as secondary data for vulnerability assessments. Twelve islands in five atolls spread across north to south of the country have been studied by a team of specialists. The atolls covered are Haa Dhaalu, Kaafu, Meemu, Laamu and Seenu. Secondary data has been collected essentially to help in the assessment of physical vulnerability. Primary data through Participatory Rapid Assessment (PRA) exercises have been conducted essentially to help in social vulnerability assessment. Focused group discussions were conducted in every island community.

Vulnerability and risk associated with buildings in various islands are proportional to the hazard, value of building assets, construction material, age and number of storeys. Much of this data has been taken from Maldives' *Census 2000*. The primary survey data from UNDP's *Vulnerability and Poverty Assessment Report 2004* formed the basis of the social vulnerability assessment. However, to correlate it with qualitative and perceptional data from the field, a series of community based rapid appraisal exercises were carried out. The dimensions of social vulnerability are lack of coping capacity, threat to life, chance of injury, food insecurity and livelihood insecurity, and there are several indicators identified to explain one or more of these dimensions. Separate physical and social vulnerability risk assessments have been carried out for each of the hazards; and all hazards combined (multi -hazard) for every inhabited island. A risk index of 1-5 has been used to map every island indicating very low, low, moderate, high and very high risk levels. A matrix showing islands in rows and hazard zones and risk indices in columns has been developed with cells numbered 1-5. This is the final output for the risk profiling of Maldives.

3. Key Findings

Maldives faces tsunami threat largely from the east and relatively low threat from the north and south. So, islands along the eastern fringe are more prone to tsunami hazard than those along the northern and southern fringes. Islands along the western fringe experience a relatively low tsunami hazard. Historically, Maldives has been affected by three earthquakes which had their sources in the Indian Ocean. Of the 85 tsunamis generated since 1816, 67 originated from the Sumatra Subduction zone in the east and 13 from the Makran Coast Zone in the north and Carlsburg Transform Fault Zone in the south. The probable maximum tsunami wave height is estimated at 4.5 metres in Zone 5. The return period of the kind of tsunami that struck Maldives on 26th December 2004 is estimated to be 219 years (one of numerous probable events).

The northern atolls have a greater risk of cyclonic winds and storm surges. This reduces gradually to very low hazard risk in the southern atolls. The maximum probable wind speed in Zone 5 is 96.8 knots (180 kilometers per hour) and the cyclonic storm category is a lower Category 3 on Suffir-Simpson scale. At this speed, high damage is expected from wind, rain and storm surge hazards.

Except for Seenu, Gnaviyani and Gaafu atolls, earthquake hazard is low across the country. The probable maximum Modified Mercalli Intensity (MMI) is estimated between 7-8 in Zone 5. This level of MMI can cause moderate to high damages.

Sea level rise due to climate change is a uniform hazard throughout the country. The Inter Governmental Panel on Climate Change (IPCC) in its Third Assessment Report (2001) estimated a projected sea level rise of 0.09 metres to 0.88 metres between 1990 - 2100. The impact on Maldives depends on the elevation of islands. With about three-quarters of the land area of Maldives being less than a meter above mean sea level, the slightest rise in sea level will prove extremely threatening.

Male is estimated to be inundated by 15 per cent by 2025 and 50 per cent by 2100 due to climate change and consequent sea level rise. Due to non-availability of high resolution topographic data, impacts on other islands could not be estimated.

Overall, Maldives faces moderate hazard risk except for the low probability and high consequential tsunami hazard in the near future, and high probability and high consequential sea level rise hazard in the distant future.

Risk arising from physical vulnerability has been treated as a function of exposure concentration. Male tops the list with highest risk. The islands with risk index 5 (very high) and risk index 1 (very low) are given in the tables below. Risk index 1 implies “safe island” in relative terms.

Table 1: Islands and Atolls with Very High Multi hazard Physical Risk Index

Sl. No.	Island	Atoll	Multi hazard Physical Risk Index
1	Male	Kaafu	5
2	Foammulah	Gnaviyani	5
3	Kulhuduffushi	Haa dhaalu	5
4	Hulhudhoo	Seenu	5
5	Dhidhdhoo	Haa alifu	5
6	Dhidhdhoo	Alifu dhaalu	5
7	Kelaa	Haa alifu	5
8	Nolhivaramu	Haa dhaalu	5
9	Gadhdhoo	Gaafu dhaalu	5
10	Naifaru	Lhaviyani	5
11	Thoddoo	Alifu alifu	5
12	Eydhafushi	Baa	5
13	Kalhaidhoo	Laamu	5

Table 2: Islands and Atolls with Very Low Multi hazard Physical Risk Index

Sl. No.	Island	Atoll	Multi hazard Physical Risk Index
1	Bodufolhudhoo	Alifu alifu	1
2	Himendhoo	Alifu alifu	1
3	Maalhoss	Alifu alifu	1
4	Mathiveri	Alifu alifu	1
5	Ukulhas	Alifu alifu	1
6	Mandhoo	Alifu dhaalu	1
7	Dhonfanu	Baa	1
8	Kihaadhoo	Baa	1
9	Kudarikilu	Baa	1
10	Hulhudheli	Dhaalu	1
11	Meedhoo	Dhaalu	1
12	Ribudhoo	Dhaalu	1
13	Dharanboodhoo	Faafu	1
14	Magoodhoo	Faafu	1
15	Thinadhoo	Gaafu dhaalu	1
16	Fodhdhoo	Noonu	1
17	Kandoodhoo	Thaa	1
18	Omadhoo	Thaa	1
19	Vandhoo	Thaa	1
20	Rakeedhoo	Vaavu	1

Risks arising from social vulnerability have no definite trend except that Male is at low risk. The risks are randomly spread across the country as several factors influence vulnerability. The tables below give islands with risk index 5 (very high) and risk index 1 (very low). Risk index 1 implies a "safe island" in relative terms

Table 3: Islands and Atolls with Very High Multi hazard Social Risk Index

Sl. No.	Island	Atoll	Multi hazard Social Risk Index
1	Thuraakunu	Haa alifu	5
2	Berinmadhoo	Haa alifu	5
3	Hathifushi	Haa alifu	5
4	Nolhivaramu	Haa dhaalu	5
5	Alifushi	Raa	5
6	Hulhudhuffaaru	Raa	5
7	Buruni	Thaa	5
8	Dhiyadhoo	Gaafu alifu	5
9	Gadhdhoo	Gaafu dhaalu	5
10	Meedhoo	Seenu	5
11	Hithadhoo	Seenu	5
12	Feydhoo	Seenu	5

Table 4: Islands and Atolls with Very Low Multi hazard Social Risk Index

Sl. No.	Island	Atoll	Multi hazard Social Risk Index
1	Bodufolhudhoo	Alifu alifu	1
2	Feridhoo	Alifu alifu	1
3	Himendhoo	Alifu alifu	1
4	Maalhoss	Alifu alifu	1
5	Mathiveri	Alifu alifu	1
6	Rasdhoo	Alifu alifu	1
7	Thoddoo	Alifu alifu	1
8	Mandhoo	Alifu dhaalu	1
9	Kamadhoo	Baa	1
10	Kudarikilu	Baa	1
11	Dharanboodhoo	Faafu	1
12	Fieealee	Faafu	1
13	Magoodhoo	Faafu	1
14	Nilandhoo	Faafu	1
15	Maduvvari	Raa	1
16	Meedhoo	Raa	1
17	Kandoodhoo	Thaa	1
18	Omadhoo	Thaa	1
19	Vandhoo	Thaa	1
20	Rakeedhoo	Vaavu	1

4. Recommendations

The study has identified certain key areas that call for attention from the development planners in general and disaster risk reduction practitioners in particular. The recommendations have broadly been categorized into two sections –those that address long -term sustainable development issues and those that relate to the next steps for disaster risk management.

A. Issues in Sustainable Development:

i. Integration of Disaster Management into national planning and development processes: Disaster management is a multi sectoral and multi disciplinary subject and as such no single ministry or department can address the subject in its entirety. Considering the fact that vulnerability of Maldives is aggravated due to its geography and population dispersion, an interdepartmental focus that will ensure its integration into national planning would be more appropriate. In addition, institutions and legal mechanisms supported by policy and legislation to reduce risks are necessary.

ii. Diversification of income options for the people and strengthening of the fishing and tourism industries: The country's economy is dependent on two main sources; tourism and fisheries, both of which are vulnerable to hazards related to the sea. This lack of diversified economic base due to limited natural resources, physical space and labor, limits income opportunities from industry and agriculture. While serious thinking into diversifying the income sources could be made, more efforts to safeguard and strengthen the two sectors are crucial. With the ranking available for all islands including the resort islands, mitigation measures for protection of the islands and specific measures for preparedness and response should be made mandatory. The ranking may also be used as a guide for selection of islands for developing resorts in future.

iii. Disaster Risk Reduction through tsunami reconstruction: Reconstruction after the tsunami should be used as an opportunity for rebuilding livelihoods and planning in a manner that reduces risks and builds community resilience to disasters**.** In a country comprising a chain of low -lying small islands, rebuilding all public utilities and infrastructure such as school and health facilities with higher plinth level and high elevation to prevent flooding is required. These buildings, especially the schools, could also be turned into safe shelters during a disaster, as that would ensure the best use of available and limited space and infrastructure in the islands. The safety of all expensive equipments needs to be taken care of.

iv. A detailed risk and vulnerability analysis of Male: The capital city Male has the highest concentration of population and assets in the country. Its vulnerability also stems from the fact that it houses all vital installations and key services for the country. The airport, harbor, food godowns, government offices and tertiary hospital services centers are all located in this island and this makes it an important center that needs specific actions for upgrading its safety. Rapid urbanization of Male and the increasing congestion causes a strain on the basic services and increases disaster risk significantly. While efforts are ongoing to ease out the population congestion in Male, risks and vulnerability of the capital city, its vital installations and exposure to hazards such as fire need to be studied in detail. Further analysis of physical vulnerabilities due to its topography and its large building stock will also help strengthen an understanding of specific risks of the capital where a third of the population reside. Male is likewise confronted by the challenge of rapid urbanization as revealed by the Second Vulnerability and Poverty Assessment Report of the Maldives, 2005. This trend of urbanization will most likely lead to disintegration of family structures and thereby reduce coping capacities of communities. Vulnerabilities in Male are also compounded by the fact that income opportunities are limited and this may lead to low resilience of the community. Specific measures to address these socio-economic vulnerabilities need to be put in place.

B. Issues for Disaster Risk Management

i. Prevention

Promotion of a culture of prevention, including mobilization of adequate resources and investing the same on disaster risk reduction: Further risk assessment studies of the islands in the country and putting up of end-to-end early warning systems are some of the key investments that protect and save lives, property and livelihoods, contribute to the sustainability of development, and are far more cost-effective in strengthening coping mechanisms than relying primarily on post-disaster response and recovery (HFA). The country's future development choices and plans should take into consideration proactive measures in a way that build community resilience and reduce vulnerabilities to future disaster risks.

ii. Mitigation

Undertake proactive disaster risk mitigation measures: The hazard and risk information generated by the study needs to be incorporated into the national policy and planning. Proactive planning and investments in mitigation measures – structural and non-structural - go a long way in mitigating the long term impacts of natural disasters. A beginning needs to be made to construct buildings and structures that can resist natural hazard forces at least in zones 5 and 4. Islands should be carefully selected for development activities based on the hazard and risk information.

iii. Preparedness

a. Strengthen disaster preparedness for effective response at all levels: In Maldives, inhabited islands with small population may be targeted for building community's capacity to face natural disasters. This would require suitable training for Island Chiefs and Atoll Chiefs. Island-wide Disaster Management Plans would be a useful point to begin; activities such as preparedness drills can be conducted. Other influential local stakeholders such as school teachers, religious heads and boat owners would also need to be targeted with customized training programmes and related activities.

b. Intensify raising public awareness promotion on basic concept of disaster risk management and reduction at all levels: Public awareness is a core element of successful disaster risk reduction. Basic disaster awareness which encourages families to have their own disaster plans, communities to build emergency water and food supply systems and house owners/construction workers to be sensitive to safe building construction practices may be promoted through awareness programmes using various locally appropriate media.

c. Undertake School Safety programmes: There is an urgent need for introducing school safety programmes in all the islands. The country has a robust educational infrastructure which may be suitably equipped to deal with disasters. School safety programmes would promote a culture of safety in the community. The programme may cover multi-hazards, and can include the following components: training of teachers and students, formal curriculum based education, non-formal aspects such as school disaster management plans, preparedness drills, structural and non-structural mitigation exercises.

d. Enhance capacity of atoll hospitals on emergency preparedness including basic hospital casualty drills: During the study, interaction with the local hospital administration and community leaders indicated that hospitals need to build upon basic casualty drills including 'triage'. Hospital emergency preparedness programmes are necessary across all islands, particularly building capacity of the atoll hospitals.

iv. Early Warning

Set up Early Warning dissemination systems and mechanisms at all levels: Early warning systems developed must be people-centered, in particular systems whose warnings are timely and understandable to those at risk (HFA). This should also include provision of guidance and building people's capacities on how to act after receiving warnings. Setting up of community -level early warning systems to complement the mechanisms at the national level would ensure effective response to disasters. In Maldives, the northern atolls have a high risk of cyclones and the eastern atolls are at risk during tsunamis. The communities in these atolls need to be well prepared to receive warnings promptly and react appropriately. The island offices and well established GSM network in the country are potentially the most useful tools for dissemination of early warnings. Requisite infrastructure and training is needed to promote better preparedness.

5. Future Scope of Study

The present study has been conducted at a macro-level on the national scale. It does not necessarily capture the inter and intra island heterogeneity and issues there in. More detailed and micro-level studies are required focusing on few islands to get insights into the issues at the island level. The following are few such studies recommended for future work.

a. Any island planning should consider not only the picture in a national setting but also the characteristics within the island, especially for big islands. An island- wise detailed study focusing on big islands would enrich the results of the present study and be more relevant to island planning and development. This could be addressed by multi-hazard risk mapping done at the community level.

b. A detailed risk assessment of islands that are designated as "safe islands" in relative terms needs to be undertaken to identify special safety measures that should be implemented to make them truly safe.

c. Additionally, a detailed analysis of building stock in islands in earthquake zones 5 and 4 need to be undertaken to recommend retrofitting measures and changes to building codes and by-laws.

d. A detailed study on identifying means and alternatives for livelihood resilience will be useful. Socio-economic issues concerning vulnerability of agriculture and fisheries and adaptation to natural hazards need to be studied. Considering the impact of the tsunami on the country's tourism industry and its economy, the study can help strengthen the underlying causes that enhance vulnerability of fishing and tourism sectors.

e. Study on local governance system and local social institutions, and their capacities to absorb decentralized community based disaster risk management needs to be taken up.

1 INTRODUCTION

1.1 Background and Context

The disaster risk scenario for Maldives can be described as moderate in general. Despite this, Maldives was severely affected by the Asian tsunami on 26th December, 2004. The tsunami caused severe damages to the physical infrastructure of many islands and set back the high levels of social progress and prosperity achieved over recent years. The total damages are estimated at US$ 470 million, amounting to 62 per cent of the Gross Domestic Product or GDP (World Bank, 2005). Of these, direct losses amount to US$ 298 million which is eight per cent of the replacement cost of the national capital stock.

Maldives' vulnerability can be attributed to a number of factors- its geographical location, topographical features, probable effects of climate change, the nature of its economy and associated trends of population concentration. Located in the north Indian Ocean, the chain of islands that comprise Maldives are regularly exposed to multiple natural hazards such as storms, droughts, heavy rains and high waves caused by cyclones in the southern Indian Ocean. Given that Maldives is a nation of islands no more than two meters above sea level, the country is at particular risk due to rising sea levels associated with climate change. In addition, the country is susceptible to oil spills and aviation-related hazards. It is important to add that the country's economy is predominantly dependant upon tourism and fisheries, thereby increasing its economic and social vulnerability to hazards related to the sea.

The recent tsunami has exposed multiple vulnerabilities of the people of Maldives. It has thereby also presented an opportunity to closely examine the dynamics of such vulnerabilities so that they may be effectively dealt with, to reduce future disaster risks. This requires a detailed risk assessment which will map out *where* the risks from multiple hazards, both natural and man-made, are concentrated in Maldives, and also examine *who* is affected and *how*. A risk assessment is analytically based on documenting and assessing the hazard, followed by an evaluation of the vulnerability of a population or region to this hazard. Thereby, the two main components of risk assessment in Maldives would comprise (a) multi- hazard assessment and (b) vulnerability assessment.

In this context, the United Nations Development Programme (UNDP) Maldives has initiated this study to develop a disaster risk profile for Maldives under a broader Disaster Risk Management Programme. RMSI, an Indian company with expertise in information technology engaged in providing risk modeling and geospatial solutions, has undertaken the study. To enrich the section on social vulnerability assessment, RMSI in turn involved SEEDS, an Indian Non Government Organization engaged in community based disaster management.

1.2 Objectives of the Study

For an assessment of disaster risk in Maldives, the study had the following objectives :

1. To determine the probability of hazards occurring across different regions of Maldives based on geological evidence, historical data, and future projections derived from theoretical analysis. This analysis will help map out the overall hazard scenario of Maldives and its corresponding aspects of vulnerability as shaped by topographical, environmental and socio-economic factors.

2. To assess the complete range of vulnerabilities experienced throughout Maldives with reference to multiple hazard events. This analysis will assess the range of vulnerabilities experienced post the tsunami and extrapolate how these experiences, narrated in retrospect, have informed lessons learned in coping and developing adaptive strategies for the future. Such learning will be captured at the local and national levels.

3. To influence inter-sectoral DRM strategies towards recognizing the dynamic form of vulnerabilities which are differentially experienced across regions, communities and time periods. Factoring such an understanding into the institutional measures taken for disaster preparedness, planning and risk mitigation activities will be crucial in contributing to a sustainable system of recovery.

1.3 Country Overview

The Republic of Maldives comprises 1,190 small, low- lying islands grouped into 26 atolls that together form a chain over 820 kilometers in length, over an area of more than 90,000 square kilometers in the Indian Ocean. These islands stretch from latitude $7^0 6'35''$N, crossing the equator and extending up to 0^0 $42'24''$S and between longitudes 72^0 $33'19''$E and 73^0 $46'13''$E. The islands are mostly flat, with very low elevation of hardly 1.5 meters above the sea level. They are surrounded by coral reefs which protect them from the impact of strong waves.

Maldives enjoys a warm and humid tropical climate, with two monsoon periods: the southwest monsoon (the wet period from May to November) and the northeast monsoon (the dry period from January to March).

Of the total islands, only 199 are inhabited. The islands are small in size, 33 inhabited islands have a land area of more than one square kilometers; 67 islands have a population of less than 500, while 144 islands have a population of less than 1,000 inhabitants. The total population of Maldive is 339,330.

The remoteness and inaccessibility of the islands presents a challenge in delivery of basic services and high diseconomies of scale. High dependence on imports even for essential items further compounds the vulnerability. The predominant dependence of the country's economy is on two sources- tourism and fisheries. It enhances the vulnerability of the economy and the community from hazards related to the sea. Lack of diversified economic base due to lack of natural resources such as minerals and fresh water and other resources such as physical space and labor, limits income opportunities from industry and agriculture. Yet dependence on agriculture is high and in inhabited islands about 75 per cent of the land is used for agricultural activities. 941 uninhabited islands are leased out through the traditional leasing system for developmental activities including agriculture. There are other occupation categories in which people who are mostly self- employed skilled labor such as carpenters, masons, electricians, skilled craftsmen who are mainly dependent on local economy and have limited market demand for their livelihood. A summary of the key indicators of Maldives is given in Table 5.

Table 5: Key Indicators of Maldives

Indicator	1994	2004
Census population	240,255	293,746
GDP (in mil. US$, 1995)	338	700.8
GDP per capita (US$, 1995)	1451	2,421
Share of industry in GDP (per cent)	10.1	8.5
Share of services in GDP (per cent)	73.4	77.2
Share of agriculture in GDP (per cent)	3.8	2.8

(Source: *Maldives – Key Indicators 2004*, Ministry of Planning and National Development)

1.4 Structure of the Report

The report consists of two volumes. Volume 1 is the main report which includes the methodology, the key results and the findings. Volume 2 has Annexures including the results and field notes as well as base maps in Arc View and Map Info software. The main report is organized the way the study has been implemented and comprises ten chapters. The first one is introductory, Chapters 2-3 explain the methodological framework and the steps involved to create the digital base map of the country respectively. Chapters 4-7 describe the methodology and results for each of the four natural hazards considered in the study – tsunami, storm, earthquake and sea level rise respectively. Chapters 8 and 9 describe methodology and results for assessment of the physical and social vulnerability respectively, while Chapter 10 gives the key conclusions and recommendations.

2 METHODOLOGICAL FRAMEWORK

The Catastrophe Risk Modeling Framework, followed as the best practice in the global insurance industry, has been adopted with minor necessary changes to suit the present study. There are three components in sequence, each feeding its output as input to the next component as illustrated in Figure 2. The two main components of risk assessment comprise: (i) multi- hazard assessment and (ii) vulnerability analysis. In the third component, risk indices are assigned to every island using weights to aggregate individual hazards and parameters defining the vulnerability.

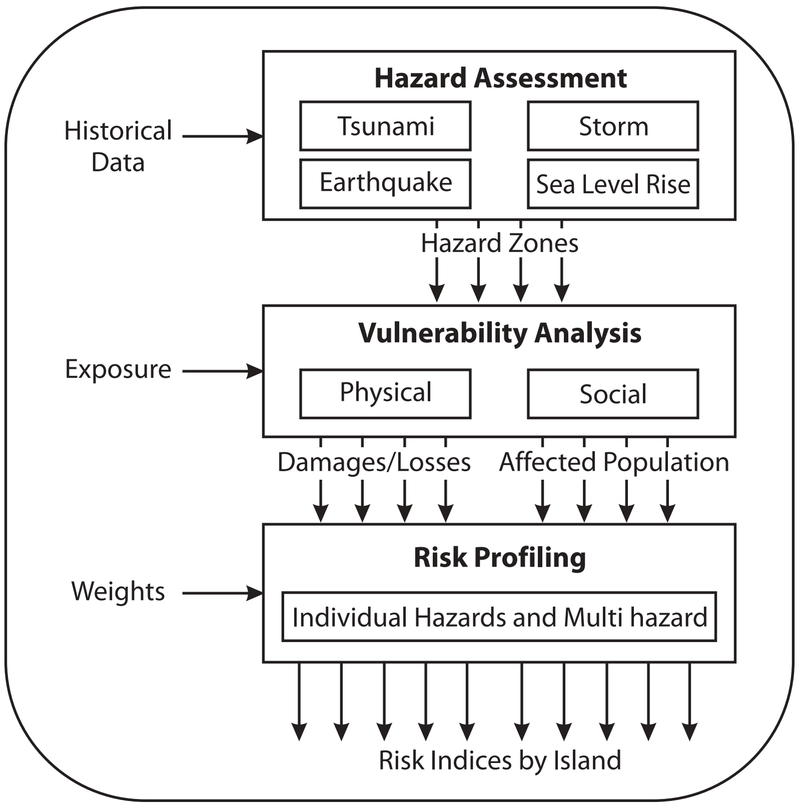


Figure 2: Methodological Framework

As the first step, a digital base map of Maldives comprising island boundaries and their attribute information has been created where 1037 islands have been captured using remote sensing images. The attribute information includes names of islands, names of atolls, island types etc. The base map is fundamental to any geospatial analysis such as GIS.

The natural hazards that can have impact on Maldives in future include tsunami, storm, earthquake and sea level rise. The term 'storm' here includes wind, rainfall and surge hazards. Tsunami, storm and earthquake hazards have been modeled using probabilistic techniques and their probable maximum intensities have been determined. Usually building codes recommend a hazard intensity that has a 10 per cent chance of exceeding in 50 years (normally considered as the life span of a building), which corresponds to a return period of 475 years. The same has been considered as probable maximum here, and has been used to create a hazard zone map. Zones have been given a scale of 1-5, indicating very low, low, moderate, high and very high hazard risks respectively. The base map has been superimposed through the overlay technique on each of the hazard maps in a GIS environment and a hazard zone has been assigned to each island. For sea level rise, projections given by UNFCCC have been considered.

Vulnerability assessments have been undertaken for the physical and social aspects separately. Field visits were conducted to collect primary as well as secondary data for these assessments. Twelve islands in five atolls spread across north to south were studied by a team of specialists. The atolls covered were Haa Dhaalu, Kaafu, Meemu, Laamu and Seenu. Secondary data has been collected to help in the assessment of physical vulnerability, while primary data through Participatory Rapid Assessment (PRA) exercises have been collected for the assessment of social vulnerability. Focused group discussions were conducted in every island community.

Vulnerability and risk associated with buildings in various islands is related to the level of hazard, value of building assets, construction material, age and number of storeys. Much of this data has been taken from Maldives' *Census 2000*. The primary survey data from UNDP's *Vulnerability and Poverty Assessment Report 2004* formed the basis for the social vulnerability assessment. However, to correlate it with qualitative and perceptional data from the field, a series of community based rapid appraisal exercises were undertaken. Separate physical and social vulnerability risk assessments have been carried out for each of the hazards individually; and for all hazards combined (multi- hazard) for each inhabited island. A risk index of 1-5 has been used to map every island indicating very low, low, moderate, high and very high hazard risks. A matrix has been created with names of islands in rows and hazard zones and risk indices in columns; the cells are filled with numbers between 1-5. This is one of the final outputs of the risk profiling for Maldives.

3 DIGITAL BASE MAP

Analytical solutions applying GIS and other geospatial technologies such as remote sensing are common in natural hazard risk assessments. A digital base map is fundamental to any geospatial analysis and modeling. Unfortunately, no such map of Maldives was available during this study. Hence, a digital base map for Maldives, probably the first of its kind, has been created using remote sensing data.

3.1 Methodology

Land use/land cover data derived from a combination of United States Geological Survey Landsat images and Aster images have been used to identify vegetation and land masses. Landmass with vegetation is the basis for identifying an island, 1037 such landmasses have been identified and converted into vector polygons using GIS software.

Islands have been classified into inhabited, uninhabited, resorts and proposed resorts. Island names have been updated on the base map derived from *Atlas of the Maldives* (Godfrey, 2004). Only 1037 islands are named in the Atlas. Thus, the tiny uninhabited islands have not been captured in the base map. The Atlas has also been used to undertake quality checks of the digital base map.

The following images have been used for deriving the land use/land cover data: Landsat from 1999 onwards and Aster images from 2001 onwards till mid-2004. Aster images have been used for deriving land use/land cover and wherever there were clouds, Landsat images have been used.

3.2 Meta Data of the Base Map

Resolution:

- Landsat images (Pan chromatic – 15m, Multi spectral – 30m)
- Aster images – 15m.

Maldives Base Map:

- Format : Map Info tab.

Projection system:

Two project systems have been provided.

Planar coordinate system

- Projection : Universal Transverse Mercator

- Datum : WGS84
- Hemisphere : North
- Zone : 43
- Units : Meter

Geographic coordinate system

- Projection : Geographic
- Datum : WGS84
- Units : Degree

Attributes Present in the base map:

- ID : Island Unique id
- Island : Island name
- Atoll : Atoll name
- Category : Category of island
- Atoll code : Atoll code (internal)
- Island number : Island number (internal)
- Island code : Island unique code (internal)
- X : Centroid of the Island - X coordinate, longitude (internal)
- Y : Centroid of the Island - Y coordinate, latitude (internal)
- Remarks : Any specific information about an island (e.g. airport).

There are 1037 islands in the map, their break-ups by types are given below:

Inhabited Islands	: 205 (including Male, Villingili)
Resorts	: 87
Proposed Resorts	: 13
Uninhabited Islands	: 732

There are 26 natural atolls that are divided into 20 administrative atolls. Some snapshots of atolls are presented below to showcase uses of the digital base map.

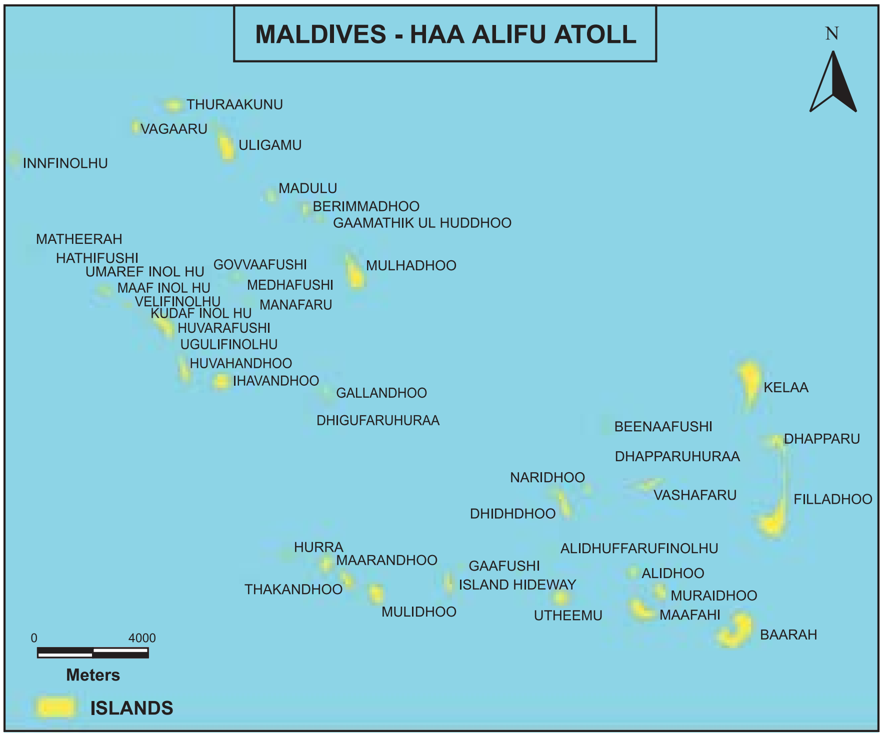


Figure 3: Base Map of Haa Alifu Atoll

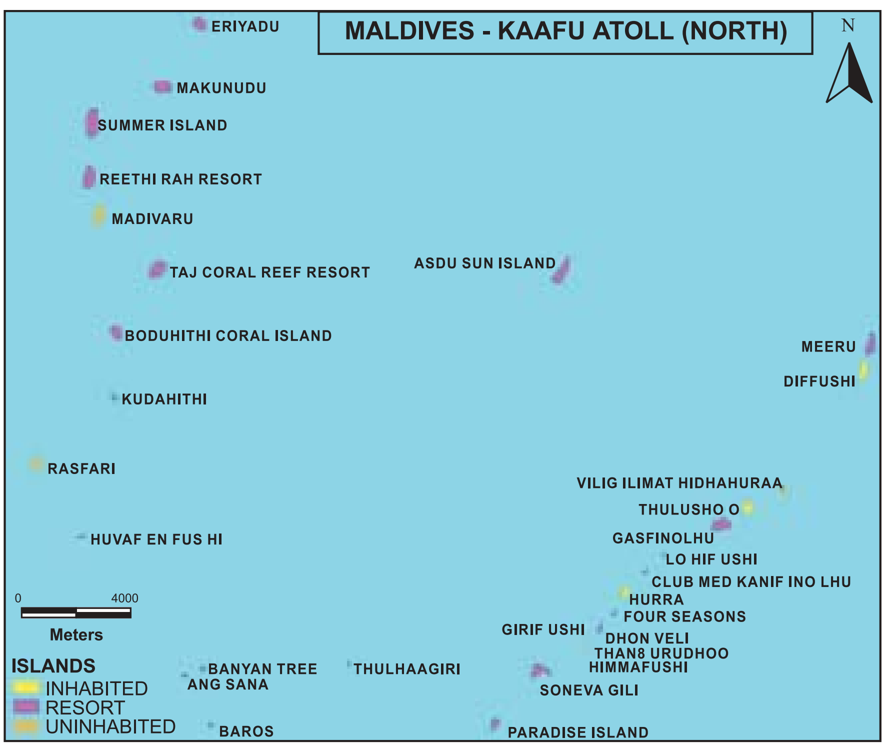


Figure 4: Base Map of Kaafu Atoll (North)

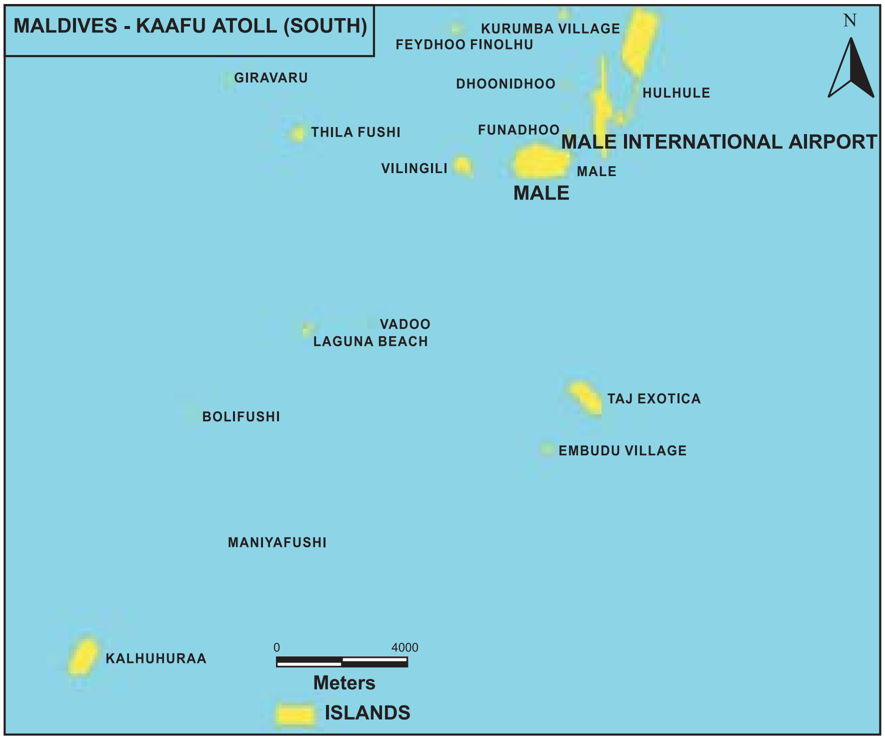


Figure 5: Base Map of Kaafu Atoll (South)

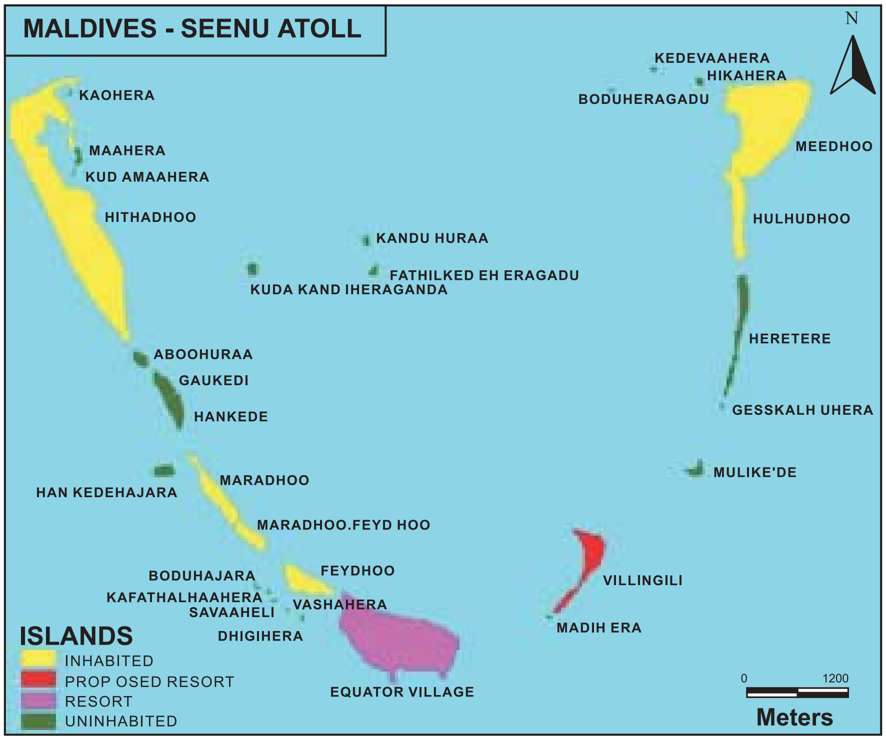


Figure 6: Base Map of Seenu Atoll

4 TSUNAMI HAZARD

4.1 Introduction

The word 'tsunami' is derived from two Japanese words '*tsu*' and '*nami*' which mean 'harbour waves'. Tsunamis are distructive sea waves generated due to disturbances on the sea floor, such as an earthquake, a volcanic eruption, an underwater landslide or even the impact of a meteorite. Large vertical movements of the sea floor often occur at plate boundaries. Around the margins of the Pacific Ocean, for example, denser oceanic plates slip under lighter continental plates in a process known as 'subduction'. Regions of subduction usually experience large, shallow earthquakes with an epicenter near or on the ocean floor. Such earthquakes tilt, offset, or displace large areas of the ocean floor from a few kilometers to as much as a 1,200 kilometers or more.

The disturbances on the sea floor vertically displace overlying sea water: the potential energy that results from pushing water above mean sea level is then transformed into kinetic energy. The displaced sea water, under the influence of gravity, attempts to regain its equilibrium and waves are formed. The waves can travel great distances from the source region; they travel across the open ocean at great speeds and build into giant waves in the shallow water near the coast. Earthquakes exceeding a magnitude of 7.5 can displace ocean floors to produce destructive tsunamis. Such earthquakes are called 'tsunamigenic earthquakes'.

4.2 Indian Ocean Tsunami, 2004

At 00:58:53 UTC on December 26th, 2004, an earthquake (Mw 9.0) hit Indonesia off the west coast of northern Sumatra. This was the second largest tsunamigenic earthquake globally, in recorded history. The total energy released by the earthquake was of the order of 20 x 1017 Joules or 475 megatons of the explosive trinitrotoluene, or the equivalent of 23,000 atom bombs, such as the one that destroyed Hiroshima. Earlier in 1833, the total energy released during the last series of explosions of Krakatoa volcano in Indonesia, which caused the biggest sound that humanity had ever heard, and generated the largest tsunami known till then, was 8.4 x 1017 Joules or 200 megatons. At 04:21:28 UTC the same day another earthquake of magnitude 7.2 occured 81 kilometers west of Pulo Kunji (Great Nicobar, India). These earthquakes set off giant tsunamis 3-10 meters high travelling 2000 kilometers across the Indian Ocean. The killer waves struck the coasts of several countries in south and southeast Asia, viz., India, Indonesia, Malaysia, Maldives, Sri Lanka and Thailand.

Maldives was devastated by the 2004 tsunami. Tidal waves ranging from 1.2 to 4.2 meters swept across all parts of the country. Out of the 198 inhabitat islands, thirteen islands were distroyed, 56 sustained major physical damage and 121 were impacted by moderate damage due to flooding. Over 2500 houses were destroyed and more than 3500 others were severely damaged. Vegetation and top-soil were washed away from agricultural land and fresh water sources were contaminated by sea water. Nearly a third of Maldives' population was severely affected, about 29,580 residents were displaced and around 12,000 were rendered homeless. Several fishermen lost their boats and women's home-based fish processing business were badly affected; nearly 15,000 farmers lost one year's harvest due to salt-water contamination of agricultural land.

Tourism, which accounts for more than 30 per cent of the economy of Maldives, suffered badly– 19 out of 87 tourist resorts were closed after the tsunami. Tourism, fisheries and agriculture, which together comprise more than half of GDP were among the hardest hit sectors. Severe damage was caused to habitats, vital infrastructure such as wharves, fish processing facilities, hospitals, schools, transportation, and communication facilities. The World Bank-ADB-UN System estimated the total damage at US$ 470 million, which equals 62 per cent of the country's GDP.

The tsunami has etched a deep fear in the minds of the Maldivians. Can such an event recur? Which are the vulnerable regions in case another tsunami sweeps across the country? The following sections addresses some of these queries.

4.3 Tsunami Modeling Approach

Data

Records of historical tsunami events that occurred in Indian Ocean region were collected from National Oceanic and Atmospheric Administration (NOAA) tsunami catalogue. Wave height data recorded at various locations in Maldives was obtained from the tsunami laboratory website[1]. The maximum tsunami amplitude for the 2004 event generated through numerical modeling by the Institute of Marine Science and Tsunami Warning Center, Alaska (Kowalik, 2005) has been used. Bathymetry data at two-minute grid resolution has been taken from the National Geophysical Data Center (NGDC) of NOAA. Tsunami affected areas in Maldives were visited and damage data were collected by a field survey of islands spread across the country.

To demarcate the zones around Maldives that can generate tsunamigenic earthquakes, referred to as 'source zone' hence forth, the seismotectonics of the region around Maldives was studied. A total of 85 historical tsunami events generated from the demarcated sources since 1816 have been compiled from the catalogue given by NGDC[2] and studied for the generation of maximum tsunami amplitude waves at source and their propagation. Three main tsunami source zones have been identified on the basis of seismotectonics and historical events: a) Sunda Arc including three segments of Sumatra Subduction Zones, b) Transform Fault Zone in Carlsburg Ridge and c) Makran Coast region. Figure 7 shows the three zones along with locations of historical tsunami events. Figure 8 shows the break-up of historical events by source and mechanism.

Sumatra Subduction Zone: Sumatra Subduction Zone is the maximum tsunami-producing zone. About 90 per cent - 75 out of 85- tsunamis were generated from this seismic zone. This zone is characterized by deep-ocean trenches (the Sunda Trench), shallow to deep earthquakes and mountain ranges containing active volcanoes. The tectonic plates meet at the Sunda Trench, a subduction zone that runs 5,500 kilometers from Myanmar towards the south past Sumatra and Java, and then east towards Australia. The Indian plate dives beneath the Asian plate along a fault that dips about 8-

[1] http://tsun.sscc.ru/tsulab/20041226wave_h.htm

[2] http://www.ngdc.noaa.gov/seg/hazard/tsu_db.shtml

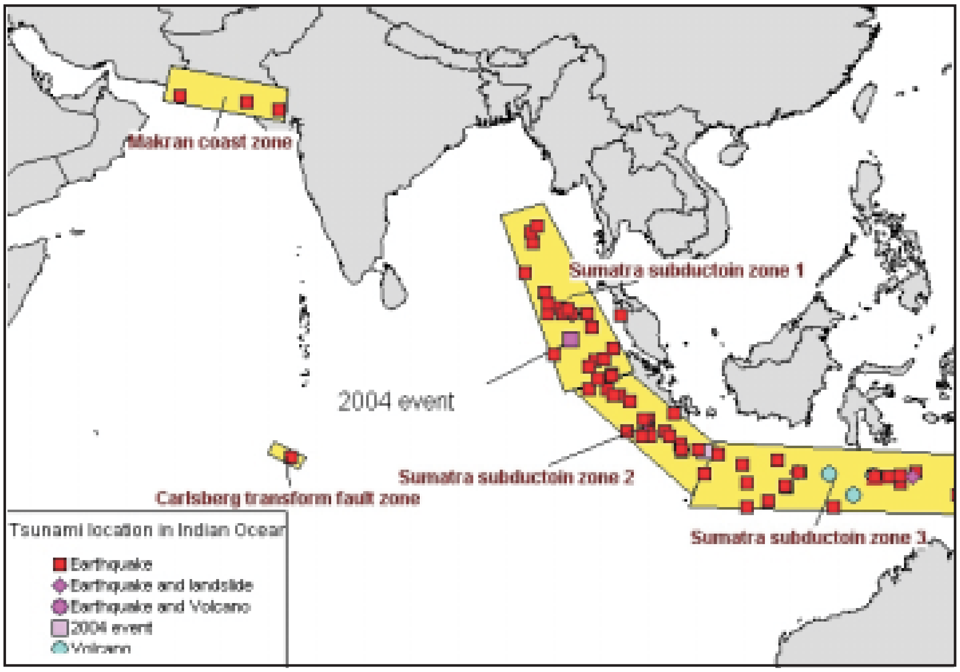


Figure 7: Locations of Historic Tsunami Events and Source Zones

20° into the earth. Because of the low dip angle, earthquakes can rupture along a very large surface area of the fault. In fact, the ten largest earthquakes since 1900 have occurred at this subduction zone. The zone accommodates a dip-slip motion in offshore (42±4 milimeters per year) while, the great Sumatran Fault, located on land accommodates right- lateral, strike-slip motion of 24±4 milimeters per year (Genrich et al., 2000).

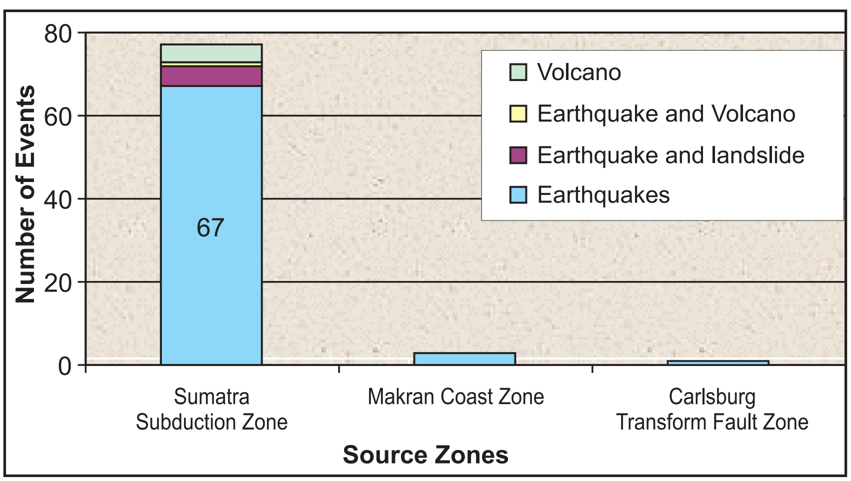


Figure 8: Historical Tsunami Events by Source and Mechanism

In general, tsunamis were generated from large tsunamigenic earthquakes; five were generated from sea floor volcanoes and landslides. A huge tsunami was generated from the Krakatoa volcanic eruption in 1833 while 25 tsunamis had generated very low insignificant waves. In addition to that, 30 stochastic events have also been considered in the analysis.

The Carlsberg Transform Fault Zone: Carlsberg Ridge is a mid-ocean ridge, located in the Arabian Sea between India and northern Africa. It marks the boundary between Indian and African plates. Mid-ocean ridges are divergent plate boundaries, where two tectonic plates move apart from each other and new oceanic crust is formed as magma rises up between the two diverging plates. The Carlsberg Ridge is a slow-spreading ridge, near the epicenter, the Indian plate is moving away from the African plate at the rate of 33 milimeters per year in a northeasterly direction. The ridge has a rough topography and a depth that varies from 1700-4400 meters. Active spreading ridges are offset by transform faults, where plates slide horizontally past each other,neither destroying nor forming crust. This gives a zigzag pattern the to plate boundary. Ridges are marked by a belt of shallow and low magnitude earthquakes caused by the release of tensional stress in the uplifted ridge; however, large earthquakes of the magnitude of 7.5 - 8 are associated with horizontal movement of plates along the transform faults. Earthquakes in the transform fault zone have strike slip components. Recently, an earthquake of M 7.8 on 20 November 1983, along a transform fault zone had generated local tsunami waves that damaged Diego Gracia.

Makran Coast Zone : The Makran Coast zone is another zone of subduction, where the oceanic lithosphere of the Arabian plate is subducting under the continental Eurasian plate. This zone forms the boundary between the Arabian and the Iranian micro-plates, where the former dives beneath the latter. The convergence rate between the Arabian and Eurasian Plates has been estimated to be 30-50 milimeters per year (Platt et al., 1998). Thrust zones run along the Kirthar, Sulaiman and Salt ranges and extend up to the Rann of Kutchh. These are characterized by four faults including the Allah Bund fault and the Pubb fault. Seismic activity along these faults had caused extensive damages in the past centuries along the deltaic areas. The destruction of Bhanbhor in the 13th century and damages to Shahbundar in 1896 were caused by seismic activity along these faults. Reports say that the great 1819 earthquake associated with Allah Bund fault had also generated tsunami waves. The worst case was in 1945 when an earthquake of magnitude 7.9 struck the Makran Coast and huge tidal waves as high as 12 meters were reported to affect the coast of Pakistan and India. Tsunami waves also reached Mumbai with a run up of 1.96 meters.

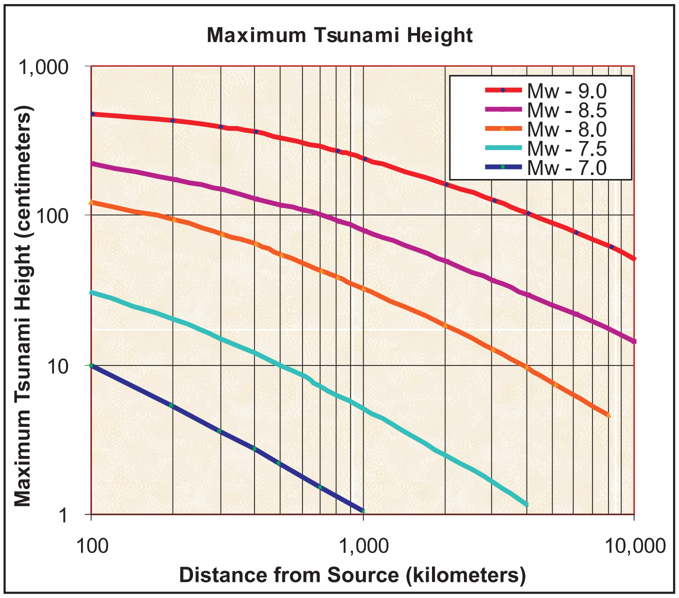


Figure 9: Re-computed Maximum Open Ocean Tsunami Height and its Attenuation

Tsunami Maximum Amplitude

For forecasting maximum tsunami wave heights in the open sea, detailed fault plane solutions of tsunamigenic earthquakes are generally used to determine the maximum amplitude of the tsunami waves generated at the source. However, in the absence of detailed fault plane solutions for historical events, three important earthquake parameters have been considered – moment magnitude, fault mechanism and depth.

Table 6: Computed Maximum and Minimum Run-ups of the Tsunami of December 26, 2004

Region	Maximum Wave Amplitude* (metres)	Shoaling Factor		Run Ups (metres)		Remarks
		Max	Min	Max	Min	
Sri Lanka (1400 kilometers from source)	1.32	6.22	-	8.21	-	8.12 metres reported
Maldives (2500 kilometres from source)	1.04	4.12	1.95	4.56	2.16	4.35metres (max) and 1.98metres (min) reported

* In open sea computed from Figure 1 for Mw=9.0

Seismotectonics of the seismic regions define the mechanism of the earthquakes. Large earthquakes generated in Sunda Subduction Zone and Makran Coast zone have a dip-slip component, while earthquakes associated with Carlsburg Transform Fault zone have a strike- slip component. Strike-slip earthquakes produce three to four times lesser tsunami waves as compared to dip-slip earthquakes of the same magnitude. Shallow events generate about three times more waves than deeper events at depths of 30 kilometers (Ward, 1999).

To determine maximum tsunami amplitude in the open sea, the basic modeled relationship of Steve N Ward (1999) as a function of moment magnitude and distance from source, with consideration of fault mechanism and dip of the fault has been used. Figure 9 gives the relationship of computed peak tsunami height attenuation in open sea (without shoaling factor) vs magnitude thrust fault dipping at 8-15^0 and shallow depth ~10 kilometers. This relationship is used to compute tsunami wave height of 2004 events at Sri Lanka and Maldives for validation (Table 6) and for all historical and stochastic events at Maldives.

Bathymetry around Maldives reflect largely to shoaling phenomena (amplifying tsunami waves in proximity to island or continent). It plays a two-way role in propagation of tsunami waves- loss due to ocean bed topography and amplification in proximity to island or continent. The shoaling factor can be computed using Green's $S_L=(h/h_s)^{1/4}$. In order to compute wave height, tsunami propagation path (ocean floor topography) is considered and adjusted with their values with respect to open uniform depth ones. With this, shoaling factor at Sri Lanka with uniform depth is 6.22 metres and the computed maximum run-up wave height is 8.21 metres (as compared to reported 8.12metres). It is observed that tsunamis from the east, as in the case of the 2004 event, loose their amplitude to a large extent when they go beyond Sri Lanka; this is due to the large variation in sea floor topography between Sri Lanka and Maldives. Considering the topography and local bathymetry around the individual Maldives' islands, the applied shoaling factors for different islands range from a maximum of 4.12 metres to a minimum of 1.12 metres (Table 6). Figure 10 shows the topographic variations in the path of the 2004 tsunami.

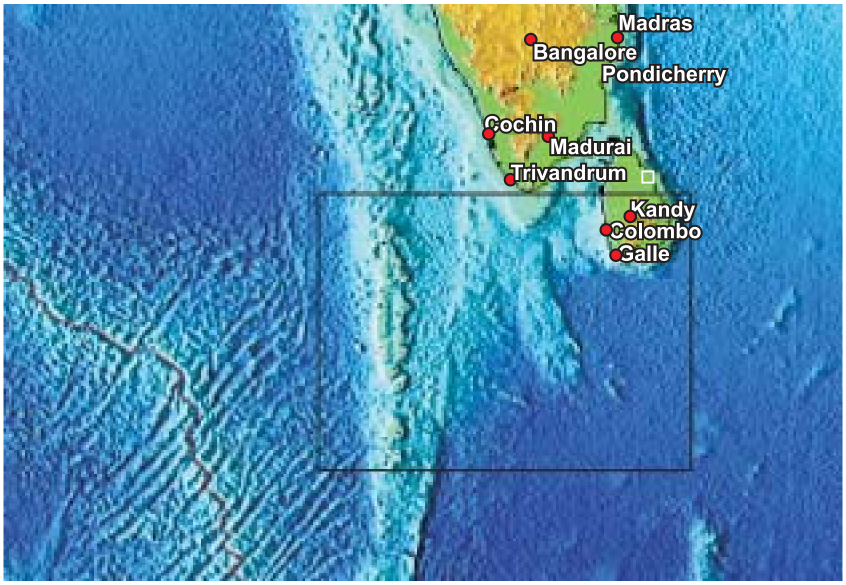


Figure 10: Ocean bed Topography depicting Large Variations in Ocean Depth between Sri Lanka and Maldives

Maximum amplitude in the Indian Ocean has been computed through numerical modeling at Alaska Tsunami Warning Center, by Kowalik et al (2005). The shoaling factor close to eastern coast of Sri Lanka is 6.22. Taking this value as reference the shoaling factors for the islands of Maldives have been computed considering the local topography and bathymetry around these islands. Thus the expected wave height computations for Maldives islands are based on island specific shoaling factors rather than the factor for Sri Lankan coast. The Tsunami disaster risk index assigned to individual islands are therefore more accurate. The values vary from a maximum of 4.12 to minimum of 1.12 (Table 6). Figure 11 illustrates the loss in maximum amplitude due to sea floor depth and enhancement in the proximity of islands.

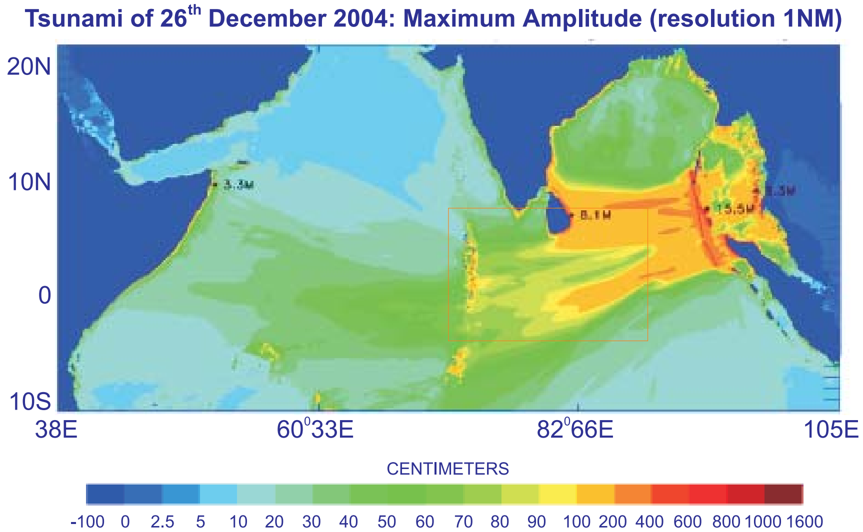


Figure 11: Maximum Computed Amplitude through Numerical Modeling at Alaska Tsunami Warning Center

Return Periods of Tsunami Wave Heights from Various Sources

Taking into account earthquake magnitude, fault mechanism and dip angle, maximum and minimum wave heights of tsunamis have been computed for all historical and stochastic events affecting Maldives. Table 8 provides the maximum and minimum computed wave heights and return periods for some of the historical as well as stochastic tsunamigenic events from various sources.

Figure 12 provides the relationship between return period and maximum wave height for each source as well as the combined sources. From a plotting of combined sources, the following inferences can be drawn. Any tsunami impacting Maldives with a two meter wave height has a return period of 50 years, four meter wave height has a return period of 100 years and so on[2]. The return period of the 2004 event is computed at 219 years.

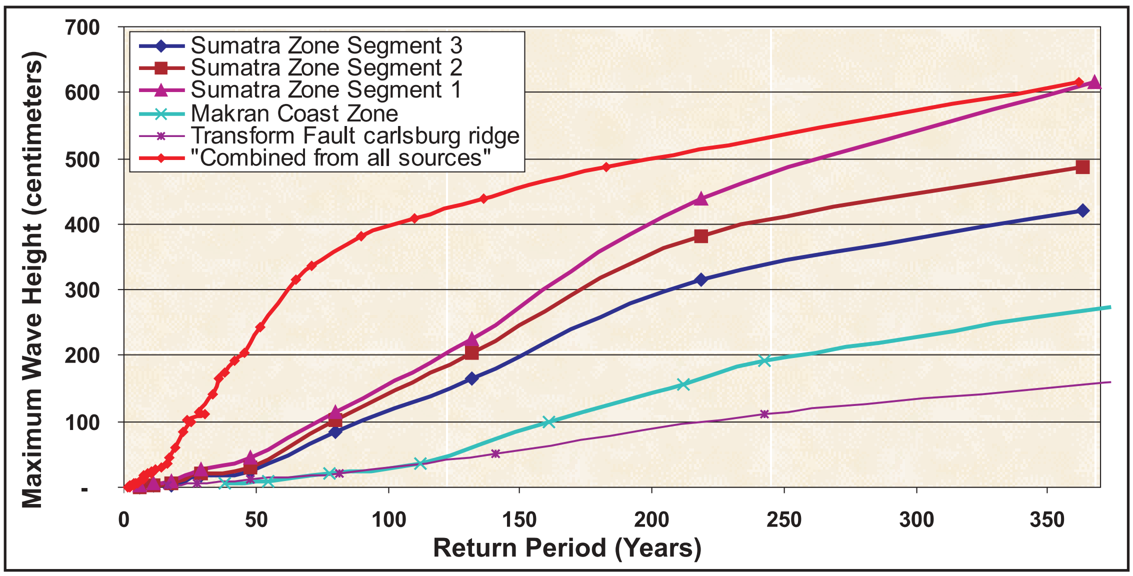


Figure 12: Return Periods of Maximum Tsunami Wave Heights from various Source Zones

4.4 Tsunami Hazard Zoning

Considering tsunami hazards from all three source zones, as well as the local shoaling factor reflected from bathometry contours drawn at 50 meters intervals, tsunami hazard zones have been created using five categories (Zone 1 to Zone5). Zone 5 has the highest risk from hazards. The group of islands lying along the eastern side of Maldives are most prone to tsunami waves (Zone 4-5), as 95 per cent of tsunamis that affected Maldives are generated from eastern source zone – the three segments of Sumatra Subduction Zone. Table 7 gives the probable maximum tsunami wave heights for various hazard zones. The geographic locations of certain groups of islands are such that they are protected from tsunami waves. These islands are classified under Zones 1-2. Local bathymetry around an individual island decides the local shoaling factor for that island. In general, due to the presence of large coral reefs around the islands, most of the islands are protected from the impact of waves.

[2] Statistically, these are expected events when averaged over a very long period (say, 1000 years). They do not mean that a 50 year or a 100 year return period event does not occur in the next one year.

Table 7: Probable Maximum Wave Height by Tsunami Hazard Zone	
Hazard Zone	**Range of Probable Maximum Wave Height (centimeters)**
1	less than 30
2	30-80
3	80-250
4	250-320
5	320-450

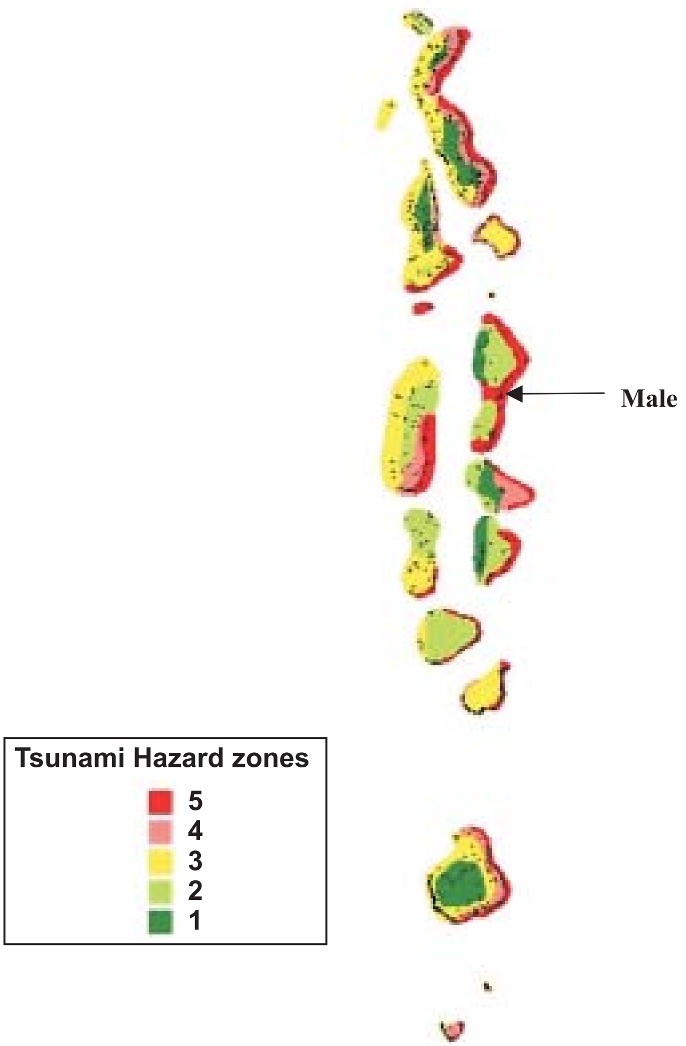


Figure 13: Tsunami Hazard Zones

Table 8: Computed Minimum and Maximum Wave Heights and their Return Periods from Major Historical and Stochastic Events

TID	Year	Runups_ Associated	Tsunami Max Runup (m)	Earthquake Magnitude MS	Type of event	Max wave height (cm)	Min wave height (cm)	Source_Zone	Return period of occurrence	Remarks
329				7	Stochastic	6	1	Makran Zone	38	
333				8	Stochastic	100	26	Makran Zone	161	
239	1945	6	15.24	8.3	Historical	189	94	Makran Zone		1.98m reported at Mumbai
335				8.5	Stochastic	191	103	Makran Zone	243	
320				7.25	Stochastic	2	1	Sumatra Zone 1	6	
321				7.5	Stochastic	6	3	Sumatra Zone 1	11	
323				8	Stochastic	26	16	Sumatra Zone 1	29	
324				8.25	Stochastic	45	22	Sumatra Zone 1	48	
193	1907	7	2.8	7.6	Historical	75	37	Sumatra Zone 1		
325				8.5	Stochastic	114	57	Sumatra Zone 1	80	
327				9	Stochastic	440	212	Sumatra Zone 1	219	
292	2004	117	35	9.0	Historical	434	216	Sumatra Zone 1		0.8 to 4.3m reported from Maldives
328				9.25	Stochastic	617	307	Sumatra Zone 1	368	
311				7.25	Stochastic	1	1	Sumatra Zone 2	6	
312				7.50	Stochastic	4	2	Sumatra Zone 2	11	
313				7.75	Stochastic	5	3	Sumatra Zone 2	18	
226	1931		31.4	7.5	Historical	5	3	Sumatra Zone 2		
314				8.00	Stochastic	22	11	Sumatra Zone 2	29	
315				8.25	Stochastic	31	16	Sumatra Zone 2	48	
195	1908	1	1.4	7.5	Historical	36	18	Sumatra Zone 2		
197	1909		1.4	7.7	Historical	36	18	Sumatra Zone 2		
316				8.50	Stochastic	102	51	Sumatra Zone 2	80	
318				9.00	Stochastic	381	189	Sumatra Zone 2	219	
319				9.25	Stochastic	485	242	Sumatra Zone 2	363	
221	1928	2	10	3.0	Volcano	-	-	Sumatra Zone 3		
119	1815	4	3.5		Volcano	-	-	Sumatra Zone 3		
204	1917		2	6.5	Historical	-	-	Sumatra Zone 3		
302				7.25	Stochastic	1	1	Sumatra Zone 3	6	
283	1995	1	4	6.9	EQ & LAND#	2	1	Sumatra Zone 3		
303				7.5	Stochastic	3	2	Sumatra Zone 3	11	
145	1857	2	3	7	Historical	4	2	Sumatra Zone 3		
146	1857	2	3	7	Historical	4	2	Sumatra Zone 3		
278	1994	15	13	7.2	Historical	4	2	Sumatra Zone 3		
304				7.75	Stochastic	4	2	Sumatra Zone 3	18	
261	1979	2	10	7	EQ & LAND#	5	3	Sumatra Zone 3		
305				8	Stochastic	17	9	Sumatra Zone 3	29	
274	1992	18	26.2	7.5	Historical	20	10	Sumatra Zone 3		
260	1977	9	15	8	Historical	22	11	Sumatra Zone 3		
306				8.25	Stochastic	25	13	Sumatra Zone 3	48	
307				8.5	Stochastic	84	42	Sumatra Zone 3	80	
309				9	Stochastic	315	157	Sumatra Zone 3	219	
310				9.25	Stochastic	422	198	Sumatra Zone 3	363	
337				7	Stochastic	2.8	1.2	Transform Fault Carlsbug Ridge	16	
269	1983		2	7.7	Historical	29	14	Transform Fault Carlsbug Ridge		

[#] Earthquake and Land Slides

5 STORM HAZARD

5.1 Introduction

Besides heavy rains and strong winds during monsoons, hazardous weather events which regularly affect Maldives are tropical storms or 'tropical cyclones', (hereafter called 'cyclones') and severe local storms (thunder storms/ thunder squalls). The people of Maldives popularly refer to such severe local storms as 'freak storms' (Maniku, 1990).

At times, tropical cyclones hitting Maldives are destructive due to associated strong winds that exceed a speed of 150 kilometres per hour, rainfall of above 30 to 40 centimeters in 24 hours and storm tides that often exceed four to five meters. Strong winds can damage vegetation, houses, communication systems, roads and bridges; heavy rainfall can cause serious flooding. Cyclonic winds sometimes can cause a sudden rise in sea-level along the coast, leading to a storm surge. The combined effect of surge and tide is knows as 'storm tide'. Storm tides can cause catastrophe in low-lying areas, flat coasts and islands such as Maldives.

Maldives is also affected by severe local storms- thunder storms/ thunder squalls. Hazards associated with thunder storms are strong winds, often exceeding a speed of 100 kilometres per hour, heavy rainfall, lightning and hail; they also give rise to tornadoes in some regions. In general, thunderstorms are more frequent in the equatorial region than elsewhere, and land areas are more frequently hit by thunderstorms as compared to open oceans. However, thunder storms close to the equator are less violent when compared with those in the tropical regions and beyond. Maldives being close to the equator, thunder storms are quite frequent but less violent here. Strong winds generated by severe local storms generate large wind-driven waves which are hazardous for Maldives.

5.2 Methodology for Wind and Surge Hazards

Cyclones are classified according to wind speeds in their circulation and these classifications vary from country to country. Cyclones being infrequent in the country, Maldives has no cyclone classification of its own (World Meteorological Organisation, 2003). The Indian classification, also applicable to low pressure systems in the north Indian Ocean region, are applied here (Table 9).

Before 1998, the term 'severe cyclonic storm' was used for the core of hurricane winds for all the low pressure systems with wind speed equal to or above 64 knots. The term 'super cyclone' was introduced in 1998. 'Cyclone' is a generic term to indicate all the four categories of disturbances under serial numbers 4-7 in Table 9, while 'cyclonic disturbance' represents low pressure systems belonging to all categories mentioned in the table.

Table 9: Classification of Low -pressure Systems in the North Indian Ocean by the India Meteorological Department	
Disturbances	**Associated Wind Speed in knots***
1. Low Pressure Area	Less than 17 knots (less than 31 kilometres per hour)
2. Depression	17 - 27 knots (31 - 49 kilometres per hour)
3. Deep Depression	28 - 33 knots (50 - 61 kilometres per hour)
4. Cyclonic Storm	34 - 47 knots (62 - 88 kilometres per hour)
5. Severe Cyclonic Storm	48 - 63 knots (89 - 117 kilometres per hour)
6. Very Severe Cyclonic Storm	64 - 119 knots (118 - 220 kilometres per hour)
7. Super Cyclonic Storm	120 knots and above (222 kilometres per hour and above)

*1 knot = 1.85 kilometres per hour

Tropical cyclone track data for the north Indian Ocean, i.e., the Bay of Bengal and the Arabian Sea for the period 1877 - 2004 have been compiled by the National Climatic Data Center (NCDC), USA. In the data, storm tracks between 1877-1980 have been obtained from the India Meteorological Department (IMD) and tracks of cyclones after 1980 have been obtained from the Joint Typhoon Warning Center (JTWC), USA.

The data of each cyclonic disturbance consists of six hourly (00, 06, 12 and 18 Greenwich Mean Time or GMT) track positions (latitude and longitude) and Maximum Sustained Surface Wind Speed (MSW) in the form of stages of intensity before 1980. The four stages of the intensity are 17-33 knots (depression), 34-47 knots (cyclonic storm), 48-63 knots (severe cyclonic storm) and above or equal to 64 knots (very severe cyclonic storm). If MSW was more than 64 knots in the life history of the cyclone, it was given as 64 knots in the track data before 1980.

Tropical cyclones originating in the north Indian Ocean region during 1877-1990 were identified from the tracks available in the *Storm Track Atlas* (IMD, 1996) by comparing the NCDC track data. The Storm Track Atlas contains tracks of all cyclonic disturbances of the north Indian Ocean in the form of charts. These tracks show positions at 03 and 12 GMT along with information on intensity in three stages, viz., depression, cyclonic storms and severe cyclonic storms in terms of symbols. The charts were therefore useful in deciding whether a system was a depression, a cyclone or a severe cyclone and on which date and time they acquired these intensities. Tracks after 1990 were compared with the reports of the Regional Specialised Meteorological Center (RSMC) -Tropical Cyclones, New Delhi, published by IMD to remove inconsistencies, if any. The reports contain maximum sustained surface wind speed and central pressure of cyclones formed in the north Indian Ocean basin.

From an alysis of data it can be seen that the frequency of cyclones crossing individual islands in Maldives in a year is small. However, the destructive area of a cyclone is quite large, about 100 to 150 kilometers from the center. Thus cyclones that pass through some distance, say 100 to 150 kilometers away from a location could be equally destructive for the location. Hence, cyclones entering within 500 kilometers scan radius around Male have been taken into consideration. Within this zone, cyclones have been captured for a period of 128 years (1877-2004). In the next step, wind speeds were assigned to each cyclone. From the six hourly position of a track, positions and surface wind speeds of the cyclone within the circle have been determined. For each cyclone, the highest wind speed out of these positions have been assigned as the intensity of a storm. The wind speed thus computed was used as the intensity information for further analysis.

Records of storm surge from Maldives are not available. In the absence of actual data, the methodology used for the estimation of surge hazard has basically been driven by scientific reasoning and known concepts of surge estimation.

For the estimation of surge for Maldives, the following factors have been considered:

- Landfalling cyclones (numbers)
- Intensity (highest wind speed/central pressure)
- Bearing of tracks
- Average speed of movement
- Radius of maximum wind
- Bathymetry

The bathymetry data of 2-minute grid resolution has been obtained from NGDC[1]. The landfalling cyclones used in the surge analysis are shown in Figure 14. Data on local storms from Maniku (1990) have been used to identify islands that were affected by these events. The data contains dates of events that have occurred during 1958 - 1988. It appears that the data is not complete.

5.3 Results and Discussion

Storm Climatology - Cyclones

The islands of Maldives are less prone to tropical cyclones. The northern islands of the country were affected by weak cyclones that formed in the southern part of the Bay of Bengal and the Arabian Sea. Figure 14 shows the tracks of cyclones affecting Maldives during the period 1877 - 2004. The number of cyclones directly crossing Maldives is small. Only 11 cyclones crossed the islands over the entire span of 128 years. Most of the cyclones crossed Maldives north of 6.0° N and none of them crossed south of 2.7° N during the period. All the cyclones that affected Maldives were formed during the months of October to January except one, which formed in April. Maldives has not been affected by cyclones after 1993. As cyclones affect an area within a radius of 200-300 kilometers, those coming within certain distance from a location have been included for determining their annual occurrence rates.

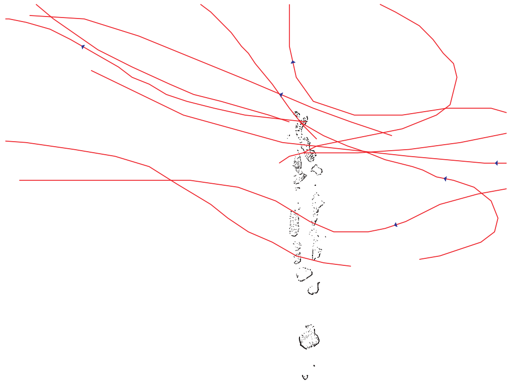


Figure 14: Tracks of Cyclones affecting Maldives, 1877-2004

[1] United States Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center, 2001. 2-minute Gridded Global Relief Data (ETOPO2). http://ngdc.noaa.gov/mgg/fliers/01mgg04.html

Storm Climatology- Severe Local Storms

Maldives is affected by severe local storms which are thunder storms/thunder squalls, locally known as 'freak storms'. Sometimes, storms accompanied with rainfall and high waves affect the southern parts of the islands during April and December, which is the interim period between the northeast and southwest monsoon seasons. From an analysis of local storm data it can be seen that these affect almost all the islands of Maldives. During 1958 to 1988, these events affected 92 islands. Data shows that 'freak storms' affected the islands throughout the year with peak seasons during May - July. Male was affected by seven such storms. The high number of storms reported for Male may be attributed to more observation and reports from locals as this island is the most populated one. It is seen from the data that local storms are reported as affecting islands from 0.2° N to 7.0° N. It appears that the data is not complete. Therefore, hazard zones have not been drawn for the local storms.

Return Periods of Cyclonic Wind Speeds in Maldives

There were 21 cyclonic disturbances within the 500 kilometers radius during 1877-2004, of which 15 were depressions with an average wind speed of about 28 knots. The highest wind speed due to cyclonic disturbances that affected the islands during that time was about 65 knots. Figure 15 shows the tracks of cyclonic disturbances that passed through the circle with 500 kilometers radius. These disturbances had their landfall sites on the eastern side of the islands and most them crossed perpendicular to the coast. Majority of these moved in a west-north-westerly direction.

Figure 15: Tracks of Cyclones passed within the Scan Radius of 500 kilometres

Using the wind speeds of 21 cyclonic disturbances, the probabilities and return periods of wind speeds have been calculated according to the method described by Chu and Wang (1998). Figure 16 shows the return periods for various categories of cyclones. The return period of a cyclonic storm with a wind speed of 34 knots will be about 23 years. For deep depressions with wind speeds 28-33 knots, the return period varies between 10 -20 years. From the return period analysis it has also been found that very severe cyclonic storm with surface winds having a speed of 65 knots are expected to recur once in 135 years in Maldives.

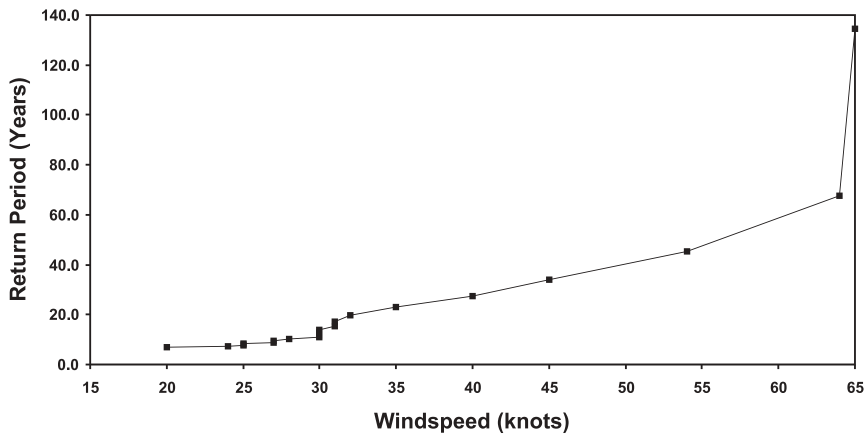


Figure 16: Return Period of Wind Speeds associated with Cyclones in Maldives

5.4 Cyclonic Wind Hazard Zoning

Exeedance Probability (EP) is the probability of exceeding specified loss thresholds. In risk analysis, the EP curve defines the probability of various levels of potential loss for a defined structure, or the assets at a risk of loss due to natural hazards.

For dividing Maldives into zones with varying scales of cyclone hazards, five regions have been created based on a qualitative judgement of the gradiant of the storm tracks from north to south. Figure 17 shows the regions used to compute the highest wind speed of each cyclone captured within the region. Majority of the cyclonic disturbances crossed the northern region. The frequency and wind speed decreases from northern region to southern region. Region 1 is not affected by any storm.

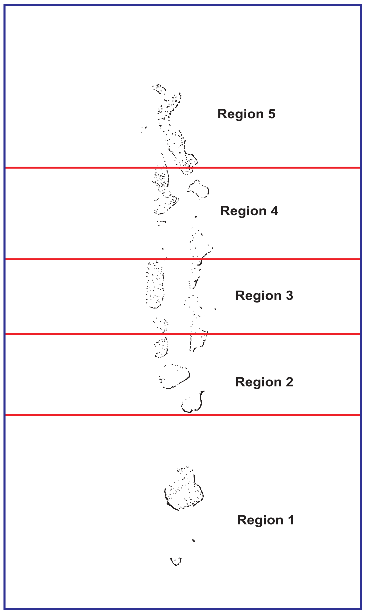


Figure 17: Regions to capture Cyclones passing through Maldives for Hazard Zoning

Exeedance Probability (EP) is the probability of exceeding specified loss thresholds. In risk analysis, the EP curve defines the probability of various levels of potential loss for a defined structure, or the assets at a risk of loss due to natural hazards.

The Exceedance Probability (EP) curve constructed from the empirical Cumulative Distribution Function (CDF) using the 21 historical events have been used to define regional hazard zones. The regional EPs have been computed by using the EP at the country level. The highest wind speed for each region has been identified from the distribution of wind speeds by regions. The country level EP has been divided into regional EPs based on the highest wind speed of a region. Gumbel's theoretical distribution has been used to fit the historical data. It has been assumed that events with wind speeds less than the highest wind speed in a region are other probable events in the distribution.

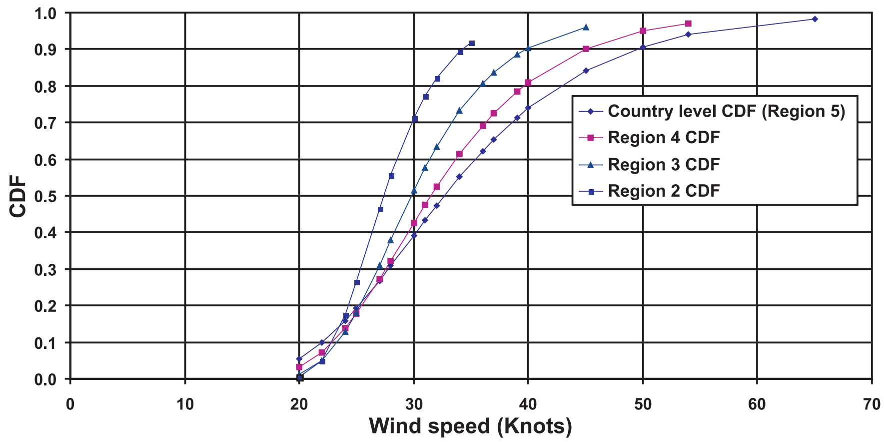


Figure 18: Wind speed Cumulative Distribution Functions by Region

Table 10: Cyclone Hazard Zone in Maldives and the Probable Maximum Wind Speed		
Hazard Zone	**Probable Maximum Wind Speed (knots)**	**Saffir-Simpson Scale**
1	0.0	0
2	55.9	0
3	69.6	1
4	84.2	2
5	96.8	3

For each hazard zone, probable maximum wind speed has been computed. In this study a 500 year return period has been considered for the probable maximum wind speed estimation. Table 10 shows the probable maximum wind speed for each zone computed from the regional EP curves.

The cyclone hazard zones of Maldives have been classified into five regions according to the 500 year return period wind speed of each region. Figure 19 shows the cyclonic wind hazard zones by islands– it shows that the northern most islands are in Zone 5 and the hazard risk decreases from north to south. The probable maximum wind speed in Table 10 is the 1-minute average wind speed so as to convert them into Saffir-Simpson hurricane scale. In Region 5 the probable maximum wind speed comes under Category 3 in the Saffir-Simpson hurricane scale.

Saffir Simpson Hurricane Scale				
Saffir-Simpson Category	**Maximum sustained wind speed**			**Minimum Surface pressure (in milibars)**
	mi/h	**m/s**	**kt**	
1	74-95	33-42	64-82	greater than 980
2	96-110	43-49	83-95	979-965
3	111-130	50-58	96-113	964-945
4	131-155	59-69	114-135	944-920
5	>155	70+	136+	less than 920

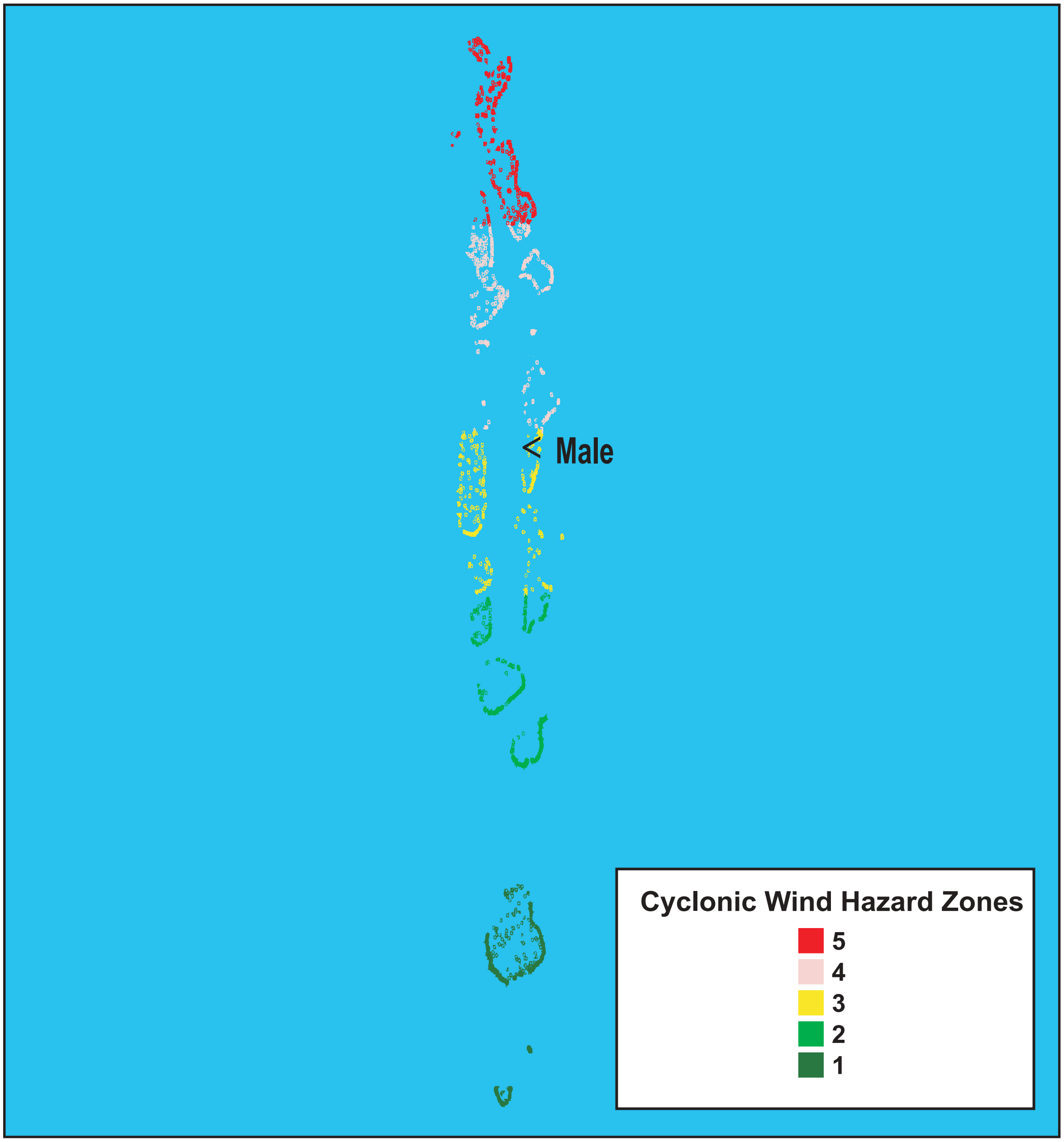


Figure 19: Cyclonic Wind Hazard Map

5.5 Storm Surge Hazard Zoning

In the previous section, it has been discussed that between 1877-2004 only 11 cyclones crossed Maldives, most of whom cross the northern part; cyclone frequency decreases from north to south. Thus, Maldives can be divided into three cyclone hazard zones – the northern zone with high cyclone hazard, central zone with moderate cyclone hazard and the southern zone with very little cyclone hazard.

Bathymetry around Maldives shows that the ocean slope close to east coast is steeper than the west coast. Figures 20 and 21 show the two and three-dimensional views of coastal bathymetry around Maldives. These give us a qualitative knowledge about the coastal bathymetry of the region. From these figures it can be concluded that the eastern islands of Maldives are vulnerable to higher surge hazard compared to the western islands.

Thus, the entire Maldives can further be sub-divided into two hazard zones namely, the eastern zone and the western zone. Considering all the above factors, the country can be divided into five broad storm surge hazard zones (Figure 22).

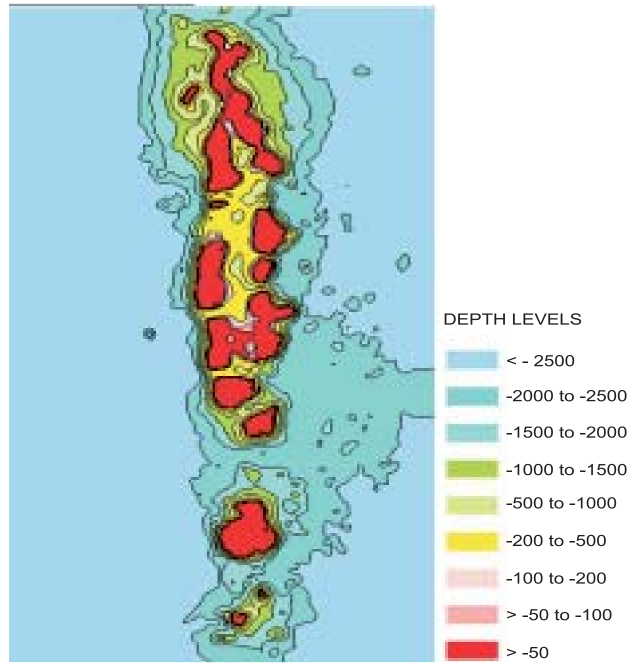


Figure 20: Bathymetry of Maldives (depth in meters)

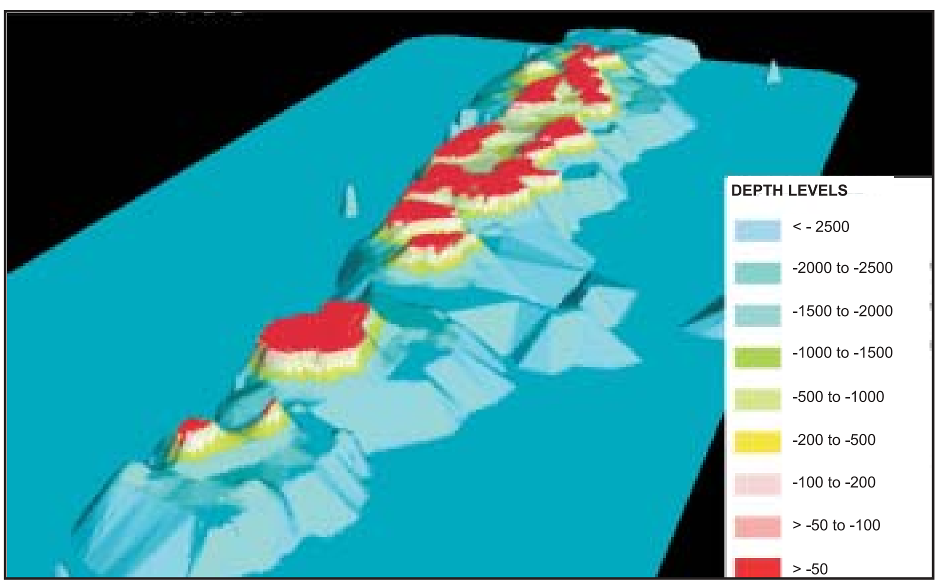


Figure 21: Three Dimensional View of Bathymetry of Maldives (depth in meters)

From historical data, probable maximum winds and probable maximum pressure drops have been computed for different return periods. Probable maximum pressure drop for the 500 year return period was computed to be 30 hecta Pascal, for a 100 year return period, it was 20 hecta Pascal. Considering analogous surge nomograms and basic storm parameters (historical), storm surge has been estimated for Maldives islands. The bathymetry information has been used for shoaling amplification. Height of average astronomical tide was added to that of storm surge to obtain the height of the storm tide. Relevant data has been presented in Table 11. In Table 12, zone-wise surge hazard have been provided. Data indicate that the probable maximum storm tide in northeastern islands of Maldives can be about 2.3 metres, which can inundate most of the northern islands.

Table 11: Probable Maximum Storm Tide

Return Period (Years)	Pressure drop hPa	Storm Surge Height (m)	Average Tide height (m)	Storm Tide (m)
100	20	0.84	0.98	1.82
500	30	1.32	0.98	2.30

Table 12: Probable Maximum Storm Tide by Hazard Zone

Hazard Zone	Pressure drop hPa	Storm Surge Height (m)	Average Tide height (m)	Storm Tide (m)
1	-	-	-	0.00
2	15	0.45	0.93	1.38
3	15	0.60	0.93	1.53
4	30	0.99	0.98	1.97
5	30	1.32	0.98	2.30

Figure 22: Storm Surge Hazard Zones with Cyclones Affected

5.6 Methodology for Rainfall Hazard

In this section, available rainfall data for Maldives has been analyzed. National Meteorological Center of Maldives provided daily rainfall data for three stations of Maldives – Hanimaadhoo, Hulhule (near Male) and Gan Islands representing northern, central and southern territories of the Republic. From daily rainfall data, monthly and yearly rainfall for all the stations for the entire period has been computed. Data periods for all the stations are not uniform. Rainfall data for Hulhule is available for 31 years (1975 to 2004) for Gan for 27 years (1978 to 2004) and for Hanimaadhoo for 13 years (1992 to 2004).

5.7 Results and Discussion

Average annual rainfall for three stations is shown in Table 13. The average for Maldives, 203.6 centimeters, has been calculated based on data from the three stations, Gan, Hulhule and Hanimaadhoo. Thus, Maldives can be placed amongst the heavy rainfall zones of the tropics. The data shows that rainfall decreases from south to north from about 230 centimeters in Gan to 182 centimeters in Hanimaadhoo. A comparison of the standard deviation figures show that the standard deviation is greatest at Gan and lowest at Hulhule.

Table 13: Average Annual Rainfall of three stations and Maldives

Station	Mean (milimetres)	Standard Deviation (milimetres)
Hanimaadhoo	1818.7	316.4
Hulhule	1991.5	291.2
Gan	2299.3	364.8
Maldives	2036.5	324.1

Table 14 provides monthly mean rainfall data which presents different pictures for different stations (Figure 23). While Hanimaadhoo shows mono-modal distribution in rainfall with a single peak in July, Hulhule and Gan islands show bi-modal characteristics with a primary peak in November (Hulhule) and October (Gan) and secondary peaks in May coinciding with onset of monsoon, and retreating summer monsoon/beginning of northeast monsoons respectively. Fluctuation of rainfall in Maldives mostly depends on general monsoon conditions and movements of the Inter Tropical Convergence Zone with embedded disturbances and frequency of 'freak storms'.

Table 14: Mean Monthly Rainfall of three stations

Station Name	January	February	March	April	May	June	July	August	September	October	November	December
Hanimaadhoo	49.3	30.4	12.8	88.3	225.0	231.6	289.0	220.5	174.6	206.0	199.5	91.5
Hulhule	101.8	43.7	62.7	133.9	220.4	169.5	174.4	178.6	227.2	217.9	234.7	226.8
Gan	208.8	100.8	129.6	164.7	224.0	163.8	175.4	188.5	211.1	278.5	193.7	260.7

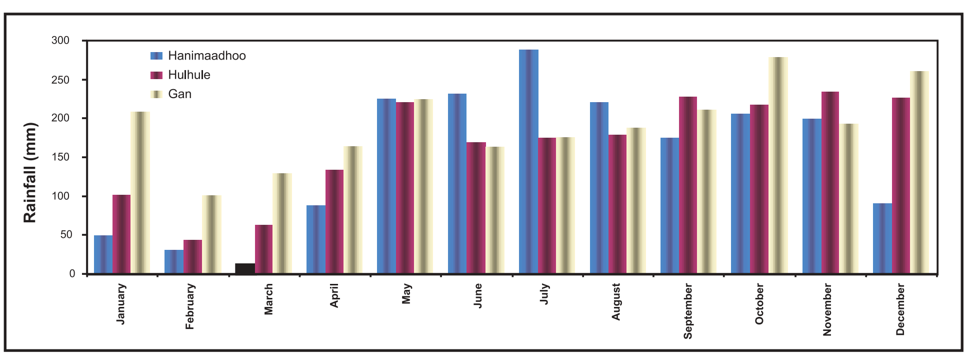


Figure 23: Mean Monthly Rainfall of three stations

In Table 15, annual rainfall and its percentage departure from long-period average values have been presented for three stations . Inter-annual variations of rainfall in Maldives are large. In Gan, it varies from +38.5 per cent in 1978 to –32.6 per cent in 1999; in Hulhule it was varies from +34.1 per cent in 1978 to –29.4 per cent in 1995 and in Hanimaadhoo, from +23.2 per cent in 1993 to –26 per cent in 2002. The implications of deviation of rainfall from average figure are discussed in greater details in the following sections.

Table 15: Rainfall with per cent Departure from Normal by Stations

	Hanimaadhoo		Hulhule		Gan	
Years	Rainfall (milimeters)	Per cent deviation	Rainfall (milimeters)	Per cent deviation	Rainfall (milimeters)	Per cent deviation
1975	-	-	2202.0	10.6	-	-
1976	-	-	1890.4	-5.1	-	-
1977	-	-	2322.5	16.6	-	-
1978	-	-	2670.4	34.1	3185.7	38.5
1979	-	-	2301.9	15.6	2251.3	-2.1
1980	-	-	1800.4	-9.6	1812.5	-21.2
1981	-	-	1642.9	-17.5	2012.9	-12.5
1982	-	-	2320.5	16.5	1980.8	-13.9
1983	-	-	1640.3	-17.6	2401.9	4.5
1984	-	-	1973.3	-0.9	2286.2	-0.6
1985	-	-	1988.7	-0.1	2307.3	0.3
1986	-	-	1795.9	-9.8	2194.8	-4.5
1987	-	-	2163.5	8.6	2375.4	3.3
1988	-	-	1772.4	-11.0	2251.6	-2.1
1989	-	-	1913.8	-3.9	2482.2	8.0
1990	-	-	1616.8	-18.8	2432.3	5.8
1991	-	-	1814.1	-8.9	2870.8	24.9
1992	1713.1	-5.8	1650.0	-17.1	2415.0	5.0
1993	2240.5	23.2	2402.8	20.7	2133.2	-7.2
1994	2099.3	15.4	2141.1	7.5	2837.4	23.4
1995	1583.2	-12.9	1407.0	-29.4	2402.5	4.5
1996	1441.3	-20.7	1950.5	-2.1	2031.6	-11.6
1997	1860.1	2.3	2056.3	3.3	2132.7	-7.2
1998	2086.7	14.7	2136.8	7.3	2384.0	3.7
1999	2001.8	10.1	2049.2	2.9	1548.8	-32.6
2000	1711.2	-5.9	1767.9	-11.2	2131.0	-7.3
2001	1662.5	-8.6	1727.5	-13.3	2066.7	-10.1
2002	1346.5	-26.0	2140.5	7.5	3056.5	32.9
2003	1687.2	-7.2	2473.4	24.2	1887.2	-17.9
2004	2209.3	21.5	2013.5	1.1	2209.5	-3.9

Floods and droughts

One of the parameters for finding out years in which an area has been affected by floods and droughts is the standard deviation of rainfall. If in a particular year, the per cent departure of rainfall from its long- term mean is greater than one standard deviation, it may be considered as a year of excess rainfall or flood. Conversely, if the difference is less than one standard deviation, it may be considered as a deficient or drought year.

From the rainfall data of Maldives, the standard deviation of rainfall has been worked out to be about 16 per cent. Following the above criterion, the number of excess, normal and deficient years for the above stations for the data period have been calculated (Table 16). The same has been represented through Figures 24, 25 and 26.

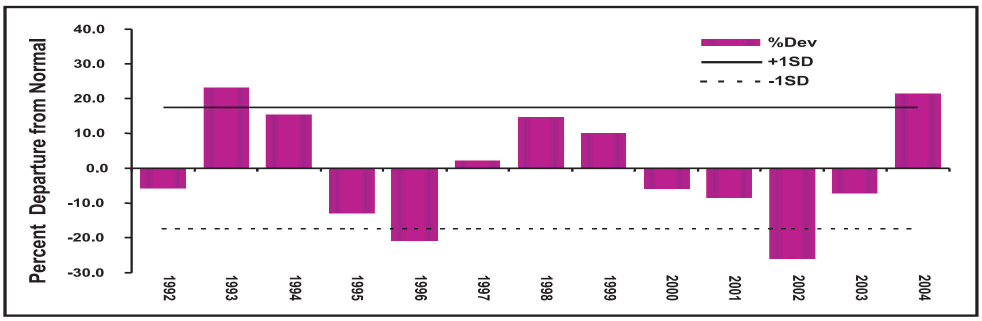


Figure 24: Excess, Normal and Deficient Rainfall Years of Hanimaadhoo

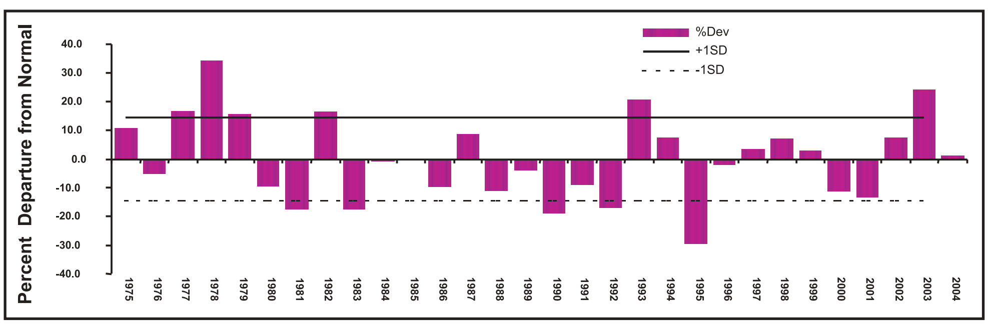


Figure 25: Excess, Normal and Deficient Rainfall Years of Hulhule

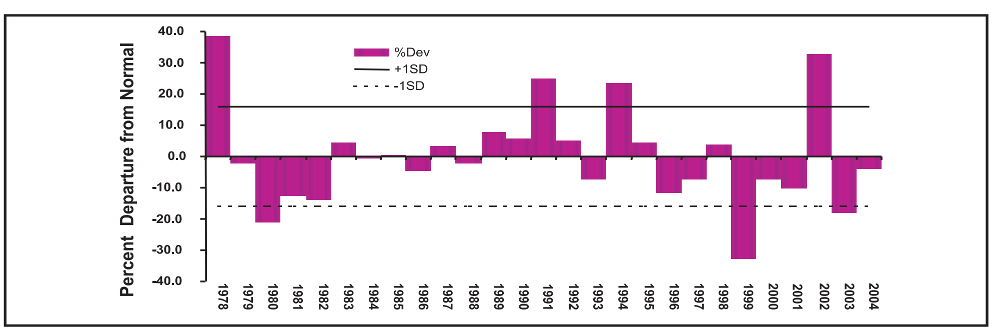


Figure 26: Excess, Normal and Deficient Rainfall Years of Gan

Table 16: Frequency of Excess and Deficient Rainfall Years (per cent departure in brackets)				
Station Name	**Number of drought years**	**Extreme drought years**	**Number of flood years**	**Extreme flood years**
Hanimaadhoo (1992 to 2004)	2	2002 (-26.0)	2	1993 (23.2)
Hulhule (1975 to 2004)	5	1995 (-29.4)	6	1978 (34.1)
Gan (1978 to 2004)	3	1999 (-32.6)	4	1978 (38.5)

The above results indicate that the southern parts of Maldives are less prone to drought and floods compared to northern part, though frequency of flood/drought years is small (about 15 to 16 per cent of the years). In India, monsoon rainfall is considered 'deficient' if it is less than –10 per cent of the seasonal long-period average value, and 'excess', if it is greater than 10 per cent. It has been observed that on many occasions, rainfall at Hulhule is negatively correlated to Indian monsoon rainfall. For example in 1981, 1983, 1988, 1990, 1992 and 1995 when Hulhule received below long period average rainfall, Indian monsoon rainfall during these years were either excess or towards the positive side of long period average. It has also been seen that when the northern parts of Maldives have received more rainfall, the southern parts on many occasions have received deficient rainfall though there is no one-to-one relationship.

5.8 Probable Maximum Precipitation (PMP)

Probable maximum precipitation for 24 hours is an important parameter for designing drainage systems in a scientific manner and for many other purposes of planning, such as design of dam safety. The design of drainage should consider PMP values, the catchment area of drains and characteristics of the catchment area to avoid local flooding. To calculate PMP in Maldives, a theoretical distribution has been fitted to the extreme daily rainfall for three stations using Gumbel's Type I extreme value distribution function. The function has been used to estimate the probabilities and the return period of rainfall for 50, 100, 200 and 500-years. The relevant data of PMP for different return periods for three stations in Maldives are given in Table 17 below.

Table 17: Probable Maximum Precipitation for various Return Periods				
Station	**Return Period**			
	50 years	100 years	200 years	500 years
Hanimaadhoo	141.5	151.8	162.1	175.6
Hulhule	187.4	203.6	219.8	241.1
Gan	218.1	238.1	258.1	284.4

6

EARTHQUAKE HAZARD

6.1 Introduction

The scope of the study encompasses a seismic risk assessment for all islands of Maldives. The study involves compilation of historical earthquake data, identification of seismic sources, generation of stochastic events and computation of site-specific ground motion. The standard procedure for computing hazards has been adopted from published research.

6.2 Methodology

Historical Earthquake Catalogue

The historical catalogue compiled by RMSI serves as the basis for the earthquake model. The major source for the RMSI catalogue is the one published by the International Society for Earthquake Technology (ISET), which covers a period dating back from history up to 1979. Data from 1979 up to 2004 has been augmented using other sources including USGS and NOAA. Verification has been done to ensure reliability and quality of the data. The catalogue thus obtained has been cleaned for all foreshocks, aftershocks and duplicate events. Figure 27 shows historical earthquakes around Maldives. Three major events of magnitude above 7.0 had struck the region

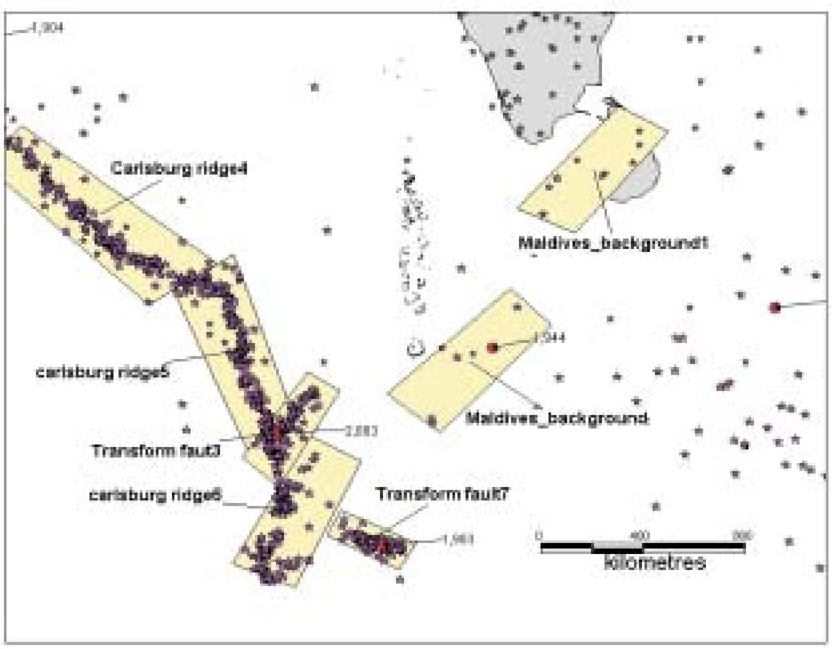


Figure 27: Earthquake Epicenters around Maldives

Seismic Sources and Stochastic Event Set

The seimotectonics of the region has been studied for the preparation of seismic zones. The study area lies in the vicinity of the Carlsburg Ridge. For defining the source zones and pattern of earthquake epicenters, fault systems described by Banghar and Sykes (1969) have been considered.

As discussed earlier in chapter 4, Carlsberg Ridge is a mid-ocean ridge, located in the Arabian Sea between India and northern Africa; it marks the boundary between the Indian and African plates. Near the epicenter the Indian plate is moving away from the African Plate in a northeasterly direction at the rate of 33 milimeters per year.

Seven seismic sources have been delineated, based on seismotectonic features and homogeneity of seismic activity. For each seismic source, it has been assumed that the past earthquake activity is a reliable parameter for predicting future activity. Three seismic zones are different segments of Carlsberg Ridge, two are of the transform fault associated with strike slip movement characterized by large earthquakes and two others are to cover background seismicity. These select sources along with the maximum magnitude in each source are shown in Figure 28.

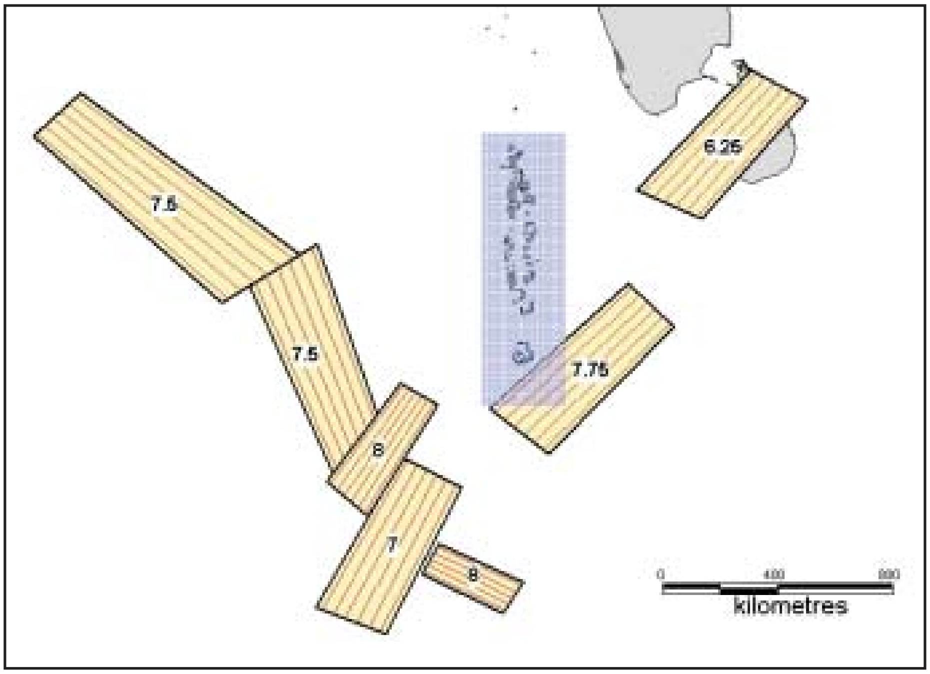


Figure 28: Modeled Fault line Sources within Each Area Seismic Source

Modeled Sources with Maximum Magnitudes

The area sources identified above are modeled by a series of line segment sources of uniform seismicity distributed evenly within the area source (Fig. 28). Each line represents a fault rupture. The total seismicity of the component line sources is equal to the seismicity of the entire area source. Orientation of the line source is done with respect to the main fault within the area source. The various stochastic events at 0.25-magnitude intervals to maximum-modeled magnitude are assigned to the sources chosen for the analysis on a one-on-one basis. A total of 1210 stochastic events have been generated from seven source zones.

Earthquake Rates of Occurrence

After the seismic sources were defined, it has been assumed that future activity will be limited to those seismic sources and follow a pattern similar to past activity. The Poisson model is the most common way of representing the seismic activity of an earthquake source. The basic assumption of the Poisson model is that the parameters governing earthquake occurrence is independent of time, magnitude and space. In other words, the model considers how events occur on an average and treats the probability of future earthquakes as independent of any previous earthquakes. The input required for this model is the average rate of occurrence of each magnitude of interest. This relationship, often described as the Gutenberg-Richter relationship, is described by the equation

$$\text{Log } N = \alpha + \beta M$$

where N is the cumulative number of events greater than magnitude M
α and β are constants based on regression analysis.

For each source, the constants α and β of the recurrence relationship are obtained by regression analysis of the historical record of earthquakes.

Ground Motion

Once the parameters of each earthquake in the stochastic set were defined, the intensity of ground shaking has been calculated for each earthquake at centroids of 10 kilometers grid created around Maldives. The intensity of an earthquake has been modeled from attenuation of the ground shaking intensity, which depends on its magnitude, depth and earthquake mechanism, and then, local modifications to the shaking that are caused by the prevailing soil conditions.

For a given earthquake, the attenuation, or rate of decay of peak ground acceleration (PGA) has been estimated from the epicenter to the site of interest. Based on some initial review of the literature it was decided to use the Boore, Fumal and Joyner (1997) attenuation equation for this study. Once the PGA was obtained, it has been converted to the Modified Mercalli Intensity (MMI) scale. The MMI is a measure of the local damage potential of the earthquake. Limited studies have been performed to determine the correlation between structural damage and ground motion in the region. The present study employs Trifunac – Brady's relationship to convert PGA to MMI.

6.3 Seismic Hazard Zoning

Using above ground motion, PGA and MMI values have been computed at each 10 kilometre grid point from all stochastic event sets. Each stochastic event is associated with event rate. At each grid point, an integrated amount of PGA has been computed as combined affect from all 1210 stochastic events, with in-house developed tools. With this approach, return- period PGA and MMI maps have been prepared for 100, 200 and 475 years. The 475 years return period map has been used to demarcate Maldives into five seismic hazard zones (Figure 29). Table 18 gives the range of PGA values for various hazard zones.

Table 18: Probable Maximum PGA values in each Hazard Zone	
Seismic Hazard Zones	**PGA values for 475 yrs return period**
1	Less than 0.04
2	0.04 to 0.05
3	0.05 to 0.07
4	0.07 to 0.18
5	0.18 to 0.32

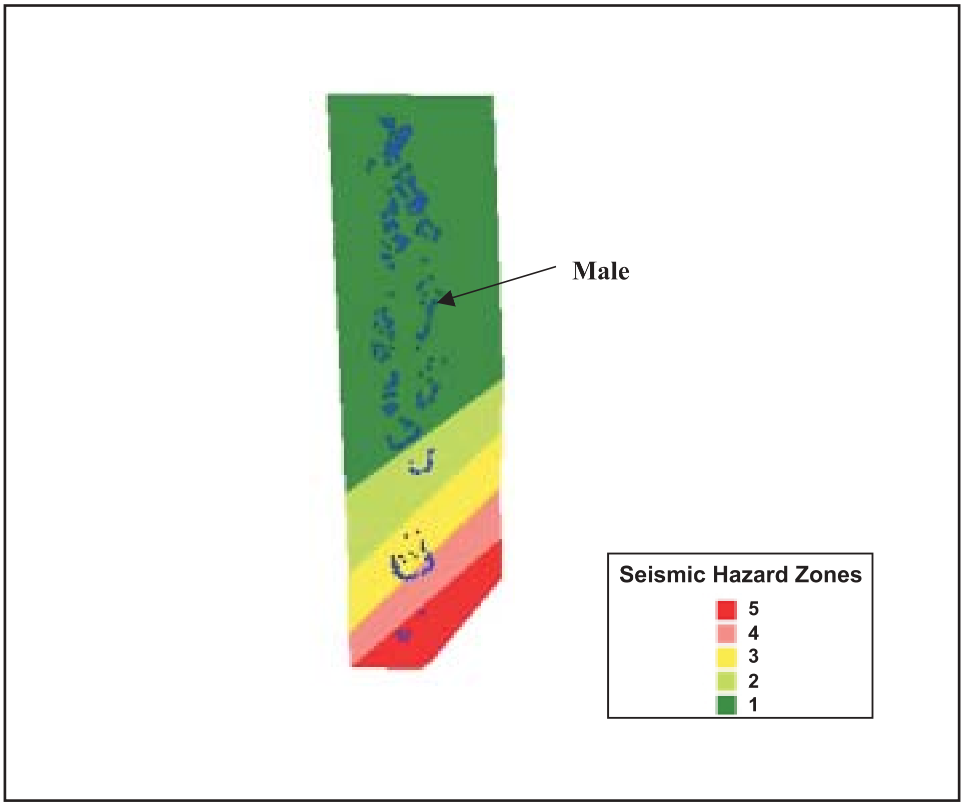


Figure 29: Maldives Seismic Hazard Zones

7

HAZARD OF SEA LEVEL RISE

7.1 The Hazard of Sea Level Rise

Sea level rise at a particular location is a combination of the global rise in sea levels and local trends. In its 2001 assessment of global warming, the Intergovernmental Panel on Climate Change (IPCC) projected that global mean sea level is expected to rise between nine and 88 centimetres by 2100, with a 'best estimate' of 50 centimetres (IPCC, 2001b). Increase in greenhouse gases in the atmosphere produce a positive radiative forcing of the climate system and a consequent warming of surface temperatures. A warmer world will have a higher sea-level as the temperature of land and lower atmosphere increase, heat is transferred to the oceans. When materials are heated they expand, a process known as thermal expansion- thus, heat that is transferred causes sea water to expand, which then results in a rise in sea level. In addition, glaciers and ice sheets may melt and add to the rise.

As a result of the rise in sea levels, a variety of impacts may be expected in Maldives. These include loss of land, flooding of low-lying coastal areas, displacement of population, loss of crop yield, salinization, impacts on coastal aquaculture, and erosion of sandy beaches. Impacts of sea level rise are also dependent upon the coastal geomorphology and physiographic characteristics of the coastline. In many places, a rise by 50 centimetres would imply entire beaches being washed away, together with a significant chunk of the coastline. Over 80 per cent of the land area in Maldives is hardly one metre above mean sea level. For people living on low-lying islands, a rise in sea levels by 50 centimetres could see significant portions of the islands being washed away by erosion or being inundated.

As most of the economic activities in Maldives are heavily dependent on the coastal ecosystem, sea-level rise will impact the social and economic development of the country. Residential areas, industry and vital infrastructure of the country lie close to the shoreline, within 0.8 to 2 metres of mean sea level. Even now some islands are seriously affected by loss not only of shoreline but also of houses, schools and other infrastructure, compelling the government to initiate urgent coastal protection measures.

7.2 Future Climate Change Scenarios

Sea level rise projections for Maldives are available by HadCM2 model for three periods and for IS92a (medium) and IS92e (high) emission scenarios. HadCM2 is a coupled atmosphere-ocean general circulation model developed at the Hadley Centre and described in detail by Johns et al (1997).

Table 19: Climate Change Scenarios									
	2025			2050			2100		
Model/Scenario	Temp (°C)	Rainfall (per cent)	Sea Level (cm)	Temp (°C)	Rainfall (per cent)	Sea Level (cm)	Temp (°C)	Rainfall (per cent)	Sea Level (cm)
CSIRO-Mk2 IS92a (med)	0.4	1.6	-	0.9	3	-	2	5.9	-
CSIRO-Mk2 IS92e (high)	0.6	2.5	-	1.4	3.6	-	2.8	8.1	-
HadCM2 IS92a (med)	0.7	12.1	9.3	1.4	23	19.9	2.6	44.3	48.9
HadCM2 IS92e (high)	1	18.9	19.7	1.7	38.6	39.7	3.8	77.4	94.1

The model projections (Table 7.1) show a good agreement on the future temperature scenarios. But for rainfall, the models show very distinct scenarios with relatively high rainfall in future according to the HadCM2 model. The models used here predict that by the end of this century, the sea level may rise between 49 centimeters to 95 centimeters (UNFCCC, 2001).

With the modeled sea level rise, it is estimated that by 2025 15 per cent of Male will be inundated (UNFCCC, 2001). The area of inundation will increase to 31 per cent by 2050. It is projected that the island will be completely inundated by 2100 in high emission scenario. Even the conservative projections of climate change estimate 15 per cent inundation of Male by 2025 and 50per cent by 2100.

There is no data on elevation of islands available to the study. The average elevation of islands is between 1 - 1.5 meters, thus, unless data on elevation with contour intervals of 50 centimeters or less are available, it is not possible to study the impact of sea level rise on islands. Due to this limitation, it was not possible to analyze inundation of other islands.

8 PHYSICAL VULNERABILITY AND RISK

8.1 Introduction

Physical vulnerability can be defined as a condition resulting from physical factors and processes that increase the susceptibility of a community to the impact of a hazard. In this study, only buildings and agricultural assets in Maldives have been considered due to limited data on other important assets such as fisheries. Assessment of physical vulnerability and risk has been carried out for earthquake, wind, storm surge and tsunami, and multiple hazards for all inhabited islands in Maldives. Resort islands are not within the scope of this study; they are supposed to be insured and hence do not receive financial support from the Government.

8.2 Risk to Buildings

Risk associated with exposed assets on various islands in Maldives is proportional to the level of hazard, the value of building assets and the vulnerability of the assets to various hazards, expressed in terms of hazard-specific risk indices assigned to each island. This has been done to allow comparison of risk among various islands. The risk indices have been computed with respect to three hazards i.e. earthquake, cyclone and tsunami. The three hazard-specific indices have also been integrated for a combined risk index for each island. In this study, risk has been quantified for each island based on the following factors:

1. Level of hazard
2. Number of buildings
3. Relative average size of buildings
4. Material of construction used in walls and roof
5. Age
6. Storey height

Number of Buildings

The total value of building assets in an island can be computed from the number of buildings, average size of the buildings and the average cost of buildings. In the absence of any data on cost variations across islands the combination of number of buildings and average size has been assumed to represent the value of building assets. According to the Housing Census of Maldives 2000, among all the islands, Male has the largest number of buildings while Berinmadhoo Island in Haa Alifu atoll has the lowest number of buildings. The distribution of buildings in various islands has been represented in Figure 30.

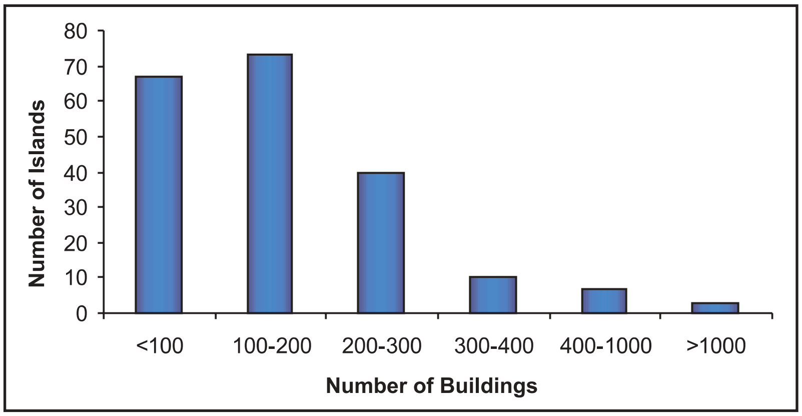


Figure 30: Distribution of Buildings in Islands of Maldives

Relative Size of Buildings

The average size of buildings vary from island to island. To account for this variation, a relative average floor area index has been computed for each island. The floor area in buildings has been first estimated using the data on distribution of buildings by size in terms of number of rooms. The floor area per building has then been computed for each island and compared with other islands to determine and index for relative average building size for each island. The relative building size index in Maldives varies from 0.9 to 9.7, for Male the index is 3.8.

Material of Construction

Vulnerability of buildings varies, based on their material of construction. While the degree of damage due to earthquake and hydro-meteorological hazards primarily depend upon the wall material, the degree of damage during a cyclone depends primarily on the roof material. The Housing Census 2000 provides the count of buildings in each of the inhabited islands by wall and roof materials. Wall materials in Maldives include plastered and non-plastered brick, concrete, wood, thatch, sheets etc. However the predominant material used in walls is plastered or non-plastered brick. The distribution of buildings by wall material in Maldives has been shown in Figure 31.

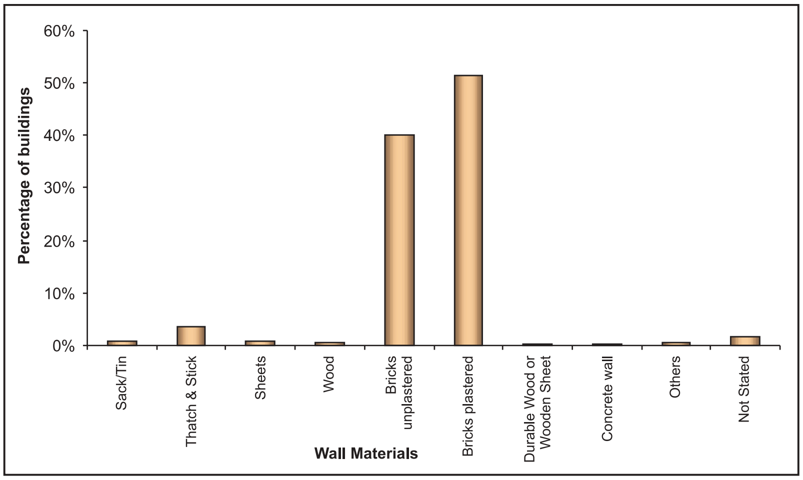


Figure 31: Distribution of Buildings in Maldives by Wall Material

Roof materials in Maldives include thatch, galvanized sheet, eite, concrete etc. However, the pre-dominant material used in roofs is galvanized sheets. Figure 32 provides the distribution of buildings in Maldives by roof materials. Thus the most common type of building in Maldives has brick walls and galvanized sheet as roof. While during an earthquake, such roofs will not collapse and kill people, during cyclones, these can fly-off and injure people outside. Thus, galvanized sheets, if well-tied will be safe during cyclones.

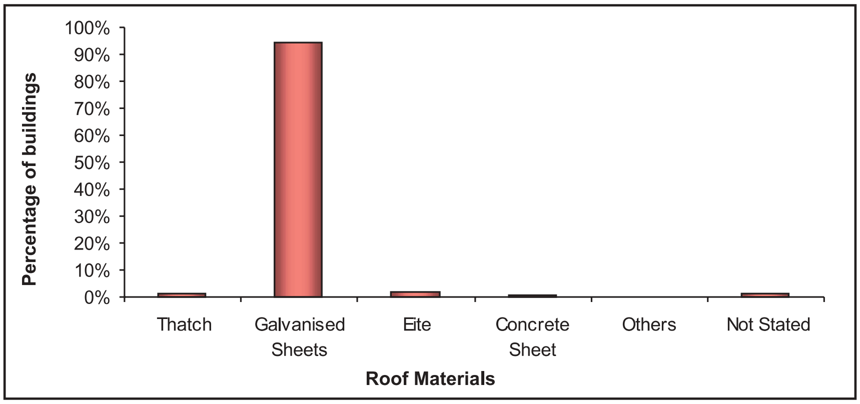


Figure 32: Distribution of Buildings in Maldives by Roof Material

To compare the vulnerability of building stocks in different islands, a relative vulnerability factor has been assigned to each material depending on its damage risk during various hazards. Using these factors a composite material index has been computed for each island. The material index varies from 0.61 to 1.7 for earthquake hazard and from 1.0 to 1.5 for hydro-meterological hazards for various islands in Maldives. For Male, the index is 1.0 for both hazards.

Age

Age of a building is known to have significant impact on the damage potential of buildings. Older buildings in general are known to behave adversely as compared to new buildings during natural hazards. The reasons are wear and tear, state of material strength, quality of construction, environmental effects, relatively inferior design etc. The Housing Census of Maldives 2000 provides information on age of buildings at the island level. The distribution of buildings by age categories in Maldives has been indicated in Figure 33. Based on relative 'damageability' of buildings pertaining to different age categories, an age index has been derived for the building stock of each island. The age index varies from 0.66 to 1.31 across islands in Maldives. For Male the index is 1.0.

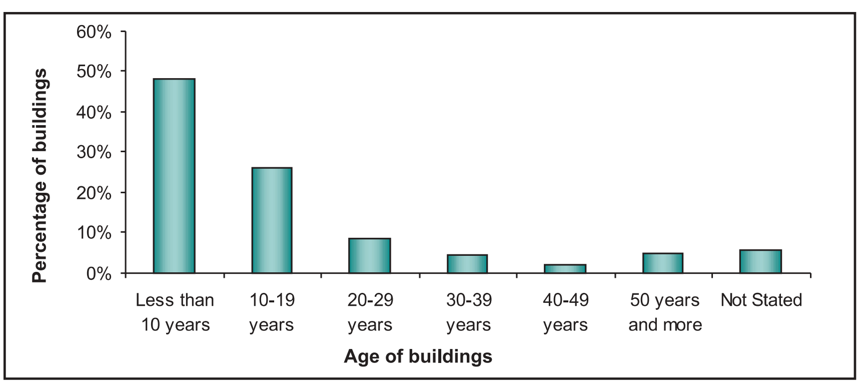


Figure 33: Distribution of Buildings in Maldives by Age

Storey Height

Heights of buildings have significant impact on their damage potential during natural hazards. Taller buildings are subjected to higher loads during earthquakes and windstorms. However, during storm surge and tsunamis, height is an advantage. Data on distribution of buildings by storey height available from the Housing Census of Maldives 2000 has been used to derive a relative height index for building stocks in various islands. Most buildings in Maldives are single-storeyed. Figure 34 shows the distribution of buildings by storeys in Maldives. The height index varies from 0.76 to 1.07 for various islands while for Male it is 1.0.

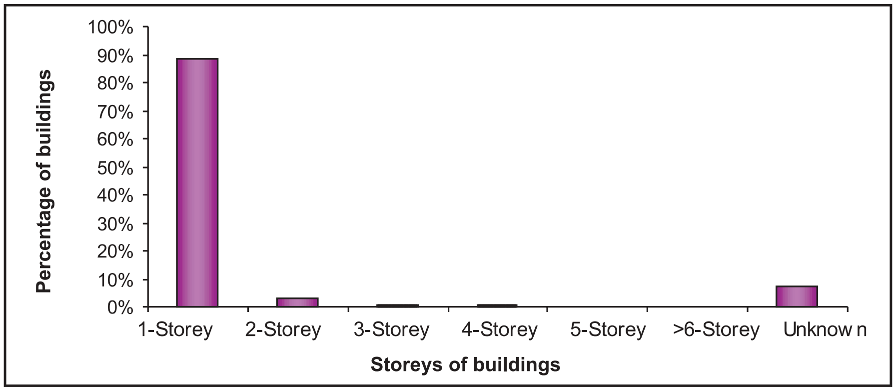


Figure 34: Distribution of Buildings in Maldives by Storeys

The methodology for computing risk indices comprises the following steps.

Step 1: Normalization of Exposure at Island Level

In the absence of any information on the cost, exposed value of buildings of a particular type is assumed to be proportional to the total number of buildings of the particular type. For each of the building parameters i.e. age, height (number of stories), wall material, roof material and size (number of rooms), the number of buildings have been normalized with respect to one reference category using relative weights. For example, normalization of exposure with respect to wall material has been done using weights stated in Table 20. The reference wall material being "bricks plastered", all other materials have been normalized against this material. The normalized exposure has been computed as the weighted average of all buildings in the island. The weights are based on expected relative vulnerability for the particular hazard.

Table 20: Weights for Wall Material

Wall Material	Tsunami	Earthquake
Bricks plastered	1.0	1.0
Thatch and Stick	1.8	0.2
Sheets	1.5	0.3
Wood	1.3	0.5
Bricks Unplastered	1.1	2.0
Durable Wood or Wooden Sheet	1.2	0.4
Concrete Wall	0.8	0.6
Sack/Tin	2.0	0.0
Others	1.0	1.0
Not Stated	1.0	1.0

For buildings with wall material 1 to i:

Normalized number of buildings (Wall material) = (∑ Number of buildings i x Weight i) / Total number of buildings.

A wall material index has been assigned to each island computed as

Wall Material Index = Normalized number of buildings (Wall material) / Total number of buildings

Similar indices have been derived for age, height (number of stories), wall and roof material and size (number of rooms). The weights assumed for each parameter is provided in Tables 21 through 8.5.

Table 21: Weights for Number of Storeys

Story Height	Tsunami	Earthquake and Windstorm
1	1.0	1.0
2	1.0	1.2
3	0.8	1.5
4	0.8	1.6
5	0.6	1.8
6+	0.5	2.0
Not stated	0.9	1.0

Table 22: Weights for Roof Material

Roof Material	Windstorm
Galvanized Sheets	1.0
Thatch	1.2
Eite	0.5
Concrete Sheet	0.3
Others	1.0
Not Stated	1.0

Table 23: Weights for Age of Buildings

Age	All Hazards
Less than 10 years	0.3
10-19 years	0.7
20-29 years	1.0
30-39 years	1.3
40-49 years	1.4
50 years and more	1.4
Not Stated	1.0

Table 24: Weights for Size of Buildings	
Number of rooms	**All Hazards**
1	0.2
2	0.5
3	0.7
4	0.8
5	1.0
6	1.1
7	1.2
8	1.1
9	1.2
9+	1.4
Not stated	0.8

Normalized exposure or number of buildings for an island is then computed as:

Normalized number of buildings (All parameters) = (Total number of buildings) x (Wall material index) x (Roof material index) x (Story Height index) x (Age index) x (Size index)

Step 2: Computation of Hazard specific Risk Index at Island Level

To assign hazard specific risk index, hazard damage factors correlating hazard index with damage/ loss have been defined for the typical buildings with walls that are bricks- plastered, roofs of galvanized sheets , one story height, 20-29 year old and having five rooms. The hazard- specific damage factors have been shown in Figure 35.

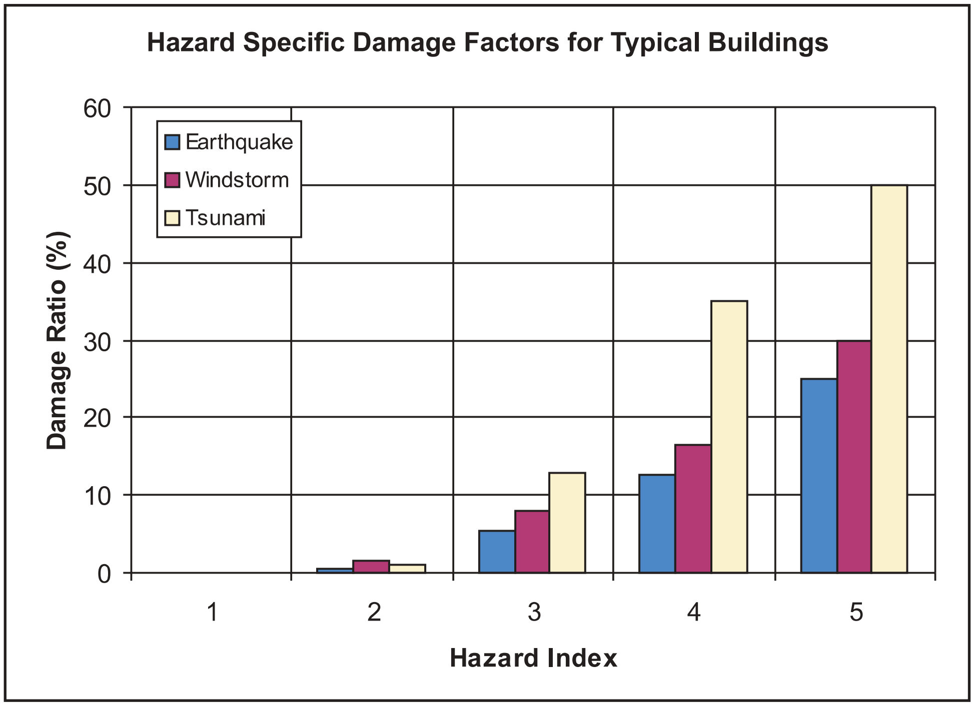


Figure 35: Hazard-specific Damage Factors for Typical Buildings

For an island assigned with a certain hazard index, damage factor has been picked up from the vulnerability function corresponding to the hazard index. The risk value is then computed as:

Risk Value = Normalized number of buildings x Damage factor corresponding to the hazard index.

8.3 Risk to Agriculture

Trees and crops are at risk of being washed away or damaged during windstorms and tsunamis. Data on income from crops marketed to Male in 2004 along with hazard index has been used to assign relative agricultural risk for various islands, including those that are uninhabited but are used for agriculture. The risk to agricultural assets is high for Thoddoo, Fuvahmulah, Hithadhoo, Isdhoo, Foakaidhoo and Hulhudhoo islands. The major crops grown in these islands include banana, watermelon, cucumber, pepper, coconut, etc.

In the absence of any detailed loss information for various hazards, risk has been assumed to be proportional to the level of hazard and value of annual agricultural produce for various islands in Maldives. To compute risk values, hazard- specific damage factors varying by hazard levels have been combined with the value of annual agricultural produce. Distribution of agricultural risk across various islands has been shown in Figure 36.

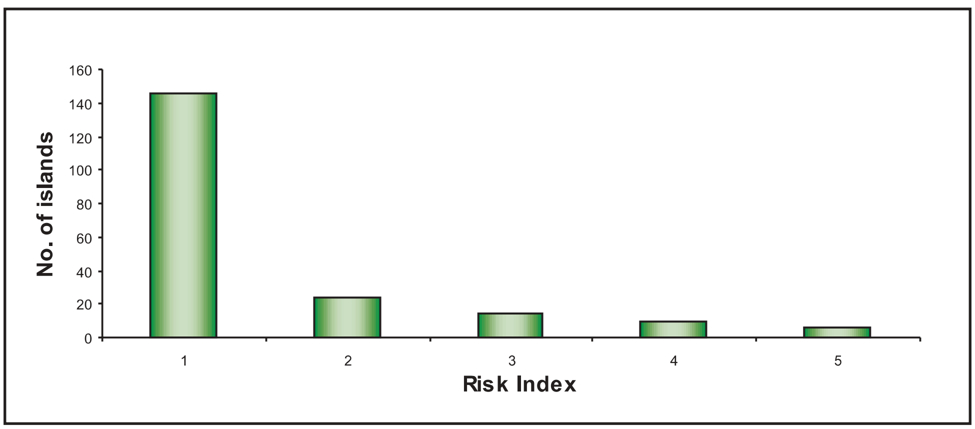


Figure 36: Distribution of Risk to Agriculture across Islands in Maldives

Hazard- specific risk values associated with building assets and agricultural assets have been combined for all islands to derive the combined risk value.

8.4 Physical Risk Index by Hazard

Island- wise risk index has been computed for earthquake, storm and tsunami hazards for each island by integrating the hazard and vulnerability indices. The hazard- specific risk values for all the islands in Maldives have been put in an ascending order and the values have been split into five segments, each representing a Risk Index i.e. 1, 2, 3, 4 and 5.

Earthquake Risk Index

The islands having high risk or loss potential with respect to earthquakes include Foammulah, Hulhudhoo and Maradhoo. Male, despite having a large exposure (stock of buildings) has a low loss potential due to very low earthquake hazard (Zone 1). Distribution of earthquake risk across various islands has been shown in Figure 37. The top 20 islands facing the highest risk due to earthquakes have been listed in Table 25.

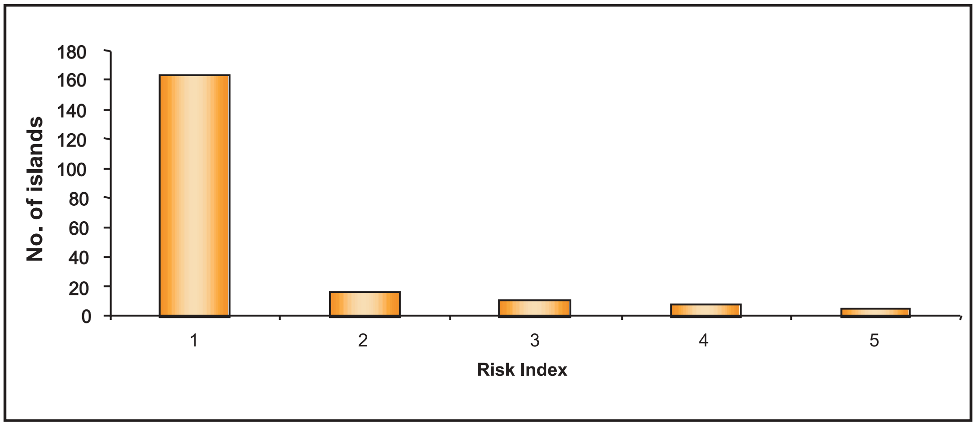


Figure 37: Distribution of Earthquake Risk to Physical Assets across Islands in Maldives

Table 25: Top 20 Islands with Earthquake Risk

Sl. No.	Island	Atoll	Population (2000)	Earthquake Hazard	Earthquake Risk Index
1	Foammulah	Gnaviyani	7,528	5	5
2	Hulhudhoo	Seenu	1,439	5	5
3	Maradhoo	Seenu	2,066	5	5
4	Meedhoo	Seenu	1,681	5	5
5	Maradhoo-Feydhoo	Seenu	1,023	5	5
6	Gadhdhoo	Gaafu Dhaalu	1,701	4	4
7	Feydhoo	Seenu	2,829	5	4
8	Hithadhoo	Seenu	9,461	5	4
9	Gemanafushi	Gaafu Alifu	899	4	4
10	Vilingili	Gaafu Alifu	2,261	3	4
11	Faress	Gaafu Dhaalu	450	4	4
12	Maathoda	Gaafu Dhaalu	485	4	4
13	Kaduhulhudhoo	Gaafu Alifu	375	4	4
14	Madaveli	Gaafu Dhaalu	939	3	3
15	Dhaandhoo	Gaafu Alifu	1,150	3	3
16	Kolamaafushi	Gaafu Alifu	1,139	3	3
17	Fiyoari	Gaafu Dhaalu	847	3	3
18	Rathafandhoo	Gaafu Dhaalu	610	3	3
19	Nilandhoo	Gaafu Alifu	432	3	3
20	Vaadhoo	Gaafu Dhaalu	733	4	3

Storm Risk Index

The islands having high risk or loss potential with respect to wind storms include Male (Kaafu), Dhidhdhoo (Haa Alifu) and Kuhuduffushi (Haa Dhaalu). Male has the highest storm risk with respect to physical assets. Distribution of wind and storm serge risk across various islands has been shown in Figure 38. The top 20 islands facing the highest risk due to windstorms have been listed in Table 26.

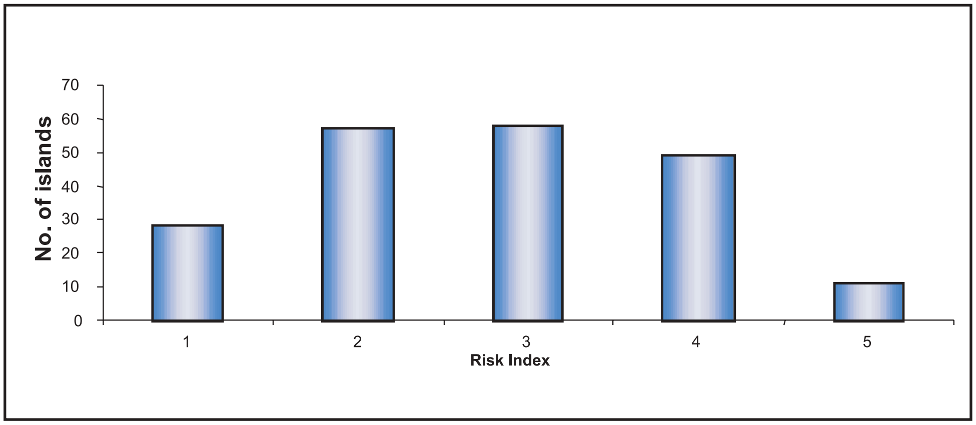


Figure 38: Distribution of Wind and Storm Surge Risk to Physical Assets across Islands

Table 26: Top 20 islands with Windstorm Risk

Sl. No.	Island	Atoll	Population (2000)	Storm Hazard	Storm Risk Index
1	Male	Kaafu	74,069	3	5
2	Kulhuduffushi	Haa Dhaalu	6,581	5	5
3	Dhidhdhoo	Haa Alifu	2,766	5	5
4	Huvarafushi	Haa Alifu	2,221	5	5
5	Alifushi	Raa	1,737	5	5
6	Kelaa	Haa Alifu	1,196	5	5
7	Nolhivaramu	Haa Dhaalu	1,556	5	5
8	Thoddoo	Alifu Alifu	1,071	3	5
9	Holhudhoo	Noonu	1,562	5	5
10	Komandhoo	Shaviyani	1,525	5	5
11	Ihavandhoo	Haa Alifu	2,062	5	5
12	Vaikaradhoo	Haa Dhaalu	1,210	5	4
13	Maakadoodhoo	Shaviyani	1,606	5	4
14	Foakaidhoo	Shaviyani	1,061	5	4
15	Baarah	Haa Alifu	1,270	5	4
16	Manadhoo	Noonu	1,239	5	4
17	Hulhudhuffaaru	Raa	939	5	4
18	Hanimaadhoo	Haa Dhaalu	1,009	5	4
19	Funadhoo	Shaviyani	799	5	4
20	Kedhikolhudhoo	Noonu	1,114	5	4

Tsunami Risk Index

The islands having high risk or loss potential with respect to tsunamis include Male (Kaafu), Foammulah (Gnavyani) and Kuhuduffushi (Haa Dhaalu). Male has the highest level of storm risk with respect to physical assets. Distribution of tsunami risk across various islands has been shown in Figure 39. The top 20 islands facing the highest risk due to tsunamis are listed in Table 27.

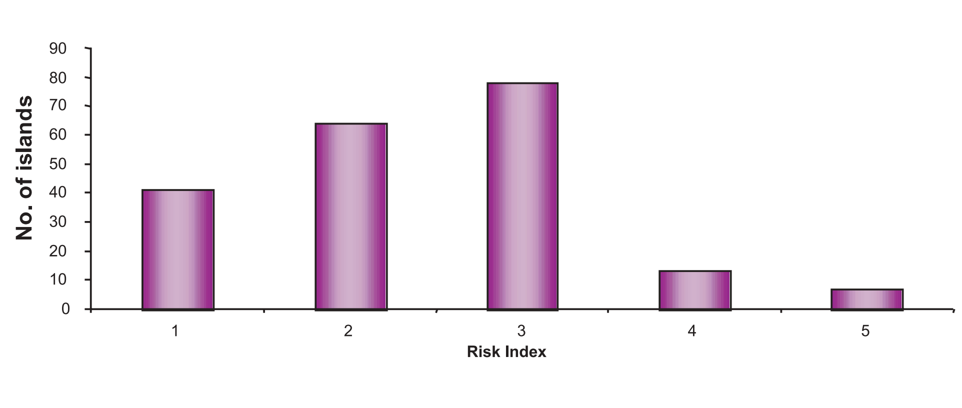


Figure 39: Distribution of Tsunami Risk to Physical Assets across Islands

Table 27: Top 20 Islands with Tsunami Risk

Sl. No.	Island	Atoll	Population (2000)	Tsunami Hazard	Tsunami Risk Index
1	Male	Kaafu	74,069	5	5
2	Foammulah	Gnaviyani	7,528	5	5
3	Kulhuduffushi	Haa Dhaalu	6,581	5	5
4	Dhidhdhoo	Alifu Dhaalu	113	5	5
5	Hulhudhoo	Seenu	1,439	5	5
6	Gadhdhoo	Gaafu Dhaalu	1,701	5	5
7	Eydhafushi	Baa	2,401	5	5
8	Kalhaidhoo	Laamu	433	5	5
9	Vilingili	Gaafu Alifu	2,261	5	4
10	Naifaru	Lhaviyani	3,707	4	5
11	Kelaa	Haa Alifu	1,196	5	4
12	Nolhivaramu	Haa Dhaalu	1,556	5	4
13	Dhidhdhoo	Haa Alifu	2,766	4	4
14	Gan	Laamu	2,244	5	4
15	Thoddoo	Alifu Alifu	1,071	3	4
16	Kasshidhoo	Kaafu	1,572	5	4
17	Fonadhoo	Laamu	1,740	5	4
18	Hinnavaru	Lhaviyani	3,212	4	4
19	Thulhaadhoo	Baa	1,941	5	4
20	Thimarafushi	Thaa	1,537	5	4

Risk Index for Multiple Hazards

The risk to physical assets from the three different hazards have been combined together by summing up the hazard- specific risk values representing loss potential for each individual hazard. A multiple hazard risk index has been computed for each island by putting combined risk values in ascending order and splitting the values into five categories, representing a risk index.

The islands Male (Kaafu), Foammulah (Gnavyani) and Kuhuduffushi (Haa Dhaalu) have a high loss potential when all the three hazards are considered. Male, with the large exposure (stock of buildings) has the highest loss potential from multiple hazards. Distribution of multiple hazard risk across various islands has been shown in Figure 40. The top 20 islands facing the highest risk due to multiple hazards have been listed in Table 28 and shown in Figure 41.

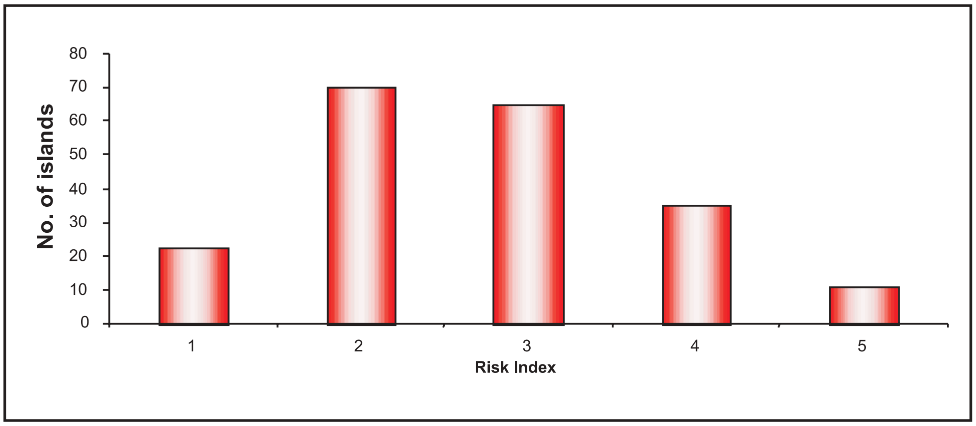


Figure 40: Distribution of Multiple Hazard Risk to Physical Assets across Islands

Table 28: Top 20 Islands with Multi-hazard Physical Vulnerability Risk

Sl. No.	Island	Atoll	Population(2000)	Multi- Hazard Risk Index
1	Male	Kaafu	74,069	5
2	Foammulah	Gnaviyani	7,528	5
3	Kulhudhuffushi	Haa Dhaalu	6,581	5
4	Hulhudhoo	Seenu	1,439	5
5	Dhidhdhoo	Haa Alifu	2,766	5
6	Dhidhdhoo	Alifu Dhaalu	113	5
7	Kelaa	Haa Alifu	1,196	5
8	Nolhivaramu	Haa Dhaalu	1,556	5
9	Gadhdhoo	Gaafu Dhaalu	1,701	5
10	Naifaru	Lhaviyani	3,707	5
11	Thoddoo	Alifu Alifu	1,071	5
12	Eydhafushi	Baa	2,401	5
13	Kalhaidhoo	Laamu	433	5
14	Vilingili	Gaafu Alifu	2,261	4
15	Maakadoodhoo	Shaviyani	1,606	4
16	Hinnavaru	Lhaviyani	3,212	4
17	Baarah	Haa Alifu	1,270	4
18	Meedhoo	Seenu	1,681	4
19	Kasshidhoo	Kaafu	1,572	4
20	Velidhoo	Noonu	1,866	4

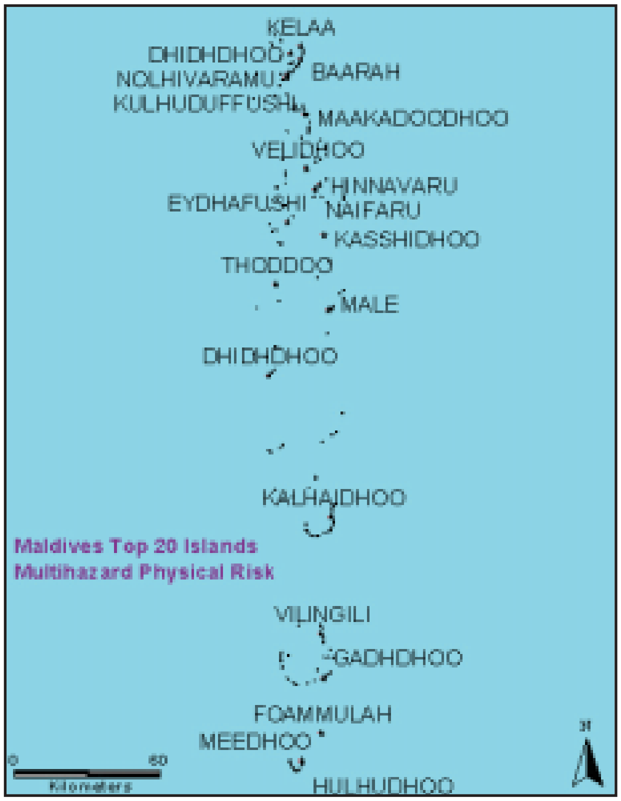


Figure 41: Top 20 Islands with Multi-hazard Physical Vulnerability Risk

9

SOCIAL VULNERABILITY AND RISK

9.1 Introduction

Social Vulnerability is defined as a condition resulting from social factors or processes, which increases the susceptibility of a community to the impact of a hazard. Often the social factors in question are directly linked to physical or economic factors, and may need to take these into consideration as secondary factors or indicators. Social vulnerability in Maldives is a result of the small size of population and its exposure, due to dispersion across small islands. The present study assesses social vulnerability in Maldives based on a consideration of a wide range of indicators for various hazards across different inhabited islands.

9.2 Review of Social Vulnerability Studies and Models

a. UNDP Vulnerability and Poverty Assessment of Maldives

The first Vulnerability and Poverty Assessment survey (VPA) was conducted in 1997/98 to collect a wide range of data to measure the poverty, deprivation and vulnerability arising from geographical, social and economic conditions in Maldives. The survey was the most comprehensive investigation in terms of its geographical coverage and statistical data (UNDP, 1988). Major findings and results of the survey were presented in a report that provided amongst others, a composite index of human vulnerability at the national, atoll and island levels.

Results of VPA-97 provided important information that help the Government formulate development strategies over the past years. The Ministry of Planning and National Development decided to conduct a follow up survey in 2004 with technical assistance of UNDP and the World Bank. The main objective was to produce a wide range of statistics on various aspects of poverty and vulnerability of households. The survey results allowed measuring the changes that have occurred in individual islands, in atolls and in the country since the last survey in 1997.

The VPA questionnaire comprised ten distinct forms designed for household level survey, island-level survey and committee-level survey for all islands. Being the largest survey in terms of its geographical coverage, it has enabled to produce a new frame with the recent number of households, labour force statistics, household income and expenditure and other information thereby helping update the current national database.

b. Community Vulnerability Assessment Methodology, NOAA

To assist the community leaders in their hazard mitigation planning recommendations, the US National Oceanic and Atmospheric Administration's Coastal Services Centre uses the Community Vulnerability

Assessment Methodology (Cannon et al., 2004). The results of the analysis are used to support various disaster preparedness activities, as well as in designating special consideration areas for disaster response and possible reconstruction efforts. The application was also designed to support land use and development planning decisions. The application led to the following findings:

1. Limitations of spatial data for use in consistent vulnerability analysis are significant
2. Availability of spatial data to support multi-disciplinary analysis is limited
3. The necessity for continuous local inputs requires time-consuming commitment to local planning processes
4. There is a lack of consistent and accurate probability and risk data to support local decision- making. In addition, it is difficult to get the scientific community to reach consensus or acknowledge the fact that local decisions will be made in the absence of any data
5. Multi-hazard analysis can be made complex for acceptance and use in local decision-making.

c. Social Vulnerability and Capacity Analysis (VCA) Methods

A workshop was organised by the Provention Consortium at the International Federation of the Red Cross and Red Crescent Societies in Geneva in May 2004 on social vulnerability and capacity analysis (Davis, 2004). It recognised that a diverse range of vulnerability and capacity assessment tools have been developed and field tested, mainly by NGOs and community-based organisations, with a particular emphasis on participatory and people–oriented approaches. Indeed, the influence of social development methodologies, such as participatory rural assessment techniques, is very much evident in VCA. A key element, therefore, of the VCA approach is the dual interest in both vulnerability and capacity. Examples include:

- The CVA matrix developed by Mary Anderson and Peter Woodrow's in "Rising from the Ashes, Development Strategies in Times of Disaster" which has formed the template for many of the currently used assessment tools.
- International Federation of Red Cross and Red Cresent Societies VCA toolkit which has been used for assessing both the capacities and vulnerabilities of the communities in which they work as well as the organizational capacities and vulnerabilities of their member National Societies.
- The *Citizen's Disaster Response Center and Network (CDRC/N)* in the Philippines has adopted the CVA methodology since the early 1990s, as part of their Citizenry-Based and Development-Oriented Disaster Response (CBDO-DR) approach
- The *La Red* Network has build up considerable experience in participatory community risk assessment in Latin America.
- The *Peri Peri* network has actively promoted the use of VCA in southern Africa.
- OXFAM developed a Participatory Capacities and Vulnerabilities Assessment tool.
- CARE has developed a Household Livelihood Security Assessment tool kit.

However, despite this growing recognition of the importance and potential benefits of VCA, the methodologies and standard practices are not systematically factored into the main risk assessment process. One reason is that the data concerning the different assessment methodologies have not been compiled, compared and analyzed. Another reason is the lack of knowledge of their relative accuracy, effectiveness and quality. These important constraints can only be addressed by comparative analysis, interdisciplinary research and, above all, the sharing of knowledge, learning and experience between the community of actors involved in VCA (Prevention Consortium, 2005).

SEEDS assessment methodology for Community Based Disaster Management

Gujarat Sustainable Community Initiative, a community based disaster management programme conducted for the Gujarat State Disaster Management Authority was based on a vulnerability assessment in a multi-hazard context, with indicators covering infrastructure, socio-economic indicators, disaster incidence and disaster preparedness. Emphasis was laid on a capacity-vulnerability assessment rather than only vulnerability. Programme interventions in later stages stressed on building of capacities as a vulnerability reduction strategy.

Global Earthquake Safety Initiative methodology, developed under a global initiative of the United Nations Centre for Regional Development and GeoHazards International) has been used by SEEDS in Delhi, and has been further adapted for use in Himachal Pradesh. The methodology taps the latent knowledge of local informants from a set range of subjects. Correlation of whatever sketchy physical data is available, with key information leads to a seamless information base for decision-making.

Participatory tools such as use of flash cards, models, audio-visual aids, formats etc. have been tried in various programmes in Gujarat, Himachal Pradesh, Delhi, Orissa, Uttaranchal, various parts of Afghanistan, and more recently in the Andaman and Nicobar Islands under the tsunami recovery work. Such participatory tools make assessment processes more interactive rather than being centrally driven focus group discussions that are traditionally used for such assessments.

9.3 Methodology

The methodology followed under the current study comprises the following four stages:

1. Identification of major hazards
2. Defining dimensions of social vulnerability
3. Selection of indicators
4. Verification through participatory rapid appraisal carried out in the field
5. Analysis of data and assignment of weights

This process is illustrated in the Figure 42.

Step 1:
Identification of major hazards

Step 2:
Defining dimensions of social vulnerability

Scoring	Vulnerability dimensions for earthquake				
	Social Capital	Life Loss	Injury	Food insecurity	Livelihood Insecurity
5					
4					
3					
2					
1					
0					

Step 3:
Identification of indicators

Scoring	Indicators for life loss potential in earthquake		
	1	2	3….
5			
4			
3			
2			
1			
0			

Note:
Based on identification of available data that best describes these indicators

Step 4:
Participatory Vulnerability Assessment

Verification through participatory rapid appraisal carried out in the field in seven locations across four atolls.

Tools used:

- Focus Group Discussions
- Transect Walks
- Key Informant Interviews

Step 5:
Analysis of data and assignment of weights

Data analysis was carried out for all inhabited islands across the three identified hazards and the five identified dimensions of social vulnerability.

Results brought out through:

- Statistical analysis
- Case studies from participatory
- Detailed description of specific results

Figure 42: Methodology Chart

Identification of Major Hazards

Social vulnerability analysis needs to be carried out in the context of specific hazards. Earthquake, tsunami, cyclone and sea-level rise were identified in the first round as those that pose a threat to Maldives. Of these, earthquake, tsunami and cyclone were selected for data analysis, since the impacts of sea-level rise are not yet easy to define or quantify in the absence of adequate scientific data and local perceptions.

Defining dimensions of social vulnerability

For the purpose of this study, social vulnerability has been viewed as a composite of the following five parameters, which are considered the primary dimensions of social vulnerability:

1. *Organisational and psychological impact potential*

   Disasters have impacts on organizational systems and psychologies of societies and the individuals therein. Usually these impacts are not very visible, but from the social vulnerability point of view they are long lasting and have many related detrimental impacts. The means for countering these impacts lie in building social and institutional capacities.

2. *Life loss potential*

   The most crucial and visible impact of disasters is the loss of human lives. Though the value of human life may be difficult to quantify, loss of life is the worst impact of a disaster, and the most crucial efforts in any vulnerability reduction initiative have to be to curb loss of lives. This is achieved by building life saving capacities.

3. *Injury/morbidity potential*

   The same impact of disasters as their life loss potential, but to a lower degree, is accounted for as injury or morbidity potential. It has related loss potential in terms of livelihood loss during periods of inability, and financial loss for dealing with the injury or morbidity. Injury and morbidity prevention capacities need to be built in communities to reduce this loss potential.

4. *Hunger potential*

   Hunger potential is a result of food insecurity, which may arise from sudden depletion of food resources, or a constant condition of low food reserves and accessibility. It can have a short or long-term debilitating effect on a community and can lead to secondary impacts. To eliminate hunger potential, food security systems and food safety nets need to be built in a community.

5. *Loss of income potential*

   One of the greatest hardships resulting from disasters is the disruption in livelihoods of the survivors. In a situation where additional resources are desperately needed for recovery, survivors lose their income due to loss of tools of trade, buildings, resource base, ability to work, or market. Livelihood resilience, security and options need to be built to reduce the vulnerability arising from potential of income loss.

The above-discussed dimensions of social vulnerability and the identified vulnerability reduction measures are illustrated in Figure 9.2.

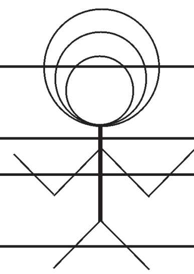
Dimension ofSocial Vulnerability		**Vulnerability Reduction Measures**
1. Organisational impact potential		• Social/institutional capacity
2. Life loss potential		• Life saving capacity
3. Injury/morbidity potential		• Injury/morbidity prevention capacity
4. Hunger potential		• Food security
5. Loss of income potential	**Affected Population – varying size**	• Livelihood resilience

Figure 43: Dimensions of Social Vulnerability

Defining Social Vulnerability for Maldives

In defining the social vulnerability of the islands, attention was given to factors such as social capital, food security and livelihood resilience and population exposure to disasters, rather than on the presence of economic instruments. The focus during the field visits was on ascertaining effectiveness of local institutions that could potentially help local communities cope during disasters. Whereas, preliminary secondary studies had revealed a very limited presence of civil society organizations, the presence of local institutions such as Island Committees provided an opportunity which was studied in detail during field visits. A large proportion of the Maldivian economy is based on tourism and related activities. Tourism in itself poses a huge risk in disaster situations as was seen after the recent tsunami, with a large number of workers dependent on this sector. The team explored livelihood resilience locally as this would be a major factor defining vulnerability.

An important factor that defines the vulnerability is the distribution and size of human settlements in Maldives. In islands, where the population is high, the densities are high as well. In islands where population is low, the lack of island resources and their access to critical infrastructure such as health, communication and education defines their vulnerability. In either case, the extreme situations increase vulnerability. Field studies were hence aimed at defining viable population sizes with minimum threat to disasters. Focus group discussions were to be carried out with local leaders, teachers, island-elders both in islands where there is a threat to disaster as well as ones which were exposed to the recent Tsunami.

Field studies were thus aimed at verifying the final selection and assignment of weights to the indicators identified from available studies.

Selection of indicators from existing survey data

In an attempt to identify how these indicators contribute to the vulnerability, data relating to social risk perception were identified from the Vulnerability and Poverty Assessment (VPA) survey data collected in 2004, under a study conducted by the Ministry of Planning and National Development with technical assistance of UNDP and the World Bank. The identification of indicators was carried out in sets for different hazards. The hazards covered under the analysis are earthquakes, tsunamis and cyclones.

The questions selected for data analysis pertained to the following aspects: hardships faced by women-headed households; number of volunteers in a community; accessibility to islands in normal times; accessibility to islands in times of emergency; presence of community based organisations; food crisis faced in the past; population size; population of women; population of children; population of elderly people; local availability of medicines; coastal protection measures in place; incidence of beach erosion; water sufficiency for public consumption; scale of kitchen gardening; incidence of affected food supply in the past; quality of ground water and risk to livelihood.

In addition to the questionnaire data, secondary data was also sourced from the following sources:

- Population data for different islands from www.atolls.gov.mv website
- Data for wind speed and wave height from the meteorological department

For each of the three hazards, all the five dimensions of social vulnerability as identified for the study were covered. Under each dimension a unique set of indicators was identified from the UNDP VPA questionnaire survey data. Scoring was carried out for the data set based on relative severity of impact. The hazards, dimensions of social vulnerability, indicators and tools used in the study are illustrated in Figure 44.

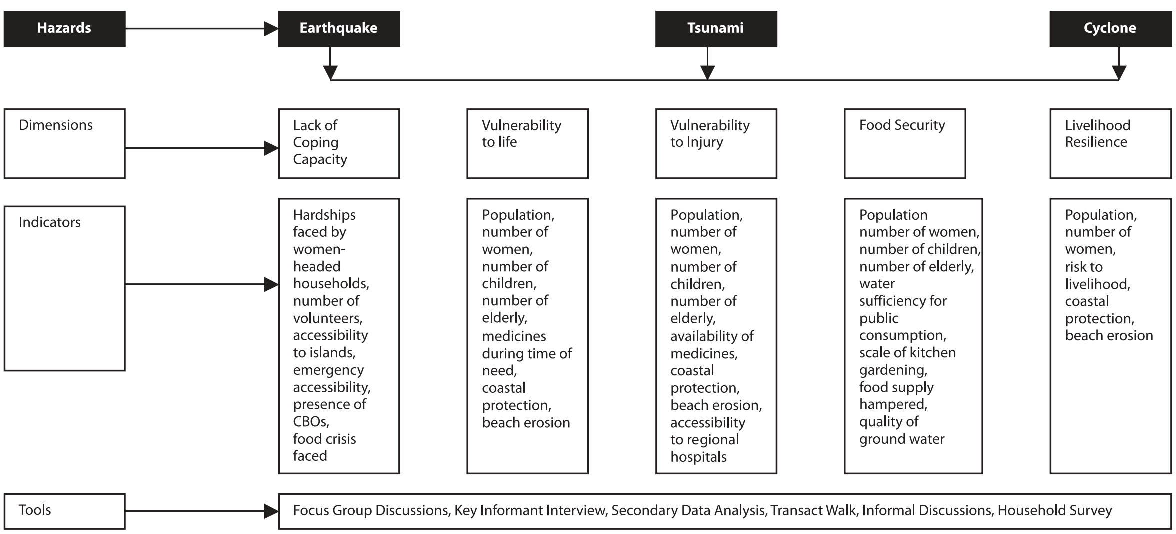


Figure 44: Gathering and Structuring of Datasets

Verification through PRA Exercises in the Field

The primary survey data from UNDP VPA formed the base for the present study. However, to correlate it with qualitative and perceptional data from the field, a series of community based participatory rapid appraisal (PRA) exercises were carried out in August 2005. Detailed field notes including the inferences drawn are provided in Volume II, Annexures. The field work was carried out in eight islands across four atolls. These islands were selected on the basis of the following criteria:

- Location wise: north, south and central atolls, extreme north and south
- Eastern and western fringes of the atolls

- Hazard zone-tsunami impact and cyclones
- Inhabited islands
- Population size
- Distance from Male and atoll capital

Based on the above criteria, the following islands were selected and field work was carried out in each:

On Haa Dhaalu (South Thiladhunmathi) Atoll:

1. Kulhudhuffushi
2. Faridhoo

On Meemu (Mulaku) Atoll

3. Muli
4. Kolhufushi/Kolhuvaariyaafushi

On Addu (Seenu) Atoll

5. Hithadoo
6. Hulhudhoo

On South Male Atoll

7. Guraidhoo

The process of PRA in the field comprised the following steps:

- Validating class representation based on selection criteria
- Carrying out vulnerability assessment with community groups at the selected islands
- Understanding the effect of perceptions of vulnerability of the population strata based on class representation
- Assessing the dimensions of vulnerability at the individual, household and community levels
- Verification of secondary data

The vulnerability assessment exercises with community groups were designed by:

- Selecting and developing vulnerability indicators
- Selecting and developing parameters of selected indicators
- Designing tools for conducting survey in the form of Focus Group Discussion, Key Informant Interview

Details of the select islands are given in Table 29.

Table 29: Islands Selected and Surveyed

Sr. No	Name of Atoll	Name of the Island	Location	Distance from Male	Distance from Atoll Capital	Population (In 2000)	Criteria of selection	PRA Activities carried Out	Number of People
1	Haa Dhaalu (South Thiladhunmathi)	Kulhudhuffushi	North +East	276.6 km	0.0	6581	1. Atoll Capital 2. Vulnerable to cyclones 3. Wave height during tsunami was 1.9 meters 4. Damage of infrastructure, food crops and vegetation during tsunami 5. Erosion of coast line during tsunami 6. Falls in major tsunami impact zone 7. Third largest populated island after Male 8. 36 /38 (Island/atoll) buildings damaged.	· Focus Group Discussion with IDC and people· Discussion with teaching and administrative staff of secondary school · Discussion with teaching and administrative staff of primary school· Discussion with medical and administrative staff at regional hospital · Discussion with administrative staff of pre-school· Interaction with household and community · Interaction with fish processing unit· Interaction with carpentry workshop· Interaction with care taker of nursery	20
		Faridhoo	North +East	294.9	18.3	159	1. Population below 500 2. It has an island reef. 3. No building damage and flooding during tsunami	· FGD with IWC and community members · Site visit to agricultural plots with the community · Interactions with community at the households	10-15
2	Meemu (Mulaku)	Muli	Central +East	139.4 km	0.0	2401	1. Atoll capital 2. Coral reef area 3. Flooded completely during tsunami 4. Damage of infrastructure, food crops and vegetation during tsunami 5. Erosion of coast line during tsunami 6. Falls in major tsunami impact zones 7. Severe beach erosion reported since 1990 8. Wave height during tsunami was 3.0 meters 9. 135/ 346 (Island/atoll) buildings damaged.	· FGD with IDC · Interactions with households in the community	25
		Kolhufushi/ Kolhuvaariya afushi	Central +East	155.1 km	23.3	936	1. Coral reef area 2. Falls in major tsunami impact zone 3. Completely flooded during tsunami 4. Damage of infrastructure, food crops and vegetation during tsunami 5. Erosion of coast line during tsunami 6. Falls in major tsunami impact zones 7. Severe beach erosion reported since 1990 8. Wave height during tsunami was 3.0 meters 9. 146/346 (Island/atoll) buildings damaged.	· Group work with IDC and IWC members	35
3	Addu (Seenu Atoll)	Hithadoo	South+ West	533.7	0.0	9461	1. Atoll Capital 2. Located in western part of island 3. Coral reef area 4. Largest populated island after Male	· FGD with IDC members· FGD with medical and administrative staff at regional hospital · Interaction with household level · Interaction with people at fish processing unit· FGD with teachers and staff at the secondary school	10-12

		Hulhudhoo	South	530.7	15.5	1439	1. 30/30 (Island/atoll) buildings damaged.	· FGD with community people· Interaction and ward visit with health personnel and staff at the health centre · Interaction with the community· Interaction with boat making unit· Discussion with teachers and administrative staff of primary school	10
4	South Male Atoll	Guraidhoo	Central + East	30.7	58.0	1225	1. Falls in major tsunami impact zone 2. Tourist resort 3. Flooded during tsunami 4. Extensive damage to environment and vegetation 5. Erosion reported during tsunami 6. Wave height during tsunami was 0.71-1.52 meter 7. 70/482 (Island/atoll) buildings damaged. 8. Island on barrier reef	· FGD with IDC and community members 15-20	

Verifying Social Vulnerability Indicators through Field Exercises

Each region and community lies within its own unique framework of vulnerability. The field visits carried out in selected atolls across the country proved extremely useful in short-listing indicators that could help develop the social vulnerability profile of the entire country.

a. Social/Institutional Capacity:

In Maldives, it can be inferred that the presence of good kinship ties and community cohesion strengthens the community in facing adversities. Moreover, the social systems are governed by factors like government policies, governance at the local level and the delivery of legal services. The presence of Island Development Community (IDC) and Island Women Community (IWC) at times provide good leadership in times of crisis but if they are not active, absence of leadership may cause chaos. Delayed judgment is often a cause for people not registering cases. The schools in some cases have been active and have promoted awareness programmes. The outreach to the general community also acts as a positive factor. The increased capacity due to the presence of trained cadets and active Parent Teacher Association is also marked.

Coping capacity was also reflected in the transportation linkages between islands and their atoll capitals, especially in case of emergencies. In specific cases, it was found that due to the time taken to transport sick patients, lives were put at risk. Availability of vessels for transportation adds to the resilience but the high cost of private speed boats in case of emergencies reduces it and increases the vulnerability. Thus accessibility was taken as an important indicator for island communities.

Clearly, wherever local institutions were strong and there was a strong participation from the community following the tsunami the community displayed greater confidence in dealing with disasters. With greater capacity building at schools and training leaders of IDCs and IWCs, the capacity of the community to cope with disasters can significantly increase.

Haa: Kulhudhuffushi: School's outreach in the community and its vulnerability

The Jalallaudin Secondary School has a good outreach in the community. The Principal is motivated person. The school has cadets who are trained in first aid. The role of the cadets in handling the recent tsunami is highly laudable. Within few minutes, the cadets trained in first aid were called. They were involved in cleaning, first aid etc and worked for five days.

The teachers gave a number of suggestions: for communicating and awareness raising regarding disasters among the community, schools, community leaders and public workshops can be used. Also, ward level leaders and boat owners can be contacted as they are the most respected by the community. Home visits should be conducted by health workers, ward level interventions should be encouraged and school safety programmes should be held. The children and parents need special programmes for awareness. Public announcement for assembling people, informing them about disasters, seeking help etc should be used. Use of public van with speaker should also be encouraged.

On the other hand there is a small preschool which had around 4 feet water in the school. The highest point is a three feet platform in the school where the children can be kept in case of such a disaster. The staff there is still very afraid as they do not know what they will do if the same event recurs while children are there in the school.

The primary school children were saved since it was a holiday. During the tsunami, this school was affected and around 50-100 children suffered trauma and needed psychosocial support. Psychosocial support training was conducted by NDMC and Red Cross at the atoll level in which two staff members had participated.

b. Life saving/injury/morbidity prevention:

In Maldives, islands with high population and high hazard ranking are at greatest risk to loss of lives and injury. Certain islands with high population also had problems related to population density. There was an increasing pressure on limited land, as this was beginning to put pressure on scarce resources and limited infrastructure. It was observed that where there is an increase in density, people have to resort to drinking water from the ground water tanks which are contaminated, it leads to health hazards even in normal circumstances. Most of the tsunami hit islands have reported complaints of contaminated ground water. Environmental degradation has also contributed to the severity. Similarly garbage disposal by the households as well as the hospital also contributes to health hazards.

With limited opportunities for livelihood and education on the islands, there were numerous difficulties for women-headed households and the elderly. The breaking up of families to fulfill needs of education or livelihood often results in large number of women and children living on the island all by themselves. The elderly population is often left behind on the islands, which contribute to their vulnerability.

The health facility plays a very important role in meeting the demands of health care services during emergencies. This is more so in the case of island nations like Maldives. If there is inadequate staff or medical facilities, it adds to the vulnerability. Moreover, even in the case of atoll or regional hospitals, the demands of medical relief may not be met as a sizable population is dependent on these. In the absence of trained paramedical staff or volunteers, the requirement of first aid may not be met. Apart from this, even the bed capacity can affect the medical relief. There are islands where people have to travel far for getting further medical relief.

It was also observed that there are increasing cases of beach erosion putting lives at greater risk. In inhabited islands, such instances with lack of any protection measures are a threat to life.

c. Food security:

There is a mixed pattern observed on the islands regarding storing food. On some islands people store food and on some they do not. But most of the islands are inter-dependent for food supply. The islands are heavily dependent on Male for food supply and the STO is the sole provider. Most of the islands do anticipate food crisis during disasters. The islands being small, the storage capacity is often found to be less. Where people buy food daily, food crisis is observed in case of disruption of food supply during an emergency. The presence of agricultural plots and horticulture on the islands often augment emergency food supply on the island. Presence of plants like potatoes and tarro (a vegetable similar to sweet potato) enables people to cope during crisis situations. Moreover, food like *rusti* –the transparent roti which last for around one month–can act as emergency food in case of anticipated disasters like cyclones. Fruits like water melon grown by women farmers also add to food security. Small agricultural plots managed on the island itself acts as a factor contributing to self sufficiency to some extent. Moreover, the promotion of nursery for horticulture is also a good attempt to increase self sufficiency of the islands. Information on nutritional value of food, its biological use etc. was not available at the time of study and hence only two points were covered.

Though mostly rainwater is used for drinking, in case of a large population, people have to resort to underground water for drinking. Due to the leakage of a septic tank, often the case where island population is increasing rapidly, ground water is often found to be contaminated thus increasing the vulnerability. The presence of community wells often enables the community to overcome problems of water crisis. In case of emergency, water for cooking or drinking had to be shipped from Male in case of one island which would increase its vulnerability to food security.

d. Livelihood resilience:

In Maldives, most of the people are dependent on either the fishery or tourism industry. Livelihood options are few and hence people who were dependent only on tourism have suffered during the recent tsunami. People who get educated often leave the island and take up jobs in Male or other areas breaking the family unit and setting in new trends of migration. With regard to livelihoods, when men travel to tourist islands, the women, children and the elderly are often left alone on the islands. The number of women-headed households on islands is an indicator for a higher rate of out-migration.

The closure of garment factories and the inability to provide alternative livelihoods has rendered many women jobless in one of the islands. Commercial fish processing has also forced women to take up alternative livelihood and while in some cases they have been able to find one, in others this has hampered the individual householder's income from fish processing.

The boat making units also provide employment opportunities but mostly it is labor from outside who work in these units. The dependence of the men at sea on celestial patterns of forecast often renders them vulnerable. But presence of coast guard and radio sets helps them in case of emergencies.

Haa: Faridhoo: Population, Food security, Medical facilities

Faridhoo is a small island with population of just 159 people. A notable aspect on the island is the number of women, children and elderly as compared to the men. The men have to go along with children who study at other places as the island fails to provide education facilities after the initial stages. Moreover, in absence of livelihood options, men have to go to other places. Thus often, the basic unit of society, the family is falling apart as children once educated do not return to the island. These factors contribute to the vulnerability of the island.

The island has a unique practice of agricultural plots being managed by the IWC. They grow water melons, chilies, beans, pumpkins etc which act as emergency food for the islanders. It is worthwhile to note that they buy food everyday from nearby islands and are dependent on that for food. The small size of the population also contributes to availability of rainwater for drinking throughout the year.

The island is vulnerable since there is no jetty or availability of vehicle in case of emergency. Infant mortality is high due to transportation problems, according to the people.

Analysis of data and assignment of weights

The data analysis has been carried out hazard-wise, disaggregated at the level of the indicators identified for each hazard, and tabulated at the island level. Weights have been assigned to the vulnerability dimensions, and accordingly the composite results derived for each hazard. The composite result thus is the product of the scored indicators weighed and assimilated for all five dimensions. This exercise has been carried out for each of the three hazards. The dimensions and indicators of social vulnerability along with their weights are given in the Table 30.

The weights have been assigned through a Delphi process involving experts from the fields of emergency response, structural mitigation, urban planning, regional planning, sociology, psychology, architecture and management. The final weights taken are the averages of the range of weights assigned by individual panelists. The generation rationale for the weights is as follows:

Vulnerability to life: The highest weight assigned is to vulnerability to life, at 30 percent. This is because the prime directive of any disaster mitigation, preparedness or management effort is to save human lives.

Lack of coping capacity: The aspect of local coping capacity is of great importance within social vulnerability. Reduction of social vulnerability through building of social capital is the primary means for reducing disaster risk as part of a community based disaster management process. This aspect has been assigned the second highest weight at 25 percent.

Vulnerability of injury, food insecurity and lack of livelihood resilience: Each of these three factors has been assigned a weight of 15 percent. The three factors have debilitating effects, and can have immediate impact on the affected community in terms of shocks or long term impacts in terms of stresses.

Table 30: Social Vulnerability Dimensions and Indicators		
Level I Dimension	**Level I Weight**	**Level II Indicators (scored on a scale of 5)**
Lack of Coping Capacity	25 per cent	• Hardships faced by women-headed households· • Number of volunteers· • Accessibility to islands • Emergency accessibility of vessel • Presence of CBO • Food crisis faced during past 12 months
Vulnerability to life	30 per cent	• Total population of the island • Number of women • Number of children • Number of elderly • Availability of medicines • Coastal protection measures taken by the island • Incidence of beach erosion on the island
Vulnerability to Injury	15 per cent	• Total population of the island • Number of women • Number of children • Number of elderly • Availability of medicines • Coastal protection measures taken by the island • Incidence of beach erosion on the island • Accessibility to regional hospital
Food Security	15 per cent	• Total population of the island • Number of women • Number of children • Number of elderly • Water sufficiency for public consumption from public rain water tanks • Scale of kitchen gardening on the island • Food supply hampered in past one year • Quality of ground water
Livelihood Resilience	15 per cent	• Total population of the island • Number of women • Risk to livelihood • Coastal protection measures taken by the island • Incidence of beach erosion on the island

9.4 Results and Discussion

Primary interpretations of results are as given below. The tabulation of results are given in the Annexure. Results and case studies from the field-work on participatory vulnerability assessment are in the subsequent sections.

Earthquakes

The likelihood of earthquakes with magnitude of 5 and above in Maldives is limited to only the southern parts of the country, namely Seenu, Gnaviyani, Gaafu Alifu and Gaafu Dhaalu atolls. Since earthquakes of this scale are known to cause damage to life and property, the population of these atolls are at high risks.

From among the vulnerable atoll islands, the atoll capitals would need critical interventions on earthquake risk reduction in future. As such, high loss of life and property in the larger islands would further exacerbate loss in small inhabited islands dependent on them for essential needs.

Islands in Seenu and Gnaviyani atolls have high earthquake hazard ranking. Being old settlements these islands have a relatively high population. After Kaafu (includes Male), Seenu has the highest population of 18,515, and Gnaviyani has only one island (Foamullah) with a population of 7,528. This population concentration accentuates their risk to earthquakes.

In relative terms, the proportion of children in Gaafu Alifu and Gaafu Dhaalu atolls is high. These atolls may expect earthquakes of magnitude 5 or more. This makes them particularly vulnerable.

Earthquakes, being sudden events, cause unexpected shortage of food and water. Adequacy of these resources lowers vulnerability of the population to this disaster. In overall terms, food insecurity (including transitory food insecurity) ranks low among all islands; however, a majority of the islands have faced problems of drinking water supply in the past.

In earthquakes, whereas livelihoods such as agriculture and fisheries are affected less, secondary and tertiary sectors of the economy get adversely affected to a great degree. The field observations revealed that a vast proportion of the working populations in Seenu engaged in manufacturing units were rendered unemployed when these units suddenly stopped functioning post WTO. This has led to an increase in vulnerability.

During the participatory vulnerability assessments carried out at the site, respondents revealed little or no knowledge about earthquakes and the likely damage they can cause. One of the priority areas of interventions for future disaster reduction programmes in the country would be to build capacity locally on earthquake preparedness and response. Even regional hospitals do not practice mass casualty drills. The regional hospital in Hithadhoo Island on Seenu Atoll will have to be sufficiently equipped to handle earthquake casualties.

Cyclones

In Maldives, the northern atolls are more exposed to cyclonic impacts than the southern atolls. The islands in the northern atolls have a low population base. As such the size of population of the country exposed to cyclones is low.

The vulnerability of the islands in the northern atolls is heightened due to their poor accessibility compared to other parts of the country. In a post-cyclone situation, affected areas are inaccessible for several days due to poor weather and rough sea conditions.

Food security and availability of sufficient fresh water is therefore critical. The islands in the northern atolls have low levels of food insecurity; however the availability of fresh water for public consumption in emergency situations is a major problem.

In cyclones, risk to livelihoods in the primary sectors such as agriculture and fishing, and in the service sectors is high. The risk to livelihood due to cyclone is uniformly high in the northern atolls. Cyclone risk can be substantially mitigated with effective early warning systems. In the northern atolls, due to poor accessibility and few community-based organizations, the likelihood of warnings reaching the population in time appears low. For preparedness against cyclones, suitable measures are recommended for improving the early warning system.

Tsunamis

The risk of tsunamis is particularly high along the eastern fringe of eastern atolls, though eastern fringe of western atolls may also experience affects of tsunamis. As such, the islands with lower elevation and higher population are at greater risk.

The southern atolls with a strong likelihood of earthquakes require attention for protection against tsunami tidal waves as well as earthquake damage, whereas the northern atolls with a strong likelihood of cyclones require protection against high winds as well as tidal waves due to storm surge and tsunami. The central atolls require attention to protect themselves against tsunami tidal waves. A combination of safe building practices and sound early warning systems to facilitate early evacuation are important areas of intervention.

With water availability being insufficient for public consumption during emergencies in most islands, and the likelihood of ground water getting contaminated in a tsunami, the overall vulnerability of populations on islands with tsunami risk is high.

Participatory vulnerability assessment revealed lack of knowledge about tsunami disasters. The recent tsunami disaster being unprecedented in people's memory, the lessons learnt would need to be sustained through a comprehensive public awareness campaign throughout the country. The impact of tsunami hazard was taken as a combination of earthquake damage and coastal flooding. All such indicators that best describe impact of these two hazards were considered.

SEEDS experiences from comparable situations in the Andaman and Nicobar Islands where earthquake and tsunami both had a severe impact in recent times suggest that in Maldives attention should be given to both earthquake and tsunami risks. Inferences can be drawn from the damage profile of the Andaman and Nicobar Islands, and lessons learnt for protection of populations exposed to earthquake and tsunami impacts, and more vulnerable due to marginal economic status and low local coping capacity.

Multi hazards

Top 20 islands with multi hazard social vulnerability risk are given in Table 31 and also shown in the map in Figure 45.

Table 31: Top 20 islands with Multi-hazard Social Vulnerability Risk			
S. No.	**Island**	**Atolln**	**Multi Hazard Social Risk**
1	Thuraakunu	Haa Alifu	5
2	Berinmadhoo	Haa Alifu	5
3	Hathifushi	Haa Alifu	5
4	Nolhivaramu	Haa Dhaalu	5
5	Alifushi	Raa	5
6	Hulhudhuffaaru	Raa	5
7	Buruni	Thaa	5
8	Dhiyadhoo	Gaafu Alifu	5
9	Gadhdhoo	Gaafu Dhaalu	5
10	Meedhoo	Seenu	5
11	Hithadhoo	Seenu	5
12	Feydhoo	Seenu	5
13	Hoarafushi	Haa Alifu	4
14	Dhidhdhoo	Haa Alifu	4
15	Kulhudhuffushi	Haa Dhaalu	4
16	Thulhaadhoo	Baa	4
17	Isdhoo	Laamu	4
18	Fua-mulah	Gnaviyani	4
19	Maradhoo	Seenu	4
20	Hulhudhoo	Seenu	4

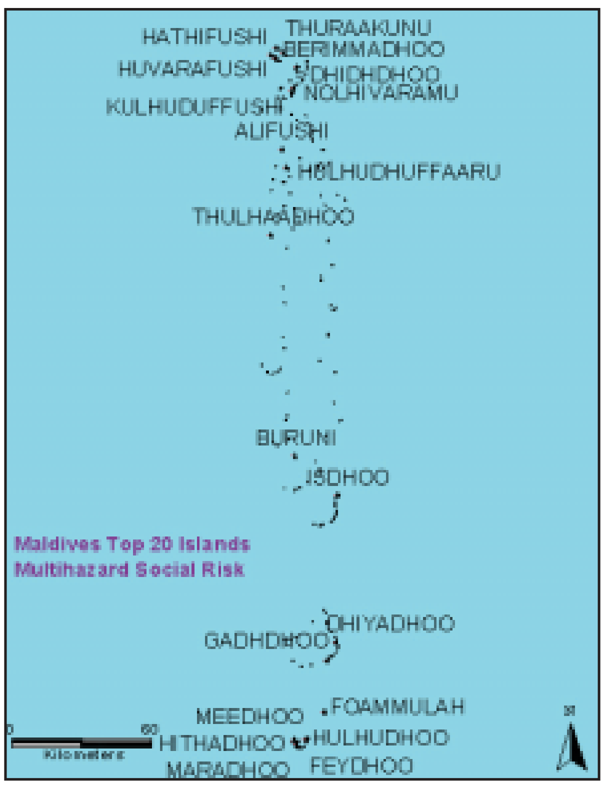


Figure 45: Top 20 Islands with Multi-hazard Social Vulnerability Risk

9.5 Limitations and Assumptions

The study is based primarily on information available through secondary sources. A comprehensive island wise primary survey was beyond the scope of the current exercise. Most of the information has been derived from the Vulnerability and Poverty Assessment data gathered in 2004 by the Maldives Government, UNDP and World Bank initiative. Though many of the vulnerability parameters to be used in the present study could be derived out of this data indirectly, the range of available data limited the selection of final parameters.

The verification process involved primary data collection from the field in the form of participatory vulnerability assessment. The research team carried out the assessment on seven islands across four atolls in Maldives. Though the process was rapid and wide-ranging to gather verifiable indicators within a short time span, the triangulation process was limited to a range level and not at disaggregated data level. This has been effectively used to develop findings from the participatory assessment and to draw out case studies from the islands covered.

Although the initial research indicated vulnerability to sea level rise, this was not included in the study due to lack of scientifically approved information and also lack of local perceptions on the subject. Following the Delphi process, the multidisciplinary team at SEEDS has carried out the scoring and weighing process for the indicators. During the scoring and ranking process it has been assumed that the coverage of threats is uniform across the community on a particular island. In case of multiple sub-indicators, it has been assumed that the sub-indicator with the highest incidence is the primary indicator for the particular island. For purpose of final result inferences in the section on earthquakes, only those islands with probability of an earthquake of magnitude 5 or above have been considered as it has been assumed that earthquake of lower magnitude will not cause any significant impact on lives of property.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Key Findings

Maldives faces tsunami threat largely from the east and relatively low threat from the north and south. As a result, islands along the eastern fringe are more vulnerable with respect to tsunami than those along the northern and southern fringes. Islands along the western fringe experience a relatively low exposure to tsunami hazard. Historically, Maldives has been affected by three earthquakes which had their sources in the Indian Ocean. Of the 85 tsunamis generated since 1816, 67 originated from the Sumatra Subduction Zone in the east and 13 from the Makran Coast Zone in the north and Carlsburg Transform Fault Zone in the south. The probable maximum tsunami wave height is estimated at 4.5 metres in Zone 5. The return period of the kind of tsunami that struck Maldives on 26th December 2004 is estimated to be 219 years (one of numerous probable events).

The northern atolls have a greater risk of cyclonic winds and storm surges. This gradually reduces to a very low hazard risk in the southern atolls. The maximum probable wind speed in Zone 5 is 96.8 knots (180 kilometers per hour) and the cyclonic storm category is a lower Category 3 on Suffir-Simpson scale. At this speed, high damage can be expected from wind, rain and storm surge hazards.

Except for Seenu, Gnaviyani and Gaafu atolls, earthquake hazard is low across the country. The probable maximum Modified Mercalli Intensity (MMI) is estimated at 7-8 in Zone 5. This level of MMI can cause moderate to high damages.

Sea level rise due to climate change is a uniform hazard throughout the country. The Inter Governmental Panel on Climate Change (IPCC) in its Third Assessment Report (2001) estimated a projected sea level rise of 0.09 metres to 0.88 metres between 1990 - 2100. The impact on Maldives depends on the elevation of islands. With about three-quarters of the land area of Maldives being less than a meter above mean sea level, the slightest rise in sea level will prove extremely threatening. Male is estimated to be inundated by 15 per cent by 2025 and 50 per cent by 2100 due to climate change and consequent sea level rise. Due to non-availability of high resolution topographic data, impacts on other islands could not be estimated.

Overall, Maldives faces moderate hazard risk except for the low probability and high consequential tsunami hazard in the near future, and high probability and high consequential sea -level rise hazard in the distant future.

Risk arising from physical vulnerability has been treated as a function of exposure concentration. Male tops the list with highest risk. The islands with risk index 5 (very high) and risk index 1 (very low) are given in the tables below. Risk index 1 implies "Safe Island" in relative terms.

Table 32: Physical Vulnerability - Safe Islands			
S. No.	Island	Atoll	Multi Hazard Physical Risk Index
1	Bodufolhudhoo	Alifu Alifu	1
2	Himendhoo	Alifu Alifu	1
3	Maalhoss	Alifu Alifu	1
4	Mathiveri	Alifu Alifu	1
5	Ukulhas	Alifu Alifu	1
6	Mandhoo	Alifu Dhaalu	1
7	Dhonfanu	Baa	1
8	Kihaadhoo	Baa	1
9	Kudarikilu	Baa	1
10	Hulhudheli	Dhaalu	1
11	Meedhoo	Dhaalu	1
12	Ribudhoo	Dhaalu	1
13	Dharanboodhoo	Faafu	1
14	Magoodhoo	Faafu	1
15	Thinadhoo	Gaafu Dhaalu	1
16	Fodhdhoo	Noonu	1
17	Kandoodhoo	Thaa	1
18	Omadhoo	Thaa	1
19	Vandhoo	Thaa	1
20	Rakeedhoo	Vaavu	1

Risk from social vulnerability has no significant trend except Male being in a zone of low risk. The risks are randomly spread across the country, as several factors drive the vulnerability. "Safe islands" in the context of social vulnerability with risk index 1 (very low) are given in Table 33.

10.2 Recommendations on Reducing Disaster Risks

1. Proactive Disaster Risk Mitigation through Policies and Plans

Risk information is the key to manage disasters better. The hazard and risk information generated by the study needs to be incorporated into national policy and planning. Proactive planning and investments in mitigation measures – structural and non-structural- go a long way in mitigating the long- term impacts of natural disasters. The study found there were no efforts to incorporate structural measures against hazard impacts into the construction of buildings and structures throughout the country. A beginning needs to be made to construct buildings and structures that can resist natural hazard forces at least in zones 5 and 4. Islands should be carefully selected for development activities based on recent hazard and risk information.

2. Community Based Disaster Risk Management

Social vulnerability, especially in islands with populations less than two thousand, can be effectively reduced through active community based disaster risk management exercises. This has been successfully demonstrated in other Asian countries, notably Bangladesh, Philippines and parts of India.

In Maldives, inhabited islands with small populations may be targeted for building community's

Table 33: Social Vulnerability - Safe Islands			
S. No.	**Island**	**Atoll**	**Multi Hazard Social Risk Index**
1	Bodufolhudhoo	Alifu Alifu	1
2	Feridhoo	Alifu Alifu	1
3	Himendhoo	Alifu Alifu	1
4	Maalhoss	Alifu Alifu	1
5	Mathiveri	Alifu Alifu	1
6	Rasdhoo	Alifu Alifu	1
7	Thoddoo	Alifu Alifu	1
8	Mandhoo	Alifu Dhaalu	1
9	Kamadhoo	Baa	1
10	Kudarikilu	Baa	1
11	Dharanboodhoo	Faafu	1
12	Fieealee	Faafu	1
13	Magoodhoo	Faafu	1
14	Nilandhoo	Faafu	1
15	Maduvvari	Raa	1
16	Meedhoo	Raa	1
17	Kandoodhoo	Thaa	1
18	Omadhoo	Thaa	1
19	Vandhoo	Thaa	1
20	Rakeedhoo	Vaavu	1

capacity to face natural disasters. This would require suitable training for Island Chiefs and Atoll Chiefs. Island-wise disaster management plans would be a useful starting point with activities like preparedness drills included. Other influential local stakeholders such as school teachers, religious heads and boat owners would also need to be targeted with customized training programmes and related activities.

Basic disaster awareness which encourages families to have their own disaster plans, communities to build emergency water and food supply systems and house owners/construction workers to be sensitive to safe building construction practices may be promoted through awareness programmes using various locally appropriate media.

3. Early Warning Dissemination

Following the 2004 tsunami and other recent catastrophic cyclones, many international initiatives are being undertaken to develop early warning systems. In order that these systems are effective, the warnings have to be efficiently disseminated at community level. In the Maldives, the northern atolls face a high risk of cyclones and the southern atolls face a risk of tsunamis. The communities in these atolls need to be well prepared to receive warnings promptly and react appropriately. The island offices and well established GSM network in the country are potentially the most useful tools for warning dissemination. Requisite infrastructure and training is needed to promote better preparedness.

4. School Safety and Hospital Casualty Drills

In the recent tsunami, schools in the affected islands played an important role in mobilizing local volunteers. Interaction with the school management and teachers as a part of this study also revealed the lack of knowledge and awareness on disaster related issues. There were also symptoms of post traumatic stress disorder (PSTD) observed among children and teachers.

There is an urgent need for introducing school safety programmes in all the islands. The country has a robust educational infrastructure which may be suitably equipped to deal with natural disasters. School safety programmes would promote a culture of safety in the community. Programmes may cover multiple hazard risks, and could include the following components: training of teachers and students, formal curriculum-based education, non-formal aspects such as school disaster management plans, preparedness drills, structural and non-structural mitigation exercises.

During the study, interactions with the local hospital administration and community leaders indicated that hospitals need to build upon basic casualty drills including triage. Hospital emergency preparedness programmes are necessary across all islands particularly building capacity of the atoll hospitals.

Social vulnerability reduction programmes require low investments of resources with specialized trainers. In the Maldives, these programmes may be implemented over a period of two to three years for activities to make visible impact in the community. The success of these programmes lies in potentially reducing loss of lives and active resilience of the community to recurrent natural disasters.

The above recommendations can be actualised in a context of ongoing disaster risk reduction initiatives in Maldives. Presently, two programmes being implemented in Maldives which will impact disaster risk reduction are the Tsunami Regional Programme and the Disaster Risk Management Programme.

Tsunami Regional Programme in Maldives

UNDP's Regional Programme on Capacity Building for Sustainable Recovery and Risk Reduction in Tsunami Affected Countries was initiated by UNDP-BCPR in response to the needs of tsunami affected countries for greater coherence in regional recovery efforts and risk reduction. The programme aims to increase the capacities of countries affected by the Indian Ocean tsunami to undertake post-disaster recovery and risk reduction initiatives in India, Sri Lanka, Maldives, Thailand and Indonesia. Based at UNDP's Regional Centre in Bangkok, the programme supports the work of UNDP Country Office Disaster Risk Management and Recovery teams. The programme combines both regional and in-country interventions to support the efforts of UNDP country offices towards strengthening national recovery programming. This combination of a regional and in-country focus ensures a coherent regional approach to UNDP's post-tsunami recovery initiatives, and also allows the programme to respond to the emerging needs and demands of country offices.

Three strategic areas of support have been identified for this regional programme to achieve its intended outcomes. The Information Management component of the programme aims at strengthening recovery efforts, increasing capacity for analyzing disaster trends, thus improving decision-making. The Learning and Training component seeks to train specialists to develop surge capacities for early recovery and risk reduction; to identify and implement regional and national frameworks for training in disaster risk reduction; and to train actors in recovery and risk reduction. The third component aims to strengthen stakeholders' efforts for end-to-end Early Warning Systems (EWS) at the local level. This will include the development of comprehensive multi-hazard risk patterns in support of local level EWS, the application of risk assessment results to recovery and EWS development and policy dialogue to incorporate EWS in legal frameworks through regulatory policies and the definition of institutional responsibilities.

Disaster Risk Management in Maldives

The Disaster Risk Management (DRM) Programme in Maldives was launched by the UNDP in response to the tsunami, for reducing future disaster risks and ensuring sustainable development in Maldives. The programme aims to establish a robust and effective institutional framework for disaster management in the country and put in place a disaster management policy to serve as a framework of action for all the relevant Ministries and agencies spanning across all sector of development. The programme emphasizes on developing multi -hazard preparedness and response plans at different levels and enhancing the levels of skill of disaster managers at different levels in particular and community members in general through training and awareness- raising activities.

The focus of the programme is on education, training and capacity building for sustainable disaster risk management at all levels, working with other actors actively involved in disaster management, including the Government of Maldives, other UN agencies, local and international NGOs, the private sector, and civil society organizations. The programme has a community-based approach to boost the local capacity to manage disasters effectively by identification and reduction of disaster risks.

The strategic areas of support that have been identified for the DRM programme to achieve its intended outcomes are as follows:

- Support for the establishment of a national Early Warning System.
- Establishment of Emergency Operation Centers with fail-safe communications at the national and regional levels.
- Provision of safe shelters in some of the most vulnerable islands.
- Enhancement of disaster management skills and capacities at the national, atoll and island levels through training and awareness programmes.
- Support the formulation of multi-hazard disaster management plans at different levels including community based disaster preparedness plans in vulnerable islands.

10.3 Limitations of the Study

A major limitation of the study is lack of topographic data of islands except Male, especially the contour data. This put a barrier while analyzing the impacts of sea level rise on the islands other than Male.

Other limitations pertain largely to lack of historical data. For example, there is not enough data to study freak storms (thunder storms/squalls) both spatially and temporally. The network of meteorological stations and their historical data are too limited to understand the behavior of damaging freak storms.

The study focuses on a national scale and island is considered as one homogenous location. Topography, land use, land cover, buildings, etc. are considered homogenous across the island. As such it ignores the intra- island variations. Even the shape of the island is ignored. Hence, the findings are more appropriate at a national scale rather than at the level of an individual island.

In-depth analyses such as housing type vis-a-vis level of risk would require undertaking detailed study of each type of housing. In the present study the focus is on a comparison of risk across different islands rather than assessing risk in absolute terms for individual islands or for specific types of buildings. Therefore the methodology adopted for comparative risk analysis involves normalization of exposures across islands.

10.4 Future Scope of Work

The present study is of a macro nature and has been conducted at a national scale. It does not necessarily capture inter and intra island heterogeneity and issues there in. More detailed and micro studies are required, focusing on few islands to get insights into the issues at island level. The following are few such studies recommended for future work.

Any island planning should consider not only the big picture in a national setting but also the characteristics within the island, especially for big islands. An island- wise detailed study focusing on large islands would enrich the results of the present study and be more relevant to island planning and development. This could be addressed by the multi-hazard risk mapping done at community level.

A detailed risk assessment of islands that are designated as “safe islands” in relative terms needs to be undertaken to identify special safety measures that need to be implemented to make them truly safe. Additionally, a detailed analysis of building stock in islands in earthquake zones 5 and 4 need to be undertaken to recommend retrofitting measures, and changes to building codes and byelaws.

A detailed study on identifying means and alternatives for livelihood resilience will be useful. Socio-economic issues concerning agriculture and fisheries' vulnerability and adaptation to natural hazards need to be studied. Considering the impact of the tsunami on the country's tourism industry and its economy, the study can help strengthen the underlying causes that enhance vulnerability of fishing and tourism sectors.

Study on local governance system and local social institutions, and their capacities to absorb decentralized community based disaster risk management needs to be taken up.

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