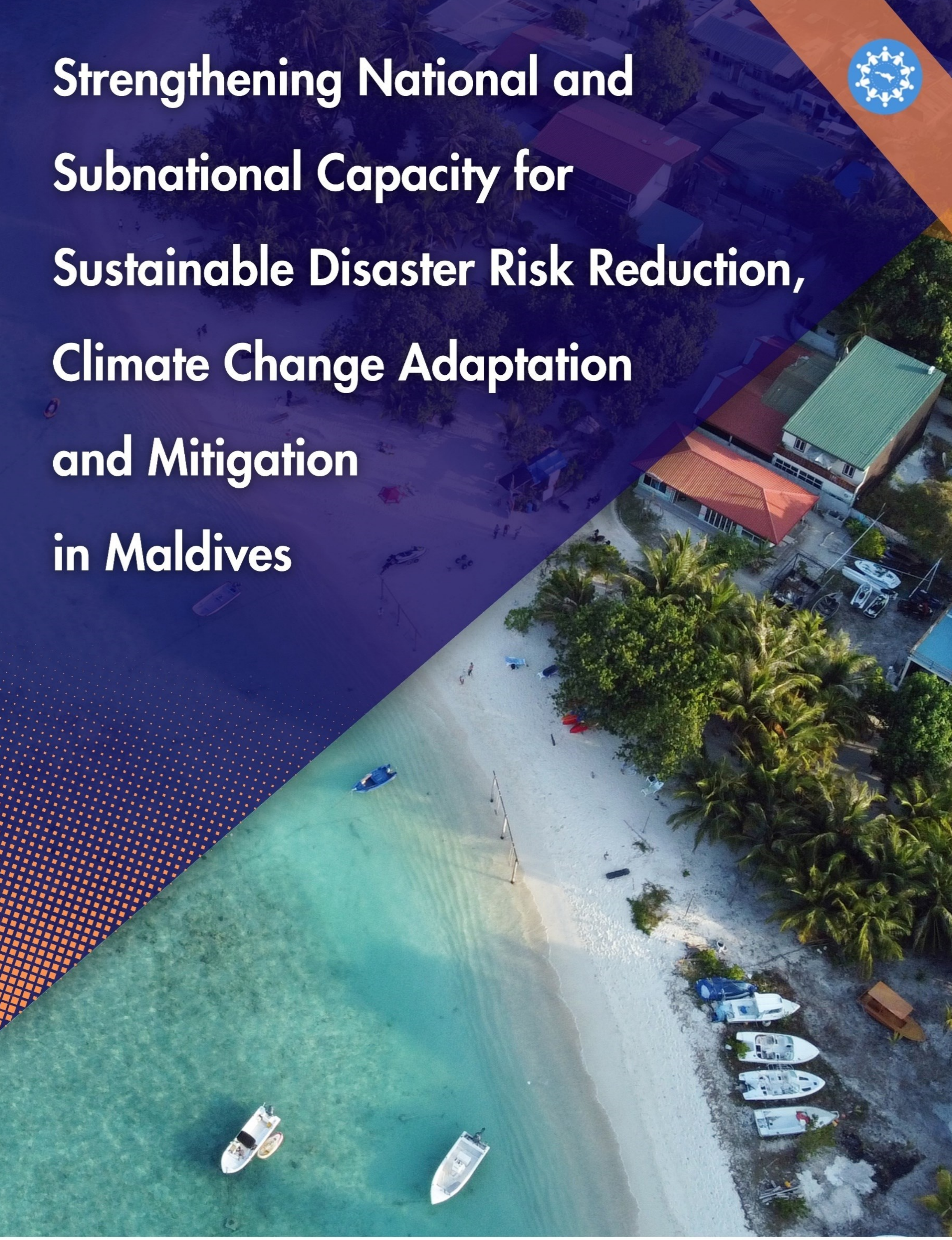
Strengthening National and Subnational Capacity for Sustainable Disaster Risk Reduction, Climate Change Adaptation and Mitigation in Maldives



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Economic and Social Commission for Asia and the Pacific

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JOINT SDG FUND

Strengthening National and Subnational Capacity for Sustainable Disaster Risk Reduction, Climate Change Adaptation and Mitigation in Maldives

Contents

Table of Figures

Figures:

Tables:

Abbreviations

Abbreviations	Full Form
AP-Plat	Asia Pacific Climate Change Adaptation Information Platform
CCA	Climate Change Adaptation
CMIP	Coupled Model Intercomparison Project
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
EU	European Union
ESCAP	Economic and Social Commission for Asia and the Pacific
EWS	Early Warning System
EW4All	Early Warnings for All
GDP	Gross Domestic Product
GHG	Greenhouse Gases
ICT	Information and Communication Technologies
IPCC	Intergovernmental Panel on Climate Change
MPI	Multidimensional Poverty Index
NAPA	National Adaptation Plan of Action
NDC	Nationally Determined Contributions
NDMA	National Disaster Management Authority
NAPA	National Adaptation Plan of Action (NAPA)
kW	Kilo Watts
RCP	Representative Concentration Pathway
SAP	Strategic Action Plan
SDG	Sustainable Development Goals
SIDS	Small Island Developing States
SSP	Shared Socio-economic Pathways
SSWA	South and South-West Asia
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
UNSDCF	United Nations Sustainable Development Co-operation Framework
USD	United States Dollar
WMO	World Meteorological Organization

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Foreword

Asia and the Pacific are experiencing some of the greatest threats of climate change-induced disasters. Over the past decades, floods, tropical cyclones, heatwaves, droughts, and earthquakes have become more frequent and intense, leading to terrible losses of lives, displacing communities, damaging people's health, and pushing millions into poverty. Immediate collaborative action is required to prevent and respond to disaster risks before climate resilience becomes unfeasible.

The Maldives, as a low-lying island nation, is among the most vulnerable countries in the world with respect to the impacts of climate change and natural hazards. As a Small Island Developing States (SIDS) with a population of over 500,000, dispersed across 186 administrative islands and spread over roughly 90,000 square Km, the country faces significant challenges in delivering public goods and services. Given the nation's stark challenges from natural hazards and climate change, the United Nations Sustainable Development Co-operation Framework (UNSDCF) 2022 - 2026 dedicates its strategic priority to a sustainable and climate-resilient environment. It envisions that by 2026, national and sub-national institutions and communities in the Maldives, particularly at-risk populations, will be better able to manage natural resources and achieve enhanced resilience to climate change and disaster impacts, natural and human-induced hazards, and environmental degradation with the support of UN-led interventions.

United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) and the United Nations Development Program (UNDP) are collaboratively implementing a two-year Joint SDG fund project, "*Strengthening National and Subnational Capacity for Sustainable Disaster Risk Reduction, Climate Change Adaptation and Mitigation in Maldives*." This program aims to anchor Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) at the heart of national and subnational development planning to ensure better achievement of SDGs and Agenda 2030 in the Maldives.

This report provides a comprehensive description of the anticipated climate risks in the Maldives for hazards like flood, storms, and sea level rise and their possible impacts on the population and socio-economy of the Maldives based on the high-resolution climate projection information. The report also highlights some potential adaptation strategies for climate hazards and suggestive ways to integrate the outcome with the policies and actions related to DRR and CCA.

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Director of the South and South-West Asia Office
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Acknowledgments

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The report is prepared by Prangya Paramita Gupta and Leila Salarpour Goodarzi under the supervision of Sanjay K. Srivastava and Rajan Sudesh Ratna. Technical inputs were provided by Udit Rana. Sakshi John contributed to the formatting and editing of the report as well as the design of the cover page. In addition, Vivan Sharma contributed to the final proofreading of the report, and Naina Tanwar supported the team in editing the executive summary.

This report was prepared as a part of a joint program between ESCAP and the UNDP Maldives under the Joint SDG-fund project "Strengthening National and Subnational Capacity for Sustainable Disaster Risk Reduction, Climate Change Adaptation and Mitigation in the Maldives."

All joint programs of the Joint SDG Fund are led by UN Resident Coordinators and implemented by the agencies, funds and programmes of the United Nations development system. With sincere appreciation for the contributions from the European Union and Governments of Belgium, Denmark, Germany, Ireland, Italy, Luxembourg, Monaco, The Netherlands, Norway, Portugal, Republic of Korea, Saudi Arabia, Spain, Sweden, Switzerland and our private sector funding partners, for a transformative movement towards achieving the SDGs by 2030.

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Executive Summary

As a low-lying small island, the Maldives is under serious threat from climate change and related hazards, which affects its natural environment, economic development, and well-being of its people. This island nation is highly vulnerable to diverse extreme weather events such as floods, sea-level rise, storm surges, and coastal erosion. Climate change has visibly increased the frequency of these events in recent decades, highlighting the urgent need to understand future climate patterns for developing effective adaptation plans.

Since 1950, the Maldives, already a hot tropical country, has been witnessing climate change through further increases in temperature. The increase in maximum and minimum temperature has been sharper in recent decades (1991-2020) mainly due to GHG emissions and socioeconomic development with frequent occurrences of high temperature-related extreme events. The IPCC's sixth assessment report highlights that temperature is likely to increase in the 21st century with probabilities of heat extremes. The increase is greater in the higher emission scenarios and for a longer term. It is likely to increase more in the northern and central atolls. The increase in average temperature may go up to 1.4°C under SSP2 4.5 and 1.6°C under SSP3 7.0.

According to the downscaled CMIP6 climate projection data, the annual precipitation is likely to increase across the country until 2100. The increase is greater in the higher emission scenarios. The central region of the country, including the capital city, is likely to receive the highest rainfall, with an enhanced risk of floods and related events. For the northern atolls (Haa Alifu, Haa Dhaalu, Raa, Shaviyani, Noonu, and Raa atoll) the increase in total annual rainfall is the highest. For the southern atolls, including Gaafu Alifu, Gaafu Dhaalu, Gnaviyani, and Seenu atolls, rainfall is likely to decrease.

The sea level anomaly is projected to go above 1m by 2060 under the SSP3 7.0 across the country compared to the level of 2014. The probable rise in sea level is high around the northern and eastern parts of the central atolls and relatively low towards the southern atolls. The northern and central atolls may experience an increase in sea level up to 0.95 m by 2040 and further up to 1.06m and 1.08m by 2060 under SSP2 and SSP3 scenarios, respectively. This trend suggests continuation, accompanied by more intense but less frequent tropical cyclones. With 80 per cent of land below sea level, the increasing threat of sea level rise is particularly significant for the low-lying areas, exacerbating problems such as saltwater intrusion. Critical infrastructures are at significant risk compounded by limited resources, intensifying the challenges posed by sea level rise.

The impacts of climate change are unevenly distributed across sectors and populations, with pre-existing vulnerabilities making it challenging to prepare for and cope with the changes. In addition to directly affecting the population, climate change threatens agriculture, critical infrastructures, and energy sectors. Highly populated areas in the Maldives, such as Malé, are expected to experience increased rainfall, temperature, and the impacts of sea level rise, with the population exposure to very high rainfall increasing under higher emission scenarios. `The central atolls' major agricultural areas will likely face more rain and related impacts.

Climate-induced disaster risk can outpace the country's resilience. Hence, risk-informed adaptation measures targeted at vulnerable sectors and communities can help avoid losses caused by disasters and enhance the resilience of the country. Identifying the priority areas and continued investment in those areas is needed to strengthen disaster resilience locally and nationally. Policy decisions based on science and evidence can enhance their social and economic outcomes.

Chapter 1: Introduction

1.1 Background and Context

Climate change is a multifaceted phenomenon that affects the Earth's climate system in various ways. According to the United Nations Framework Convention on Climate Change (UNFCCC), climate change is defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods.[1]" Since the 1800s, human activities have been the main driver of climate change primarily due to the increasing amount of greenhouse gases in the atmosphere. The burning of fossil fuels for different uses (e.g., energy production, industry use, and transportation, as well as landuse changes, agriculture, and waste management[2]) is the principal cause.

The current level of atmospheric carbon dioxide, the main greenhouse gas, is higher than at any point in the past 800,000 years[3]. The global average temperature has risen by about 1.1°C since the pre-industrial period[4], and according to the World Meteorological Organization (WMO), the past eight years were the warmest on record globally, fueled by ever-rising greenhouse gas concentrations and accumulated heat[5]. The effects of climate change are already being felt across the world. The frequency of extreme events has increased, affecting the population, especially the vulnerable ones. These effects are observable in many socioeconomic aspects, such as human health, food security, water availability, biodiversity, and livelihoods. As per the IPCC's Sixth Assessment Report, some of the observed and projected impacts of climate change include:

- Rising sea levels due to the thermal expansion of seawater and melting glaciers and ice sheets threaten coastal communities and low-lying islands with flooding, erosion, saltwater intrusion, and displacement.
- Changing precipitation patterns are causing more frequent and intense droughts and floods and are affecting water resources, agriculture, ecosystems, and human settlements.
- The increase in the frequency and intensity of extreme weather events, such as heat waves, storms, hurricanes, and wildfires, causes deaths, injuries, damage to life and properties, and disruptions in services.
- The increase in snow and ice melting causes a reduction in freshwater availability, affecting hydroelectric power generation and irrigation and altering wildlife habitats and migration patterns.

[1] "United Nations Framework Convention on Climate Change."
[2] "Climate Change | United Nations in Thailand."
[3] Intergovernmental Panel on Climate Change, "Climate Change Widespread, Rapid, and Intensifying."
[4] Intergovernmental Panel on Climate Change, "Climate Change 2021: The Physical Science Basis."
[5] World Meteorological Organization, "Past Eight Years Confirmed to Be the Eight Warmest on Record."

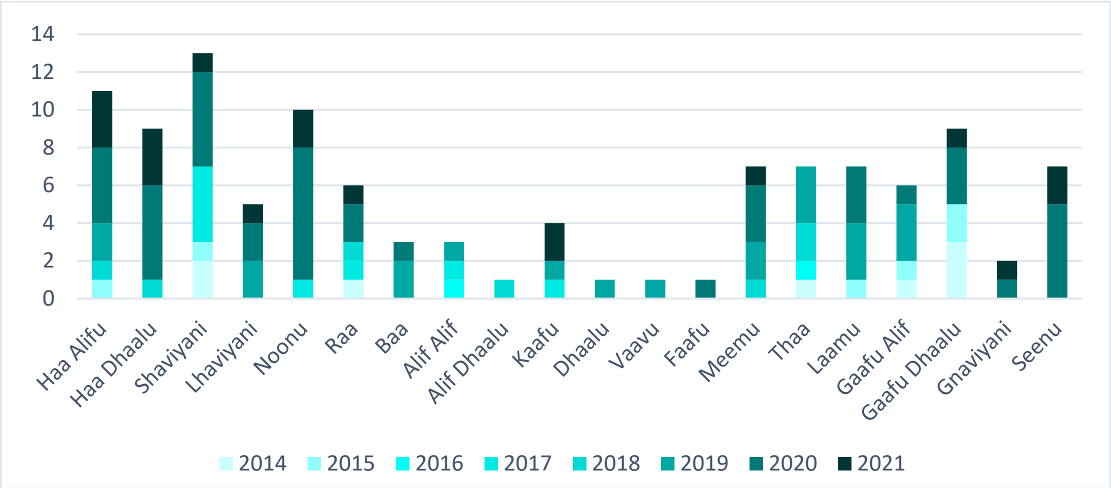
- Shift of climatic zones and seasons affects the distribution and productivity of crops, livestock, fisheries, and forests, increasing the risks of pests, diseases, and invasive species.
- A decline in biodiversity and change in the ecosystem due to the loss, fragmentation, and degradation of habitats can result in species extinction and the disruption of ecological functions, such as pollination, carbon sequestration, and water purification.

Maldives is one of the most vulnerable countries to the impacts of climate change due to its low elevation, small size, dispersed geography, and exposure to multiple climate hazards such as sea-level rise, storm surges, coastal erosion, saltwater intrusion, coral bleaching, and ocean acidification. Therefore, climate change is a serious threat to the Maldives; it affects its natural environment, economic development, and people's well-being. The trend of extreme events in the past decade suggests that many areas in the Maldives are experiencing more intense tropical cyclones, storms, and related surges. The number of precipitation-related floods and water scarcity has increased in many of the atolls in recent years[6].

Such environmental changes may cause devastating consequences for the Maldives. Loss of land and infrastructure, as sea-level rise and storm surges can inundate and damage the islands, roads, bridges, airports, harbours, and buildings. According to the World Bank, the Maldives could lose up to 13% of its GDP by 2100 due to coastal flooding[7].

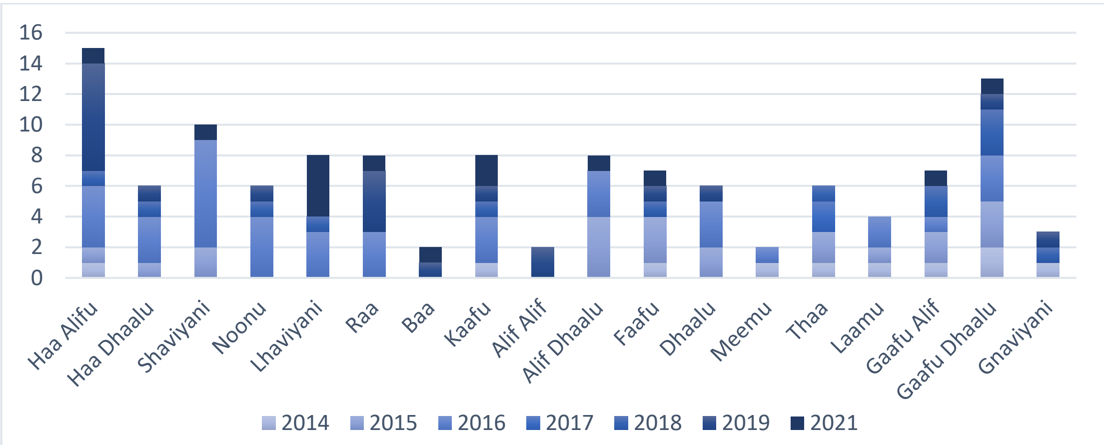
[6] NDMA database
[7] World Bank Group and Asian Development Bank, “Climate Risk Country Profile.”

Figure 1.1: Number of cyclones, storms & surges in the Maldives during 2014 – 2021



Source: NDMA, Maldives

Figure 1.2: Number of rainwater floods in the Maldives during 2014 – 2021



Source: NDMA, Maldives

Tourism is one of the main industries in the Maldives, sharing 21.4% of the national GDP while accounting for a substantive share of employment. According to the United Nations, the Maldives received about 1.7 million tourists in 2019, generating about USD 2.8 billion in revenue. However, climate change could reduce the number of tourists by up to 30% by 2100, resulting in a loss of about USD 1.2 billion annually[8].

Fisheries and agriculture are essential sectors for many rural communities and can be affected by climate change-related impacts such as flooding, water scarcity, sea level rise, and saltwater intrusion. According to the Food and Agriculture Organization, the Maldives produced about 149,000 tons of fish in 2018, providing food and income for about 30,000

[8] Hosterman and Smith, "Economic Costs and Benefits of Climate Change Impacts and Adaptation to the The Maldives Tourism Industry."

people. Climate change could reduce fish catch by up to 12% by 2050, affecting the food security and nutrition of the population as well as their economic capacities.

Another challenge is the loss of health and safety, as climate change can increase the risks of waterborne, vector-borne, and heat-related diseases, as well as injuries and fatalities from extreme weather events. The Maldives has experienced extreme weather events recently, such as the 2004 Indian Ocean tsunami and the 2016 El Niño-induced drought. Such events accounted for 45% of deaths and 79% of Maldives' economic losses between 1988-2007[9].

1.2 Objectives of the Report

As discussed, the Maldives is among the most vulnerable countries in the world to the impacts of climate change and natural disasters, and virtually every aspect of socioeconomic development in the island nation is impacted by the negative impacts of climate change. Despite this vulnerability, there is limited practice of holistic and risk-informed development and sectoral planning. Comprehensive (multi-sectoral, multi-hazard, and coherent), inclusive (people-centered, multi-stakeholder, human rights, and gender-sensitive), and evidence-based approaches to Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) planning and execution at national and subnational levels are not yet institutionalized and practically operationalized.

With this purview, one of the main targets of the joint SDG-funded project on "Strengthening National and Subnational Capacity for Sustainable Disaster Risk Reduction, Climate Change Adaptation and Mitigation in The Maldives" was to enhance the capacity of national and subnational institutions and communities to develop resilience against the impacts of natural and human-induced disasters, climate change and environmental degradation by integrating DRR and CCA into the planning and execution of activities at all levels. As a part of this project, ESCAP has updated the climate risk profile of The Maldives based on the latest climate projection scenarios and downscaled database suitable for national and sub-national analysis. The assessments in these reports are based on scientific research and are intended to inform decision-making related to climate change adaptation and mitigation.

The objective of this report is -

- To provide a comprehensive perspective on the assessment of potential future climate conditions based on various scenarios and models.
- To demonstrate the potential impacts of the projected changes on climate-sensitive sectors and the population.
- To help the government and non-government sectors at all levels understand and prepare for potential changes in climate for risk-informed planning.

This document is a complementary addition to the full data and maps which can be accessed through the partners and ESCAP Risk and Resilience Portal.[10]

[9] United Nations Office for Disaster Risk Reduction, "Disaster Risk Reduction in Republic of The Maldives."
[10] Link to RRP Maldives page

Chapter 2:

Country overview

2.1 Geography

The Maldives is geographically dispersed across the Indian Ocean, forming a unique archipelago of islands and atolls. These atolls are spread over a vast area in the Indian Ocean, covering approximately 90,000 square kilometres. They are surrounded by reefs and cut by several deep, natural channels and lagoons. Within each atoll, the central lagoon is often shallow and surrounded by submerged coral reefs. The archipelago stretches 823 km north to south and 130 km east to west[11]. Based on the data provided by the Land Survey Authority of the Government of Maldives (2021), currently, there are 1555 coral islands within 26 naturally formed Atoll systems grouped into 21 administrative atolls, including Malé City[12]. Among these islands, only 189 are inhabited. The islands vary in size, ranging from small uninhabited islets barely large enough to support vegetation to larger islands with communities and infrastructure. The area of the inhabited islands ranges from approximately 0.06 to 6 km^2. The distribution of islands within each atoll also varies, with some atolls having most of the islands located on the periphery of atolls, whereas others have islands spread across the atoll.

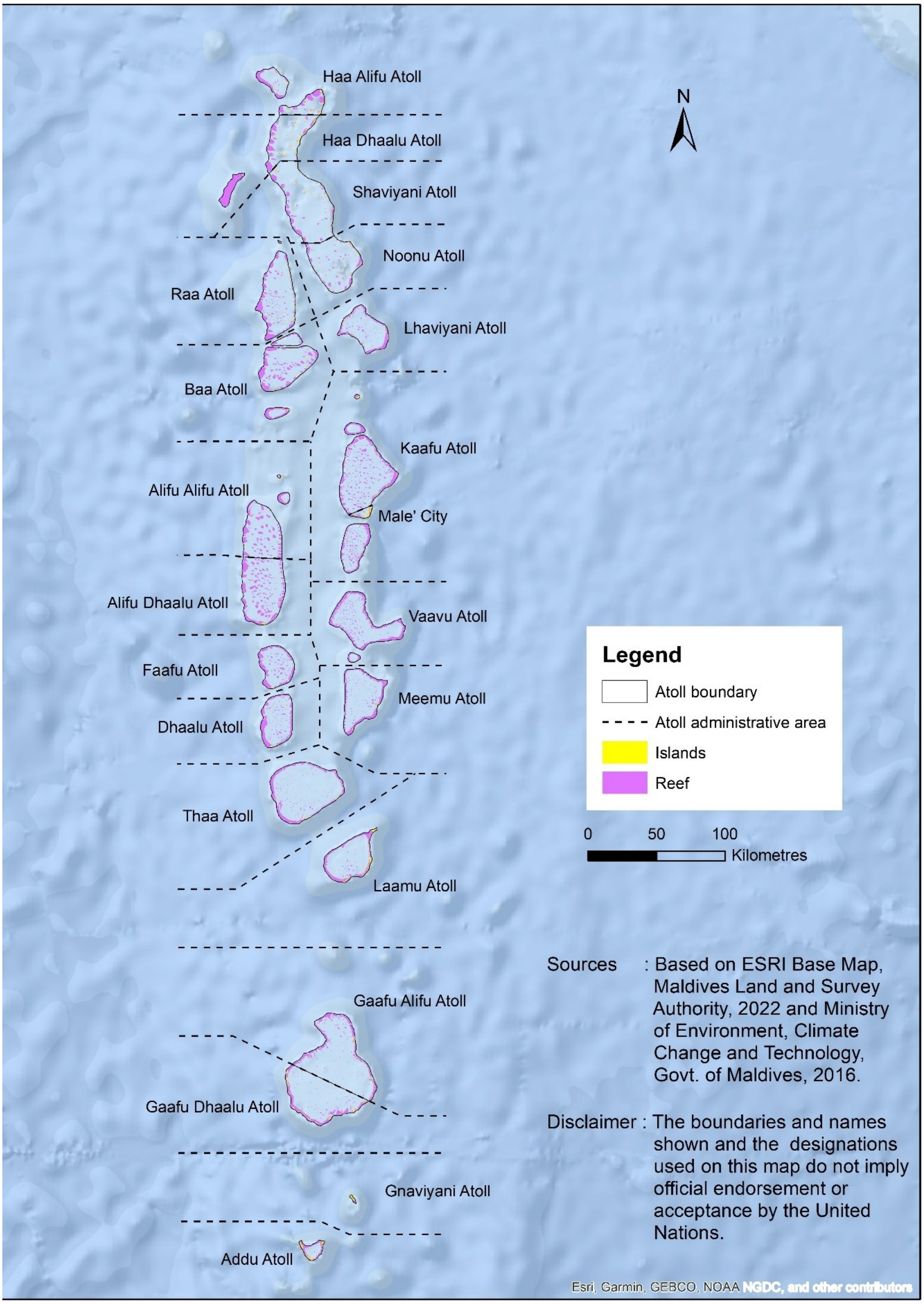
The islands of the Maldives are predominantly flat and sandy, with lush tropical vegetation, coconut palms, and mangroves. The highest point in the Maldives is only about 2.4 meters (7.9 feet) above sea level, making it one of the lowest countries in the world in terms of natural elevation[13].

[11] The Maldives National Disaster Management Center and Asian Disaster Reduction Center. Aminath Shaufa, Project Officer. 2018. https://www.adrc.asia/countryreport/ MDV/2018/The Maldives_CR2018A.pdf

[12] Land Survey Authority, The Maldives (onemap.mv)

[13] ADB2020. Multi-hazard risk atlas of The Maldives

Figure 2.1: Administrative map of The Maldives

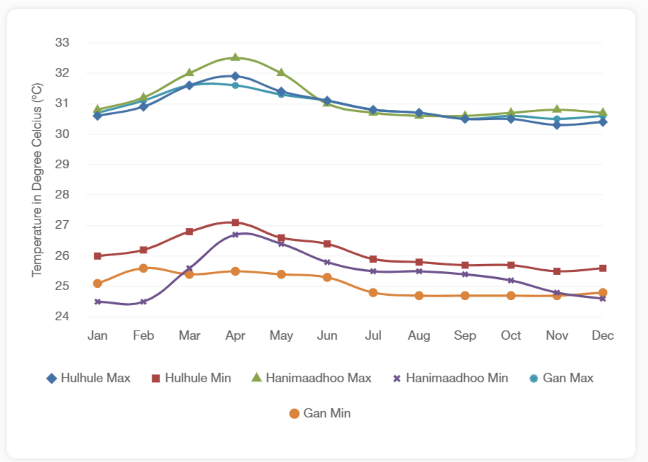


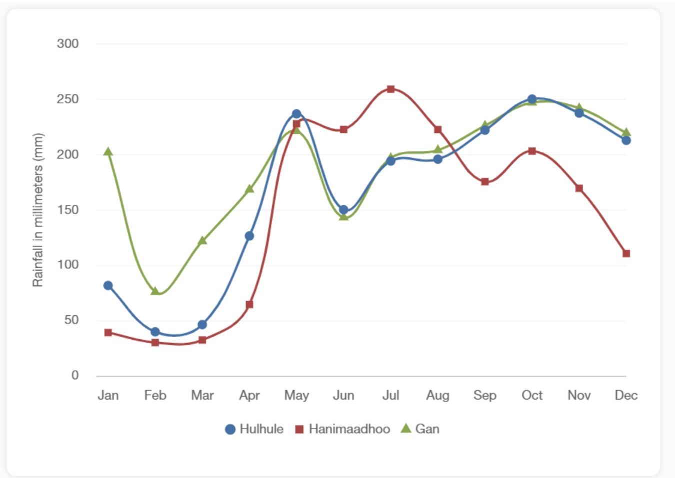
2.2 Climate

The Maldives has a warm and humid tropical climate. The average daily temperature ranges from 25°C (minimum) to 32°C (maximum), with a slight variation throughout the year. The Maldives has two distinct seasons guided by a monsoon climate. The South-West monsoon (wet-season) extends from mid-May to November, and the northeast monsoon (dry-season) extends from January to March. Months in between are considered monsoon transitional periods.

The warmest period in Maldives starts in March and may extend till mid-May until the onset of the South-West monsoon. The highest and lowest temperatures ever recorded in Maldives are 36°C (1991) and 18.2°C (2002), respectively. The annual average rainfall is about 2,130 millimetres. Southern atolls receive more rainfall than northern and central. On average, the southern atolls receive about 2,218 mm of rainfall per year, while the central and northern atolls receive 1,966 mm and 1,779 mm, respectively[14]. Figure 2.2 shows the trend in annual average temperature and total annual precipitation for three weather stations (Hulhule in the centre, Hanimaadhoo in the north, and Gan in the south) of the country.

Figure 2.2 Trend in annual average temperature (top) and total annual precipitation (bottom) in Maldives[14]





[14] https://www.meteorology.gov.mv/climate

2.3 Landuse/ Land Cover

The coral islands of Maldives are generally low-lying landforms, and they are developed from unconsolidated sediment generated by carbonate-producing organisms within the surrounding marine environments[15]. These islands are highly dynamic and adjust their shorelines depending on the changing environmental conditions. The number of islands also changes due to the natural formation of new islands as well as reclamation from the reefs.

The type of landuse and land cover in Maldives depends on the nature of the islands. The islands in Maldives have three broad categories for landuse and land cover, namely, inhabited, uninhabited, and resort islands[16]. Here, landuse is referred to as the human use of lands for socioeconomic purposes, for example, residential, agriculture, recreational areas, and industries, whereas land cover refers to physical cover (natural or man-made) on the Earth's surface, such as vegetation, water, snow, grass, and bare soil. As the name suggests, the uninhabited islands do not have any man-made infrastructures. Currently, there are 1365 uninhabited islands in the Maldives[17]. They are mainly occupied by tropical vegetation, including forests, bushes, shrubs, bare soil, and sandy beaches. The 189 inhabited islands[17] accommodate the urban or rural areas of local communities of Maldives, including industrial areas. Apart from that, the major landuse/ land cover categories in the Maldives include the following: agricultural area, vegetation (forests, palms, and shrubs), sandy beach, bare soil, wetlands, airports, and harbour. Not all the Islands have agricultural activity in them; however, there are some dedicated islands for agriculture in the Maldives, such as Thoddo and Kaashidhoo. The resort islands are dedicated to tourism activities and accommodation.

2.4 Socio-Economy

According to the latest census (2022), the total population of Maldives is 515,132, of which 311,994 are male and 203,138 are female. Around 41% of the total population (211,908) live in the capital city Malé. Apart from Malé, other major economic and population centres in the north and south of the country are Kulhudhufushi, Gan, and Addu City. Women, children and adolescents, migrants, the elderly, and people with disabilities are the main vulnerable groups in terms of disaster impacts.

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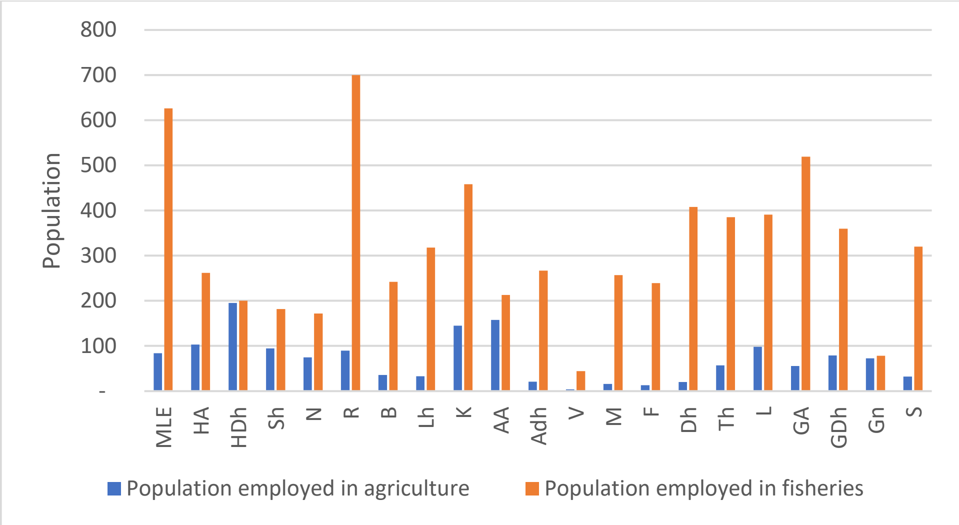
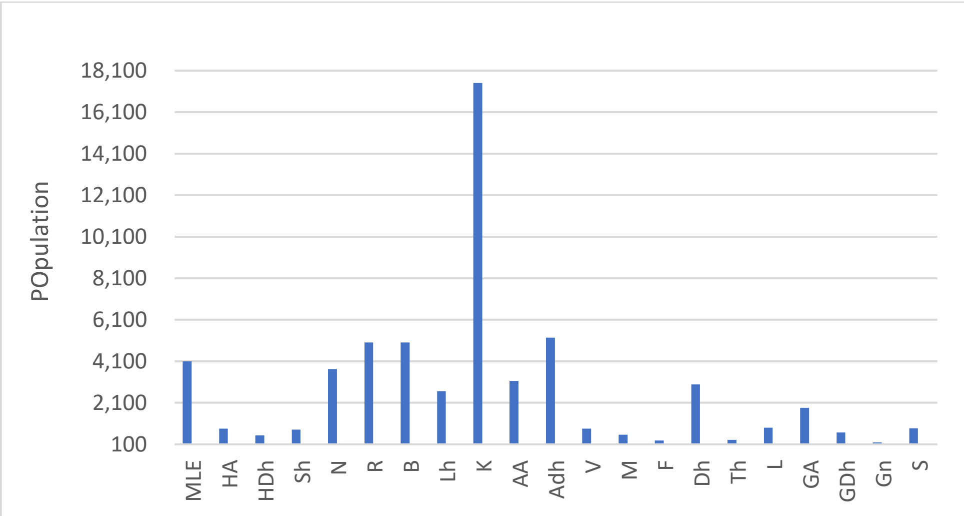
[15] Carruthers et al. 2023. Coral reef island shoreline change and the dynamic response of the freshwater lens, Huvadhoo Atoll, Maldives Front. Mar. Sci. 10:1070217. doi: 10.3389/fmars.2023.1070217

[16] Fallati et al. (2017) Landuse and land cover (LULC) of the Republic of the Maldives: first national map and LULC change analysis using remote-sensing data. Environ Monit Assess, 189:417.

[17] Maldives Land Survey Authority 2022. Available online Onemap.mv (accessed in October 2022).

Figure 2.3 Population employed in agriculture and fisheries (top) and tourism (bottom) in Maldives [18]





The Maldives is a higher middle-income country[19]. The main economic sectors in Maldives are Fishery and Tourism. Like other SIDS, Maldives is constrained by the absence of mineral resources, and the limited land resources also inhibit the scope of expansion of agriculture in Maldives. Although the contribution to the national GDP from fisheries and agriculture is relatively lower (around 4.1% and 1.2%, respectively), these sectors remain a significant source of rural livelihoods and play an important role in domestic food and nutrition security. The population employed in Fisheries (~6700) is significantly higher than in agriculture (~1500) (Figure 2.3). The tourism sector has the largest percentage share of GDP (21.4%). Tourism employs around 22,000 people in these sectors[20]. Kaafu Atoll has the highest number of population employed in the tourism sector.

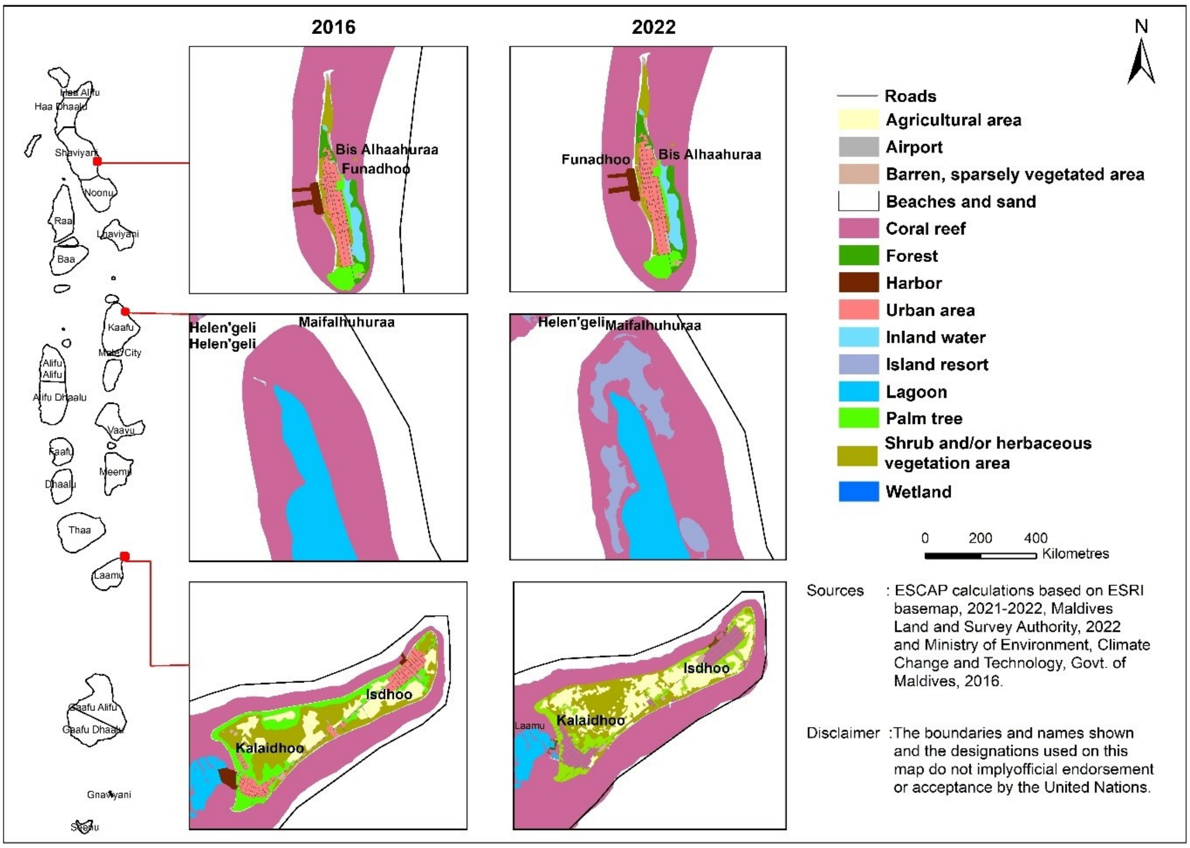
[18] Population and Housing Census, 2022, Maldives Bureau of Statistics
[19] Disaster management handbook 2021.
[20] https://statisticsmaldives.gov.mv/nbs/wp-content/uploads/2022/10/Annual-GDP-production-2022.pdf

Chapter 3:

Landuse and Land Cover

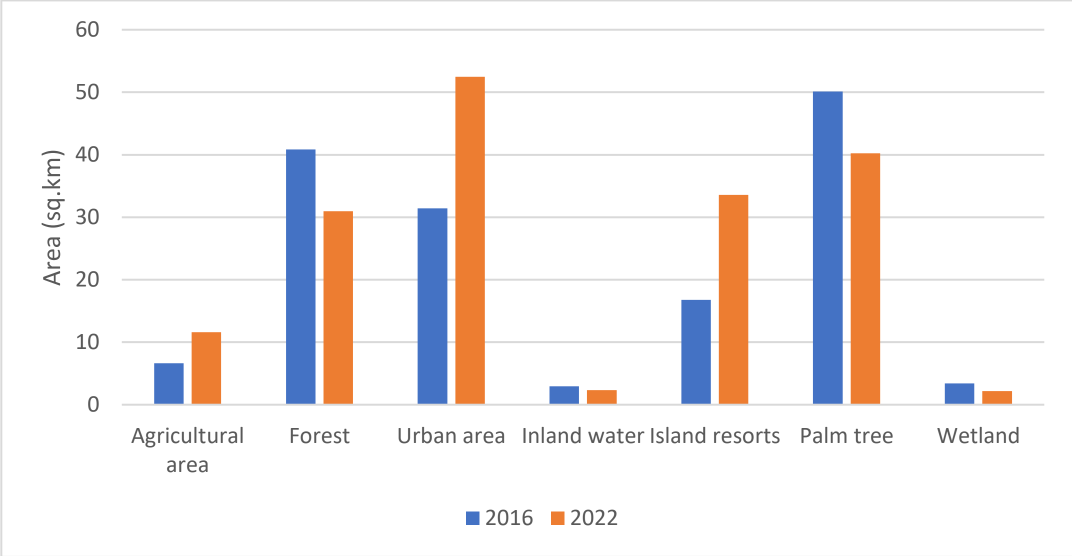
Landuse and land cover have undergone major changes in many of the islands in the Maldives. Most of the changes are related to the expansion of agricultural and urban areas by clearing either the fallow lands or vegetated lands. The number of island resorts has gone up many folds, either by converting the uninhabited islands or reclaiming lands from the coral reefs (Figure 3.1).

Figure 3.1: Examples of landuse and land cover change between 2016 and 2022 in the Maldives



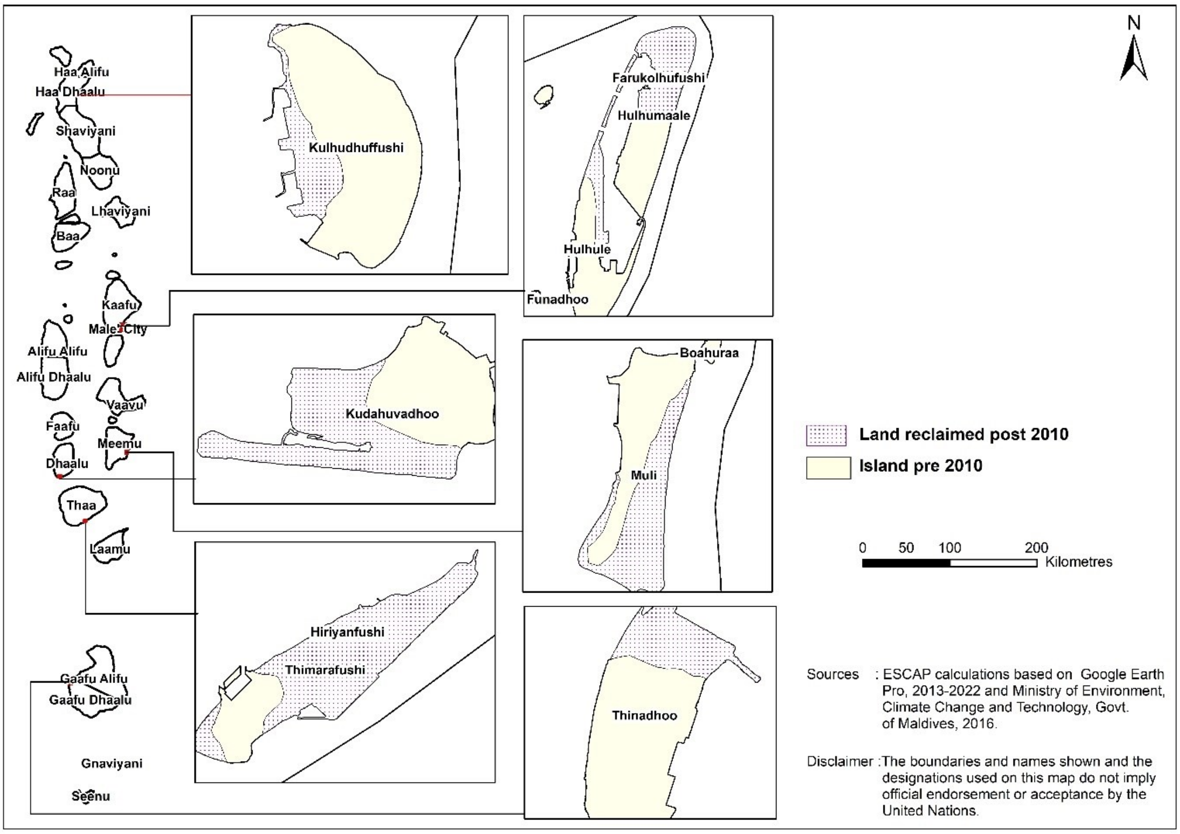
Between 2016 and 2022, agricultural areas increased by 74%, while urban areas expanded by 67%, and there was a 100% increase in the area under island resorts. Eventually, the forest areas, wetlands, and areas under palm trees decreased by 24%, 35%, and 20%, respectively (Figure 3.2).

Figure 3.2: Change in areas of landuse and land cover between 2016 and 2022 in the Maldives



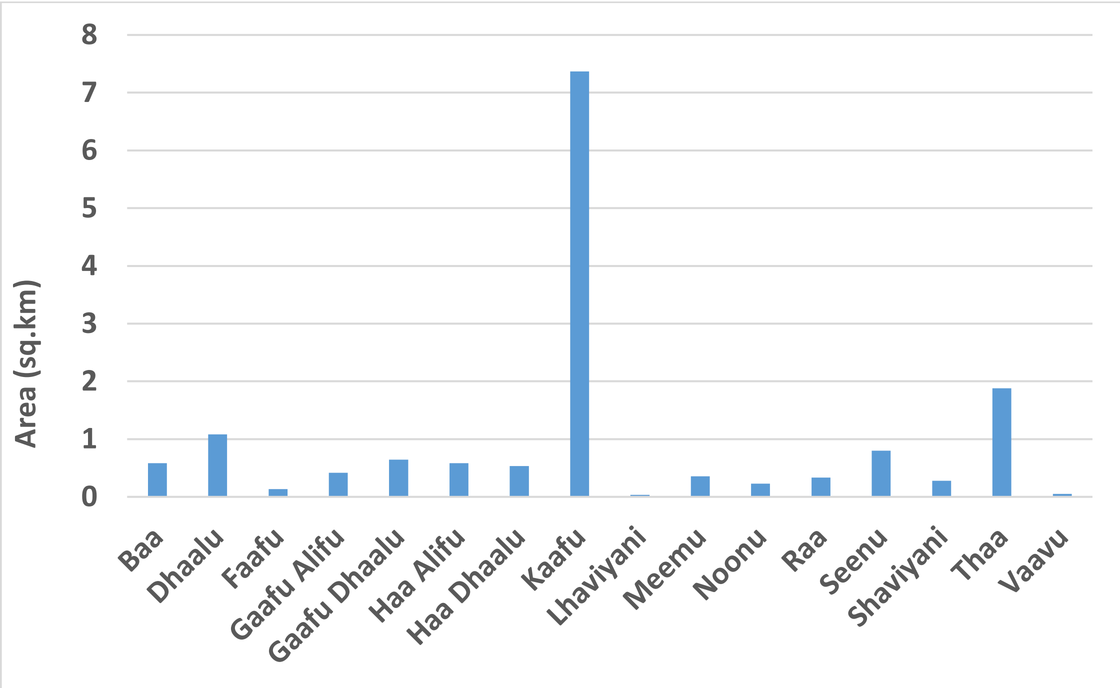
Maximum expansion of agricultural areas is observed in Laamu Atoll (~112%), followed by Alifu Alifu (~98%), Shaviyani (~94%) and Kaafu Atoll (~74%). Except in Haa Alifu, Vaavu, and Thaa Atolls, agricultural areas have increased in all other Atolls between 2016 and 2022. In the case of urban areas, the highest increase is observed in Kaafu Atoll, followed by Seenu, Haa Alifu, Haa Dhaalu, and Gaafu Dhaalu Atoll.

Figure 3.3: Land reclaimed in Maldives post-2010



In many islands, land has been reclaimed from the reefs primarily for the expansion of urban areas. Apart from that, in many atolls, land reclamation is done for tourism (Figure 3.3). Around 15.38 sq. km area has been reclaimed post 2010. Kaafu Atoll will top the list in land reclamation by 2022 (Figure 3.4).

Figure 3.4: Atoll-wise land reclaimed post-2010 in Maldives



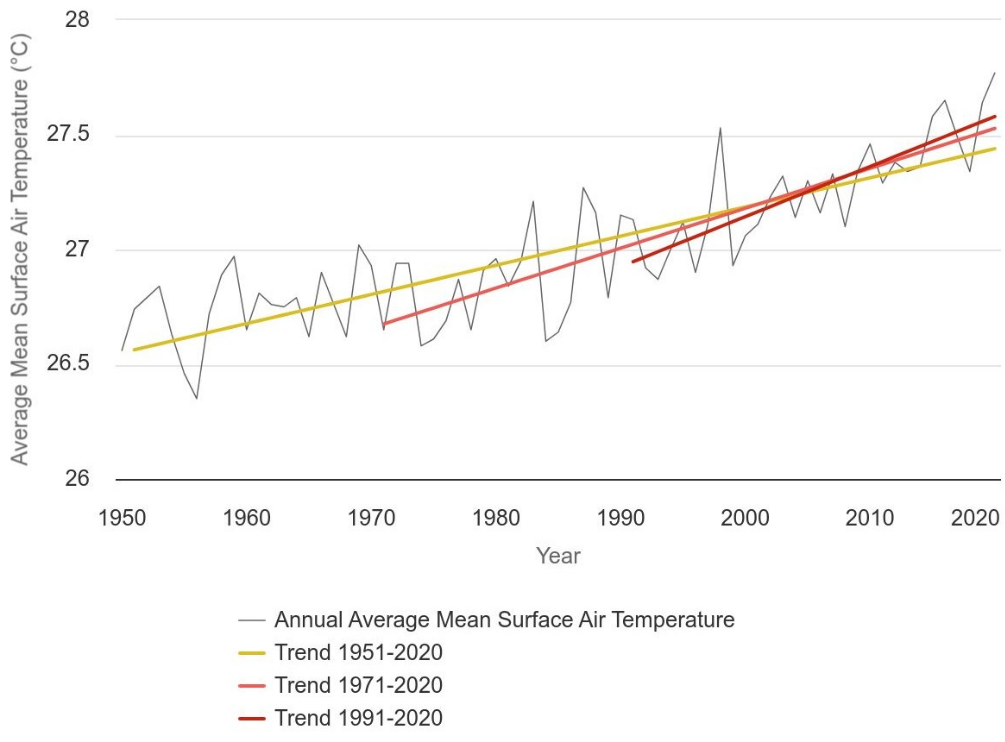
Chapter 4:

Historical Climate

4.1 Temperature

As a consequence of the rise in global temperature, the temperature in Maldives has also been rising over time. The past and current trend of average mean surface air temperature shows a consistently increasing pattern since 1950 (Figure 4.1). However, the increase in temperature in each decade surpasses the increase in the previous decade. As per the IPCC's 6th assessment report, the daily mean minimum temperature increase in the western Pacific region (including Maldives) was observed to be by 0.14°C per decade between 1951 and 2015[21]. However, in recent decades (1990-2020), the average mean surface air temperature has increased by about 1°C[22].

Figure 4.1: Average mean surface air temperature annual trends with significance of trend per decade (1951-2020), Maldives[23]

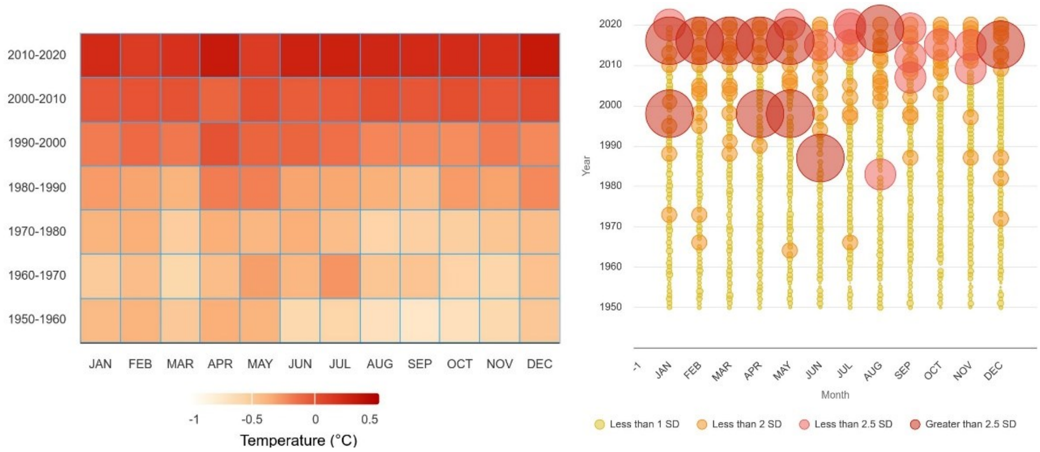


[21] Mycoo, M., M. Wairiu, D. Campbell, V. Duvat, Y. Golbuu, S. Maharaj, J. Nalau, P. Nunn, J. Pinnegar, and O. Warrick, 2022: Small Islands. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2043–2121, doi:10.1017/9781009325844.017

[22] https://climateknowledgeportal.worldbank.org/country/maldives/trends-variability-historical

The monthly trend shows the highest increase in temperature in the pre-monsoon and monsoon months, as well as in December and January over the last decade. The incidence of extreme heat (standard deviation = 2.5) is observed post-1990, and the frequency is highest in the last decade (Figure 4.2).

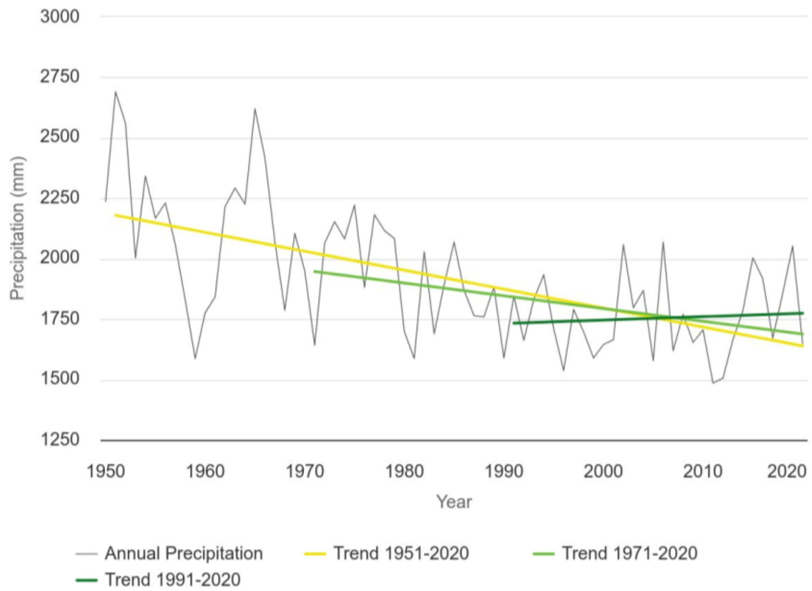
Figure 4.2: Average mean surface air temperature monthly trends 1951-2020 (left) and change in event intensity of maximum of daily max-temperature (1951-2020) (right), Maldives[23]



4.2 Precipitation

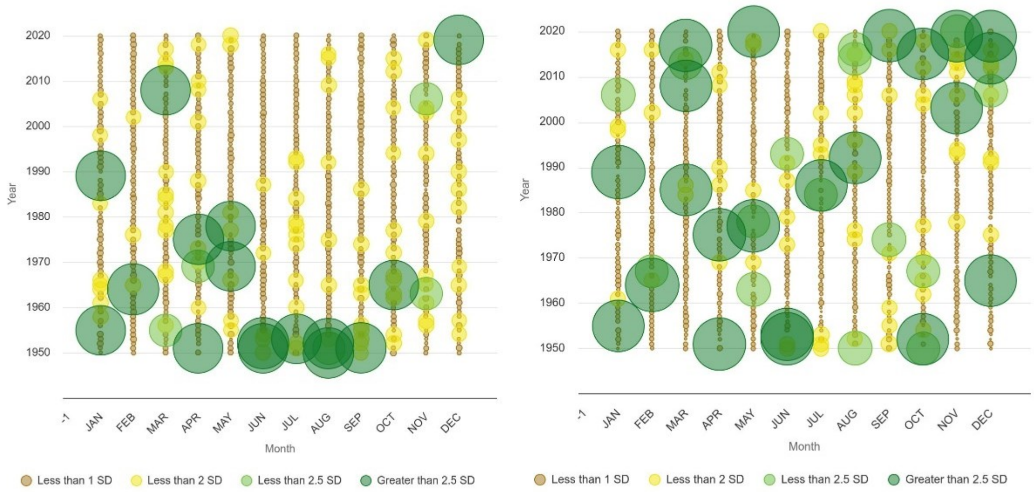
As per the IPCC 6th assessment report, there is no significant trend in precipitation in the region; however, in Maldives, the overall trend in the annual precipitation shows a decreasing pattern since 1950. The decrease is less in the recent decade than in the previous one. Post-1990, a slight increase in the annual precipitation is observed in the Maldives (Figure 3.3).

Figure 4.3: Precipitation annual trends with significance of trend per decade 1951-2020, Maldives[23]



The monthly trend shows that the precipitation variability was higher in the past than in the recent timelines. Currently, the change in monthly precipitation is less than 1 SD from the long-term normal for most of the months. However, a higher change in the intensity of the cumulative largest 1-day precipitation has been observed in recent decades, with the events mostly concentrated in the post-monsoon months (October, November, and December) (Figure 4.4).

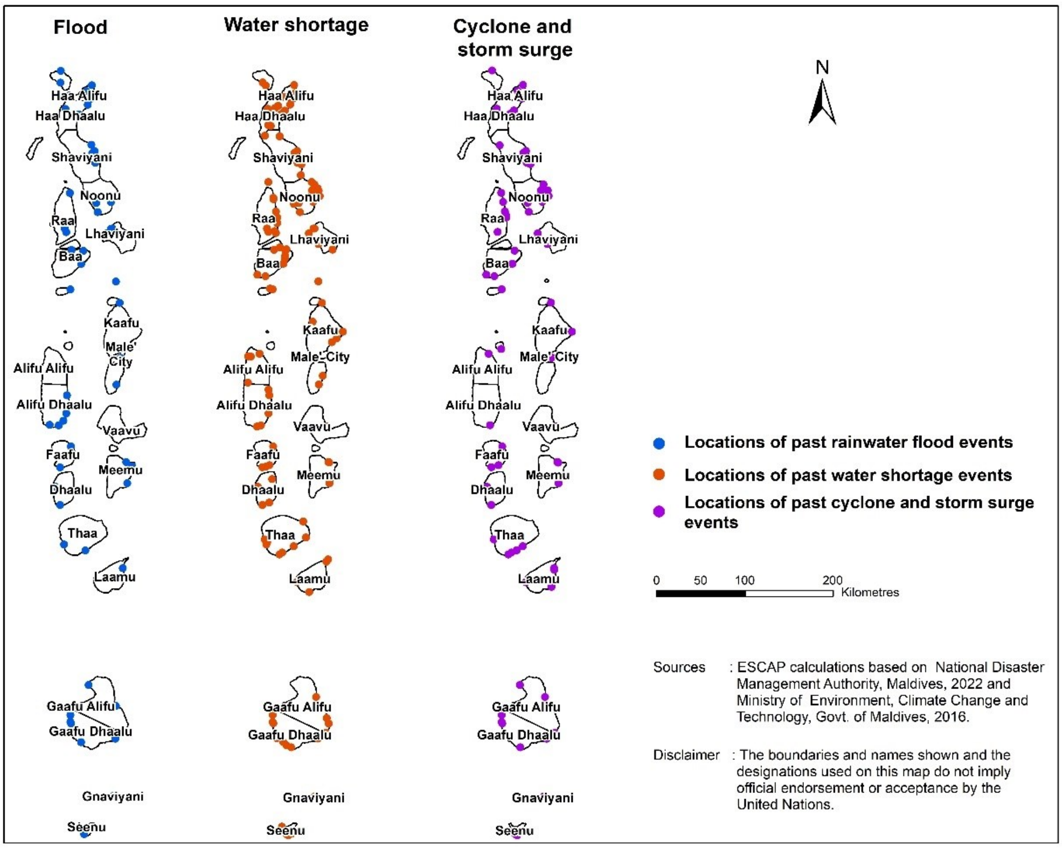
Figure 4.4: Change in event intensity of precipitation (1951-2020) (left) and Change in event intensity of average largest 1-day cumulative precipitation (1951-2020) (right), Maldives[23]



4.3 Past Disasters

Although Maldives is exposed to various climate-related hazards such as heavy rainfall and floods, tropical cyclones, tsunamis, and droughts, the frequency of large-scale events is relatively low. However, small-scale seasonal events such as monsoonal flooding, coastal erosion, saltwater intrusion, and sea surge-related flooding due to sea level rise are recurrent and cause the most damage and losses. Figure 4.1 depicts the location of flood, water scarcity, and cyclone storm surge events in the Maldives. The spatial distribution of the events suggests that the northern part of the country is more at risk of these extreme climate events.

Figure 4.5: Locations of the past hazard events (2014 – 2022)



Chapter 5:

Future Climate Projections

5.1 Overview of the Climate Projection Data Risk Assessment Method

To address the climate change-related challenges in the Maldives, it is important to visualize the risk and plan for adaptation and mitigation pathways. Most of the open-source global data (e.g., IPCC), due to their coarse resolution (100 km grid), cannot capture the local nuances in the climate variability for small island countries like the Maldives, where many of the islands have an area of less than 10 km^2. Hence, there was a need for a downscaled climate projection to understand the risk at the sub-national level. For this purpose, the following tasks were undertaken as part of this study –

- Downscaling CMIP6 climate projection data (100km) to 5 km resolution
- Assess the climate risk for the relevant socio-economic sectors

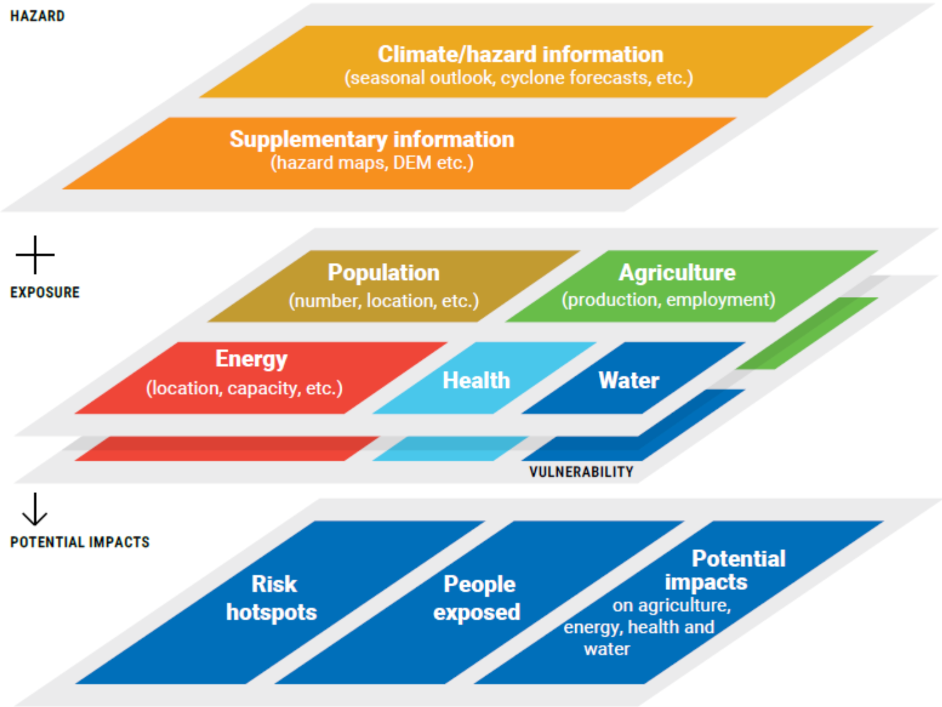
Downscaling CMIP6 data involves the development of sub-national climate projection datasets with 5 km spatial resolution for the Maldives based on global data (100 km spatial resolution). Temperature, precipitation, and surface wind are chosen to understand the future climate risks in different timescales. The data shows the projected spatial variability of temperature, precipitation and surface wind based on the ensemble of ten major climate simulation models namely CanESMS, CNRM-CM6-1, CNRM-ESM2-1, EC-Earth3, GFDL-ESM4, IPSL-CM6A-LR, MIROC-6, MPI-ESM1-2-HR, MRI-ESM2-0 and UKESM1-0-LL.CMIP6 data is developed for five Shared Socio-economic Pathways (SSPs) which are designed based on anticipated changes in the socio-economy along with the climate in the future. Among them, two, namely SSP2 4.5 and SSP3 7.0, were chosen for this study. SSP2 4.5 is considered the business-as-usual scenario as it represents the current socio-economic development pattern and related emissions. SSP3 7.0 is considered the worst-case scenario as it depicts a scenario where both adaptation and mitigation are challenging. Three different timescales were chosen for this study, namely Baseline (1981-2000), near-term (2021-2040) and mid-term (2041-2060). The downscaled data on the climate variables were developed by the Asia Pacific Climate Change Adaptation Information Platform (AP-Plat).

For sea level rise, ensemble climate projection data from the IPCC has been used for the same scenarios and timelines mentioned above. The baseline (2014) for sea level rise includes monthly mean global estimates of sea level anomaly based on satellite altimetry measurements for a twenty-year mean reference period (1993-2012). The baseline of sea level anomaly is kept as 2014 to keep the coherence with the IPCC baseline periods. The analysis identified the areas that could potentially be affected by high precipitation, temperature, surface wind, and sea level rise.

The climate risk assessment has been carried out based on the downscaled climate projection data. The hazard trends are assessed for each variable, each scenario, and each period. The hazards are categorized based on the range of values into low, medium, and high hazard risk. The exposure analysis is done by overlaying the gridded hazard data of low, medium, and high categories with the sectoral data using the methodology demonstrated in Figure 5.1.

For population exposure, gridded population data from WorldPop was used. Population exposure values are determined by overlaying the spatial variation of the 100-meter gridded population layers on the different hazard risk zones. The data on the agricultural areas and the critical infrastructures were developed using satellite images and subsequently overlaid with different hazard risk zones to assess the exposure.

Figure 5.1 Climate risk assessment methodology using downscaled climate projection data



5.2 Future Climate Projections, Projected Trends, and Hazard Risk Hotspots

5.2.1 Precipitation

The climate projection data suggests that the total annual rainfall is likely to increase across all the climate change scenarios compared to the baseline period. The average increase in rainfall is likely to be around 80mm, although the spatial distribution varies in different regions of the country. Figure 5.2 shows the trend in total annual rainfall under baseline and climate change scenarios in Maldives.

Figure 5.2 Trend in total annual rainfall under baseline and climate change scenarios in Maldives

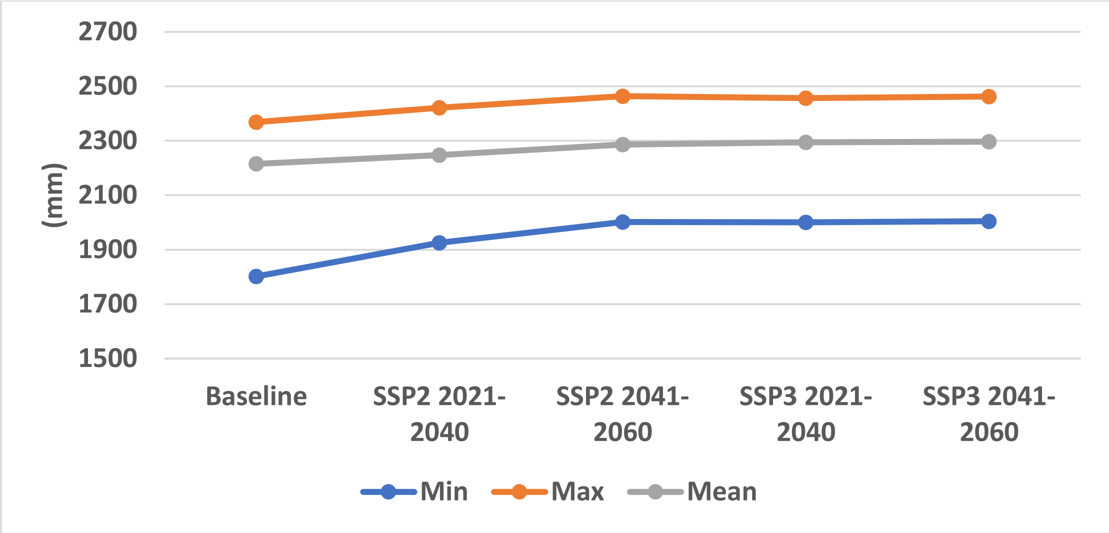
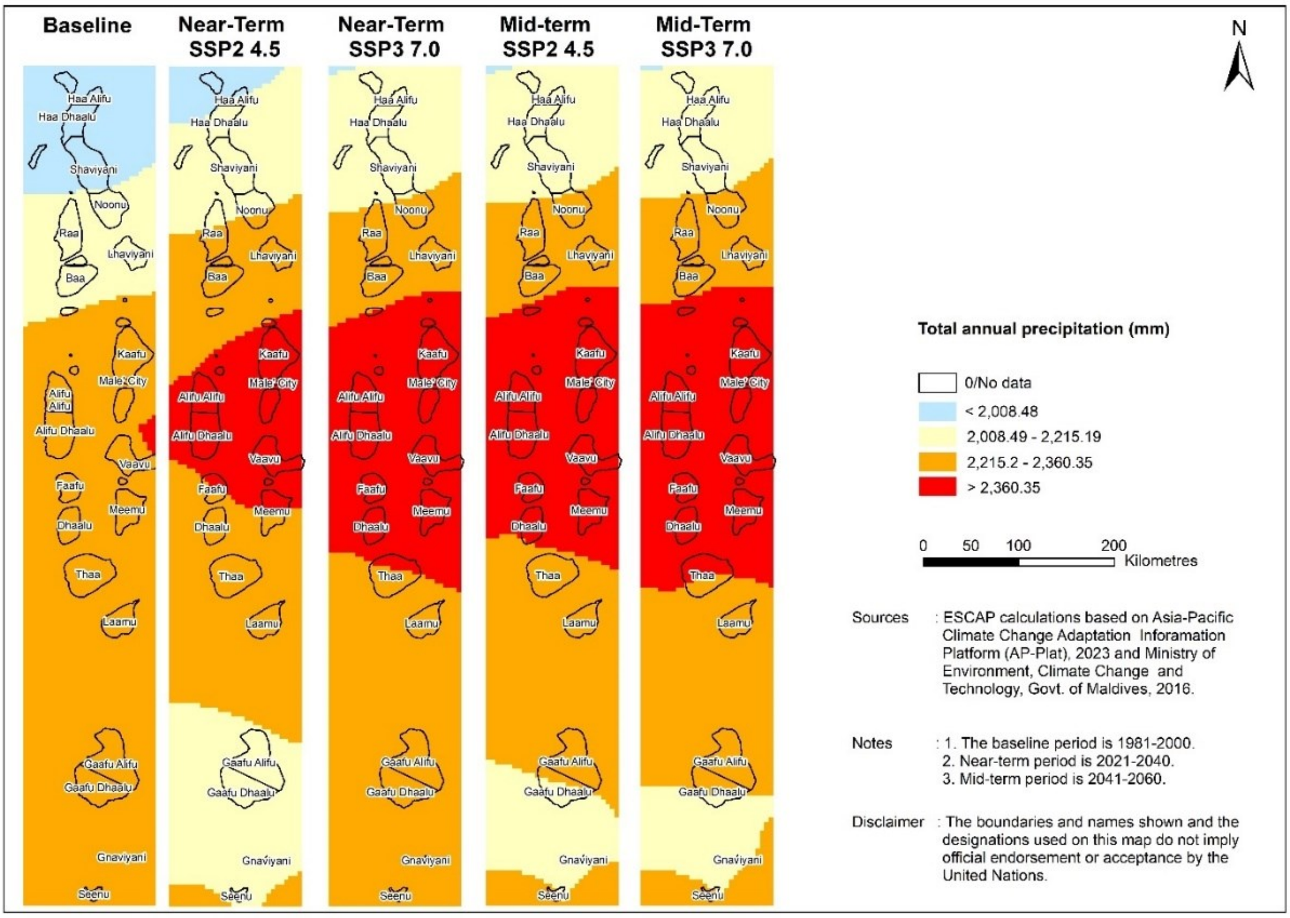


Figure 5.3 Spatial distribution of total annual rainfall under baseline and climate change scenarios in Maldives



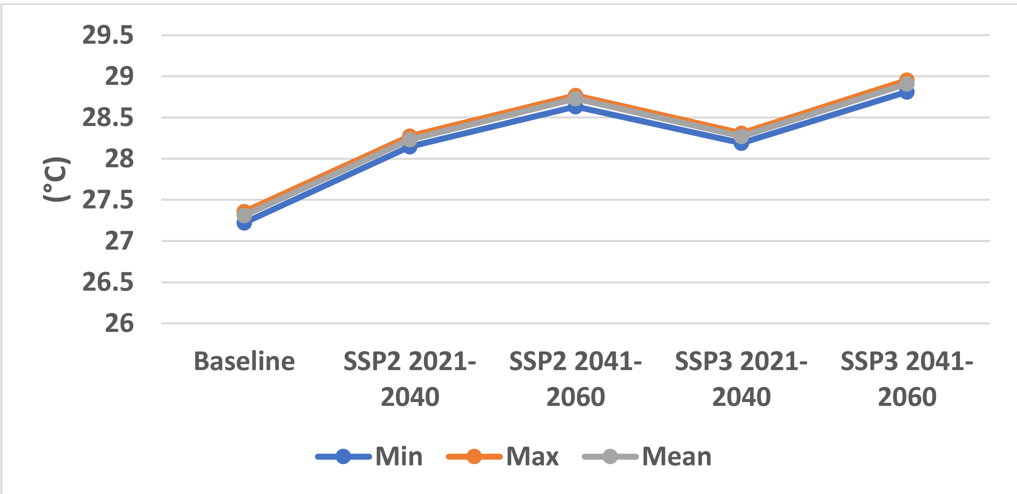
Under the baseline scenario, the country's central and southern parts receive the highest rainfall, while the northern part gets relatively low rainfall. Under the climate change scenarios, rainfall is going to increase for the areas with higher amounts of rainfall in the baseline, except for the southern part of the country. The central atolls, namely Kaafu, Alifu Alifu, Alifu Dhaalu, Vaavu, Faafu, Dhaalu, Meemu and part of the Baa and Thaa atolls, which receive the highest precipitation under the baseline scenario, are likely to receive highest amount of rainfall in the country (~2463mm), especially under long term higher emission scenario (Mid-term SSP3 7.0) (Figure 5.3). The change in total annual rainfall in the central atolls may range between 65mm (Thaa atoll) to nearly 160mm (Kaafu atoll). The northern atolls, which receive relatively low rainfall, may experience an increase in total annual rainfall of more than 200mm (Haa Alifu, Haa Dhaalu, Raa, Shaviyani, Noonu, and Raa Atoll). With the likelihood of increased rainfall, many of the flood-prone islands might face similar events in both near and mid-term scenarios (Figure 4.5).

On the contrary, in the southern part, including Gaafu Alifu, Gaafu Dhaalu, Gnaviyani, and Seenu atolls, rainfall is likely to decrease from baseline under all climate change scenarios except near-term SSP3 7.0. The maximum decrease (~63mm) in total annual rainfall is likely in Seenu Atoll under mid-term SSP3 7.0.

5.2.2 Temperature

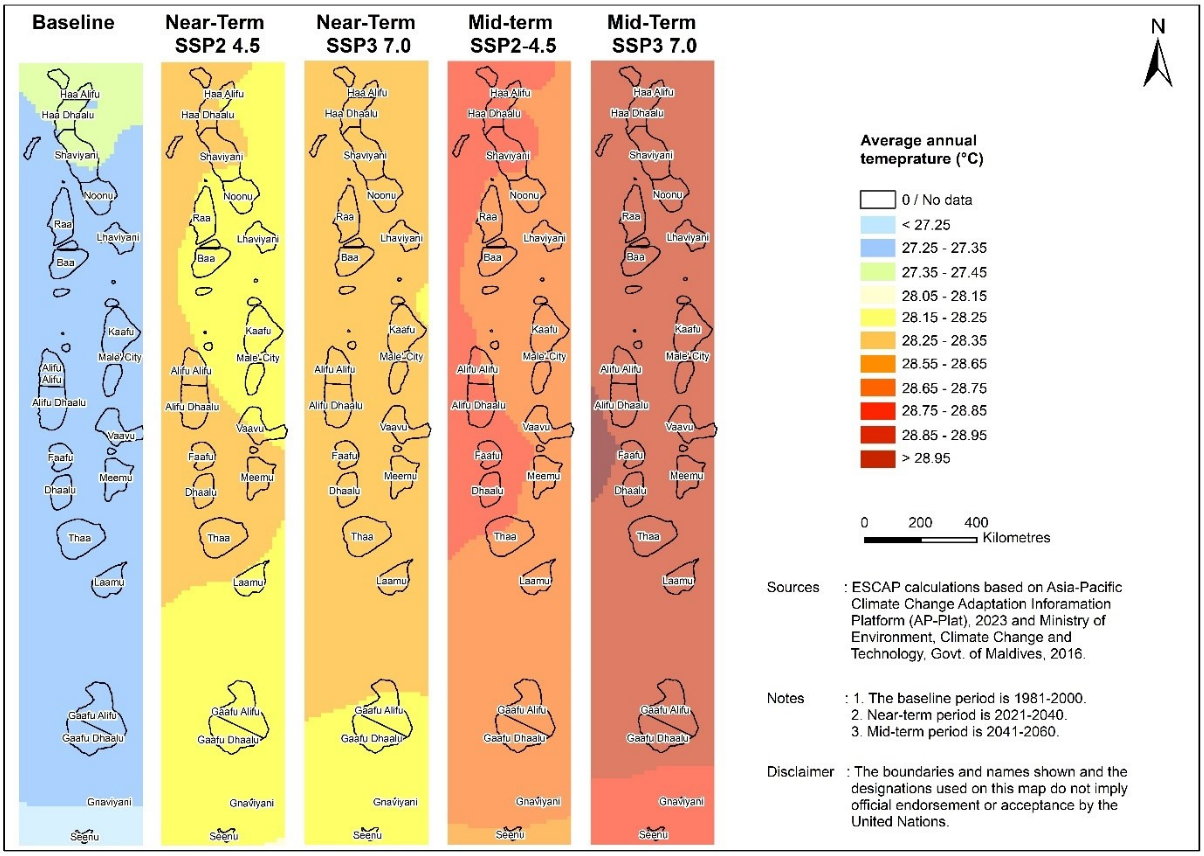
The trend in annual average temperature shows an increasing pattern across the scenario and timelines. The average increase in temperature is likely to be around 1.59°C by 2060 from the baseline to the SSP 7.0 scenario. Because of the tropical weather in Maldives, the maximum and minimum temperatures follow the same pattern as the annual average temperature. Figure 5.4 represents the trend in annual average temperature in Maldives under baseline and other climate change scenarios.

Figure 5.4: Trend in annual average temperature under baseline and climate change scenarios in the Maldives



Under the baseline scenario, the northern atolls, namely Haa Alifu, Haa Dhaalu, and Shaviyani, have higher annual average temperatures than the rest of the country, with the Seenu atoll being the lowest. Under the climate change scenario, the spatial pattern remains the same. It is likely to increase more in the northern and central atolls - Haa Alifu, Haa Dhaalu, Shaviyani, Alifu Alifu, Alifu Dhaalu, Faafu, Vaavu and Thaa. In some of the atolls (Dhaalu, Thaa, Faafu, Alifu Alifu, and Alifu Dhaalu), the increase in average temperature may go up to 1.4 °C from the baseline period under the business-as-usual scenario (SSP2 4.5) by 2040. Maximum increase (>1.43°C) is likely in Dhaalu Atoll, followed by Thaa and Faafu Atoll. By the end of 2060, under the worst-case scenario (SSP3), the average annual temperature may increase up to 1.6 °C in all the atolls except Seenu and Gnaviyani. The maximum increase (> 1.6 °C) is likely in Alifu Dhaalu, followed by Dhaalu, Faafu, Alifu Alifu, Vaavu, Meemu, Kaafu and Thaa (Figure 5.5).

Figure 5.5: Spatial distribution of annual average temperature under baseline and climate change scenarios in Maldives



5.2.3 Surface Wind

The spatial distribution of seasonal surface wind (May to October) follows the baseline trends across all the scenarios and periods; however, the wind speed is likely to decrease in both the near and mid-term periods compared to the baseline (Figure 5.6).

Most of the central and southern atolls are likely to experience a surface wind speed of ~4.7m/s during May-October. The area under this wind speed increases from near-term to mid-term and low emission to higher emission scenario. The highest wind speed (> 5 m/s) is observed across the northern atolls, namely Haa Alifu, Haa Dhaalu, Shaviyani, Noonu, Lahviyani, Kaafu, Raa and Baa. The northern atolls with existing risk of cyclone and storm-like events have the highest likelihood of similar events in the future. However, southern and central atolls are likely to remain in a baseline-like situation (Figure 5.7).

Figure 5.6: Trend in the seasonal average surface wind under baseline and climate change scenarios in the Maldives

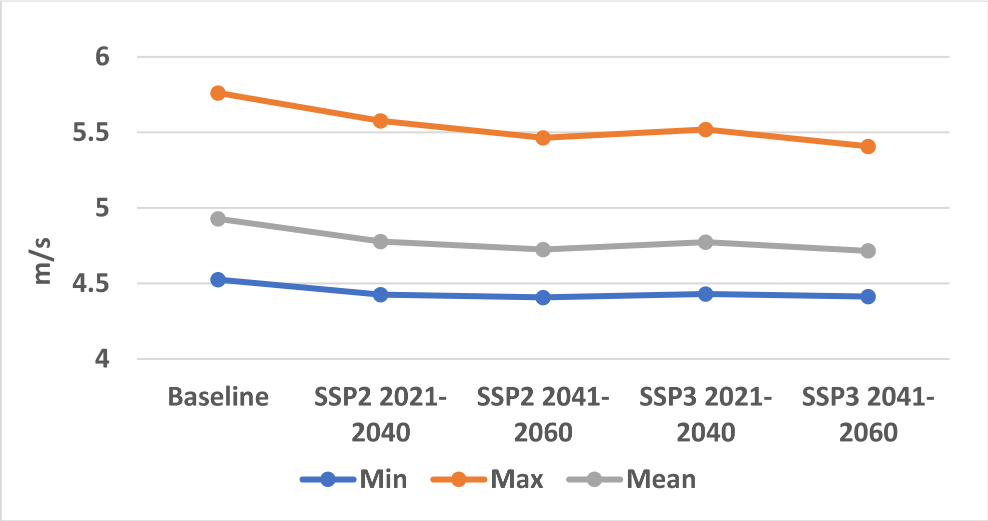
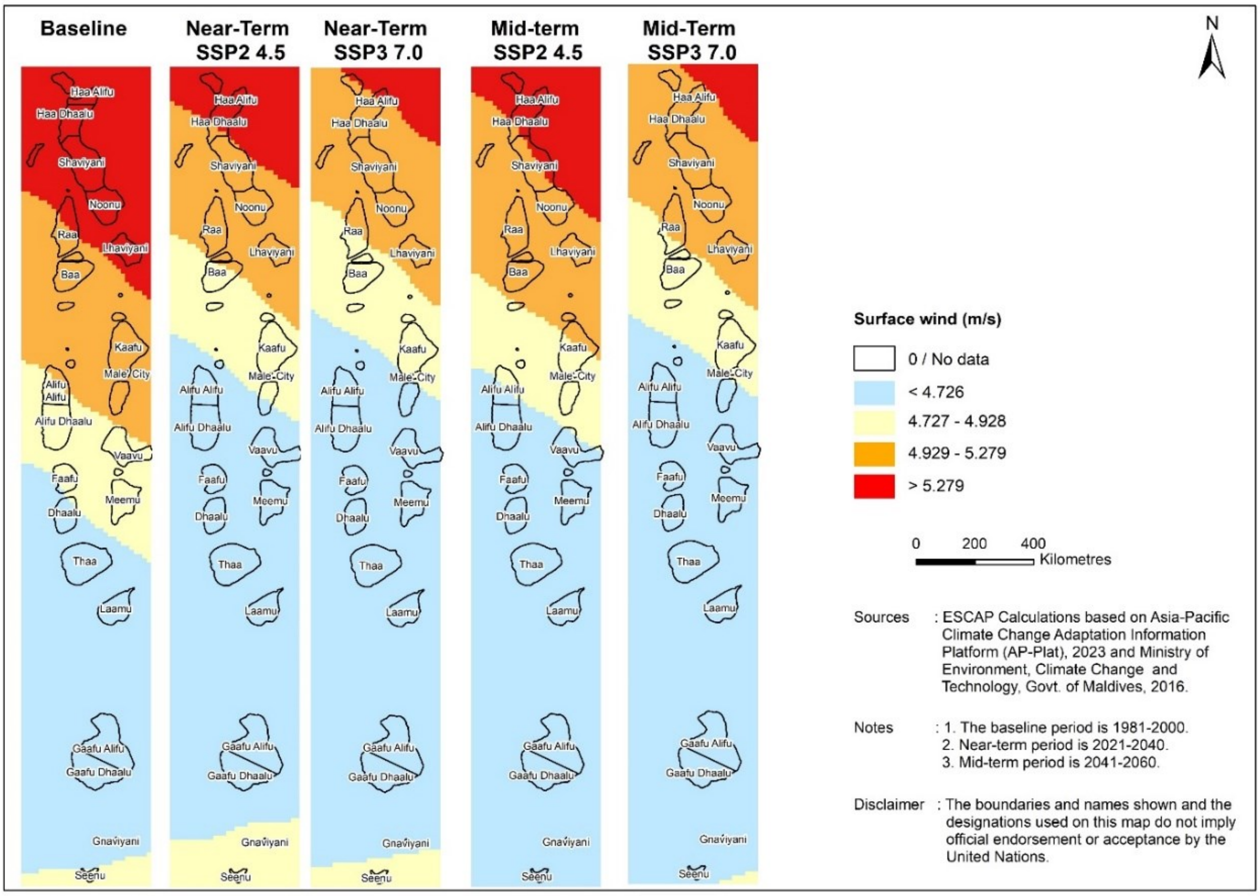


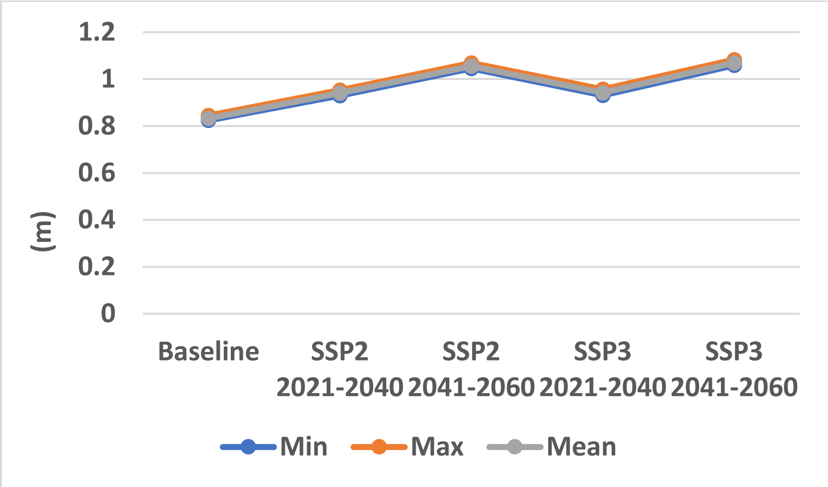
Figure 5.7: Spatial distribution of seasonal average surface wind under baseline and climate change scenarios in Maldives



5.2.4 Sea-Level Rise

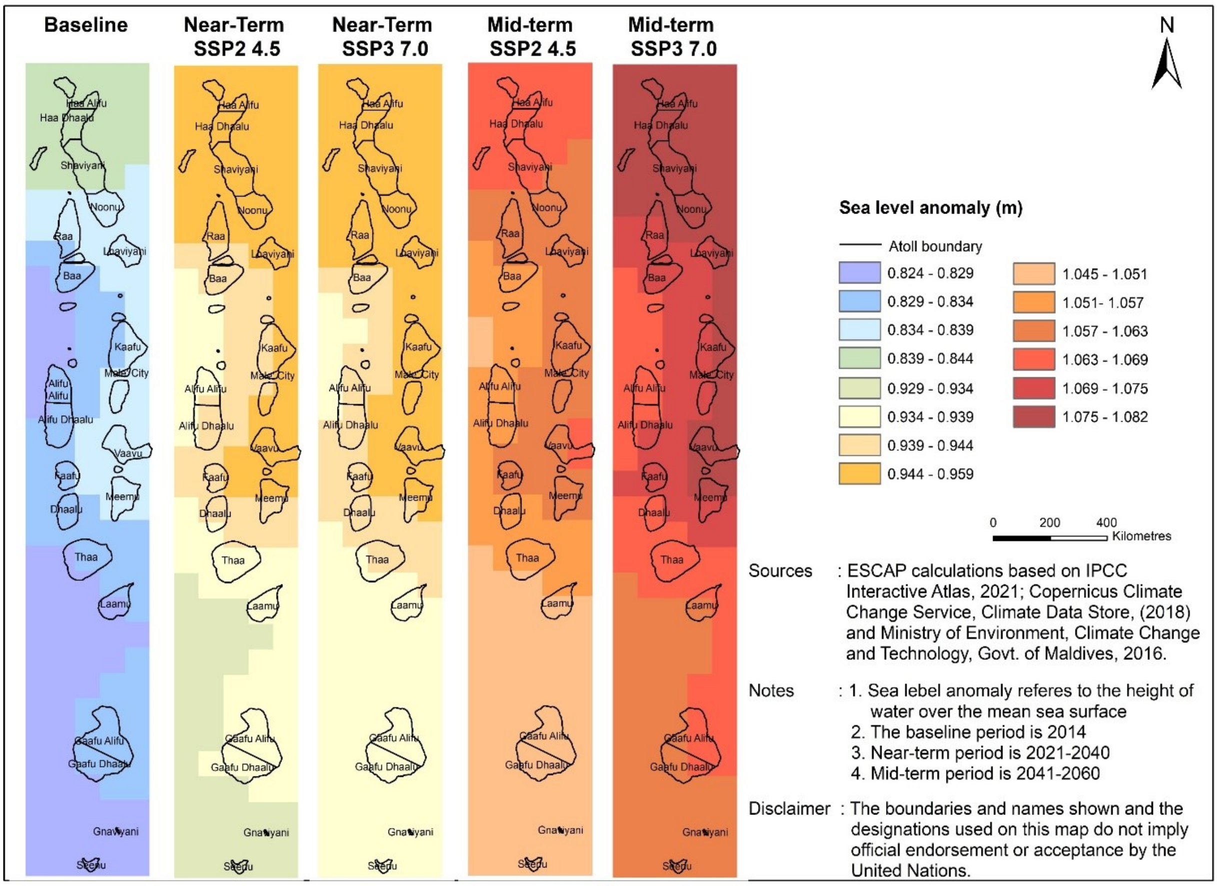
Sea-level rise has been a major threat to the Maldives, where critical infrastructure, agriculture, and settlement areas are near the coastline due to the limited availability of land resources. Globally, the sea level is likely to rise around small islands with higher emission scenarios. A similar trend is observed in Maldives, where sea level anomaly is projected to go above 1m under the mid-term (SSP3), and this is likely to occur across the country compared to the level of 2014 in all the climate projection scenarios (Figure 5.8).

Figure 5.8: Trend in sea level anomaly under baseline and climate change scenarios in Maldives



Sea level anomalies are defined as the height of water over the mean sea surface in a given time and region. Here, sea level anomalies are computed with 2014 as a reference period. The anomaly of the 2014 baseline is calculated from a twenty-year mean reference period (1993-2012). While in the baseline, the sea level anomaly is around 0.83m, under the climate change scenarios, it further increases across the country. The rise is high around the northern and eastern parts of the central atolls and relatively low towards the southern atolls. The highest rise is likely to happen in Haa Alifu, Haa Dhaalu, Shaviyani, Noonu, Lahviyani, Kaafu, Vaavu, and Meemu. The northern and central atolls may experience an increase in sea level up to 0.95 m by 2040 under both SSP2 and SSP3 scenarios but might go up to 1.06m and 1.08m by 2060 under SSP2 and SSP3 scenarios, respectively.

Figure 5.9: Spatial distribution of sea level anomaly under baseline and climate change scenarios in the Maldives



5.2.5 Multi-Hazard

Multi-hazard includes a combination of precipitation, temperature, surface wind, and sea level anomaly. To create a multi-hazard file, the individual hazards mentioned above are rescored based on the values and summed up. The analysis shows that an increasing trend of multi-hazard is likely across the country from baseline to the mid-term worst-case scenario (SSP3). Northern, central atolls, namely, Haa Alifu, Haa Dhaalu, Shaviyani, Noonu, Lahviyani, Baa, Alifu Alifu, Alifu Dhaalu, Kaafu, Faafu, Dhaalu, Thaa, Vaavu, and Meemu may experience more intense multi-hazard than the rest.

Figure 5.10: Trend in multi-hazard under baseline and climate change scenarios in Maldives

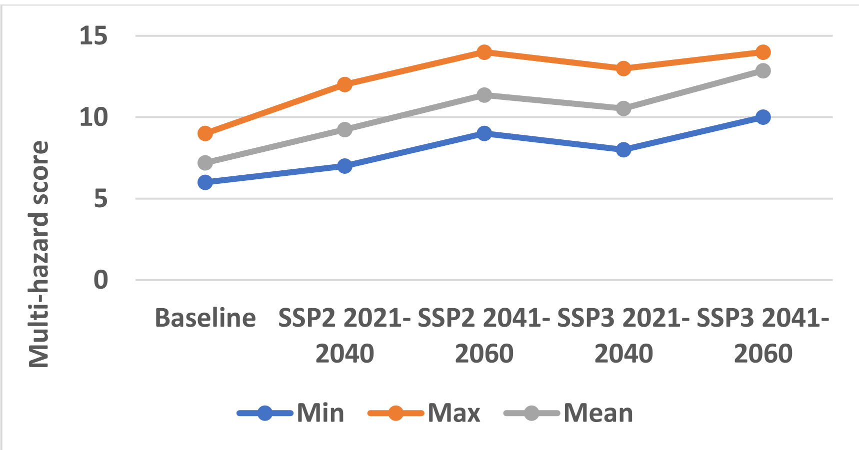
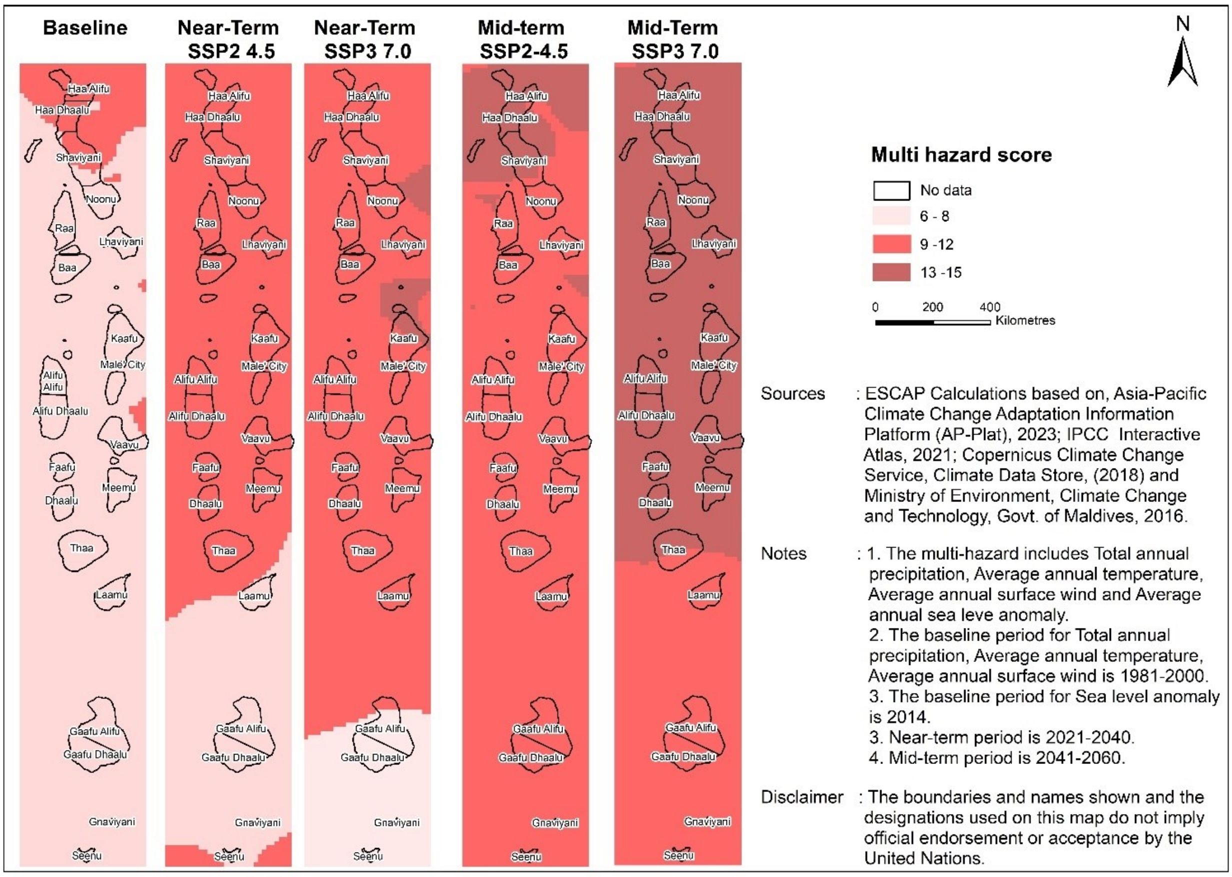


Figure 5.11: Spatial distribution of multi-hazard under baseline and climate change scenarios in Maldives



5.3 Sectoral Exposure

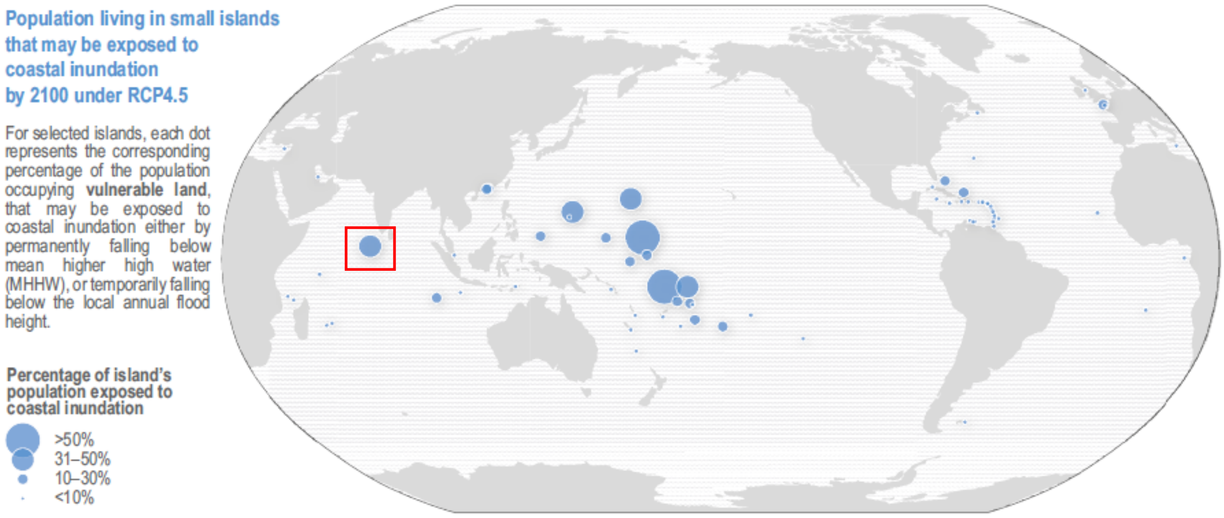
The impacts of climate change are extensive and affect various aspects of the Earth's systems, human societies, and the environment. Maldives' socioeconomic resilience is being tested by the challenge of climate change and its impacts, necessitating targeted measures to ensure sustainable development and mitigate risks. Socioeconomic exposure to climate change refers to the degree to which a society or economy is susceptible to and unable to cope with the adverse effects of climate change. Apart from the vulnerable population in the Maldives, the climate-sensitive sectors are agriculture, tourism, infrastructure, energy, and transportation. However, the initial impacts of extreme events are often directly felt by the population, particularly in the form of health risks and disruptions to their daily life.

5.3.1 Population

During 1988–2007, 80% of all disaster events in the Maldives were climate-related and caused 45% of deaths and 79% of the economic losses during this period[23]. IPCC 6th Assessment Report has highlighted that 31-50% of the vulnerable population living in the coastal areas in the Maldives are likely to be exposed to coastal inundation due to high waves or floods by 2100 under the RCP4.5 climate scenario (Figure 5.12).

[23] IFRC (2021) CLIMATE CHANGE IMPACTS ON HEALTH AND LIVELIHOODS: MALDIVES ASSESSMENT

Figure 5.12: Percentage of current population in selected small islands occupying vulnerable land (the number of people on land that may be exposed[24]



The exposure analysis based on the downscaled climate projection data shows that the population exposure to the highest amount of rainfall increases from baseline to long-term higher emission scenario (Figure 5.13). Around 50% of the total population of Maldives is likely to be exposed to the highest amount of precipitation under the business-as-usual (SSP2) scenario and around 55% under the worst-case scenario (SSP3) by 2060. The capital city, Malé, is the most populated island in the Maldives, accounting for about 40% of the population exposed to the highest amount of rainfall under all the climate change scenarios. The same is the proportion of the female population exposed to the highest amount of precipitation, with Malé having 36% of the female population exposed to the highest amount of rainfall.

Among the other atolls, the top five atolls with the highest share of the exposed population are Thaa (4%), Kaafu (4%), Alifu Dhaalu (2%), Shaviyani (1%) and Dhaalu atoll (1%) (Figure 5.13). For the female population, the top five atolls with the highest share of the exposed population are Thaa (~4.5%), Kaafu (~4%), Alifu Dhaalu (~2%), Dhaalu (~1%) and Alifu Alifu (~1%).

[24] Mycoo, M., M. Wairiu, D. Campbell, V. Duvat, Y. Golbuu, S. Maharaj, J. Nalau, P. Nunn, J. Pinnegar, and O. Warrick, 2022 Small Islands. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2043–2121, doi:10.1017/9781009325844.017.

Figure 5.13: Population exposure to high and very high rainfall under baseline and climate change scenarios

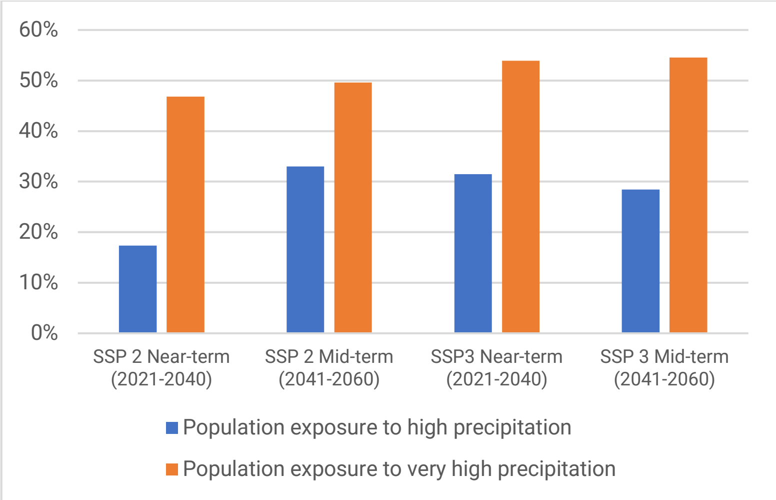
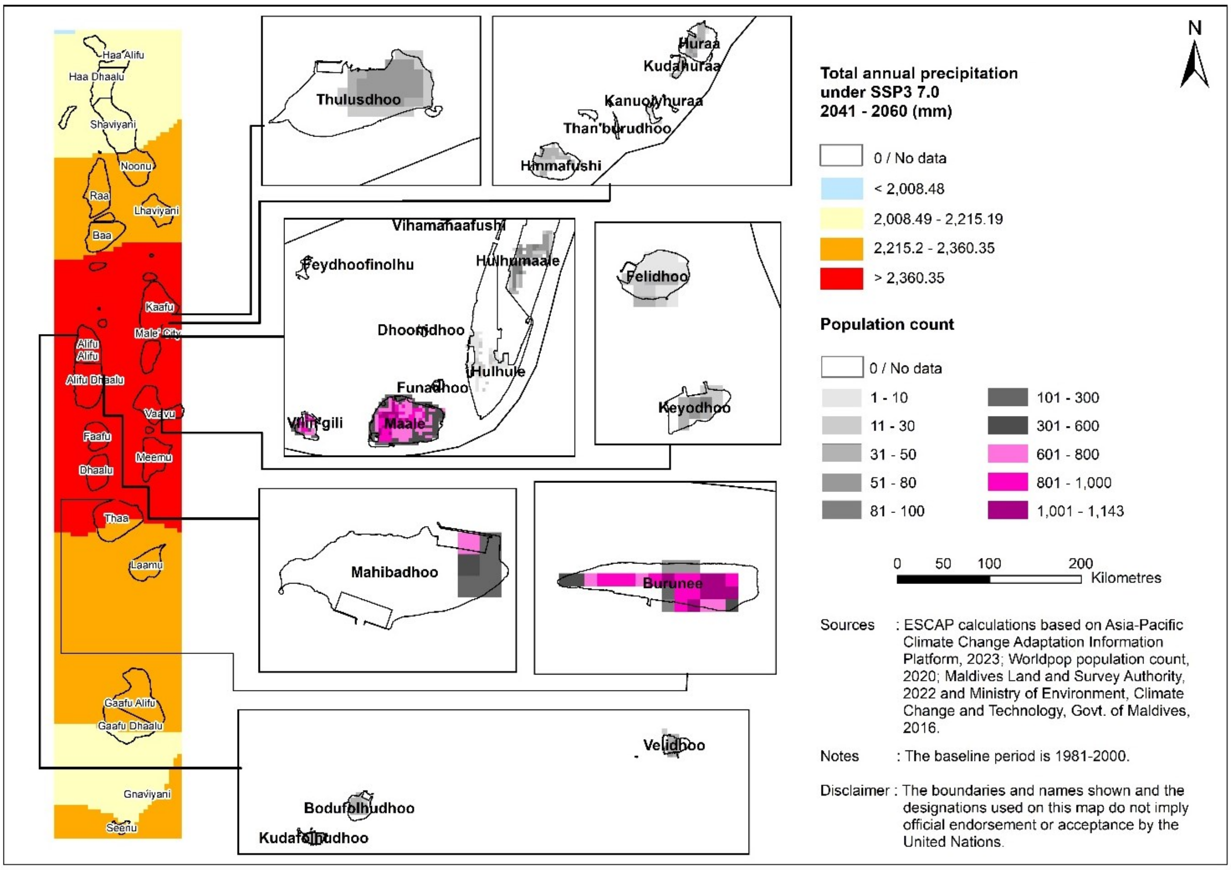


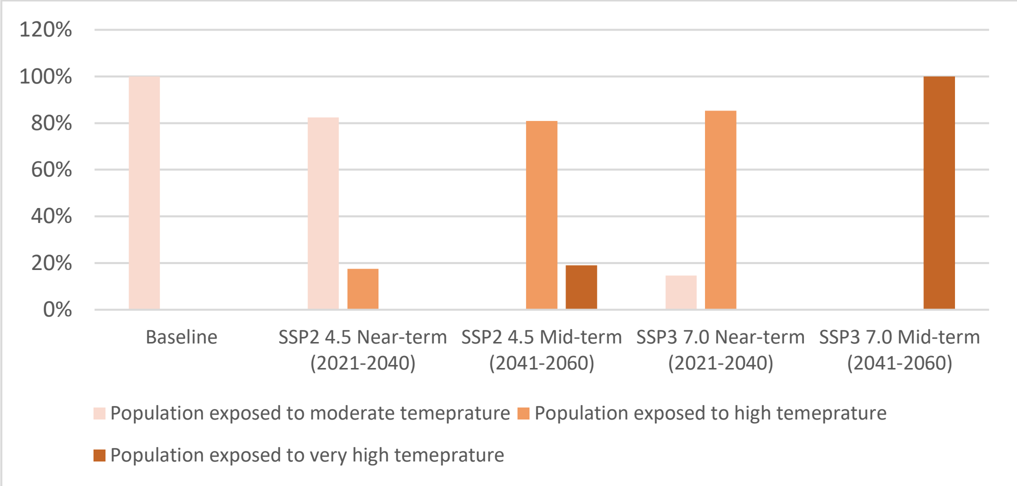
Figure 5.14: Population exposure to total annual precipitation under SSP3 7.0, 2041-2060 scenario



As the temperature increases in the higher emission scenario (SSP3), the population exposure increases as well compared to the baseline (Figure 5.14). Around 19% of the total population is likely to be exposed to up to 1.4 °C increase in annual average temperature under the SSP2-

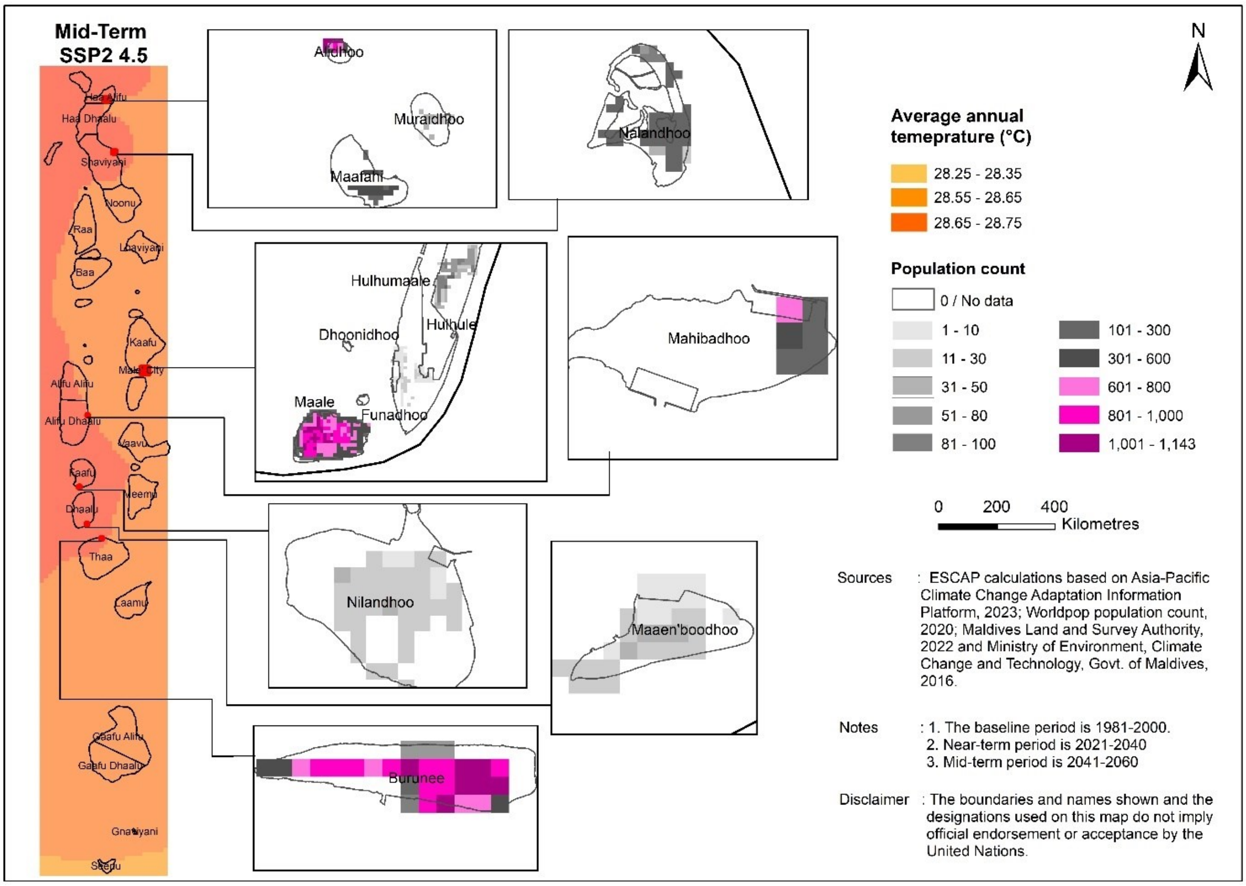
4.5 mid-term scenario, and 100% is exposed to up to 1.6 °C increase in the annual average temperature under the SSP3 mid-term scenario (Figure 5.14).

Figure 5.15: Population exposure to annual average temperature under baseline and climate change scenarios



Under the mid-term SSP2 scenario, Haa Alifu has the highest total proportion (~27%) of the population exposed to a 1.4 °C increase in annual average temperature, followed by Thaa (~23%), Shaviyani (~17%) and Haa Dhaalu atoll (~14%). Under SSP3 mid-term scenario, Malé city tops the list with 40% of the total exposed population to a 1.6 °C increase in annual average temperature, followed by Seenu (~10%), Raa (~8%) and Haa Alifu atoll (~8%) and Thaa atoll (6%). With nearly 33% of the female population in the atoll, Haa Alifu atoll tops the list in terms of female population exposure to up to 1.4 °C increase in annual average temperature by 2060 under SSP2 4.5 scenario followed by Shaviyani and Noonu atolls, whereas Malé (39%) has the highest proportion of female population exposed to 1.6 °C increase in annual average temperature under SSP3 mid-term scenario. (Figure 5.14 and 5.16)

Figure 5.16: Population exposure to annual average temperature under SSP3 7.0, 2041-2060 scenario



As an archipelago of low-lying islands and atolls in the Indian Ocean and with more than 80% of its coral islands standing less than 1 meter above sea level, the existence of many islands in the Maldives is threatened by sea level rise[25]. Around 6% of the total population is exposed to sea level rise to 1 m by 2040 under SSP2 and SSP3. Among them, Meemu (10%), Alifu Dhaalu (8%), Haa Alifu (6%), and Kaafu (5%) top the list. 16% of the population are exposed to sea level rise of more than 1m by 2060 under SSP2 and SSP3. Meemu tops the list with 47% of the population exposed to sea level rise of more than 1m followed by Alifu Dhaalu, Haa Alifu, Haa Dhaalu, and Kaafu with more than 30% of the population exposed to more than 1m sea level rise by 2060 under SSP2 and SSP3. The same scenario is observed in the case of the female population's exposure to the sea level rise. Meemu Atoll has the highest proportion of the female population exposed to sea level rise to 1 m and more.

In many islands, urban areas are expanding toward relatively coastal areas increasing the risk of inundation due to the sea level rise. Around 14% of the urban areas with 0-1m elevation are at risk of a 1 m increase in sea level under future climate scenarios by 2060 under SSP2 and SSP3 (Figure 5.17). Many of the reclaimed lands located in the northern and central atolls are also exposed to a 1m increase in sea level by 2060 under SSP2 and SSP3. Hulhule, the Island with the main airport in Maldives also has some parts with elevation less than 1m and is at risk of floods not only due to sea level rise but also due to heavy precipitation (Figure 5.18).

[25] https://earthobservatory.nasa.gov/images/148158/preparing-for-rising-seas-in-the-maldives

Figure 5.17: Urban areas exposed to more than 1m seal level anomaly under SSP3 7.0, 2041-2060 scenario

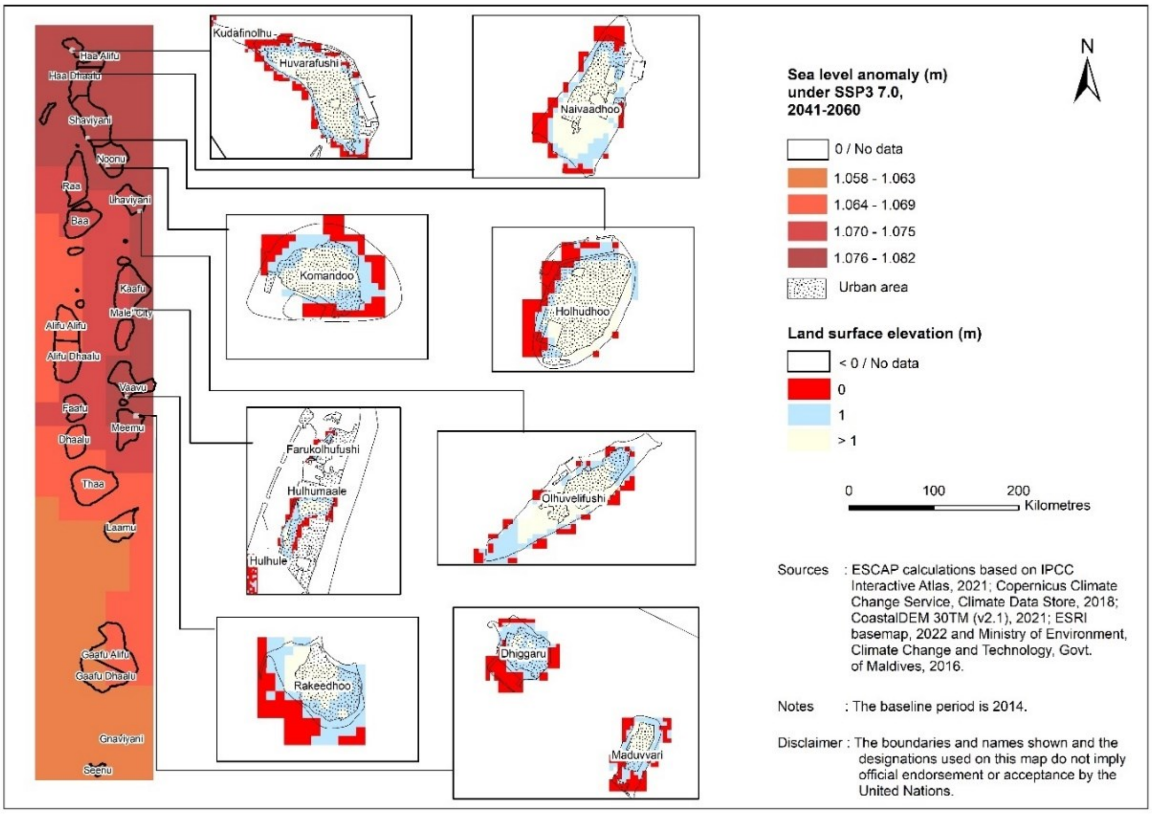
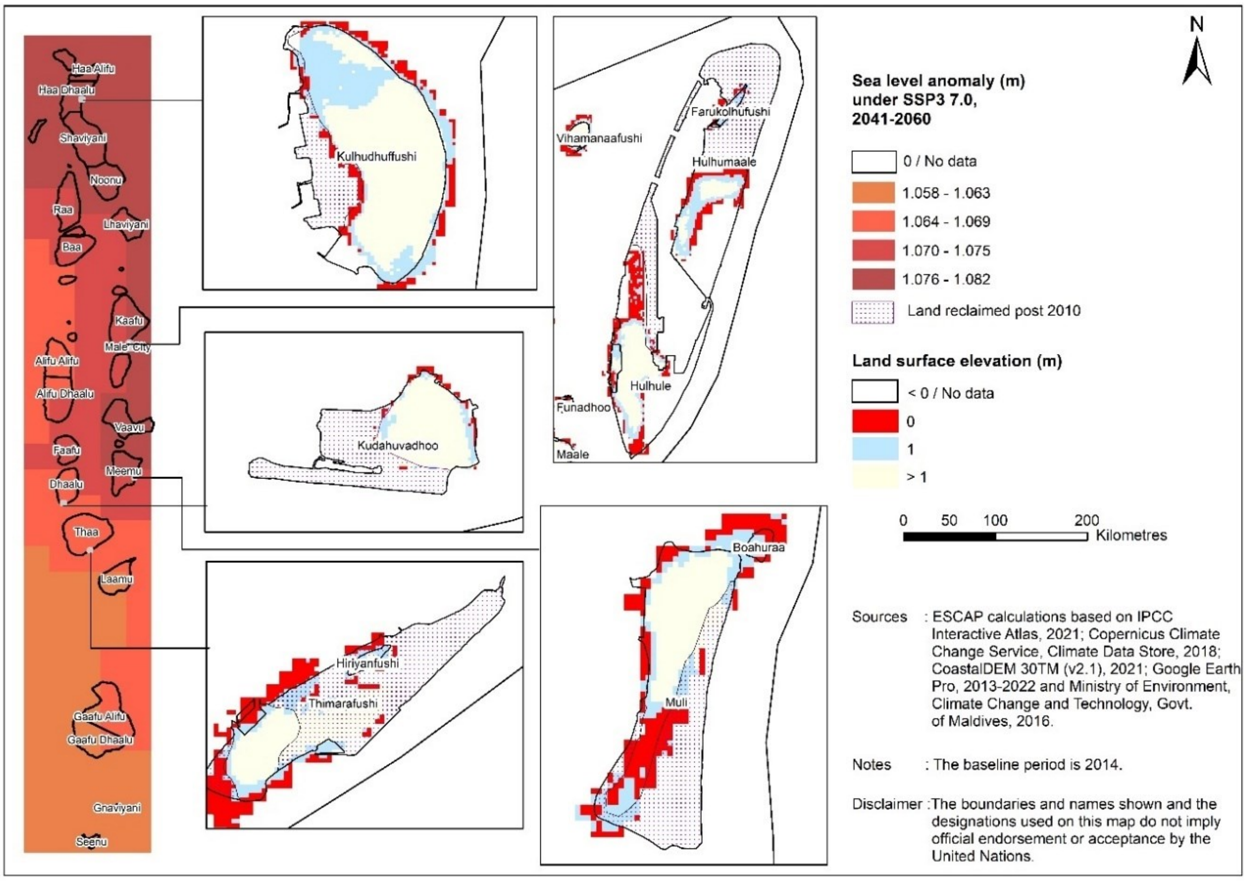


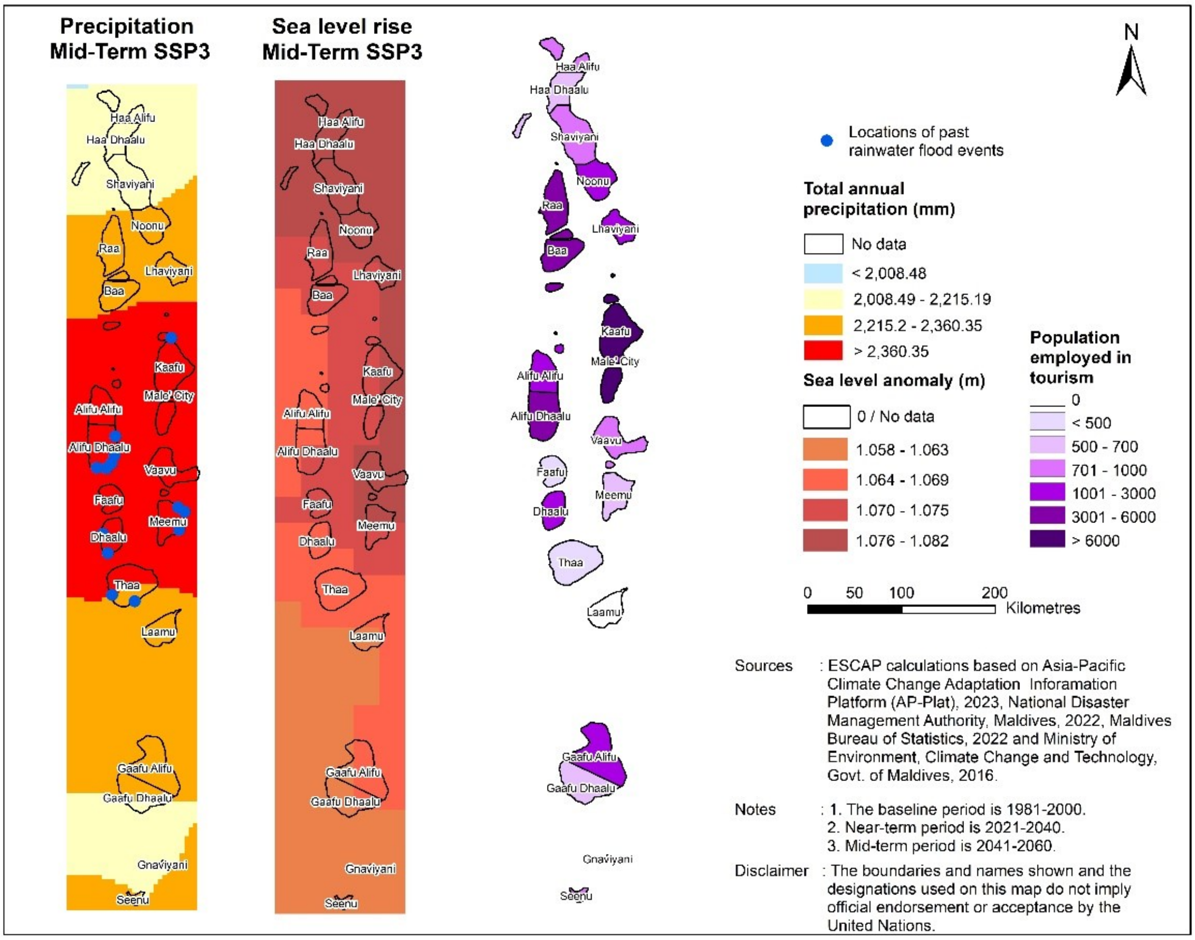
Figure 5.18: Reclaimed areas exposed to more than 1m seal level anomaly under SSP3 7.0, 2041-2060 scenario



Different populations may face similar risks of exposure to the impacts of climate change, but their actual vulnerability depends on their socioeconomic conditions, civic and social empowerment, and access to mitigation and relief resources[26]. 11% of the total population of Maldives is employed in the tourism sector across the country. 60% of them are located in the areas that are likely to be exposed to high amounts of rainfall and sea level rise more than 1m under SSP3, 2041-2060 (Figure 5.19).

[26] https://www.un.org/development/desa/disabilities/issues/disability-inclusive-disaster-risk-reduction-and-emergency-situations.html

Figure 5.19: Population employed in the tourism sector exposed to high rainfall and sea level rise under SSP3, 2041-2060

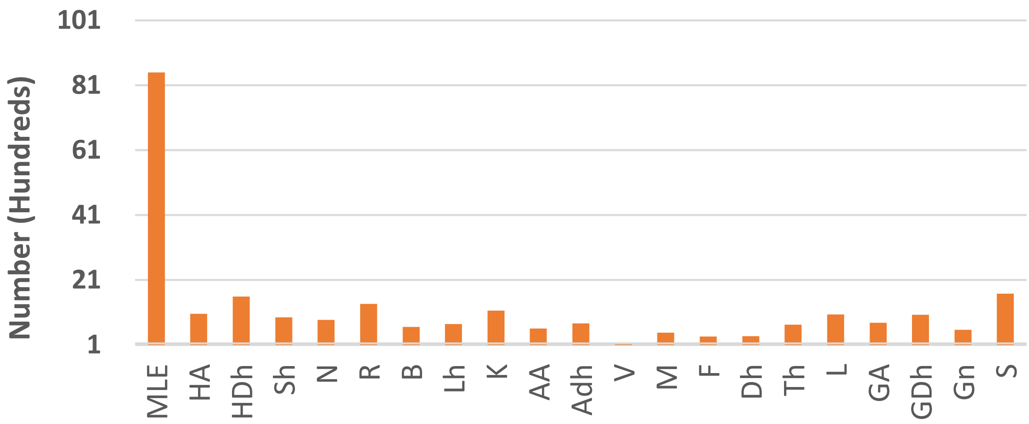


Climate change disproportionately affects the daily lives of people with disabilities, as disaster preparedness programs and early warning systems are often inaccessible to them. There is around 4.73% population with disability in the Maldives, with Malé having the highest among all, followed by Seenu, Haa Dhaalu, Raa, and Kaafu. 50% of the disabled population in Maldives will be exposed to high rainfall and related impacts under SSP3 7.0 climate change scenarios by 2060.

5.3.2 Agriculture

Maldives is not an agrarian country. It depends on the imports of most of its food needs. However, developing agriculture as the third pillar of the economy, after tourism and fishing, is one of the priorities of the government's agriculture policy. Agriculture is prioritized to increase self-sustenance in terms of food security as well[27]. Climate change and its impacts not only affect the production of crops but also impacts the well-being of the population involved in this sector especially vulnerable populations such as women.

Figure 5.20: Atoll-wise population with disabilities[28]



Agricultural areas in the Maldives are exposed to heavy precipitation-related inundation, high temperatures as well as sea level rise. Sea level rise and high waves salinize the agricultural lands, affecting soil quality and production. Up to 24% and 26% of the agricultural lands in the country are likely to be exposed to the highest amount of precipitation under SSP2 and SSP3 by 2060, respectively. The largest area under agriculture that is exposed to high precipitation is Kaafu Atoll. Thoddo and Kashidhoo islands are some of the main agricultural centres of Maldives, which are likely to be exposed to a high amount of precipitation (Figure 5.20). Around 27% of the agricultural lands are exposed to a 1.4 °C increase in average annual temperature under the SSP2 climate change scenario, and 86% of the total agricultural land is exposed to up to a 1.6 °C increase in average temperature under the SSP3 climate change scenario by 2060.

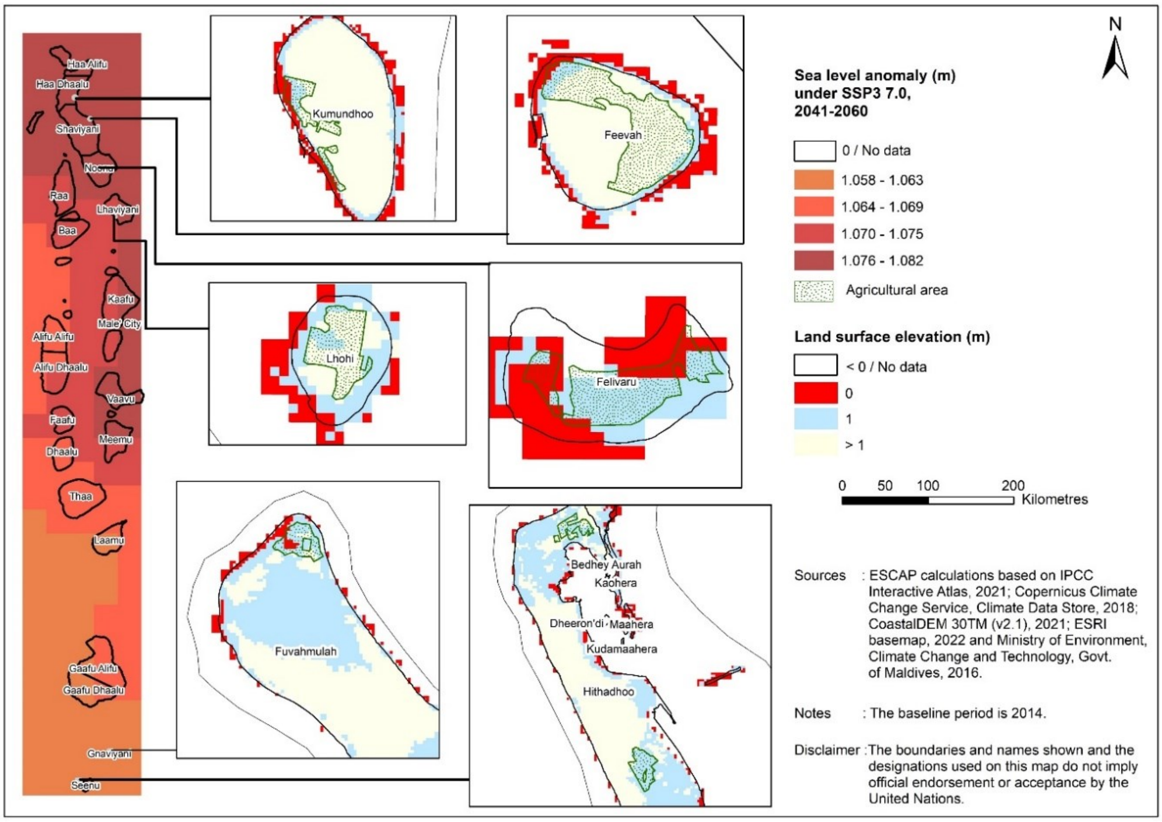
[27] National Fisheries and Agricultural Policy 2019-2029

[28] Maldives statistics bureau, 2022

Figure 5.21: Agricultural lands exposed to total annual precipitation under SSP3 7.0, 2041-2060, in The Maldives

Many agricultural lands are located along the periphery of the islands and in relatively low-lying areas with elevations of 0-1m are at high risk of sea level rise and related impacts. 13% of these areas are at risk of more than a 1m increase in sea level rise under the SSP3 7.0 climate scenario by 2060. Gnaviyani atoll has the highest area under agricultural land located at 0-1m and exposed to more than 1m sea level rise, followed by similar areas in Seenu, Haa Dhaalu, and Raa atolls (Figure 5.22)

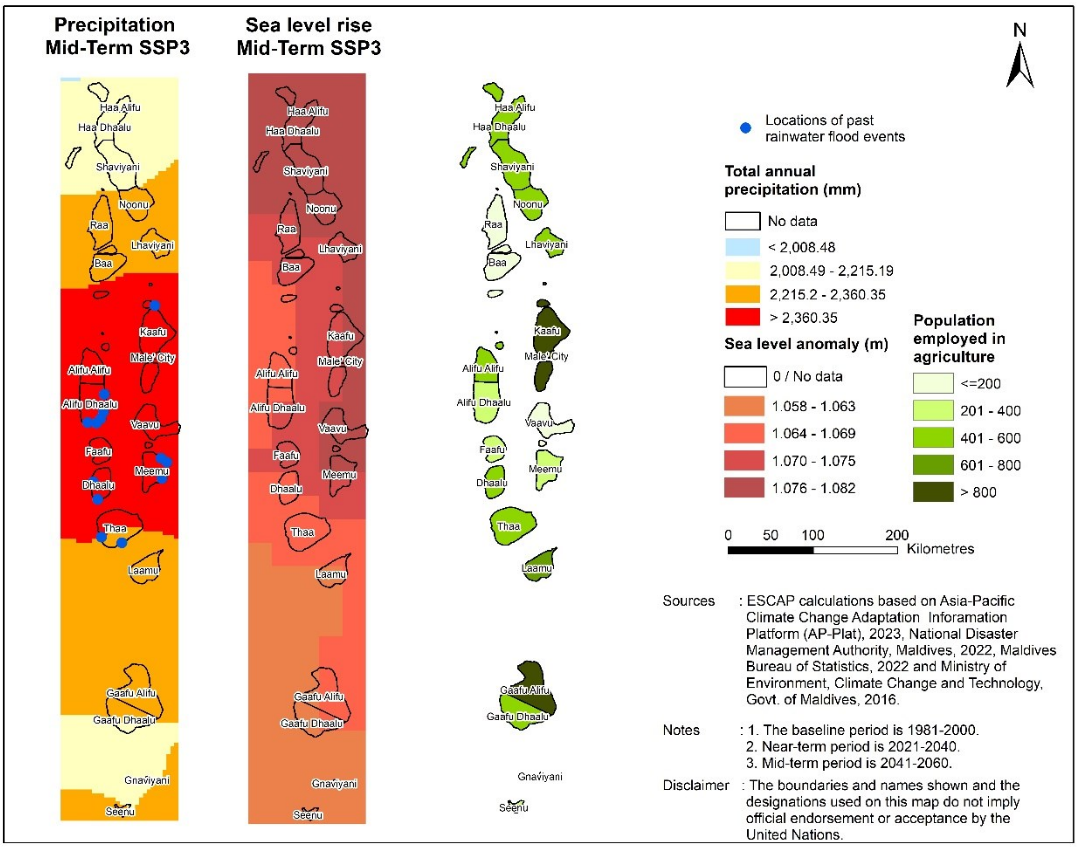
Figure 5.22: Agricultural lands in the low- lying areas exposed to sea level rise under SSP3 7.0, 2041-2060, in The Maldives



Subsistence farming is one of the main sources of food security and livelihoods for a significant number of populations[29]. Only 1.77% of the population of the country is employed in the agriculture sector. Women are mostly involved in subsistence farming and grow vegetables, fruits, and traditional starchy varieties, whereas men grow high-value commercial crops such as bananas, cucumber, mango, and watermelon. People employed in agriculture are vulnerable due to the impacts of climate change as extreme events such as heavy rainfall or coastal inundation due to sea level rise can affect crop production and limited land resources make recovery difficult. Kaafu and Gaafu Alifu atolls have the highest number of agricultural workers who are likely to be exposed to high amounts of rainfall and the impacts of sea level rise. 44% of the population employed in agriculture is likely to be exposed to high rainfall by 2060 (Figure 5.23).

[29] https://www.fao.org/family-farming/detail/en/c/289383/

Figure 5.23: Population employed in the agriculture sector exposed to high rainfall and sea level rise under SSP3, 2041-2060 in The Maldives



5.3.3 Energy and Critical Infrastructure

With the heavy dependence on imported fossil fuels for energy production, the Maldives' energy sector struggles with the high electricity cost and the power supply's unreliability, especially in the remote islands. Climate change and its impacts enhance the existing challenges in the energy sector. As most of the islands have only one power plant, the impacts of climate change on this infrastructure can disrupt many essential services. Sustainable energy supplies are important to ensure food security, essential public services, social equity, and protection of vulnerable groups, including women and children. The climate change policy framework of Maldives has already identified the building of climate-resilient energy infrastructure as one of the top priorities for addressing current and future vulnerabilities[30].

ESCAP calculations show that around 47% of the country's total energy capacity is exposed to the highest amount of precipitation by 2060 under both SSP2 and SSP3 climate change scenarios. Under near-term SSP2 and SSP3 scenarios, Meemu Atoll is likely to be most at risk of sea level rising by up to 1m as 25% of the energy capacity of Meemu Atoll is located below 1m elevation. Under near-term SSP2 and SSP3 scenarios, 2.05% of the country's total energy capacity is located at 0-1m elevation and is at risk of a 1m increase in sea level. However, in the long term around 21.53% of the total energy capacity of the country is likely to be impacted

[30] https://www.environment.gov.mv/v2/wp-content/files/publications/20150810-pub-maldives-cc-policy-framework-final-10aug2015.pdf

by the sea level rising more than 1m. Seenu, Meemu, Faafu, Noonu, and Lhaviyani Atoll are likely to be impacted most under the long-term scenario (Table 1) (Figure 5.23).

Table 1: Atolls with the highest exposure of energy capacity to sea level rise in Maldives

Atoll name	**Baseline/ SSP2_Near-term (2021-2040)/ SSP3-Near-term (2021-2040)**	**SSP2-Mid-term (2041-2060) / SSP3-Mid-term (2041-2060)**
	Energy capacity located below 1 m (0m) elevation exposed to SLR up to 1 m (kW)	**Energy capacity located within 0 -1 m elevation exposed to SLR more than 1 m (kW)**
Meemu Atoll	24.94%	62.00%
Thaa Atoll	11.93%	--
Noonu Atoll	16.80%	39.60%
Gaafu Dhaalu Atoll	13.06%	--
Seenu Atoll	--	100.00%
Lhaviyani Atoll	--	39.36%
Faafu Atoll	--	46.89%

Other infrastructures, including those for health, education, water desalinization plants, mosques, and government buildings are critical to the islands' respective essential services. Mosques and educational institutes are important in terms of disaster response as well because they are used as shelters. The analysis shows that more than 10% of these critical infrastructures are located within 0 -1 m elevation and exposed to the sea level rise of more than 1 m by 2060 under the SSP3 climate scenario. Seenu Atoll has the highest number (28) of these critical infrastructures at risk of sea level rise of more than 1m followed by Haa Alifu Atoll (13) and Gaafu Dhaalu Atoll (10) under the SSP3 scenario (Figure 5.21). 28% of the critical infrastructure is exposed to high rainfall, and many of them are in flood-prone areas with lower elevations (Figure 5.24).

Figure 5.24: Exposure of critical infrastructure to seal level anomaly under SSP3 7.0, 2041-2060 in Maldives

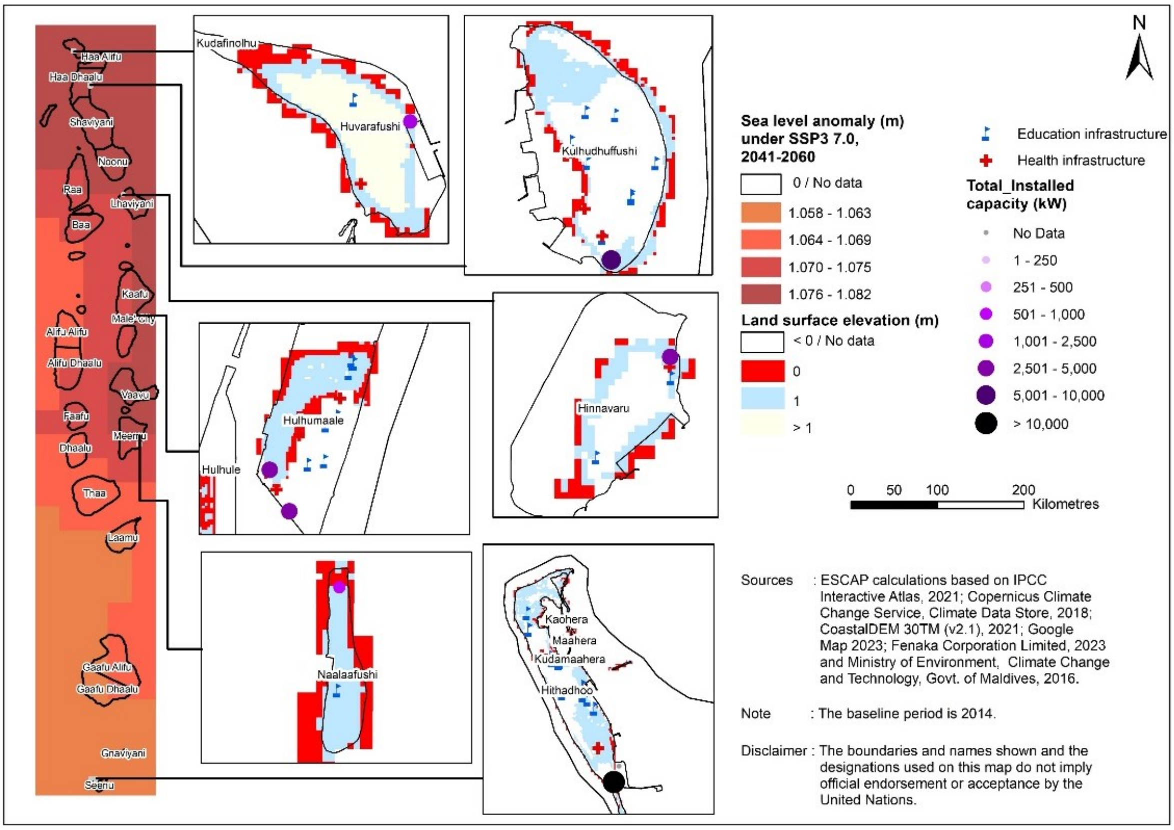
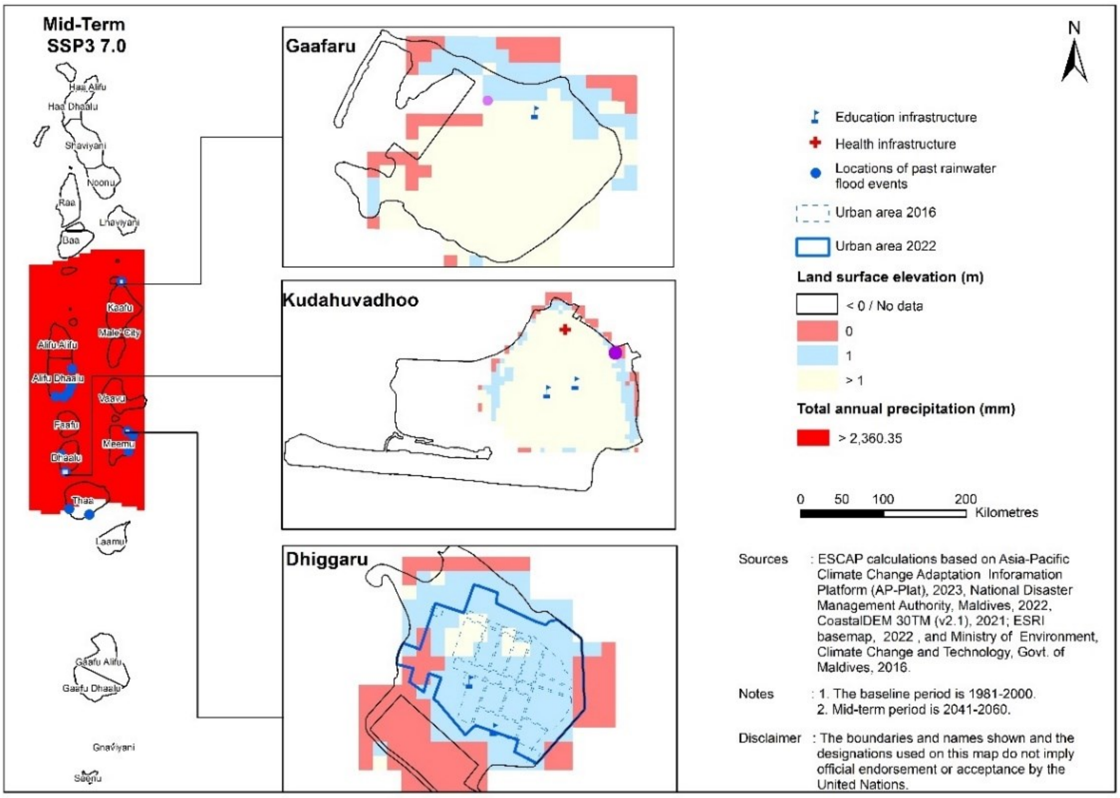


Figure 5.25: Flood-prone areas with lower elevation exposed to high precipitation under SSP3 7.0, 2041-2060 in Maldives



Chapter 6:

Recommendation for Adaptation Strategies

Despite contributing less than 0.003% percent to global emissions of greenhouse gases, Maldives is one of the most vulnerable countries to projected climate change and impacts[31]. Climate change adaptation can propel three dividends bringing about economic, social, and environmental benefits. It complements efforts to mitigate greenhouse gas emissions by addressing the unavoidable impacts of climate change along with reducing the potential impacts on the people and ecosystem. Adaptation measures not only help avoid losses caused by disasters but also prove to be economically beneficial in the short term. Enhanced resilience and future risk reduction are long-term benefits that are reflected in the social and environmental sectors. Through the National Adaptation Plan of Action (NAPA), Maldives has identified the priority sectors for adaptation which are land, beach, and human settlements; critical infrastructure; tourism; fisheries; human health; water resources; agriculture and food security; and coral reef biodiversity.

The Global Commission on Adaptation Report (2019) has proposed 5 priority adaptation actions. These priorities are improving dryland agriculture crop production, enhancing water and energy security, strengthening early warning systems, enhancing water and energy security, developing climate-resilient infrastructure, and adopting nature-based solutions. Based on the priority areas, the following two adaptation scenarios can be proposed (Figure 6.1)–

1. People-centric approach
2. Economic resilience approach

6.1 Scenario1: People-Centric Approach

Scenario 1 describes the people-centric approach. According to the National Multidimensional Poverty Index (MPI) for Maldives, 28% of the population was multidimensionally poor in 2016. The poor population is more vulnerable to the impacts of climate change due to their less accessibility to essential resources. In Maldives, the remoteness of the islands further enhances the challenges. Hence, while Malé has only 7% of the population is multidimensionally vulnerable in Malé, nearly 50% of the atolls are vulnerable[32]. The people-centric approach thus ranks the early warning system as the top priority, followed by infrastructure resilience, nature-based solutions, and agriculture, water, and energy security.

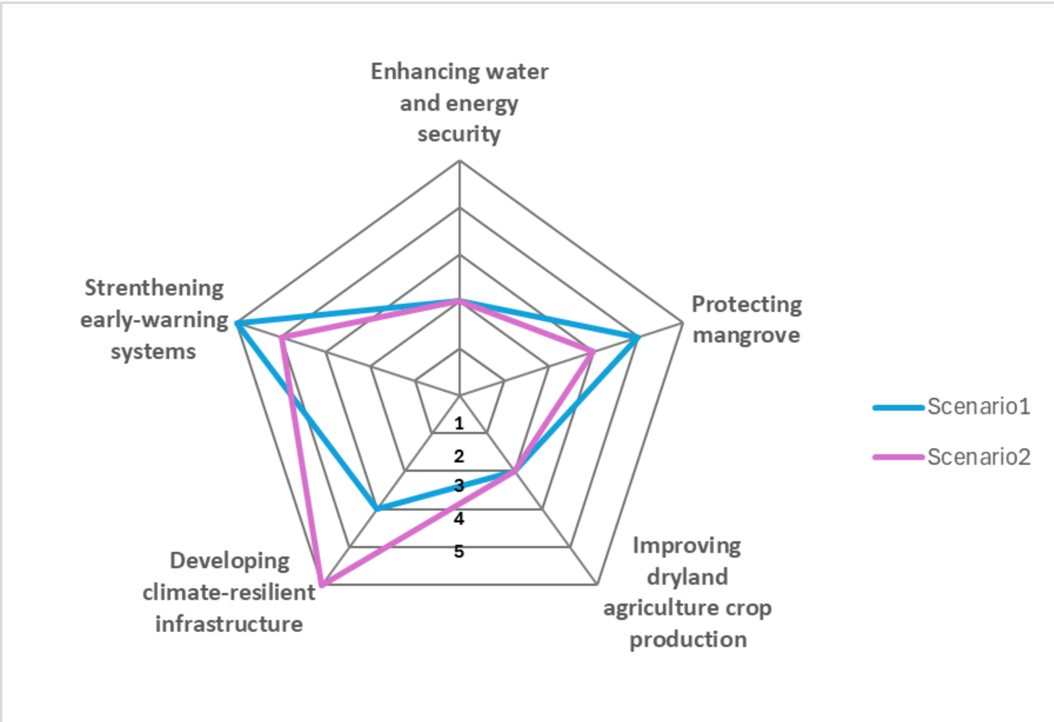
Early Warning Systems (EWS) are crucial for disaster risk reduction and climate change adaptation. Risk-informed early warning can guide early action targeted at the communities at the risk hotspots and ensure preparedness for future risks. Effective early warning can

[31] https://unfccc.int/sites/default/files/NDC/2022-06/Maldives%20Nationally%20Determined%20Contribution%202020.pdf

[32] https://statisticsmaldives.gov.mv/nbs/wp-content/uploads/2022/01/MVI-Report.pdf

minimize fatalities and impacts on the population. Scientific information on hazards & risks focusing on historical as well as future climate projections can form the base of the early warning systems. The incorporation of the latest technologies, such as Artificial Intelligence (AI) can be used for detecting, monitoring, and forecasting events in the target population. Remote sensing and satellite technologies can be useful to develop predictions and minimize climate-induced loss and damage. Innovative approaches, such as crowd-sourced data collection, social media monitoring, and participatory mapping, to improve hazard detection and response need to be explored. Collaboration and partnerships among government agencies, academic institutions, non-governmental organizations, and the private sector are to be developed to leverage expertise and resources for early warning initiatives. Policy frameworks and legislation need to be strengthened to support the development and implementation of early warning systems. To sustain the early warning system for long-term identification and allocation of financial resources as well as skilled human resources, it is necessary. Strengthening local capacities for hazard preparedness through awareness and training programs can be done to ensure relevance and ownership at the community level. Most of the disaster events in Maldives have transboundary origins. Hence regional, and sub-regional cooperation is essential for promoting collective action, sharing responsibilities, and building resilience to climate-related hazards at the regional level.

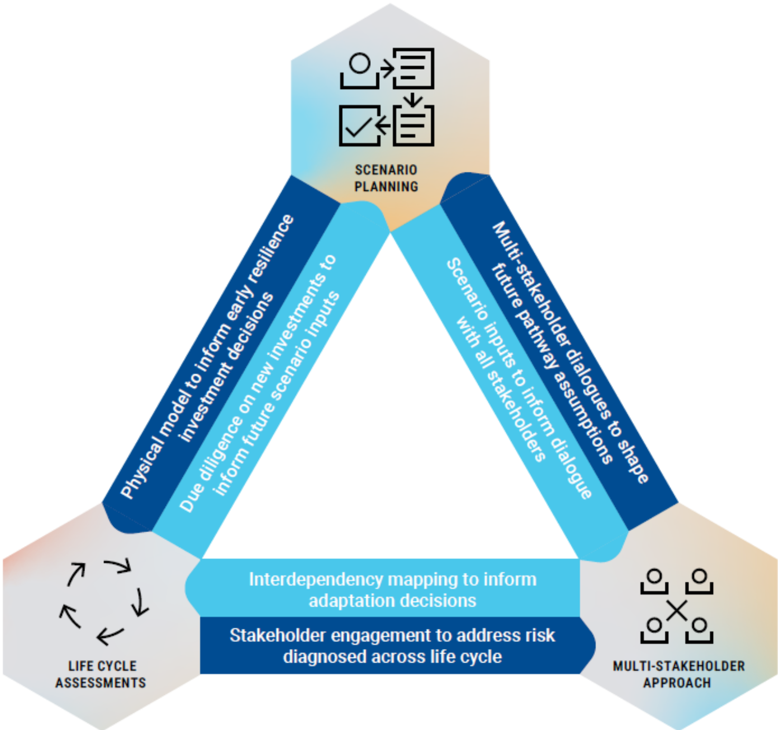
Figure 6.1: Five priority areas for climate change adaptation in Maldives



6.2 Scenario2: Economic Resilience Approach

Scenario 2 describes an economic resilience approach that prioritizes the development of climate-resilient infrastructure. Being a coastal country, the infrastructures in Maldives are highly exposed to climate hazards. Moreover, a large proportion of the critical infrastructure is located in climate risk hotspots. Disaster impacts will not only damage those infrastructures but also disrupt the services they provide. In this regard, a three-pillar approach: dynamic scenario planning, lifecycle assessments, and multi-stakeholder engagement with multiple interdependencies can be adopted[33].

Figure 6.2: The three-pillar approach to risk-informed infrastructure



In urban areas, building designs need to be improved to ensure increased resilience. Building codes should be enforced. The combination of green (mangroves) and grey infrastructure (sea walls) can be explored for coastal protection. Coastal protection needs to be developed, especially for the airports, ports, harbours, jetties, and tourist infrastructure. The climate change adaptation measures need to be incorporated into the upcoming resorts. The tourism sector contributes the highest to the national GDP. Any impact on the tourism sector will be economically challenging for Maldives. Capacity building and skill enhancements need to be done for climate-resilient infrastructure designing and planning. The reef must be protected to maintain the natural defense of the islands.

[33] Pathways to Adaptation and Resilience in South and South-West Asia: Asia-Pacific disaster report 2022.

Chapter 7:

Limitations

- The climate projection data provides the likelihood of the changes in the climate variables, not absolute confirmation.

- There are biases and assumptions in the models that might be reflected in the results of climate projection. As the climate projection data is the main input for the risk assessment, hence there are some margins of error in the risk assessment process as well.

- The risk assessment does not include the existing adaptation and mitigation measures.

- There are gaps in the Worldpop population count for Maldives. The data was used to calculate the population's exposure to different hazards. Many islands do not show any population, although there are.

- The elevation data (Coastal DEM V2.1) used in this study is based on the SRTM satellite radar during a NASA mission in 2000 with enhanced accuracy. Hence, there are gaps in the elevation data for the islands reclaimed post 2010.

- The landuse maps are developed based on satellite images and are not validated for every island.

- The locations of the critical infrastructure are collected from Google Maps. This data is not validated based on ground verification.

Chapter 8:

Way Forward

Despite the existing vulnerability, holistic and risk-informed development, as well as sectoral planning, has been limited in Maldives. Looking at the compelling evidence of climate change and its possible impacts on people and the sectors, a comprehensive approach to Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) is imperative. Moreover, the high cost of disasters and climate change justifies the need to institutionalize and practically operationalize a sustainable approach to development that considers multiple underlying risks and is inclusive, people-centred, and evidence-based, considering human rights and gender perspectives.

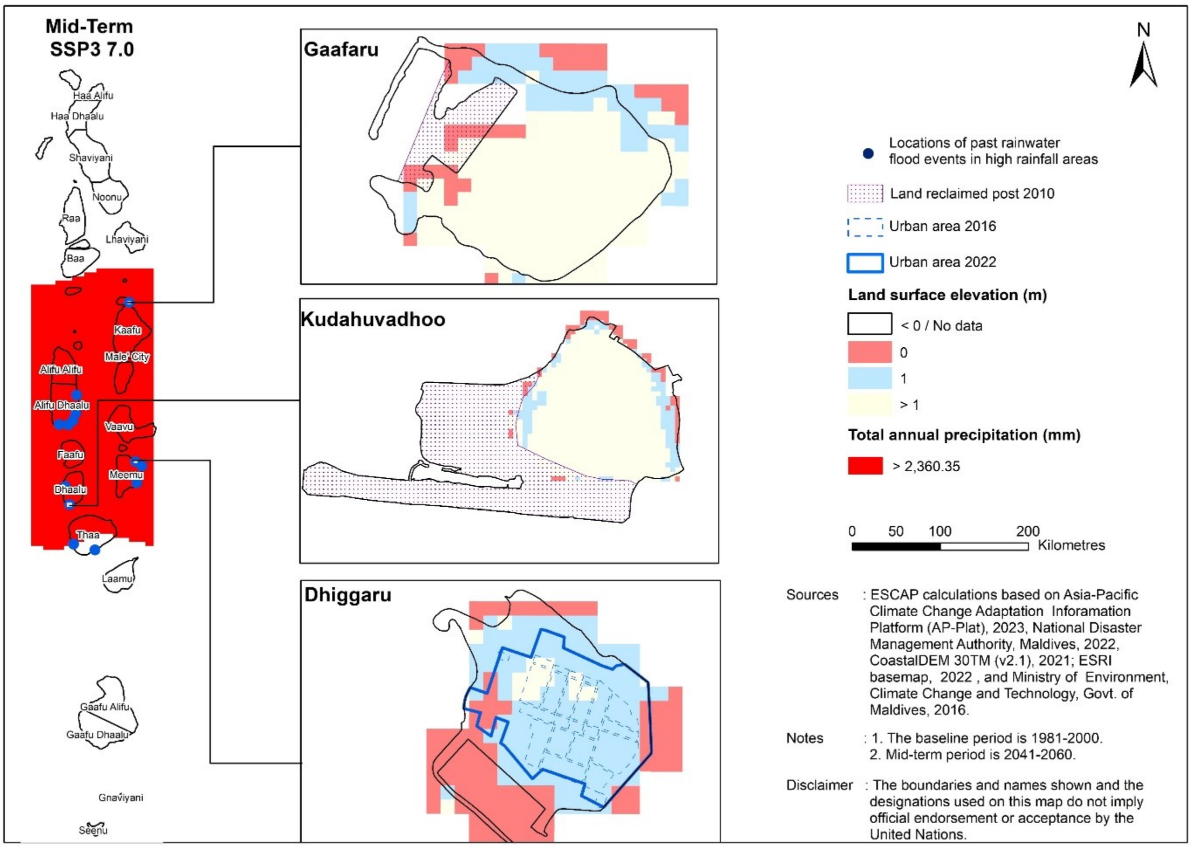
The joint project has ensured that there is improved availability, access, and use of appropriate data, information, and resources to identify and implement locally appropriate resilience-building activities while strengthening the planning and execution of sustainable disaster risk-reduction and climate change adaptation activities at national and subnational levels. Building upon the improved data and information, some examples of the next steps are furnished below.

8.1 Risk-Informed Development

Risk-informed development acknowledges that all development choices include both uncertain risks and opportunities and lead to more sustainable and resilient development. In Maldives limited land resources is a challenge for sustainable development. The decentralization of administration allows enhanced powers and responsibilities to the local councils at the island level, including developing 5-year development and land-use plans. In addition, local councils are required to support relevant authorities, such as the National Disaster Management Authority (NDMA), in implementing disaster risk-reduction regulations to prevent and mitigate the impact of disasters (including natural disasters) at the community level. However, a lack of accessible data hindered the implementation of this decentralized approach to evidence-based, climate-resilient DRR/CCA planning and implementation.

The hazard hotspots identified based on future climate and the updated landuse/land cover information facilitate the local administration to sustainably plan the island's development in the hazard-prone areas. For expansion of urban or agricultural areas, selecting climate and appropriate crop type, land reclamation, infrastructure development as well as protecting the existing infrastructures, this information will guide to choose the best possible solution.

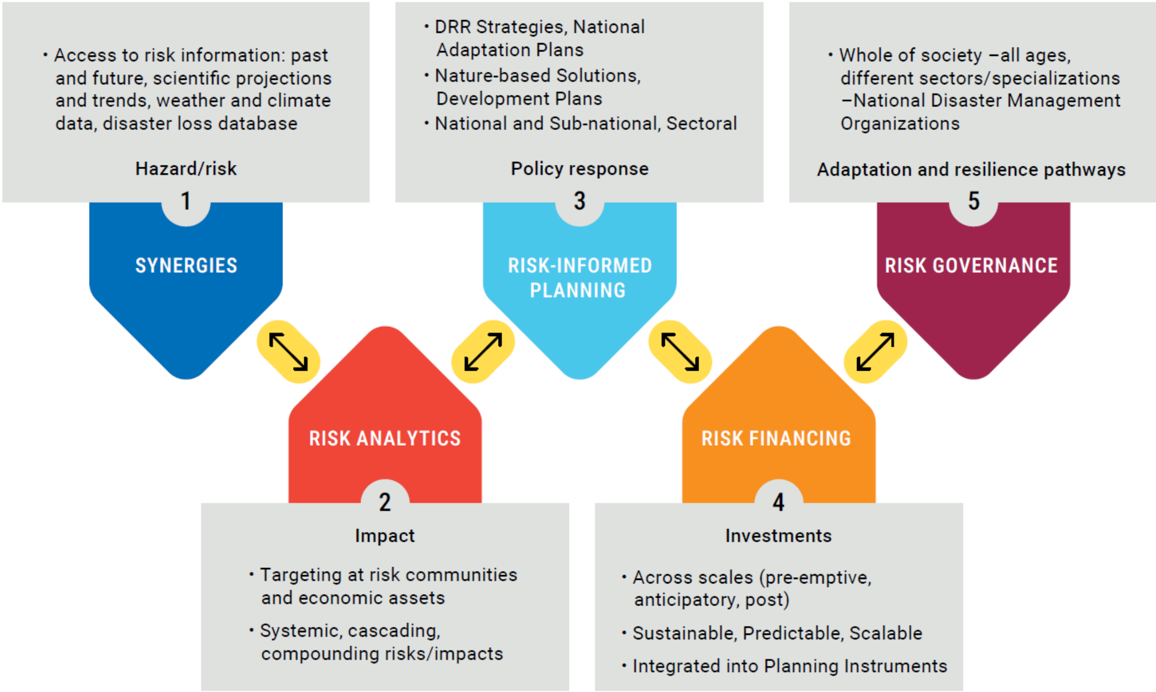
Figure 8.1: Risk-informed development at the island level



8.2 Prioritizing Climate Action and Investment in Adaptation

Knowing the current climate and future climate change scenarios and assessing climate vulnerabilities, the adaptation options at the sector, subnational, national, and other appropriate levels can be decided. Priority can be given to the areas at most risk and communities that are most vulnerable at the risk hotspots. The extent and intensity of risk can lead to the nature of adaptation or mitigation options required and accordingly estimation of the investment required. For example, in the case of the sea level rise, priority can be given to the low-lying areas with urban areas or infrastructure at high risk. With additional local information, grey infrastructure (sea walls), green (mangroves), or a combination of green and grey measures can be planned along with investment planning. This can shape risk-informed development policies, investments, and risk governance frameworks. Risks across different timescales, short-, medium-, and long-term, can be translated into meaningful information to enable more comprehensive planning and implementation (Figure 8.2).

Figure 8.2: Risk-informed policy response to development, investments, and governance[34]



8.3 Inclusive Social Development

Certain social groups are particularly vulnerable to crises, for example, female-headed households, children, persons with disabilities, Indigenous Peoples and ethnic minorities, landless tenants, migrant workers, older people, and other socially marginalized groups[35]. In Maldives, around 42% were female-headed. In Malé, 38% of the households, and in Atolls, 46% of the households are female-headed[36]. 4.73% of the population in Maldives have some kind of disability issues, and 50% of the disabled population in Maldives are exposed to high rainfall and related impacts under climate change scenarios. Around 26% of the population of Maldives are migrant workers37 , and one-third of them are undocumented38. Due to these social inequalities, a large proportion of the population is likely to face disproportionate challenges as a result of climate change and related impacts. Moreover, vulnerable populations located in the isolated islands have additional challenges in accessing resources and services, especially during extreme events.

In such cases, knowledge of the population and communities at risk can be used to develop DRR and CCA strategies targeted to the most impacted ones. Engagement of the citizens in

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[34] APDR2023

[35] https://www.worldbank.org/en/topic/social-dimensions-of-climate-change#:~:text=As%20the%20impacts%20of%20climate,identity%2C%20and%20other%20related%20risks.

[36] https://statisticsmaldives.gov.mv/nbs/wp-content/uploads/2021/04/Housing-Household-Characteristics-Updated.pdf

[37] https://census.gov.mv/2022/wp-content/uploads/2023/03/Provisional-Result-Publication.pdf

[38] https://www.ilo.org/wcmsp5/groups/public/---dgreports/---inst/documents/publication/wcms_776391.pdf

the risk hotspots in preparing micro-level planning can maximize the impacts of the measures along with addressing the needs of the local and vulnerable ones.

Moreover, communities in the risk hotspots can be encouraged as partners rather than beneficiaries to share their unique perspectives, skills, and a wealth of knowledge about the local challenges of strengthening resilience and addressing climate change. The risk knowledge can empower the development of climate finance architecture connecting communities and marginalized groups to the policy, technical, and financial assistance they need for locally relevant and effective development impacts.

8.4 Contribution to National Policies

The Government of Maldives announced its Nationally Determined Contributions (NDCs) in 2020 as part of its commitment to the Paris Agreement. Emphasis has been given to developing National mitigation and Adaptation Plans to address immediate, medium, and long-term adaptation programs, as well as the Development of appropriate policies and strategies to address the impacts of climate change on vulnerable groups. In the NDC, strengthening adaptation actions and building climate resilience infrastructure is considered a high national priority. Special emphasis has been placed on infrastructure resilience, early warning, Disaster Risk Resilience (DRR), and Disaster Risk Management (DRM). Among the 10 priority areas identified in the NDC as the potential for adaptation, the project output directly contributes to coastal protection, tourism, Early Warning and Systematic Observation, and Cross-Cutting Issues such as Climate governance and capacity building[39].

Identification of the risk hotspot for sea level rise and the population and infrastructure exposure to it will help develop coastal protection strategies, adaptation action for sustainable tourism, and risk-informed investment. Likewise, identifying vulnerable populations such as women and populations employed in climate-sensitive sectors such as agriculture and tourism in multi-hazard risk hotspots or flood risk areas will guide the formulation of effective climate governance policies such as social protection plans for vulnerable communities.

Early warning systems (EWS) are the key to disaster risk reduction and climate change adaptation, as they help reduce or avoid the impacts of climate-induced extreme events. An effective early warning should be risk-informed, targeted to vulnerable populations, and effectively disseminated to ensure preparedness and early action. Early warning based on robust scientific and technical risk knowledge and incorporating all relevant risk factors can provide maximum benefit. In COP27, the United Nations Secretary-General unveiled the Early Warning for All (EW4ALL) initiative, which targets every person on the Earth to be protected by EWS by 2027. Pillar 1 of the initiative focuses on disaster risk knowledge. As one of the first countries in the world, Maldives has already prepared a National Implementation Roadmap towards scaling up Early Warning Systems. It has identified gaps in up-to-date disaster risk profiles for natural hazards and digitized hazard maps for the islands of Maldives. The hazard & risk assessments done as part of this project, focusing on historical data (including updated hazard risk information) and scientific models and the availability of the same in the form of a digital database, can well fill the gap and directly contribute to the pillar 1 of the EW4ALL initiative in Maldives.

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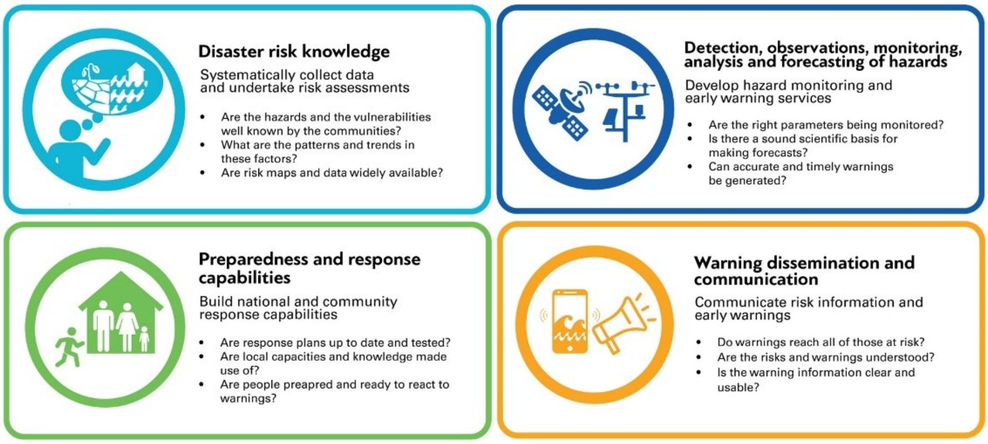
[39] https://unfccc.int/sites/default/files/NDC/2022-06/Maldives%20Nationally%20Determined%20Contribution%202020.pdf

Figure 8.3 United Nations Early Warnings for All Initiative[40]



Likewise, in the Strategic Action Plan (SAP) 2019-2023 (Jazeera Dhiriulhun), the output of the project will contribute to implementing three of the policies through strengthening adaptation actions and opportunities and building climate-resilient infrastructure and communities to address current and future vulnerabilities, promote environmentally sound technologies and practices towards building sustainable climate resilient island communities and strengthening national level disaster management information, communication and coordination system[41].

The project output will have an impact on the achievement of SDGs by streamlining DRR and CCA mandates to enable more coherent evidence-based policymaking and by creating an enabling environment for sustainable activities.

- Improved availability and access to the updated climate projection information will equip the local councils with better DRR/CCA development planning tools to help build the resilience of the poor and those in vulnerable situations. This will directly contribute to SDG 1 (No Poverty) by reducing their exposure and vulnerability to climate-related extreme events and other economic, social, and environmental shocks and disasters.
- Identifying the women in the risk hotspots will provide the required information to make risk-informed decision-making, such as gender-based budgeting and the allocation of national resources for DRR/CCA planning targeted to the most vulnerable cohorts of the population. This will help to reduce gender inequality especially triggered by climate change impacts and disasters, and accelerate the achievement of SDG5 (Gender equality).
- The risk assessment output is also expected to contribute to SDG 11 (Sustainable cities and communities) through risk-informed development of urban areas and vulnerable communities. The vast majority of the tourism infrastructure, fisheries sector, population and housing structures, and critical infrastructure are primarily located within 100m of the coastline, making the economic losses of natural disasters particularly catastrophic for the Maldives. In such a scenario, prior information on the potential risk can guide the DRR and CCA strategies, especially in urban centres, to minimize economic loss and damage.

[40] https://www.itu.int/en/ITU-D/Emergency-Telecommunications/Pages/Early-Warnings-for-All-Initiative.aspx
[41] https://presidency.gov.mv/SAP/

- The challenges of data availability were a significant bottleneck for the Maldives, particularly for achieving SDG13 (Climate Action). Using the updated risk information, the adaptive capacity to climate-related hazards and natural disasters both nationally and subrationally can be enhanced, and transparent mechanisms for resource allocation for disaster risk reduction and climate change can be established to ensure appropriate resources are allocated for both softer interventions at island level, and to ensure the duty bearing institutions are allocated the necessary resources to carry out their mandate. Interventions based on scientific evidence can help Maldives avoid cycles of relief and recovery that follow shocks and undo SDG progress, thereby improving the country's trajectory toward achieving the SDGs.

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Appendices

Appendix 1: Data Sources

Administrative boundary

Maldives is an archipelago consisting of low-lying islands and coral atolls. The islands and surrounding lagoons and reefs are very dynamic and change their spatial distribution frequently. Hence, the administrative boundaries of the islands and atolls are updated periodically. The national map of Maldives was developed and maintained by the Maldives Land and Survey Authority. They also publish updated administrative maps every year, which are open source (source: http://readme.onemap.mv/). The administrative data used in this study is collected from the Maldives Land and Survey Authority through Onemap.mv portal.

Climate projection data

The downscaled climate projection data is developed by the Asia Pacific Climate Change Adaptation Information Platform (AP-Plat) based on CMIP6 climate models and IPCC AR6 climate scenarios. It shows the projected spatial variability of precipitation and temperature at yearly and decadal scales up to 2100 based on ten major climate simulation models. From 100km of global data, downscaled data of 5km for the Maldives was developed for climate variables like precipitation, temperature, and surface wind.

For the baseline of sea level rise, Copernicus Sea level gridded data is used in this study. This dataset provides gridded daily and monthly mean global estimates of sea level anomaly based on satellite altimetry measurements. Sea level anomaly is defined as the height of water over the mean sea surface in a given time and region. In this dataset sea level anomalies are computed using a twenty-year mean reference period (1993-2012) and up-to-date altimeter standards. The data is available at ~27.75km resolution and available for daily and monthly mean values. For the climate projection of sea level, IPCC climate projection data on sea level rise is used. This data is available as an ensemble of CMIP6 models and as the change from the baseline (1995-2014). The data can be downloaded in different formats (GeoTiff, NetCDF, and PNG). The spatial resolution of this data is 100 km^2. (Source: https://interactive-atlas.ipcc.ch/)

Demographic data

The demographic data of Maldives is developed by the Maldives Bureau of Statistics periodically through population and housing census with an interval of 6-8 years. However, the gridded data is not available. The gridded population data provides spatially disaggregated population count per pixel over a continuous raster surface. This data is particularly advantageous as they can be aggregated over various levels of administrative units. This data is required to estimate the population's exposure and vulnerability to hazards. Hence, Worldpop population gridded data (unconstrained UN adjusted) was used for the total and female population used in this study.

Worldpop maps populations across the globe to produce high-resolution data for mapping human population distributions, with the ultimate goal of ensuring that everyone, everywhere is counted in decision-making. The gridded population data is available for the Maldives at 100m resolution at the equator. It is projected in the Geographic Coordinate System, WGS84.

The units are the number of people per pixel with country totals adjusted to match the corresponding official United Nations population estimates that have been prepared by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2019 Revision of World Population Prospects). This dataset was produced based on the 2020 population census/projection-based estimates for 2020. (source: https://hub.worldpop.org/project/list)

The Worldpop data is also available as the total number of people per grid square broken down by gender and age groupings (including 0-1 and by 5 years up to 80+) in 2020 for the Maldives. (Source: https://hub.worldpop.org/geodata/summary?id=50465)

Spatial data on Landuse land cover

Landuse/ land cover maps were produced as part of the Multi-hazard risk atlas published by the World Bank in 2020 for all the atolls and islands of Maldives. 17 landuse classes were identified including agricultural areas, Airports, Barren/sparsely vegetated areas, Beaches and sands, Coral reefs, Forest, Harbours, High-density urban areas, Low-density urban areas, Inland waters, Island resorts, Lagoon, areas under a palm tree, Shallow lagoons, Roads, Shrubs and/or herbaceous vegetation area and wetlands. This data has been used in his project as a base data for landuse and land cover.

For the current landuse and land cover data and the critical infrastructure such as health, education, transportation, energy, and essential services, the ESRI base map (2021-2022) is used. The landuse and land cover maps were manually prepared for the classes used in the Multi-hazard risk atlas for all the atolls and islands of the Maldives.

Disaster-related data (DesInventar/NDMA)

National Disaster Management Authority, Maldives (NDMA) has an inventory of country-wise disaster-related data. The data includes the type, location, and details of the disaster and their damage and loss data. Currently, they have data collated from 2013 to 2021.

Likewise, DesInventar has collated the disaster-related data of Maldives from 1894 until 2008. The data describes the composition, spatial distribution, and temporal behaviour of the disasters. This data was used to understand the location of past disasters and their impacts. (https://www.desinventar.net/DesInventar/profiletab.jsp?countrycode=mdv&continue=y)

Topography data

Earth's surface topography is depicted through digital elevation models (DEMs). DEMs are of particular interest for flood inundation mapping. There are several open-source DEMs available, among which is CoastalDEM, which was specifically developed for coastal areas of the world. CoastalDEM is a near-global digital elevation model specifically for ocean coastal areas available in both 90m and 30m resolution. CoastalDEM30™ v2.1 is based on NASADEM, a near-global satellite radar dataset derived from SRTM satellite radar during a NASA mission in 2000. The data was purchased in 2023 for this project. It is one of the best-performing of all leading, publicly available, global digital elevation models (DEMs) with comparatively minimum bias and it is trained on ICESat-2 Lidar data. CoastalDEM was primarily developed to evaluate coastal flood risk considering storms and sea level rise. The CoastalDEM is available at both 90m (open source) and 30m spatial resolution. As the Maldives is almost flat land with an average elevation of 2m above mean sea level, 30m DEM depicts better topographical variance than the 90m product and hence the data was used in this study. (Source: https://go.climatecentral.org/coastaldem/)

Appendix 2: Downscaling Global Climate Projection Data

Selection of climate models for future climate data

The future climate data is sourced from the CMIP6 global dataset. 10 climate models were chosen from the CMIP6 models based on the primary and secondary climate models specified by ISIMiP[42]. The selection of primary models is based on parameters such as the process representation, structural independence, climate sensitivity, and performance in the historical period. According to ISIMiP, the better-performing CMIP6 models are AWI-CM-1-1-MR, CESM2, CESM2-WACCM, GFDL-CM4, GFDL-ESM4, HadGEM3-GC31-LL, MPI-ESM1-2-HR, MPI-ESM1-2-LR, MRIESM2-0, SAM0-UNICON and UKESM1-0-LL. Additionally, based on the availability of the required variables GFDL-ESM4, MPI-ESM1-2-HR, MRI-ESM2-0, and UKESM1-0-LL as potential primary models. Another model providing data for potential variables is IPSL-CM6A-LR. Among these five models GFDL-ESM4, MPI-ESM1-2-HR, and MRI-ESM2-0 show low climate sensitivity, and IPSL-CM6A-LR, UKESM1-0-LL show high climate sensitivity. Apart from them, 5 other secondary climate models were selected based on the criteria mentioned above. Table 2 provides the details of the CMIP6 climate models included in ISIMIP3b and chosen for this study.

Table A2.1: Specs of CMIP6 climate models included in ISIMIP3b

Model	Group	Resolution	Member	piControl	ps	sfcWind
GFDL-ESM4	primary	1.0°	r1i1p1f1	0001–0500	available	available
IPSL-CM6A-LR	primary	2.0°	r1i1p1f1	1870–2369	available	available
MPI-ESM1-2-HR	primary	1.0°	r1i1p1f1	1850–2349	available	available
MRI-ESM2-0	primary	1.0°	r1i1p1f1	1850–2349	proxy	available
UKESM1-0-LL	primary	2.0°	r1i1p1f2	1960–2459	available	available
CanESM5	secondary	2.0°	r1i1p1f1	5201–5700	proxy	available
CNRM-CM6-1	secondary	1.0°	r1i1p1f2	1850–2349	proxy	proxy
CNRM-ESM2-1	secondary	1.0°	r1i1p1f2	1850–2140	proxy	proxy
EC-Earth3	secondary	0.5°	r1i1p1f1	2259–2758	proxy	available
MIROC6	secondary	1.0°	r1i1p1f1	3200–3699	proxy	proxy

Downscaling method

The monthly global data (100km) on the future projection of precipitation and temperature is collected from the repository of the National Institute of Environmental Studies (NIES), Japan for each of the 10 models mentioned above and 3 scenarios for 1981 – 2100. The data for the Maldives is extracted from global data. 30 years average (the periods of 1981-2000, 2021-2040, 2041-2060, and 2081-2100) of each of the variables are done for each month. The downscaling is done using bilinear interpolation. All the processes were automatized using a shell programming interface. The same process was repeated for all the 10 selected models and all the variables. Finally, the ensemble of models was prepared taking the average of all the models for each variable.

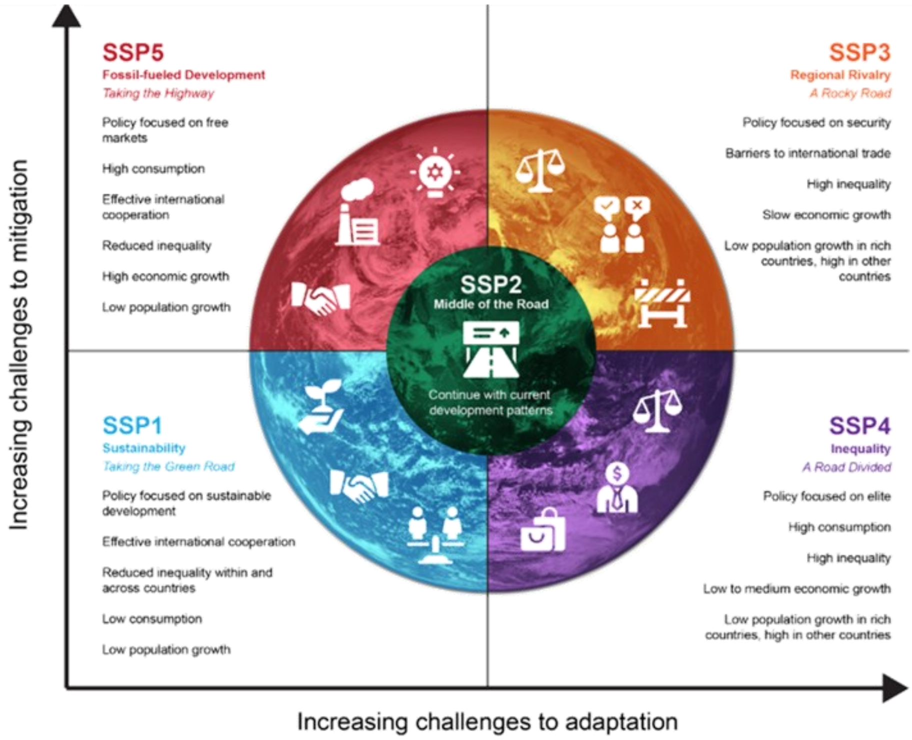
[42] https://www.isimip.org/documents/413/ISIMIP3b_bias_adjustment_fact_sheet_Gnsz7CO.pdf

Appendix 3: Shared Socio-Economic Pathways

Socioeconomic characteristics that influence greenhouse gas emissions in a standardized manner indicate the societal pathways associated with different levels of warming. The SSP scenarios consist of five narratives that describe alternative pathways of global development. These narratives are based on qualitative and quantitative information, such as population, urbanization, GDP, education, health, and inequality. In this study three of them are chosen to have an overview of the best possible case to the worst-case scenario.

- SSP1: Sustainability (Taking the Green Road) - This scenario assumes a world that shifts toward a more sustainable and inclusive path, where people respect the environment and cooperate to achieve common goals. Education and health improve, population growth decreases, and inequality is reduced. Resource and energy use become more efficient and low-carbon, and environmental degradation is reversed. This scenario has a low level of challenges for both mitigation and adaptation.
- SSP2: Dynamics as Usual (Middle of the Road) - This scenario assumes a world that follows a moderate and uneven path, where social, economic, and technological trends do not change much from the past. Development and income growth vary across regions and countries, and some achieve more progress than others. Institutions and governance are adequate but not very effective in addressing global issues. Resource and Energy use decline slightly, but environmental degradation continues. This scenario has a medium level of challenges for both mitigation and adaptation.
- SSP3: Regional Rivalry (A Rocky Road) - This scenario assumes a world that becomes more fragmented and unequal, where people focus on their interests and security. Development and income growth are slow and uneven, and many countries face poverty and instability. Institutions and governance are weak and unable to cope with global challenges. Resource and energy use are high and inefficient, and environmental degradation is severe. This scenario has a high level of challenges for both mitigation and adaptation.
- SSP4: Inequality (A Road Divided) - This scenario assumes highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor-intensive, low-tech economy. (Under this scenario, there are low challenges to mitigation but high challenges to adaptation.
- SSP5: Fossil-fueled Development (Taking the Highway) - This world places increasing faith in competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy-intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while the global population peaks and declines in the twenty-first century. In this scenario, there are high challenges to mitigation but low challenges to adaptation.

Figure A3.1: Shared Socioeconomic Pathways



Appendix 4: Exposure Numbers

Table A4.1: Exposure of the population to the highest amount of rainfall in Maldives

Atoll	Baseline (1981-2000)	SSP2 4.5 (2021-2040)	SSP2 4.5 (2041-2060)	SSP3 7.0 (2021-2040)	SSP3 7.0 (2041-2060)
Baa Atoll	0%	0%	7%	0%	7%
Lhaviyani Atoll	0%	0%	0%	0%	0%
Raa Atoll	0%	0%	0%	0%	0%
Shaviyani Atoll	0%	0%	0%	0%	0%
Alifu Alifu Atoll	100%	100%	100%	100%	100%
Dhaalu Atoll	100%	0%	100%	100%	100%
Faafu Atoll	100%	25%	100%	100%	100%
Gnaviyani Atoll	100%	0%	0%	0%	0%
Seenu Atoll	100%	0%	0%	0%	0%
Gaafu Alifu Atoll	100%	0%	0%	0%	0%
Vaavu Atoll	100%	100%	100%	100%	100%
Meemu Atoll	100%	34%	100%	100%	100%
Laamu Atoll	100%	0%	0%	0%	0%
Thaa Atoll	100%	0%	0%	78%	87%
Alifu Dhaalu Atoll	100%	100%	100%	100%	100%
Haa Alifu Atoll	0%	0%	0%	0%	0%
Haa Dhaalu Atoll	0%	0%	0%	0%	0%
Noonu Atoll	0%	0%	0%	0%	0%
Gaafu Dhaalu Atoll	100%	0%	0%	0%	0%
Malé City	100%	100%	100%	100%	100%
Kaafu Atoll	100%	91%	100%	100%	100%
Total	73%	47%	50%	54%	55%

Table A4.2: Exposure of the female population to the highest probability of multi-hazard in Maldives

Atoll	Baseline (1981-2000)	SSP2 4.5 (2021-2040)	SSP2 4.5 (2041-2060)	SSP3 7.0 (2021-2040)	SSP3 7.0 (2041-2060)
Baa Atoll	0%	100%	0%	0%	100%
Lhaviyani Atoll	0%	100%	0%	0%	100%
Raa Atoll	0%	100%	0%	0%	100%
Shaviyani Atoll	86%	100%	92%	0%	100%
Alifu Alifu Atoll	0%	100%	0%	0%	100%
Dhaalu Atoll	0%	100%	0%	0%	100%
Faafu Atoll	0%	100%	0%	0%	100%
Gnaviyani Atoll	0%	0%	0%	0%	0%
Seenu Atoll	0%	0%	0%	0%	0%
Gaafu Alifu Atoll	0%	0%	0%	0%	0%

Vaavu Atoll	0%	100%	0%	0%	100%
Meemu Atoll	0%	100%	0%	0%	100%
Laamu Atoll	0%	0%	0%	0%	0%
Thaa Atoll	0%	100%	0%	0%	79%
Alifu Dhaalu Atoll	0%	100%	0%	0%	100%
Haa Alifu Atoll	100%	100%	97%	0%	100%
Haa Dhaalu Atoll	81%	100%	90%	0%	100%
Noonu Atoll	0%	100%	0%	16%	100%
Gaafu Dhaalu Atoll	0%	0%	0%	0%	0%
Malé City	0%	100%	0%	0%	100%
Kaafu Atoll	0%	100%	0%	22%	100%
Total	13%	82%	13%	1%	81%

Table A4.3: Exposure of agricultural areas to sea level rise in Maldives

Atoll	**Agricultural area below 1 m (0m) elevation exposed to SLR up to 1 m (sq. km)**	**Agricultural area with 0 -1 m elevation exposed to SLR more than 1 m (sq. km)**
Baa Atoll	1%	10%
Lhaviyani Atoll	0%	16%
Raa Atoll	0%	18%
Shaviyani Atoll	1%	13%
Alifu Alifu Atoll	0%	0%
Dhaalu Atoll	1%	9%
Faafu Atoll	0%	17%
Gnaviyani Atoll	14%	82%
Seenu/ Addu Atoll	0%	50%
Gaafu Alifu Atoll	0%	5%
Vaavu Atoll	--	--
Meemu Atoll	3%	14%
Laamu Atoll	1%	14%
Thaa Atoll	1%	8%
Alifu Dhaalu Atoll	2%	13%
Haa Alifu Atoll	0%	4%
Haa Dhaalu Atoll	3%	19%
Noonu Atoll	3%	19%
Gaafu Dhaalu Atoll	0%	13%
Kaafu/ North and south Malé Atoll/ Malé City	0%	1%
Total	1%	13%

Table A4.4: Exposure of critical infrastructure to sea level rise

Atoll	Total no. of critical infrastructure	Critical infrastructure located below 1 m (0m) elevation exposed to SLR up to 1 m	Critical infrastructure located within 0 -1 m elevation exposed to SLR more than 1 m
Baa Atoll	52	0.00%	5.77%
Lhaviyani Atoll	24	0.00%	12.50%
Raa Atoll	79	1.27%	5.06%
Shaviyani Atoll	77	0.00%	5.19%
Alifu Alifu Atoll	20	0.00%	5.00%
Dhaalu Atoll	40	0.00%	12.50%
Faafu Atoll	33	0.00%	3.03%
Gnaviyani Atoll	45	0.00%	17.78%
Seenu Atoll	90	0.00%	31.11%
Gaafu Alifu Atoll	51	0.00%	15.69%
Vaavu Atoll	8	--	0.00%
Meemu Atoll	31	0.00%	22.58%
Laamu Atoll	91	0.00%	3.30%
Thaa Atoll	59	0.00%	3.39%
Alifu Dhaalu Atoll	39	2.56%	15.38%
Haa Alifu Atoll	84	1.19%	15.48%
Haa Dhaalu Atoll	77	1.30%	3.90%
Noonu Atoll	74	0.00%	4.05%
Gaafu Dhaalu Atoll	80	0.00%	12.50%
Malé City	75	2.67%	9.33%
Kaafu Atoll	46	0.00%	6.52%
Total	1175	0.51%	10.38%