Toward Risk-Aware and Climate-resilienT communities (TRACT)

Strengthening climate services and impact-based multi-hazard early warning in Maldives

Annex 2
Pre-Feasibility Study

Contents

List of figures

List of tables

1 BACKGROUND AND CONTEXT

1.1 Geography

The Republic of Maldives (hereafter "the Maldives") is an archipelago of 1,192 coral islands in the Indian Ocean, grouped into 26 atolls, arranged in a double chain and scattered between latitudes 7° 6' 35" N and 0° 42' 24" S in a narrow band between 72° 32' 19 E and 73° 46' 13" E.[1] While the total length of the archipelago is around 860 km long and the width varies between 80 and 120 km, the total land area of the Maldives is only about 298 km^2, which makes it is the sixth smallest country in the world in terms of land area and one of the world's most geographically dispersed countries.[2] Maldives has a population of about 515,000 (Census 2022) and it is currently the 7th most densely populated country in the world.[3,4] Administratively, Maldives is divided into 21 administrative atolls (see Figure 1).[5]

About 355 islands in the Maldives have human settlements and are used for economic activities. Out of these, only 187 islands are inhabited by the local population, while the remaining ones are used exclusively for tourist resorts.[6] The islands are small (most of the vegetated islands are less than 0.5 km^2 in land area)[7] and low-lying: more than 80% of the islands have ground-level elevation of less than 1 m above mean sea level,[8] which makes the Maldives one of the most low-lying countries in the world.[9] Due to natural oceanographic and sedimentary processes, the coral islands are morphologically unstable, changing size, shape, position and elevation over time.[10] Factors of small size, low elevation and changeability present significant shoreline management challenges for the island communities.[11]

Due to the geological formation of coral islands, Maldives does not have surface water resources except for a few wetlands. Freshwater only exists in the form of shallow water lenses several metres below the ground surface.[12] The soil is highly alkaline, and vegetation is sparse. The main vegetation types are coconut palms, salt-resistant plants, and mangroves.[13] Due to the absence of rivers and runoffs, there are almost no sediments from inland sources; therefore the waters around the Maldives are very clear and exhibit ideal conditions for coral growth.[14] The total coral reef area of the Maldives is approximately 4,513 km^2, constituting the 7th largest reef system in the world.[15]

Due to its location over the equator in the Indian Ocean, Maldives experiences a typical equatorial monsoonal climate characterised by warm and humid climate throughout the year, with seasonal fluctuations in temperature and rainfall driven by the monsoon.[16] The south-west monsoon (May – October) brings rain, and during this time ocean conditions vary from moderate to rough. The north-east monsoon period (November – April) is marked by calmer and dry conditions.[17] Although Maldives is located outside the tropical cyclone zone due to its proximity to the equator, there have been incidents of cyclonic storms passing over the country, and there is a possibility of such events in the future, particularly affecting the northern part of the Maldives.[18]

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[1] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the UNFCCC
[2] Asian Development Bank and World Bank Group, 2021. Climate Risk Country Profile. Maldives.
[3] Maldives Bureau of Statistics, 2024. Census 2022 – Statistical Releases. Available at: https://census.gov.mv/2022/statistical-releases/ (Accessed: 12 September 2024)
[4] Maldives Population 2024 (Live)
[5] CIA. The World Factbook. Administrative Divisions.
[6] Maldives Bureau of Statistics, 2024. Resident Population, Census 2022. (Accessed: 12 September 2024)
[7] Ministry of Environment, 2019. Maldives First Biennial Update Report to the UNFCCC
[8] Ministry of Tourism and Environment, 2011. State of the Environment
[9] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the UNFCCC
[10] Ministry of Environment, Energy and Water, 2007 National Adaptation Program of Action. Republic of Maldives
[11] Kench et al. A process-based assessment of engineered structures on reef islands of the Maldives. Coasts & Ports Australasian Conference 2003
[12] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the UNFCCC
[13] Ministry of Fisheries and Agriculture. Atolls of Maldives.
[14] Ministry of Fisheries and Agriculture. Atolls of Maldives.
[15] Ministry of Environment, 2019. Maldives First Biennial Update Report to the UNFCCC
[16] Asian Development Bank and World Bank Group, 2021. Climate Risk Country Profile. Maldives.
[17] Ministry of Fisheries and Agriculture. Atolls of Maldives.
[18] Ministry of Environment, Energy and Water, 2007 National Adaptation Program of Action. Republic of Maldives

Figure 1. Administrative boundaries of Maldives (Source: Asian Development Bank, 2020[19])

[19] Asian Development Bank, 2020. Multi-Hazard Risk Atlas of Maldives. Geography – Volume I

1.2 Environmental context

Maldives is remarkably rich in biodiversity. Over 1,100 species of fish, five types of marine turtles, 21 species of whales and dolphins, 180 coral species, 400 species of molluscs, and 328 species of crustaceans have been recorded. Though land-based resources are scarce, they still include 13 species of mangroves, 583 species of plants and 170 species of birds.[20] Natural capital is a backbone of the Maldivian economy which is largely based on fisheries and tourism. It is also the foundation of resilience of Maldives: coral reefs help significantly reduce flooding of the islands as well as provide sediment and sand necessary for the island buildup and habitability, mangroves (though present in patches) also serve as important buffers against flooding, while seagrass meadows stabilise bottom sediments and reduce wave energy.[21]

Ocean water parameters such as sea surface temperature (SST) and acidity (pH levels) are critical for the maintenance of healthy and productive marine ecosystems. In the past, SST increase associated with El Niño Southern Oscillation (ENSO) events led to multiple coral bleaching events.[22] It is expected that further climate change-induced SST increase and ocean acidification might lead to coral reef degradation, as well as threaten the survival of tuna larvae and juveniles.[23] In addition to climate-related factors, Maldivian natural capital is largely threatened by coastal development, pollution and unsustainable resource use.[24]

Though significantly contributing to economic development, coastal development projects including construction of harbours and ports, land reclamation, etc. have caused significant damage to coral reef ecosystems, undermining the natural defence of the islands and necessitating additional coastal protection measures. Since the 1970s, Maldives has primarily implemented “hard infrastructure” measures such as seawalls and breakwaters, which are often considered maladaptive since they can reduce the natural ability of the islands to adapt to sea level rise through destabilising sediment transportation. From 2005 – 2016 only two islands implemented “green” coastal resilience measures, as opposed to 45 islands using “hard infrastructure”.[25]

Ocean pollution with liquid and solid waste also poses a significant environmental challenge. Microplastic has been found to significantly contaminate coral reefs and fisheries in the Maldives. Wastewater is often discharged in the ocean without proper treatment, however, no studies on its environmental impact have been done due to limited water pollution monitoring in the Maldives.[26] Run-off from pesticides and fertilisers used in agricultural activities has been reported to cause excessive eutrophication leading to coral reef degradation. Furthermore, solid and liquid waste pollution has been reported to contaminate already scarce freshwater resources, reducing availability of potable water.[27]

Excessive extraction of resources is another challenge for the Maldives’ natural capital. While the population of skipjack tuna is reported to be stable, yellowfin tuna has been seriously affected by overfishing. Though in recent years sustainable practices for tuna fisheries management have been introduced, illegal, unreported and unregulated fishing still puts significant pressure on fish populations and reef ecosystems.[28] Over-exploitation of other reef resources such as sea cucumber and giant clam has also been reported as a major concern. Excessive timber harvesting has been reported to be a threat for survival of hardwood trees.[29]

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[20] UNEP / CBD Secretariat, 2024. Country Profile – Maldives. Available at: https://www.cbd.int/countries/profile?country=mv (Accessed: 19 December 2024)
[21] The World Bank, 2024. Maldives: Country Environmental Analysis. Towards a More Sustainable and Resilient Blue Economy
[22] Asian Development Bank & World Bank Group, 2021. Climate risk country profile. Maldives. Available at: https://www.adb.org/sites/default/files/publication/672361/climate-risk-country-profile-maldives.pdf
[23] Frommel, A. et al., 2016. Ocean acidification has lethal and sub-lethal effects on larval development of yellowfin tuna, Thunnus albacares. Journal of Experimental Marine Biology and Ecology, Volume 482, September 2016, Pages 18-24.
[24] The World Bank, 2024. Maldives: Country Environmental Analysis. Towards a More Sustainable and Resilient Blue Economy
[25] The World Bank, 2024. Maldives: Country Environmental Analysis. Towards a More Sustainable and Resilient Blue Economy
[26] The World Bank, 2024. Maldives: Country Environmental Analysis. Towards a More Sustainable and Resilient Blue Economy
[27] Asian Development Bank, 2007. Maldives: Environment Assessment
[28] Jaleel, A. & Smith, H., 2022. The Maldives Tuna Fishery: An Example of Best Practice. Ocean Yearbook Online.
[29] Asian Development Bank, 2007. Maldives: Environment Assessment

1.3 Political context

With the first multiparty democratic elections held only in 2008, the Maldives is one of the South Asia's youngest democracies. The new 2008 Constitution declares the Maldives to be "a sovereign, independent, democratic Republic based on the principles of Islam, and a unitary State".[30] Presidential and parliamentary elections in the Maldives are held on a five-year basis. There are currently 10 registered parties in the Maldives.

Since 2008, democracy in the Maldives has been fragile, witnessing police mutinies, political unrest and judicial interventions. There has also often been a power struggle between legislative and executive branches.[31] The most recent presidential election in 2023 was conducted in a highly peaceful and competitive manner.[32] However, the new president Mohammed Muizzu, elected from the People's National Congress Party (PNC), was immediately opposed and boycotted by a parliamentary majority from the rival Maldivian Democratic Party.[33] Concerns were raised that the President's rule could be potentially challenged by the parliamentary elections in April 2024 in the event that his party was unable to secure the majority. However, the PNC won by a landslide, which ensured consolidation of the executive and legislative branches.

1.4 Economic context

The Maldives is the only upper-middle income country in South Asia,[34] with GDP per capita in 2022 (current USD) amounting to $11,780.[35] Its economic growth has mostly been driven by the tourism industry,[36] which accounts for more than 28% of GDP and 60% of economic exchange.[37] The second most important industry is fisheries, which, though only contributing to 3.5% of GDP,[38] accounts for 98% of exports and employs 20% of the population.[39] Being the backbone of the Maldivian economy, these two sectors indirectly contribute to a much larger share of GDP.[40] Both sectors critically depend on natural capital, therefore, environmental degradation caused by excessive pressure on natural resources directly threatens the economic development of Maldives.[41]

Though economic growth remains robust, and the economy is projected to grow by 5.6% in the medium-term driven by earnings from tourism industry, the Maldives faces a number of economic challenges including high public debt and budget deficit, calling for extensive fiscal reforms and prudent debt management. According to a recent IMF statement on Maldives, "without significant policy changes, the Maldives remains at high risk of external and overall debt distress".[42] High commodity prices also pose a challenge, especially in the context of financing large-scale infrastructure projects.[43] Excessive dependency on tourism revenues increases vulnerability of the economy to a potential global slowdown[44] or external shocks, which was demonstrated during the COVID-19 pandemic when plummeting of tourist arrivals by 67% caused the economy to contract by 33%, causing the deepest recession on record.[45] Potential pathways for diversifying the economy could include aquaculture and sustainable fisheries, marine biotechnology and renewable energy, IT and e-commerce.[46] Most of these sectors largely depend on meteorological information for safe and efficient operations and could significantly benefit from

[30] Constitution of the Republic of Maldives, 2008. Available at: https://www.constituteproject.org/constitution/Maldives_2008
[31] Observer Research Foundation, 2024. The Challenges in Muizzu's Maldives: A Stocktaking
[32] Ghafoor, M., 2023. The Past, Present and Future of Maldivian democracy
[33] Deccan Herald, 2024. Maldives politics in troubled waters: Opposition boycotts President Muizzu's address
[34] World Bank Group country classification by income level
[35] World Bank Indicators. GDP per capita (current prices)
[36] World Bank. Maldives overview
[37] Michigan State University. Maldives: Economy
[38] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the UNFCCC
[39] Ministry of Economic Development and Trade. Invest Maldives – Fisheries.
[40] High commission of the Republic of Maldives, 2020. Economic profile.
[41] World Bank, 2022. Poverty and Inequality in Maldives – 2022
[42] IMF, 2024. IMF Executive Board Concludes 2024 Article IV Consultation with Maldives
[43] World Bank. Maldives overview
[44] World Bank. Maldives overview
[45] Asian Development Blog, 2023. Beyond Tourism: Diversifying the Maldivian Economy for a Sustainable Future
[46] Asian Development Blog, 2023. Beyond Tourism: Diversifying the Maldivian Economy for a Sustainable Future

improved weather and climate information services[47] through increased capacity for planning and informed decision-making.

1.5 Socio-economic indicators

Over the past decades Maldives has achieved great progress in its socio-economic development, transitioning from a low-income to low-middle income status in 1993 and to high-middle income in 2010[48].

The Human Development Index (HDI) value for 2022 for the Maldives was 0.762, placing it into the high human development category. The average annual HDI growth in 2010-2022 amounted to 0.81%, which was much higher than the world's average of 0.48%. The inequality-adjusted HDI adjusts the HDI value according to inequalities relating to health, education and income, with the 'loss' in human development due to inequality expressed as a percentage. In 2022, the overall loss for the Maldives was calculated at 21.7%, which is slightly lower than the world's average 22.1%.[49]

Poverty levels in the Maldives are much lower than average in South Asia. According to the multidimensional poverty index calculated based on 2016-17 Demographic and Health surveys, only 4.8% of the Maldivian population was vulnerable to multidimensional poverty, as opposed to the 17.9% average across South Asia. None of the population in the Maldives was deemed to be subject to severe multidimensional poverty.[50] Nevertheless, poverty is unevenly spread across the country, being 10 times higher in outer atolls than in Male', which makes the population of regions outside the capital more vulnerable to poverty.[51]

The Maldives has also largely improved its healthcare, being the only country in South Asia to achieve its mortality-based SDGs ahead of schedule. With 40% of the national budget allocated to social spending, the Maldives has the highest public spending on health in South Asia. Healthcare is free and provided through a universal health insurance scheme (Husnuvaa Aasandha). The healthcare system is well-organised in a four-tier order, and a medical facility is present on each island. However, challenges remain for providing more advanced healthcare in remote areas, mostly due to complicated logistics and low availability of tier four medical facilities. This calls for improvements in regional healthcare, as well as development of telemedicine for non-urgent care and counselling.[52]

Significant progress has been achieved in terms of education. Free schooling is provided to all children below 12, and 96% of children are enrolled in primary school. Almost all adolescents are literate in the Dhivehi language and more than 90% are literate in English. The share of persons with tertiary education aged 18 to 36 increased from 7% in 2016 to 13% in 2019. However, bottlenecks remain, preventing proliferation of higher-level education. One of the challenges is a drop in enrolment rates for both lower secondary and higher secondary levels.[53] Only 45% of children transit to higher secondary school, in part due to only 59 out of 212 schools providing higher secondary education.[54] Continued development of online education which emerged in the times of COVID-19 pandemic could be a partial solution, if regularised to complement in-person education.[55]

Some progress on women's rights has also been achieved. Adolescent birth rate has decreased from 18 births per 1,000 women aged 15-19 in 2010 to 7 in 2021.[56] Only 2% of women aged 20-24 in 2017 were first married before 18 years old, as opposed to 22% in India, 18% in Pakistan and 10% in Sri Lanka.[57] The Maldives also stands out from other South Asian countries in terms of education opportunities for women – Maldivian women are more likely than men to be educated at the secondary level or above.[58] Still, more work should be done, particularly in terms of increasing political representation (in 2021, only

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47 Rogers, D. and Tsirkunov, V., 2013. Weather and Climate Resilience Effective Preparedness through National Meteorological and Hydrological Services. The World Bank.
48 World Bank Group country classification by income level
49 UNDP, 2024. Human Development Report 2023-24.
50 UNDP, 2024. Human Development Report 2023-24.
51 World Bank, 2022. Poverty and Inequality in Maldives – 2022
52 Eya et al., 2023. Progress of island health in the Maldives
53 World Bank, 2022. Poverty and Inequality in Maldives – 2022
54 UNICEF. The Maldives - Education
55 World Bank, 2022. Poverty and Inequality in Maldives – 2022
56 World Bank Indicators. Adolescent fertility rate (births per 1,000 women ages 15-19)
57 World Bank Indicators. Women who were first married by age 18 (% of women ages 20-24)
58 World Bank, 2022. Poverty and Inequality in Maldives – 2022

4.6% of women held places in parliament), as well as opportunities to take managerial positions (in 2021, proportion of women in managerial positions was only around 20%).[59]

1.6 Summary of relevant factors

An assessment of the political, economic, socio-cultural, legal, and environmental (PESTLE) factors in the Maldives that have the potential to impact on the proposed project is presented in the table below.

Table 1. PESTLE analysis for Maldives.

Political	• Maldives transitioned to a democratic multiparty system in 2008, adopting a new constitution. • Presidential and parliamentary elections are held every five years. Regular elections ensure accountability but can cause shifts in priorities, affecting the continuity of long-term projects. • Democracy remains fragile, facing challenges such as political unrest, judicial interventions, and disputes over presidential figures. Political instability could hinder the effectiveness of project implementation, particularly where government entities are responsible for executing project interventions. • The People's Congress Party (PNC) currently controls both the executive and legislative branches. • Corruption is perceived to be a significant issue in Maldives: the Corruption Perceptions Index (CPI) ranks Maldives 93rd of 180 countries, with a score of 39 (where 0 represents a highly corrupt system, and 100 represents a system perceived to have no corruption). High levels of perceived corruption could undermine the effectiveness of the project by diverting resources, reducing accountability and transparency.[60] • Several environmental and climate-related policies highlight the relevance of the proposed project, including the 2024-2030 Disaster Risk Reduction Strategy,[61] 2020 Updated Nationally Determined Contribution,[62] and 2019-2023 Strategic Action Plan.[63] A more detailed analysis of relevant policies can be found in Sections 4.1 and 4.2. These policies create a strong political framework that supports project implementation.
Economic	• Maldives is classified as an upper-middle-income country, with a GDP per capita of $11,780 (2022).[64] This increases the chances of funding being available to sustain the project's interventions beyond the implementation period. • The country's economy is highly reliant on tourism, which contributes more than 28% of GDP and 60% of economic exchange. Fisheries are the second-largest industry, contributing 3.5% of GDP, 8% of exports, and employ 20% of the population.[65] Both tourism and fisheries are highly vulnerable to the impacts of climate change and extreme weather events, highlighting the importance of targeting these sectors through the project interventions. • Key economic challenges include high public debt, the need for fiscal reforms, inflation, and the lack of economic diversification. • The unemployment rate is 4.1%. The relatively low unemployment rate indicates that, generally, individuals are more likely to have resources

[59] UN Women. Maldives
[60] Corruption Perceptions Index - World Trends in Freedom of Expression and Media Development
[61] Disaster Risk Reduction Strategy, 2024-2030. Available at: https://ndma.gov.mv/storage/uploads/50wNZewA/mixvv4ks.pdf
[62] Maldives Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[63] Government of Maldives, 2019. Strategic Action Plan 2019-2023
[64] World Bank Indicators. GDP per capita (current prices)
[65] High commission of the Republic of Maldives, 2020. Economic profile.

	to cope with climate change impacts, though as those impacts worsen, they may still struggle to adequately respond.[66] • Micro, Small and Medium Enterprises (MSMEs) are the backbone of the Maldivian economy, representing around 94% of all businesses.[67]
Socio-cultural	• With a Human Development Index (HDI) of 0.762 (2022), the Maldives ranks 87th globally, placing it in the "High Human Development" category.[68] • Maldives is the 7th most densely populated country in the world. High population density increases the risk of widespread impacts from disasters, emphasising the need for effective early warnings.[69] • Multidimensional poverty affects only 4.8% of the population, far below the 17.9% average in South Asia. However, poverty is unevenly distributed, with outer atolls being 10 times more affected than Male'. Addressing these disparities is essential for ensuring that climate resilience measures reach the most vulnerable communities.[70] • Universal healthcare and access to medical facilities on every inhabited island ensure basic health services for all citizens, which provides an opportunity for integrating disaster preparedness and response in the entire territory. • Free schooling up to age 12 and expanding tertiary education opportunities have contributed to improved educational outcomes. Educational systems can be used to increase climate change awareness and disaster preparedness. • Although women's rights have advanced, with higher female secondary education rates and reduced instances of early marriage and childbirth, significant gender disparities remain. These are particularly evident in how women experience and navigate vulnerabilities related to climate change, EWS, economic participation, and social structures. Addressing gender disparities is critical to enhancing resilience and adaptive capacity.[71] For a detailed gender assessment, refer to Annex 4a. • The Maldivian culture is deeply influenced by Islam, which shapes societal norms and practices.
Technological	• The technological sector offers untapped opportunities for economic diversification. • Mobile network coverage reaches 100% of the Maldives, with 810,400 cellular mobile connections (2022), equivalent to 149.9 percent of the total population.[72] The extensive connectivity and coverage represents an opportunity for efficient early warning dissemination. • The hydrometeorological infrastructure is limited; modern technologies and investments in this field are critical to improving climate change assessments, real-time hazard monitoring, and disaster preparedness. • The digitalisation of public governance instruments is gradually increasing though it remains limited (*e.g.,* Disaster Management Plans

[66] https://data.worldbank.org/country/mv
[67] The World Bank Group, 2024. Maldives Financial Sector Assessment Program. Technical Note: Access to Finance for MSMEs. Available at: https://documents1.worldbank.org/curated/en/099060624144517678/pdf/P18010016f22fd0b918bd21f7a1062ad47b.pdf (Accessed: 10 December 2024)
[68] Maldives Population 2024 (Live)
[69] Maldives Population 2024 (Live)
[70] UNDP, 2024. Human Development Report 2023-24.
[71] World Bank, 2022. Poverty and Inequality in Maldives – 2022
[72] DataReportal, 2022. Digital 2022: The Maldives. Available at: https://datareportal.com/reports/digital-2022-maldives (Accessed: 12 January 2024)

	are not digitalised as of yet). Digital tools can improve overall disaster management.
Legal	• Maldives has a democratic constitution that supports its governance framework. • Political instability and judicial interventions pose significant challenges, potentially threatening legal stability and investor confidence, which could ultimately hinder the effectiveness of the project implementation. • Legal reforms are underway to improve governance, combat corruption, and strengthen the rule of law. • Maldives Meteorological Service (MMS) does not have the legal status required to formally engage in partnerships with the private sector, limiting the potential of sustaining the project results through strategic partnerships. Partnerships with the private sector are often critical for providing financing, technology, and scaling-up-potential of EWS and other climate change adaptation efforts.[73]
Environmental/ Ecological	• Maldives consists of 1,192 coral islands, of which about 355 have human settlements, spanning a total land area of about 298 km². The geographic dispersion of islands presents logistical challenges for ensuring that early warnings and disaster risk management efforts reach all communities. • Maldives has an equatorial monsoonal climate, characterised by warm and humid conditions with seasonal rainfall variations. • Over 80% of the islands are less than 1 metre above sea level, making them highly vulnerable to sea-level rise. The vulnerability to sea-level rise highlights the importance of EWS for disaster preparedness. • The country's biodiversity is rich, especially within coral reefs and marine ecosystems, but vulnerable to climate change impacts. The environmental fragility of the country is exacerbated by sparse vegetations and limited freshwater resources. • Coral reefs provide coastal protection, acting as natural barriers and shielding the islands from erosion and sea surges. Coral reefs are threatened by ocean acidification, a consequence of global warming. Preserving coral reefs enhances resilience by reducing the impact of climate-related hazards such as floods and storms.[74]

[73] Maldives Meteorology Act 2016.
[74] Maldives' Ministry of Tourism. Tourism Adaptation Project. Tourism sector: Coral reef and biodiversity protection. Available at: Tourism-Sector-Coral-Reef-and-Biodiversity-Protection.pdf (Accessed: 20 January 2025)

2 CLIMATE ANALYSIS

2.1 Key messages

Historical climate data for the Maldives reveals significant trends across most major climate variables:

- Annual mean daytime temperature is increasing by 0.1 – 0.5°C/decade and the number of days reaching 30°C each year is increasing by 7 – 20 days/decade, depending on location.
- Annual rainfall is not changing significantly. Extreme rainfall is also largely not changing, but there is evidence that the proportion of rain falling on the wettest days of the year is increasing at Gan (south).
- Drought has remained largely unchanged, except at Hanimaadhoo (north) where it is becoming more intense.
- Sea-surface temperatures are increasing in the southern and northern Maldives by 0.18°C/decade and 0.19°C/decade, respectively.
- Sea level rise (SLR) remains a major concern. Sea-level is rising at Gan (south) and Malé (central) by 3.25 cm/decade and 4.76 cm/decade, respectively.
- Significant wave height has been increasing across the Maldives since the 1950's, although due to a lack of observations this trend is based on a global reanalysis.
- Global surface ocean pH is decreasing by -0.017 per decade, indicating a significant increase in acidity.
- There is no strong evidence that the Indian Ocean Dipole (IOD) or El Niño-Southern Oscillation (ENSO) are changing.
- Climate and sector data show that vegetable production is significantly reduced when longer dry spells occur.
- Across several atolls the number of out-patients with dengue fever is significantly higher when maximum 3-day rainfall increases or when the length of dry spells decreases.
- Coral bleaching is expected to continue increasing in frequency, with ramifications for the fisheries and tourism sectors as well as for the protection of shorelines from wave energy.

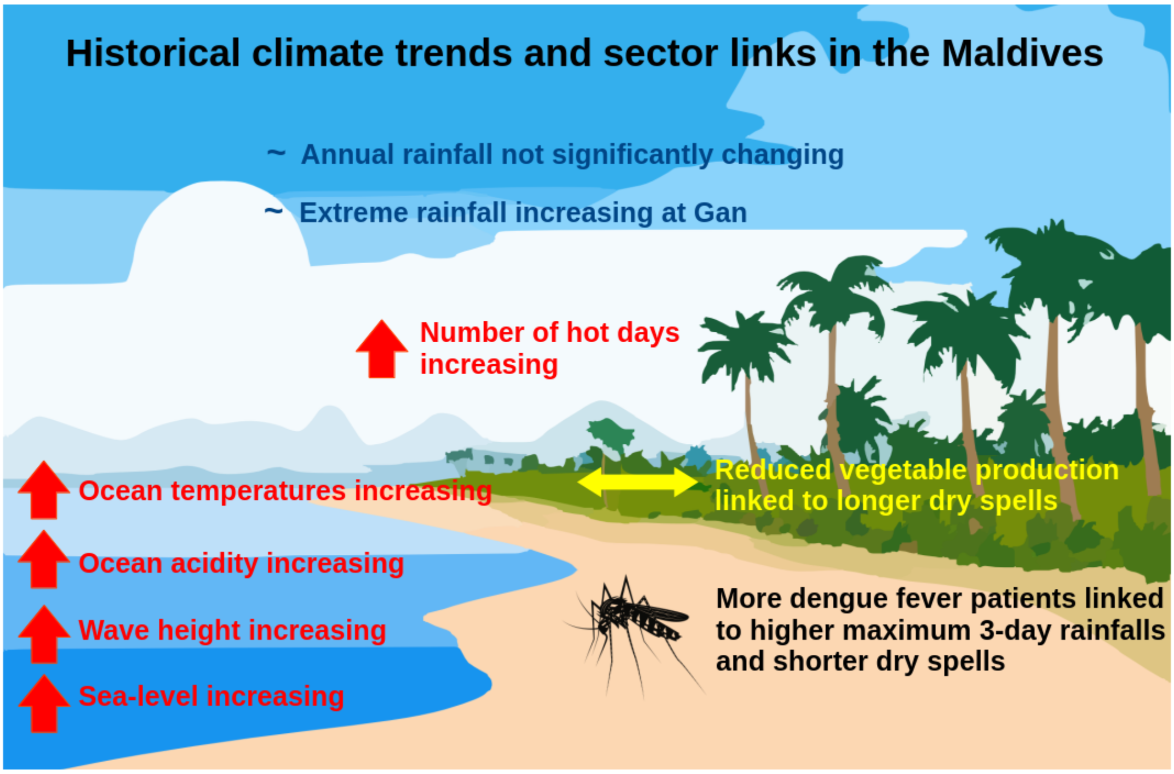

Figure 2. Overview of major climate trends and sector relationships based on historical data.

Projections for a middle-of-the-road climate change scenario (SSP2-RCP4.5) indicate many observed trends will continue until the end of the century but that new trends not currently observed will also emerge:

- Mean annual temperature is projected to warm by approximately 0.6°C, 1.3°C and 1.8°C by 2011-2040, 2041-2070 and 2071-2100, respectively.
- Mean annual rainfall is projected to increase by approximately 120 mm, 150 mm and 200 mm by 2011-2040, 2041-2070 and 2071-2100, respectively.
- Despite a projected increase in annual rainfall, the dry season is projected to become drier in the northern Maldives, with important implications for agriculture and freshwater resources.
- A higher proportion of annual rain is projected to fall on the wettest days of the year.
- The hottest day of the year is projected to warm by ~0.2°C/decade.
- Considering all climate change scenarios, sea-level is projected to rise by 0.19 – 1.44 m by 2100. Although low confidence/high risk simulations suggest this could be up to 2.6 m.
- Sea-surface temperature in the northern Indian Ocean is projected to increase by ~1.8°C by the end of the century.
- Surface ocean pH in the northern Indian Ocean is projected to decrease by -0.2 by the end of the century.
- Rainfall associated with tropical cyclones is expected to increase by 19 – 29% by the end of the century.

2.2 Introduction

The Maldives is a tropical archipelago situated in the northern Indian Ocean. It consists of 1,192 islands, 187 of which are inhabited, across 26 atolls. It has a population of 515,132, 41% of whom live in the nation's capital, Male'[75] (Figure 3). The Maldives is topographically the lowest nation in the world, with an average elevation of approximately 1.5 m and with 80% of its islands lower than 1 m above sea level.[76] The risk from climate change and many forms of severe weather are consequently very high. Despite these challenges, the Maldives has undergone dramatic economic growth over the past several decades, leveraging its marine ecosystem for the benefit of the tourism and fisheries industries, and has consequently transitioned to a middle-income country.[77]

This section assesses the historical and projected climate of the Maldives, as well as the potential impacts of climate change on prominent sectors. A proper assessment of historical climate is required in order to a) determine what changes in climate are already occurring and may require immediate adaptation; b) properly contextualise any projected climate changes; and c) illustrate links between the current climate and sector risks. All results discussed here are statistically significant unless stated otherwise.

[75] Bureau of Statistics, 2024, Statistical Yearbook of Maldives 2023, https://statisticsmaldives.gov.mv/yearbook/2023/.
[76] Ministry of Environment, 2019, Maldives First Biennial Update Report to the United Nations Framework Convention on Climate Change (UNFCCC).
[77] World Bank Group. 2024. Maldives Country Climate and Development Report. © Washington, DC: World Bank. http://hdl.handle.net/10986/41729 License: CC BY-NC-ND 3.0 IGO.

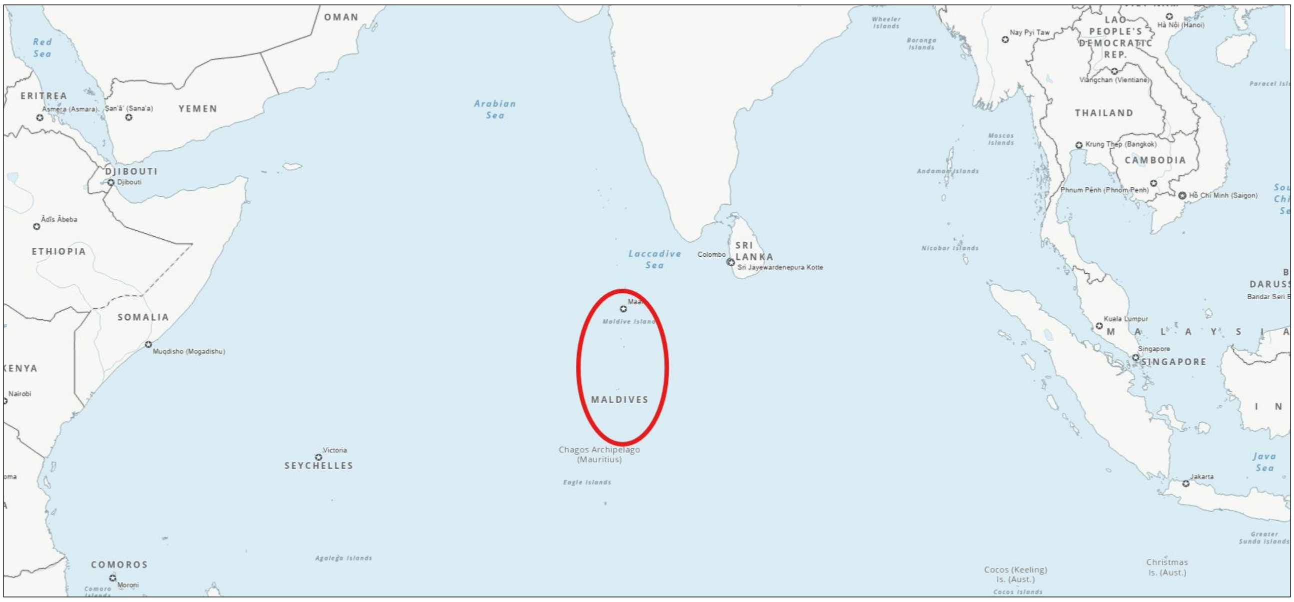

Figure 3. Location of Maldives.
Maldives (red circle) is situated just over and to the north of the equator in the northern Indian Ocean. The capital is Male'. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. (Source: UN Geospatial, 2024)

2.3 Methodology

2.3.1 Historical climate data

The primary source of historical climate data for the Maldives comes from five long-term high-quality weather stations managed by the Maldives Meteorological Service (MMS). These are reasonably spaced between the northern and southern borders of the country and are expected to be broadly representative of the national climate (Table 2). Temperature and rainfall data from all five stations were used in this climate analysis. Wind data from Hanimaadhoo, Hulhule and Gan were also used, as these were the only stations with at least 20 years of wind speed records.

Table 2. Locations of the five long term stations managed by MMS and the years used in this analysis for temperature and rainfall analysis.

Station	Duration	Latitude/Longitude
Hanimaadhoo	1992-2023	6.75/73.17
Hulhule	1975-2023	4.19/73.53
Kadhdhoo	1990-2023	1.86/73.52
Kaadedhdhoo	1994-2023	0.49/73.0
Gan	1978-2023	-0.69/73.16

2.3.2 Climate model selection

Future projections from global climate models are run under the framework of the Coupled Model Intercomparison Project, currently in its sixth phase (CMIP6). CMIP6 underpins the latest IPCC Sixth Assessment Report (AR6). CMIP6 models typically have grid cell sizes between 100 and 250 km, making local climate change assessments challenging if not impossible. Therefore, downscaling global climate model outputs either dynamically (using physical climate models similar to global climate models but focused over a region) or statistically (by deriving statistical relationships between the large scale and local climates) is necessary.

Data that has been statistically downscaled from CMIP6 models to a resolution of ~25 km[78] is used here to assess projected changes in temperature and rainfall related climate extremes. For ease of comparison and because the five stations with long historical records for the Maldives are reasonably spaced throughout the country (Table 2), time series of projected daily surface air temperature and rainfall were extracted at these same five locations. It should be noted that large uncertainties in climate model output still exist even when downscaled.

Due to time and data constraints, four downscaled CMIP6 climate models were selected for this analysis based on their performance, climate sensitivity and structural independence. These criteria ensure that well performing models with a scientifically acceptable climate sensitivity (i.e. do not suffer the 'hot model' problem) and that implement a diverse set of methods informed this assessment. The four models used in this report are MRI-ESM2-0 (Japan), NorESM2-MM (Norway), GFDL-ESM4 (USA) and ACCESS-CM2 (Australia). These models perform relatively well compared to their other CMIP6 counterparts when compared across a variety of climate extremes.[79] Their respective equilibrium climate sensitivities are 3.13°C, 2.49°C, 2.65°C and 4.66°C, which are within the 5%-95% confidence interval of 2.3 – 4.7°C derived by Sherwood et al.[80] from multiple lines of evidence. Lastly, these models are not closely related (they do not originate from the same research centres and do not share major components[81]).

An alternate downscaling product based on CMIP6 was initially preferred on the basis that it downscaled more climate change scenarios.[82] However, artificial step changes were discovered at the join between historical and future simulations, an example of which is shown in Supplementary Figure 2 (note the jump at 2015). For this reason, the dataset by Gebrechorkos et al.[83] was used, which has the benefit of leveraging more recent observations-based data in the downscaling process.

2.3.3 Climate change scenario selection

The scenarios used in CMIP6 projections are based on the framework of Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP).[84] There are five SSPs, named SSP1 through to SSP5, with each describing different projections of socioeconomic factors such as urbanisation, population and Gross Domestic Product. RCPs describe projected changes in greenhouse gases and their impact on the energy balance of the atmosphere by the end of the 21st century. There are seven RCPs which are denoted by the atmospheric energy imbalance each achieves; RCP1.9, RCP2.6, RCP3.4, RCP4.5, RCP6.0, RCP7.0 and RCP8.5 (e.g. RCP8.5 achieves an 8.5 W/m^2 energy imbalance by 2100). Four combinations of SSPs and RCPs were focused on by CMIP6; SSP1-RCP2.6, SSP2-RCP4.5, SSP3-RCP7.0 and SSP5-RCP8.5, with each representing successively more extreme climate change scenarios.

The climate change scenarios SSP2-RCP4.5 and SSP5-RCP8.5 were used in this assessment as they were the only scenarios downscaled by Gebrechorkos et al.[85]. A 1.5°C (Paris agreement) or 2°C warming scenario (SSP1-RCP1.9 and SSP1-RCP2.6, respectively) is typically included in climate assessments but this was not possible here. It is arguable that a 1.5°C scenario is unrealistic. Conversely, SSP5-

[78] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

[79] Kim, Y.H., Min, S.K., Zhang, X., Sillmann, J. and Sandstad, M., 2020. Evaluation of the CMIP6 multi-model ensemble for climate extreme indices. Weather and Climate Extremes, 29, p.100269.

[80] Sherwood, S.C., Webb, M.J., Annan, J.D., Armour, K.C., Forster, P.M., Hargreaves, J.C., Hegerl, G., Klein, S.A., Marvel, K.D., Rohling, E.J. and Watanabe, M., 2020. An assessment of Earth's climate sensitivity using multiple lines of evidence. Reviews of Geophysics, 58(4), p.e2019RG000678.

[81] Brunner, L., Pendergrass, A.G., Lehner, F., Merrifield, A.L., Lorenz, R. and Knutti, R., 2020. Reduced global warming from CMIP6 projections when weighting models by performance and independence. Earth System Dynamics, 11(4), pp.995-1012.

[82] Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T. and Nemani, R., 2022. NASA global daily downscaled projections, CMIP6. Scientific data, 9(1), p.262.

[83] Ibid, 78.

[84] Riahi, K., Van Vuuren, D.P., Kriegler, E., Edmonds, J., O'neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O. and Lutz, W., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global environmental change, 42, pp.153-168.

[85] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

RCP8.5 is considered by some to be unrealistically pessimistic.[86] This should be kept in mind particularly when interpreting temperature related results, however, the use of SSP5-RCP8.5 is highly unlikely to qualitatively change any results presented here.

2.3.4 Climate extremes

Climate extremes regarding temperature, atmospheric heatwaves, rainfall and drought were calculated using Climpact software.[87] Drought is represented using the Standardised Precipitation-Evapotranspiration Index (SPEI) with a 12-month aggregation period and is calculated by Climpact using the method presented by Vicente-Serrano et al.[88] A log-logistic distribution was used to characterise 12-month rainfall totals and evapotranspiration was calculated using the Hargreaves method.

For projected rainfall and temperature extremes, indices that count days reaching the 50 mm and 30°C thresholds were not calculated even though these indices were calculated for the historical climate. This is because climate model biases (particularly in the case of rainfall where climate models are known to 'drizzle' too much) prevent projections of such indices from being consistent with historical data.

Marine heatwaves were calculated using the XMHW Python package,[89] which implements the definition described by Hobday et al.[90]

2.3.5 Base period

The choice of base period used to calculate changes in a variable (e.g., temperature) is important as it can influence the magnitude of change. For historical data, a base period of 1994-2020 was used since 1994 was the earliest year that all five MMS stations have data (Table 2). For climate projections, a base period of 1981-2010 was used in most cases, since this was the most recent base period supported by the Intergovernmental Panel on Climate Change (IPCC) Interactive Atlas.[91,92] Projected sea-level rise used a base period of 1995-2014 as per CMIP6 conventions.

2.3.6 Extreme value analysis

Extreme value analysis was performed on historical rainfall to model 1-in-100 and 1-in-50-year events. This was done by applying a generalised extreme value distribution (GEV) to maximum daily rainfall from all available years at the five stations managed by MMS (Table 2). The L-Moments method was used to fit the GEV and all five fits passed the Kolmogorov–Smirnov goodness of fit test (Supplementary Figure 3 - Supplementary Figure 7). Bootstrapping was performed to calculate the 95% confidence interval for return levels.

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[86] Hausfather, Z. and Peters, G.P., 2020. RCP8. 5 is a problematic scenario for near-term emissions. Proceedings of the National Academy of Sciences, 117(45), pp.27791-27792.

[87] Climpact is a software tool for the calculation of indices associated with climate impacts, from historical daily temperature and precipitation data. The Climpact tool is part of the resource pack developed under the Climate Science Information for Climate Action collaboration between WMO and GCF. https://climpact-sci.org/.

[88] Vicente-Serrano, S.M., Beguería, S. and López-Moreno, J.I., 2010. A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. Journal of climate, 23(7), pp.1696-1718.

[89] https://github.com/coecms/xmhw/.

[90] Hobday, A.J., Alexander, L.V., Perkins, S.E., Smale, D.A., Straub, S.C., Oliver, E.C., Benthuysen, J.A., Burrows, M.T., Donat, M.G., Feng, M. and Holbrook, N.J., 2016. A hierarchical approach to defining marine heatwaves. Progress in oceanography, 141, pp.227-238.

[91] Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I.V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon, 2021: Atlas. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L.Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K.Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/.

[92] Iturbide, M., Fernández, J., Gutiérrez, J.M., Bedia, J., Cimadevilla, E., Díez-Sierra, J., Manzanas, R., Casanueva, A., Baño-Medina, J., Milovac, J., Herrera, S., Cofiño, A.S., San Martín, D., García-Díez, M., Hauser, M., Huard, D., Yelekci, Ö. (2021) Repository supporting the implementation of FAIR principles in the IPCC-WG1 Atlas. Zenodo, DOI: 10.5281/zenodo.3691645. Available from: https://github.com/IPCC-WG1/Atlas.

2.3.7 Sector data treatment

Sector data was downloaded from the Food and Agriculture Organisation (FAO)[93] (agricultural data), the Maldives Bureau of Statistics[94] (health and tourism data), the Ministry of Tourism[95] (tourism data), the Global Coral Bleaching Database[96] (coral bleaching events), and the Indian Ocean Tuna Commission[97] (tuna catch). This sector data was compared with climate data. The quality of the sector data is uncertain, and significant artefacts were evident in some sources. For example, agricultural yield from the FAO exhibited extreme step changes in some years, followed by near instantaneous recoveries. Whenever such artefacts were observed they were assumed to be erroneous, and the time series was truncated with only the following years used. No other data quality checks were performed (see Section 6.2.4 for recommendations in this regard). Prior to calculating correlations or regressions most sector data and climate data - where deemed necessary - was detrended and then standardised.

2.4 Historical climate overview

2.4.1 Temperature and rainfall

Maldives exists in a largely tropical monsoon climate (Koppen classification *Am*) with a tropical rainforest climate in the south (*Af*).[98] There are distinct wet (May – November) and dry (January – March) seasons driven by the Indian monsoon (Figure 4), with December and April considered transition months. This monsoon climate is greatly influenced by the Asian continent, which fuels convection of warm air over its land mass during the northern hemisphere summer, drawing moist air from the Arabian Sea eastward to the Bay of Bengal and then northward over Asia. The location of the Maldives within this circulation results in its distinct wet and dry seasons and its predominantly east/west wind profile.

Based on station records collected by MMS, the annual temperature in the Maldives ranges between 27.9 – 28.4°C, depending on location (Table 3). Mean annual rainfall ranges between 1,788 – 2,258 mm. The day and nighttime temperature difference ranges between 5.4 and 6.1°C, with larger differences in the south.

The equatorial location of the Maldives results in extremely small seasonal temperature change, with mean monthly temperature varying throughout the year by approximately 1 – 1.75°C, depending on location (Figure 4). Larger seasonality is experienced in the north of the country, likely due to increasing distance from the equator. Despite the generally small seasonality experienced in the Maldives the cooling effect of the wet season is clear (Figure 4).

Table 3. Mean annual temperature, rainfall and day-night temperature difference for the five long term stations managed by the Maldives Meteorological Service (MMS), listed from north to south. Note the different years available (Table 2) used to calculate these values.

Station	Annual temperature (°C)	Annual rainfall (mm)	Mean day-night temperature difference (°C)
Hanimaadhoo	28.3	1788	5.8
Hulhule	28.4	1992	5.4
Kadhdhoo	28.4	2226	6
Kaadedhdhoo	28	2244	6.1
Gan	27.9	2258	6

[93] FAO, 2024. FAOSTAT website, https://www.fao.org/faostat/, accessed July 2024.
[94] https://statisticsmaldives.gov.mv/yearbook/statisticalarchive/, accessed July 2024.
[95] https://www.tourism.gov.mv/statistics/publications/, accessed July 2024.
[96] Spady, Blake L.; Devotta, Denise A.; De La Cour, Jacqueline; Gomez, Andrea M.; Morgan, Jessica A.; Donner, Simon D.; Liu, Gang; Skirving, William J.; Vasile, Roxana; Geiger, Erick; Marsh, Benjamin; Eakin, C. Mark; Manzello, Derek P. (2022). Global Coral Bleaching Database (NCEI Accession 0228498). NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.25921/9xfa-0v97. Accessed July 2024.
[97] https://iotc.org/data/datasets/latest/NC/SCI, accessed August 2024.
[98] Beck, H.E., McVicar, T.R., Vergopolan, N., Berg, A., Lutsko, N.J., Dufour, A., Zeng, Z., Jiang, X., van Dijk, A.I. and Miralles, D.G., 2023. High-resolution (1 km) Köppen-Geiger maps for 1901–2099 based on constrained CMIP6 projections. Scientific data, 10(1), p.724.

Maldives is generally warmer and drier in the north and wetter and cooler in the south. During the hottest month of the year (April) there is approximately 1°C difference between Gan and Kaadedhdhoo in the south and Hanimaadhoo, Hulhule and Kadhdhoo to the north (Figure 4). Gridded remote sensing and reanalysis data confirm that the dry season is less pronounced in the south (Figure 5) and that cooling during the wet season is stronger there (Figure 6). Relationships between climate and regional scale circulation have also been shown to differ between the five station locations.[99]

With regard to trends, maximum and minimum temperatures have increased significantly at all five stations over the past several decades, with larger increases at northern locations (Figure 7). For the more southern stations of Gan, Kaadedhdhoo and Kadhdhoo nighttime temperatures have warmed faster than daytime temperatures, while the opposite is true for Hanimaadhoo in the far north. Mean annual rainfall has not significantly changed at any site (Figure 7).

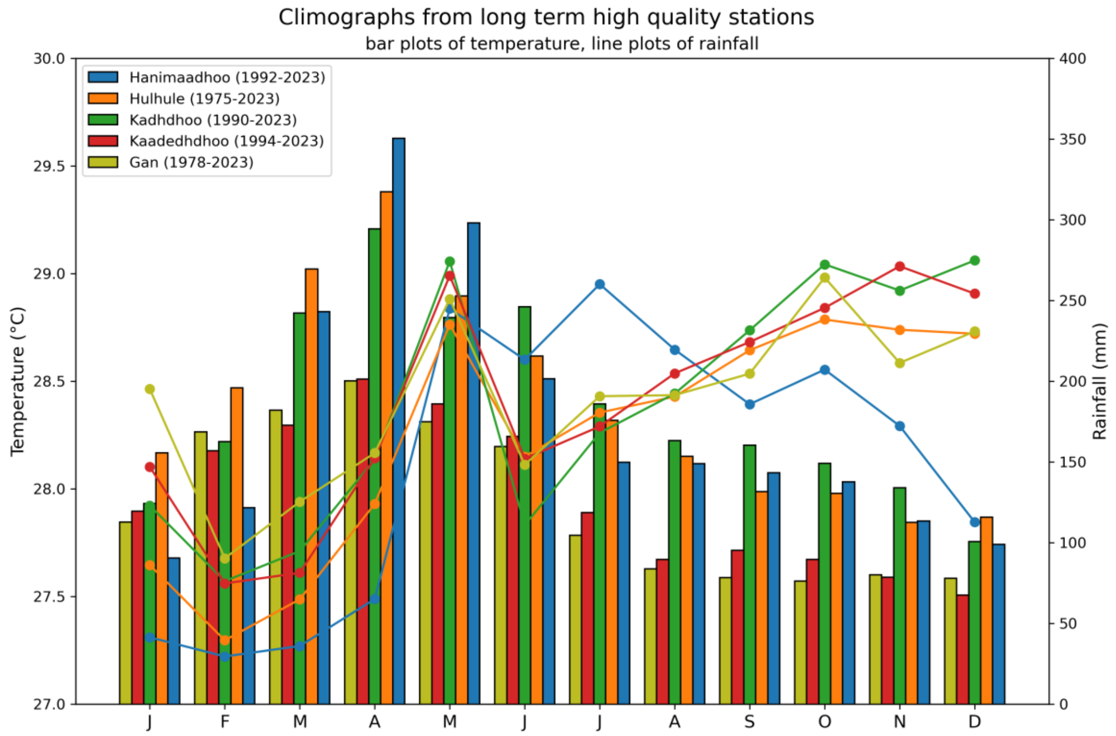

Figure 4. Monthly mean temperature (bars) and rainfall (lines) for the five stations with long high-quality records. See Figure 5a for locations. Data provided by MMS (Table 2).

[99] Foley, A. and Kelman, I., 2020. Precipitation responses to ENSO and IOD in the Maldives: Implications of large-scale modes of climate variability in weather-related preparedness. International Journal of Disaster Risk Reduction, 50, p.101726.

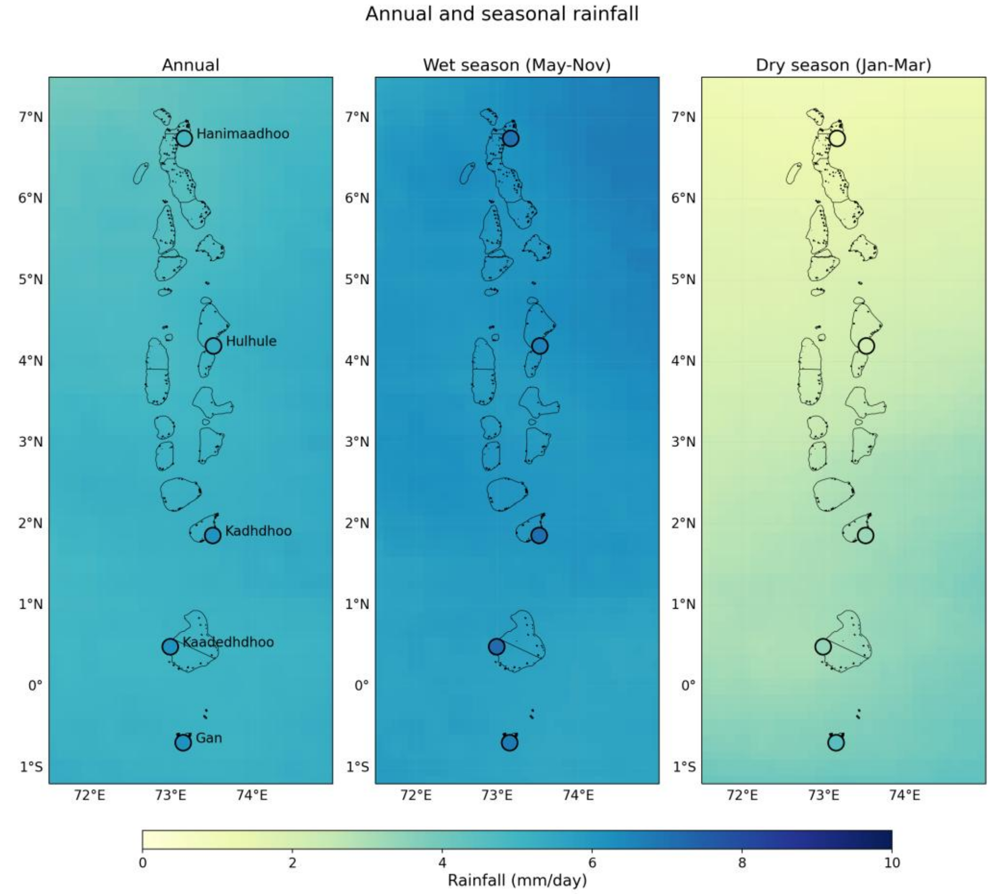

Figure 5. Mean annual (a), wet season (b) and dry season (c) rainfall rate (mm/day). Gridded data is from the ~10 km MSWEP dataset[100] and covers 1980-2023 while circles represent station records from the MMS for all full years available (Table 2). Comparison between the station and gridded data reveal a close match in actual values, wet and dry season change, and spatial gradients.

[100] Beck, H.E., Wood, E.F., Pan, M., Fisher, C.K., Miralles, D.G., Van Dijk, A.I., McVicar, T.R. and Adler, R.F., 2019. MSWEP V2 global 3-hourly 0.1 precipitation: methodology and quantitative assessment. Bulletin of the American Meteorological Society, 100(3), pp.473-500.

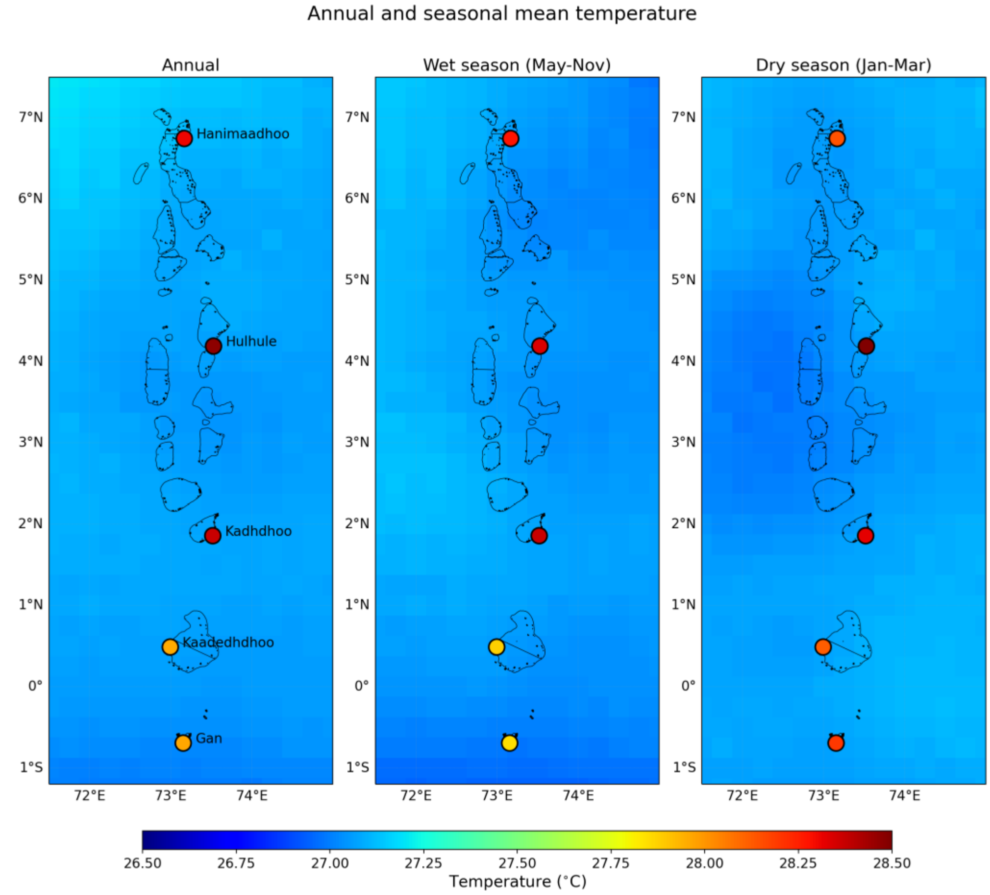

Figure 6. Mean annual (a), wet season (b) and dry season (c) 2-meter air temperature. Gridded data is from the ~30km ERA5 reanalysis[101] and covers 1980-2023 while circles represent station records from the MMS for all full years available (Table 2). A reanalysis is a global weather model that integrates observations into its calculations, thus providing more accurate results than traditional weather models along with global coverage which in-situ observation networks cannot provide. However, since reanalyses are models, they still contain biases and should only be used when reliable observations are insufficient. The significant difference between station and gridded data indicates a large bias in ERA5 2-meter air temperatures, likely due in large part to the fact that grid cells over the Maldives in ERA5 are classified as ocean.

[101] Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz‐Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D. and Simmons, A., 2020. The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146(730), pp.1999-2049.

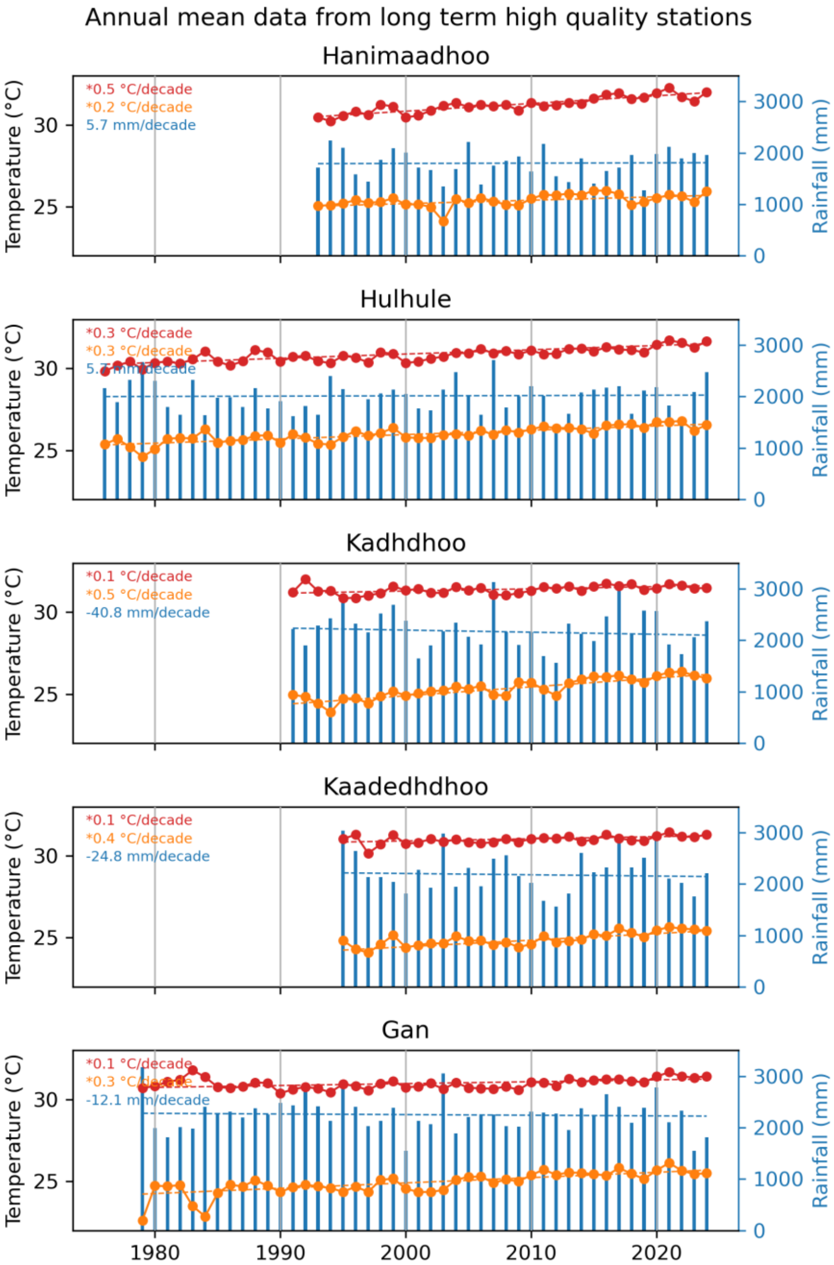

Figure 7. Trends in historical annual maximum and minimum temperature and annual rainfall, for the five stations with long high-quality records.
See Figure 5a for locations. Straight dashed lines indicate linear trend (trend size listed in legend, asterisks indicate statistical significance at p=0.05). Data provided by MMS (Table 2).

2.4.2 Sea-level rise

Sea-level rise (SLR) is seen as the most significant natural threat to the security and prosperity of the Maldives. Increases in sea level also compound the impacts of other climate extremes such as storm surge, wave height and consequently coastal flooding. Sea level in the Maldives is recorded by tide gauges at Gan, Male' and Hanimaadhoo, although the latter record only begins in 2003 and is too short for reliable trend analysis (Figure 8). At Gan and Male', sea level has been rising by an average of 3.25 and 4.76 cm/decade, respectively. Sea-level rise at Male' is faster than the global mean rate over the

2006-2018 period (3.7 cm/decade[102]), while it is slower than the global mean rate at Gan. It is unclear what contribution land subsidence makes to these trends.

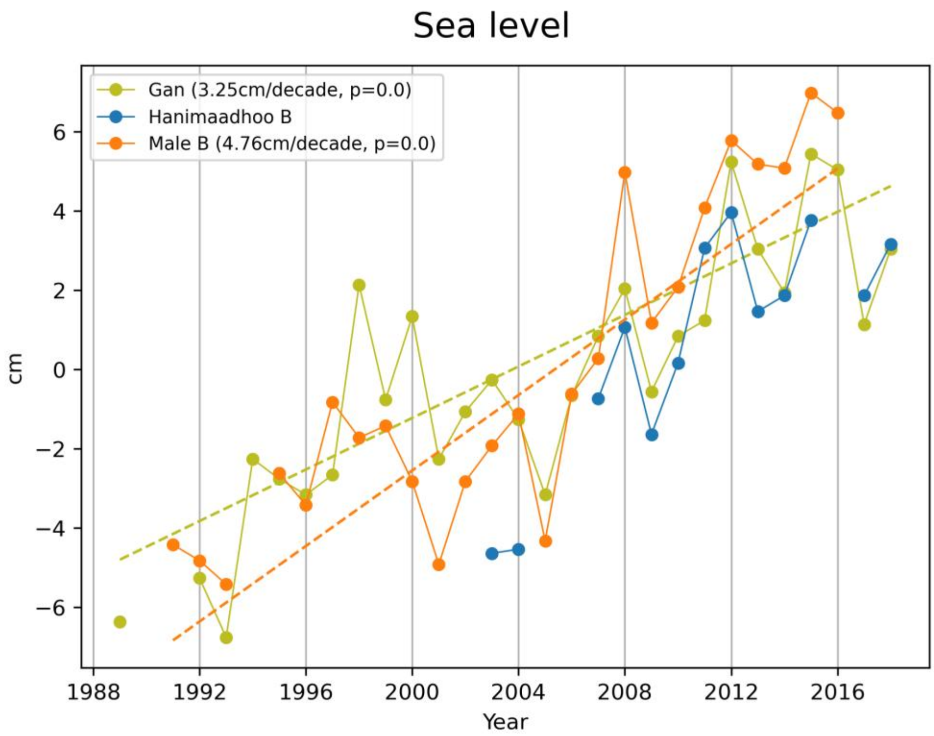

Figure 8. Sea-level relative to the 1992-2016 average.
Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Data taken from the Permanent Service for Mean Sea Level research quality tide dataset[103,104].

2.4.3 Ocean acidification

Along with increasing sea-surface temperatures (SST), ocean acidification (measured by pH) has the most direct impact on coral reefs and other marine organisms by hindering their ability to calcify shells. No long-term measurements of pH exist in the Maldives but declining global surface ocean pH (Figure 9) and its known relationship with atmospheric CO_2 provides a reliable indication of pH trends in the region. Between 1985 and 2022 global surface ocean pH declined by approximately 0.063 (-0.017/decade; Figure 9). Given the logarithmic scale that pH is measured on, this indicates the surface ocean has become approximately 16% more acidic.

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[102] Fox-Kemper, B., H.T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S.S. Drijfhout, T.L. Edwards, N.R. Golledge, M. Hemer, R.E. Kopp, G. Krinner, A. Mix, D. Notz, S. Nowicki, I.S. Nurhati, L. Ruiz, J.-B. Sallée, A.B.A. Slangen, and Y. Yu, 2021: Ocean, Cryosphere and Sea Level Change. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1211–1362, doi: 10.1017/9781009157896.011.

[103] Holgate, S.J., Matthews, A., Woodworth, P.L., Rickards, L.J., Tamisiea, M.E., Bradshaw, E., Foden, P.R., Gordon, K.M., Jevrejeva, S. and Pugh, J., 2013. New data systems and products at the permanent service for mean sea level. Journal of Coastal Research, 29(3), pp.493-504.

[104] Permanent Service for Mean Sea Level (PSMSL), 2024, "Tide Gauge Data", Retrieved 25 May 2024 from http://www.psmsl.org/data/obtaining/.

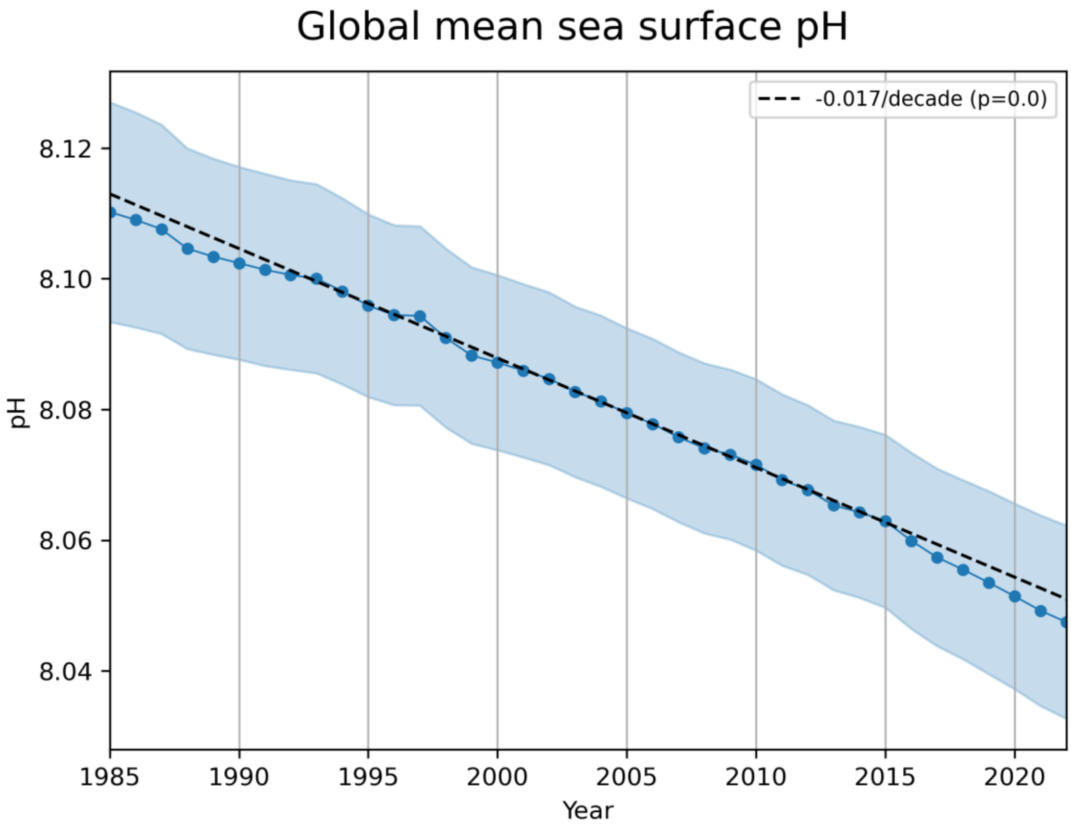

Figure 9. Global surface ocean ph.
The shaded interval represents a one standard deviation uncertainty. Straight dashed line indicates linear trend (size of trend and p-value listed in legend). Data from the E.U. Copernicus Marine Service Information[105]

2.4.4 Modes of variability

Large scale modes of climate variability such as the Indian Ocean Dipole (IOD) and El Niño-Southern Oscillation (ENSO) significantly impact the weather, and their seasonal states are often reported by the MMS.[106] The IOD is described by changes in SST between the eastern and western tropical Indian Ocean, which have direct effects on the overlying atmosphere and weather. ENSO is similarly described by east-west changes in SST but in the tropical Pacific Ocean. ENSO is the most globally influential mode of climate variability and has significant impacts outside the Pacific Ocean, including in the Indian Ocean. At Hulhule and Kadhdhoo, El-Niño and positive IOD events have been shown to bring higher rainfall during the later part of the year, with impacts on extreme rainfall more variable between locations.[107] The high temporal variability of these modes makes discerning trends difficult. However, observations (Figure 10) and paleoclimate records indicate there no long-term changes in ENSO or IOD have occurred.[108]

[105] E.U. Copernicus Marine Service Information, https://doi.org/10.48670/moi-00224, accessed August 2024.
[106] e.g., https://www.meteorology.gov.mv/downloads/258/view
[107] Foley, A. and Kelman, I., 2020. Precipitation responses to ENSO and IOD in the Maldives: Implications of large-scale modes of climate variability in weather-related preparedness. International Journal of Disaster Risk Reduction, 50, p.101726.
[108] Gulev, S.K., P.W. Thorne, J. Ahn, F.J. Dentener, C.M. Domingues, S. Gerland, D. Gong, D.S. Kaufman, H.C. Nnamchi, J. Quaas, J.A. Rivera, S. Sathyendranath, S.L. Smith, B. Trewin, K. von Schuckmann, and R.S. Vose, 2021: Changing State of the Climate System. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 287–422, doi: 10.1017/9781009157896.004.

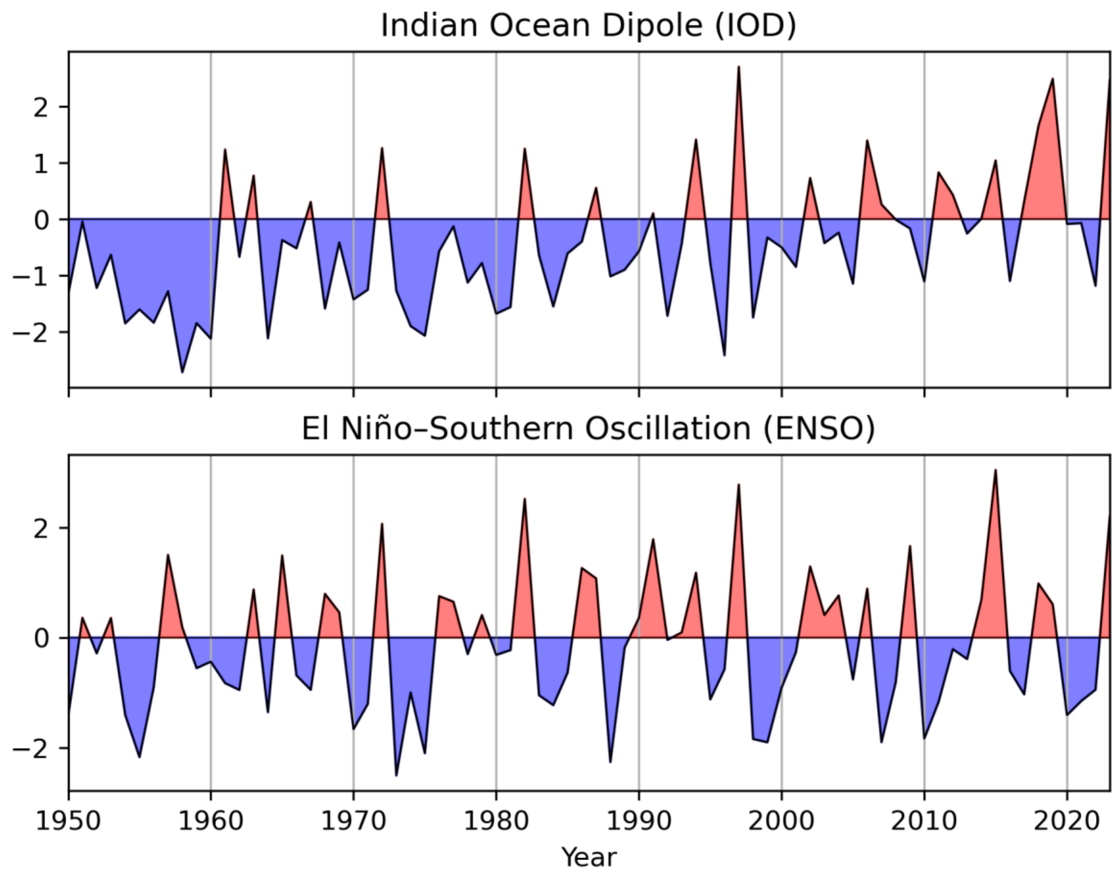

Figure 10. The Indian Ocean Dipole (IOD) and El Niño-Southern Oscillation (ENSO) from 1950-2023. Data taken from the NOAA Physical Science Laboratory, with the IOD represented by the Dipole Mode Index[109] and ENSO represented by the NINO3.4 index[110].

2.5 Historical high impact events

2.5.1 Temperature extremes

While average temperatures are increasing at all sites (Figure 7), annual maximum temperatures are only increasing at the northern and central sites of Hanimaadhoo and Hulhule and decreasing at Kadhdhoo (Figure 11). This surprising trend at Kadhdhoo is affected by two unusually high temperatures at the beginning of the record. A lack of station metadata prevents site changes from being investigated that might explain such unexpected values. In contrast to maximum temperatures, the number of days reaching 30°C has increased significantly at all sites and is quickly approaching 365 days per year (Figure 12).

[109] https://psl.noaa.gov/gcos_wgsp/Timeseries/DMI/, accessed August 2024.
[110] https://psl.noaa.gov/data/timeseries/monthly/NINO34/, accessed August 2024.

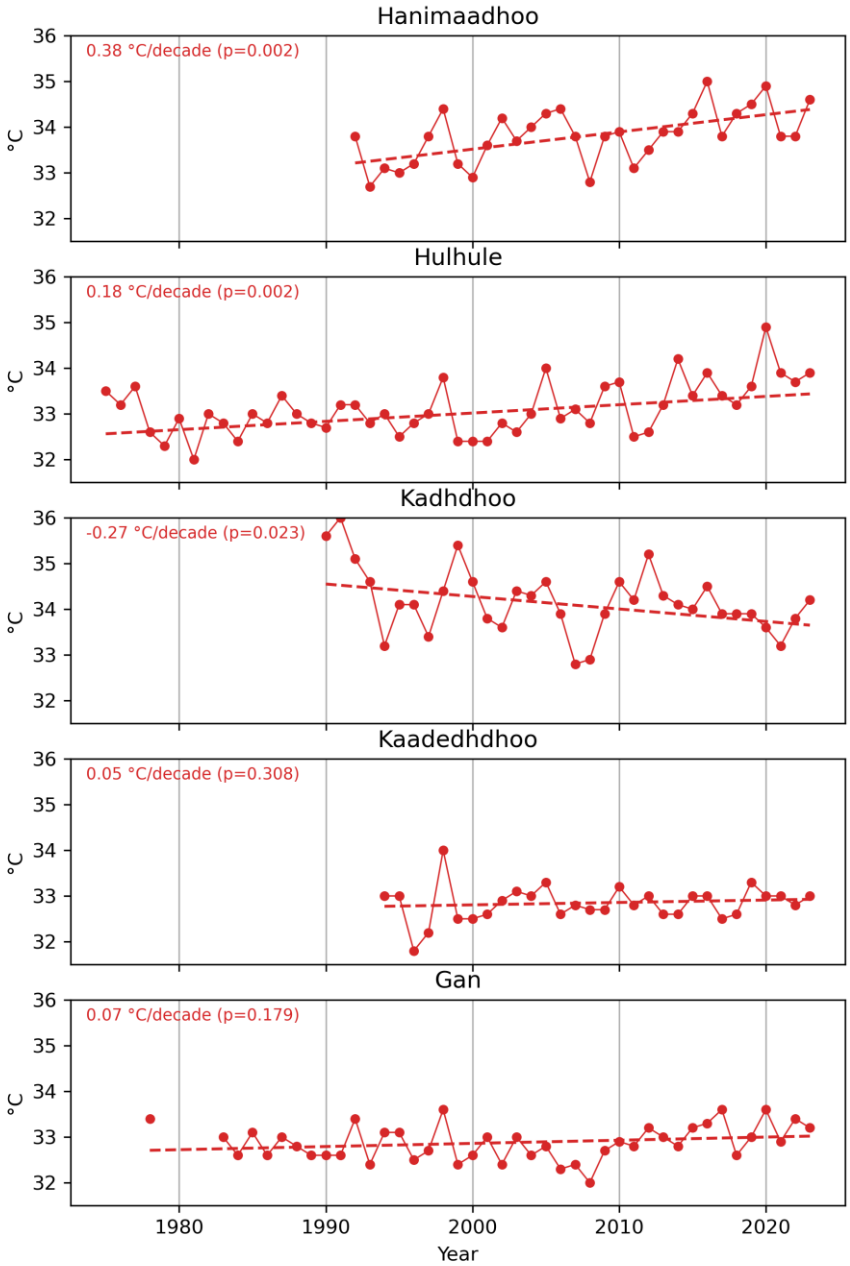

Figure 11. Annual maximum temperature for the five stations with long high-quality records. See Figure 5a for station locations. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Data provided by MMS.

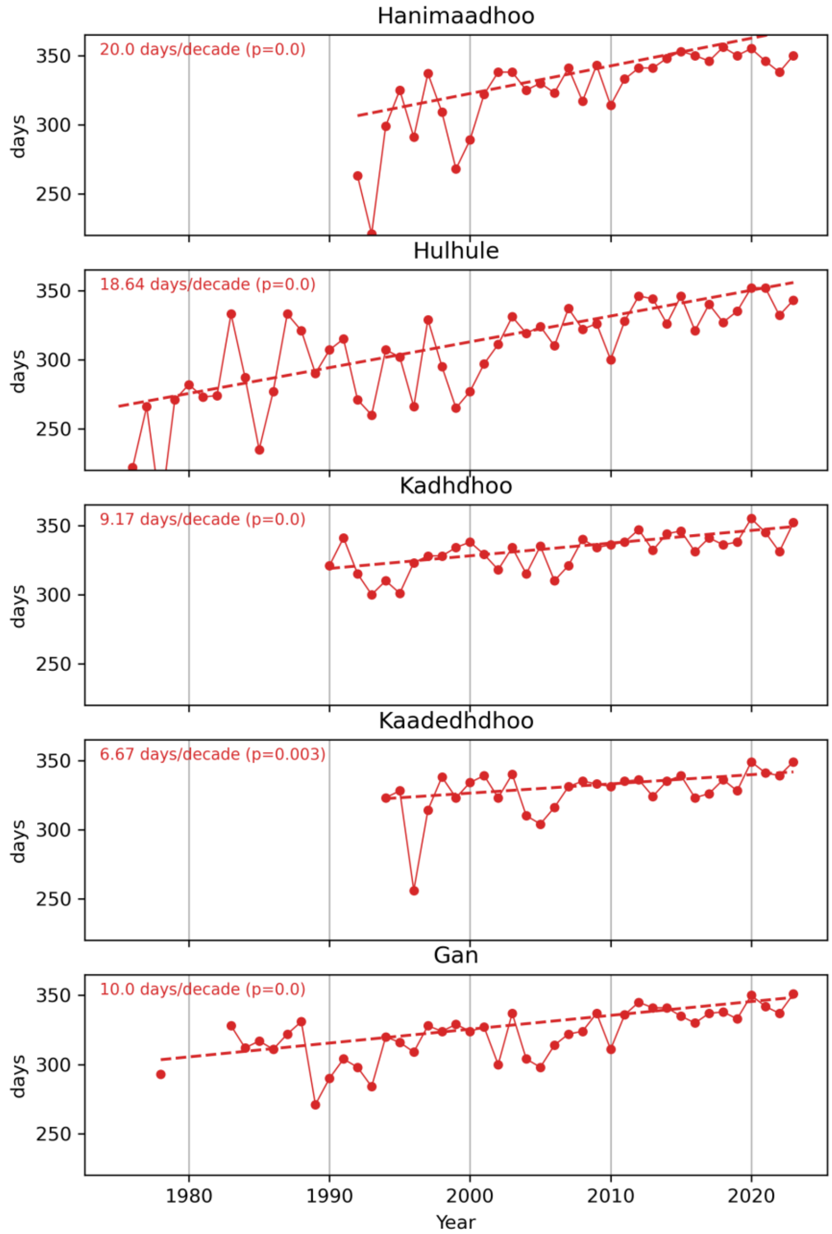

Figure 12. The number of days experiencing at least 30°C, for the five stations with long high-quality records. See Figure 5a for station locations. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Data provided by MMS.

Temperature extremes like those shown above in Figure 11 and Figure 12 reflect conditions on a single day. While they can have significant impacts, these are often mitigated if the "hot days" are followed by days or nights closer to climatological average temperatures. Heatwaves on the other hand refer to prolonged periods of heat, typically three or more days, and are therefore associated with more severe impacts. Heatwaves here are characterised by the Excess Heat Factor (EHF[111]), which considers the deviation over 3 or more days of temperatures from climatological values as well as the deviation from the previous 30 days to account for acclimatisation. Based on the EHF, the number of heatwaves occurring in the Maldives has increased dramatically, at a rate of up to 1.5 heatwaves per decade (Figure 13).

[111] Nairn, J.R. and Fawcett, R.G., 2013. Defining heatwaves: heatwave defined as a heat-impact event servicing all community and business sectors in Australia. Centre for Australian Weather and Climate Research.

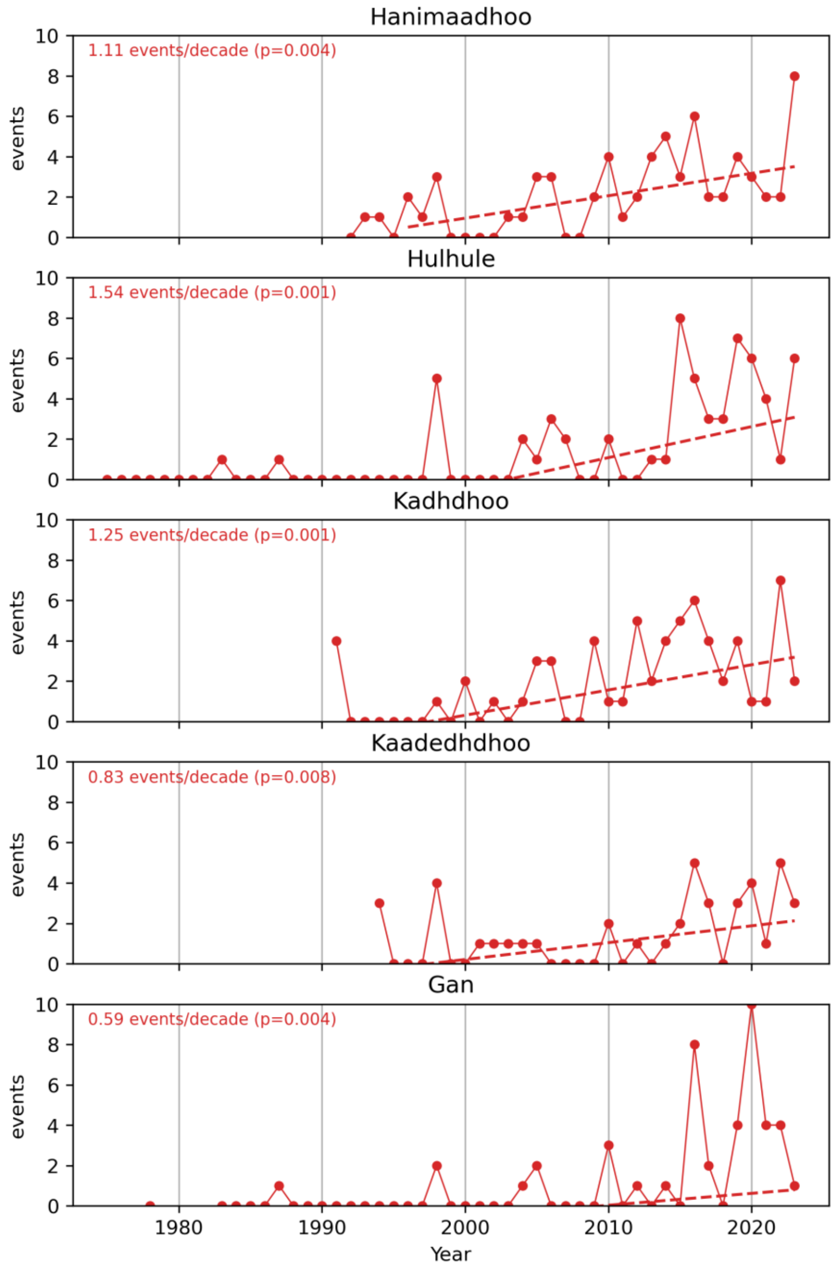

Figure 13. Annual number of heatwave events as defined by the Excess Heat Factor (EHF[112]), for the five stations with long high-quality records.
Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Note that the prevalence of zero heatwaves in the earlier parts of these records is a result of the base period being defined as 1994-2020, it does not indicate that there were no warm years. These zero heatwave years inadvertently bias the linear trends and therefore trends are calculated over 1995-2023. See Figure 5a for station locations. Data provided by MMS (Table 2).

2.5.2 Rainfall extremes

As there is no single definition of extreme rainfall, several indices describing different parts of the rainfall distribution are examined. Maximum daily rainfall has not changed significantly over the last several decades (Figure 14). The highest daily rainfall recorded at each station sits slightly above 200 mm for Gan and Kaadedhdhoo and slightly below 200 mm for Hanimaadhoo, Hulhule and Kadhdhoo.

[112] Nairn, J.R. and Fawcett, R.G., 2013. Defining heatwaves: heatwave defined as a heat-impact event servicing all community and business sectors in Australia. Centre for Australian Weather and Climate Research.

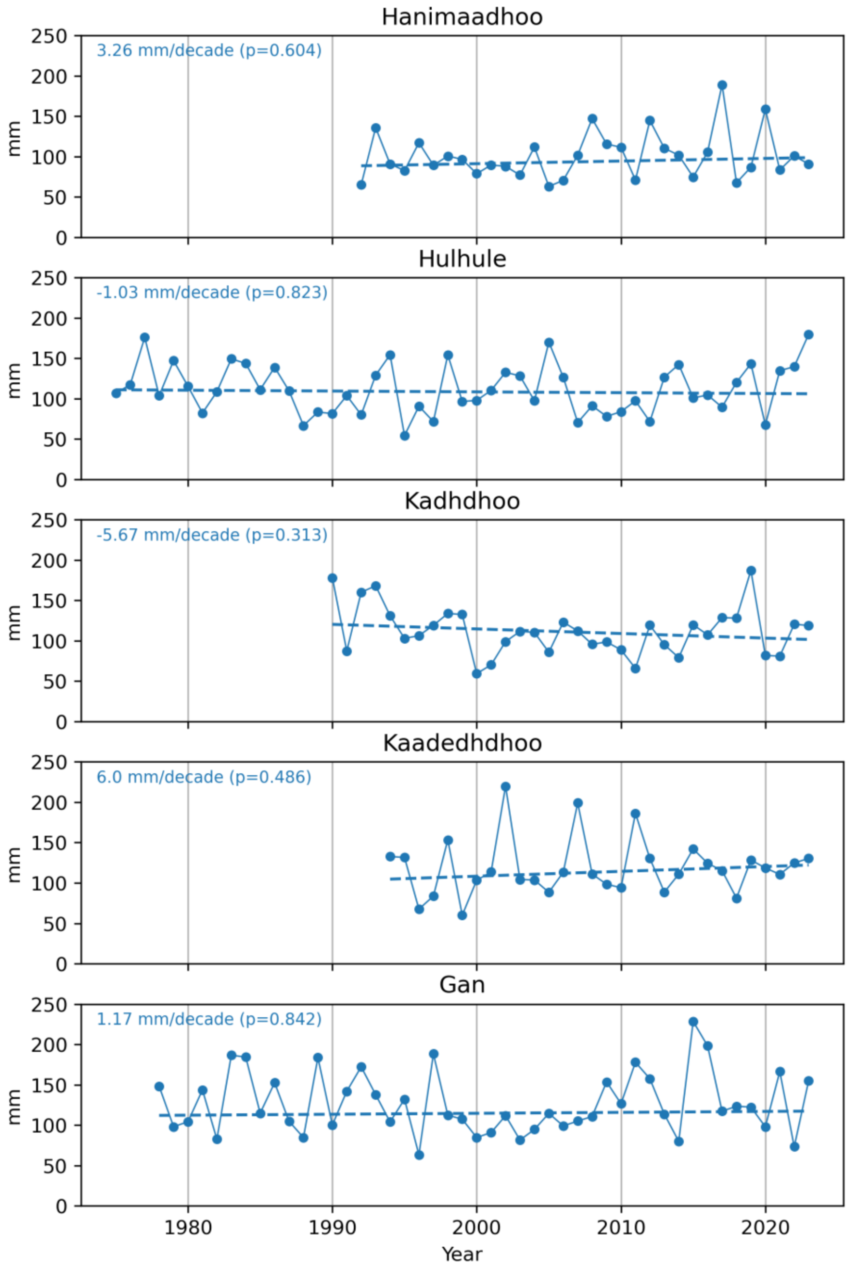

Figure 14. Maximum daily rainfall for the five stations with long high-quality records. See Figure 5a for station locations. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Data provided by MMS (Table 2).

The proportion of rain falling on extremely wet days (defined as the wettest 5% of days) has not changed at any site, with the exception of Gan, which has experienced a small but significant increase since the 1970's (Figure 15). The number of days each year experiencing at least 50 mm of rain, a locally relevant threshold associated with minor flooding,[113] has not changed significantly at any site (Figure 16).

The lack of significant changes in extreme rainfall may be partly due to its high interannual variability and the relatively short records available. In addition to examining trends, it is useful to characterise extremely rare events to support adaptation and engineering projects with long operational lifetimes. By fitting a statistical distribution to observed data the expected maximum daily rainfall amounts for events rarer than those observed can be estimated. Table 4 lists the expected maximum daily rainfalls for 1-in-50 and 1-

[113] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the United Nations Framework Convention on Climate Change: Ministry of Environment and Energy.

in-100-year events. While even rarer events can be estimated, the uncertainty often increases significantly (see Section 2.3.6 for more details).

Table 4. 1-in-50 year and 1-in-100-year daily rainfall amounts estimated based on a Generalised Extreme Value distribution fit to station data from MMS (Table 2).
These events refer to 2% and 1% annual exceedance probabilities, respectively. Note large uncertainties exist for extreme value estimates, see section 2.3.6 for details.

Location	1-in-50-year daily rainfall	1-in-100-year daily rainfall
Hanimaadhoo	184 mm	206 mm
Hulhule	183 mm	193 mm
Kadhdhoo	185 mm	197 mm
Kaadedhdhoo	212 mm	232 mm
Gan	228 mm	249 mm

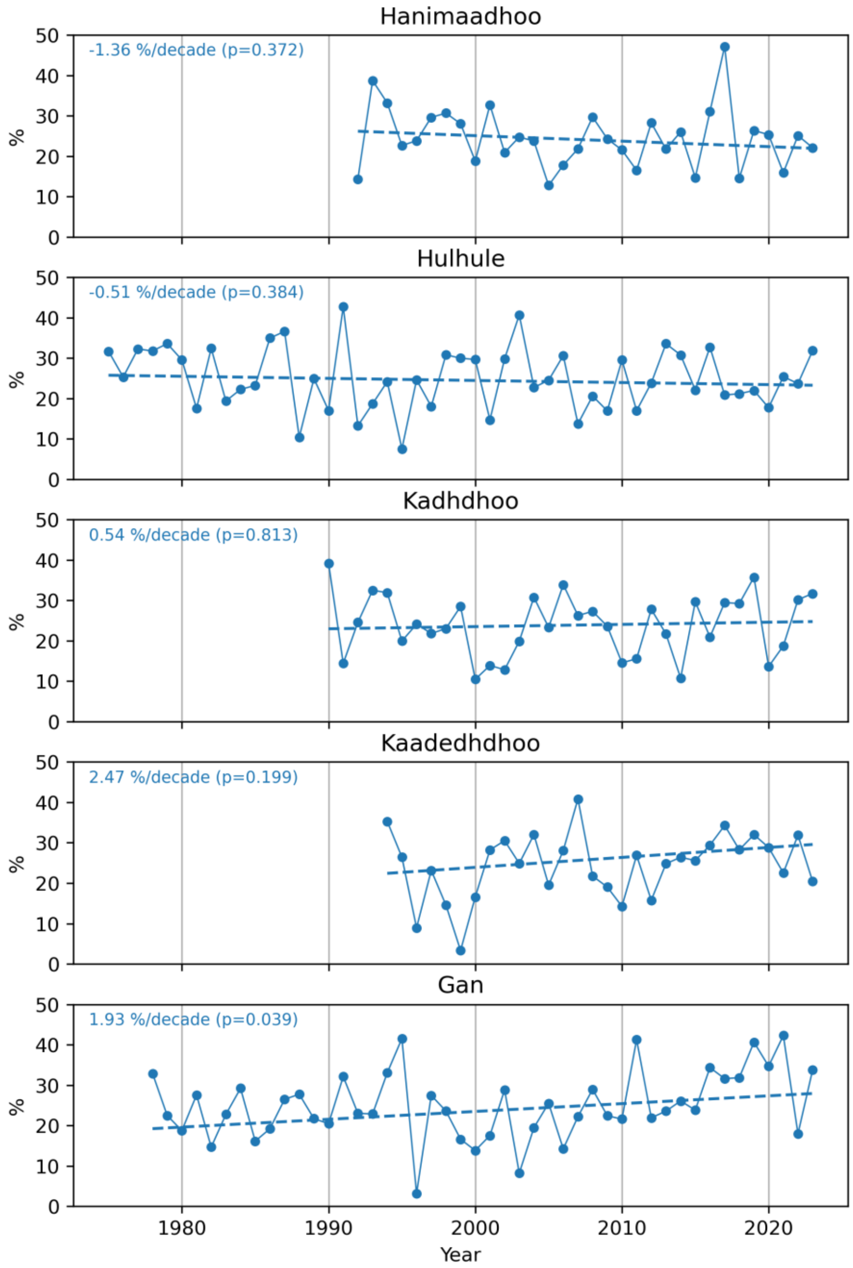

Figure 15. The percentage of total rain falling on extreme rainfall days, for the five stations with long high-quality records.

Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Data provided by MMS (Table 2).

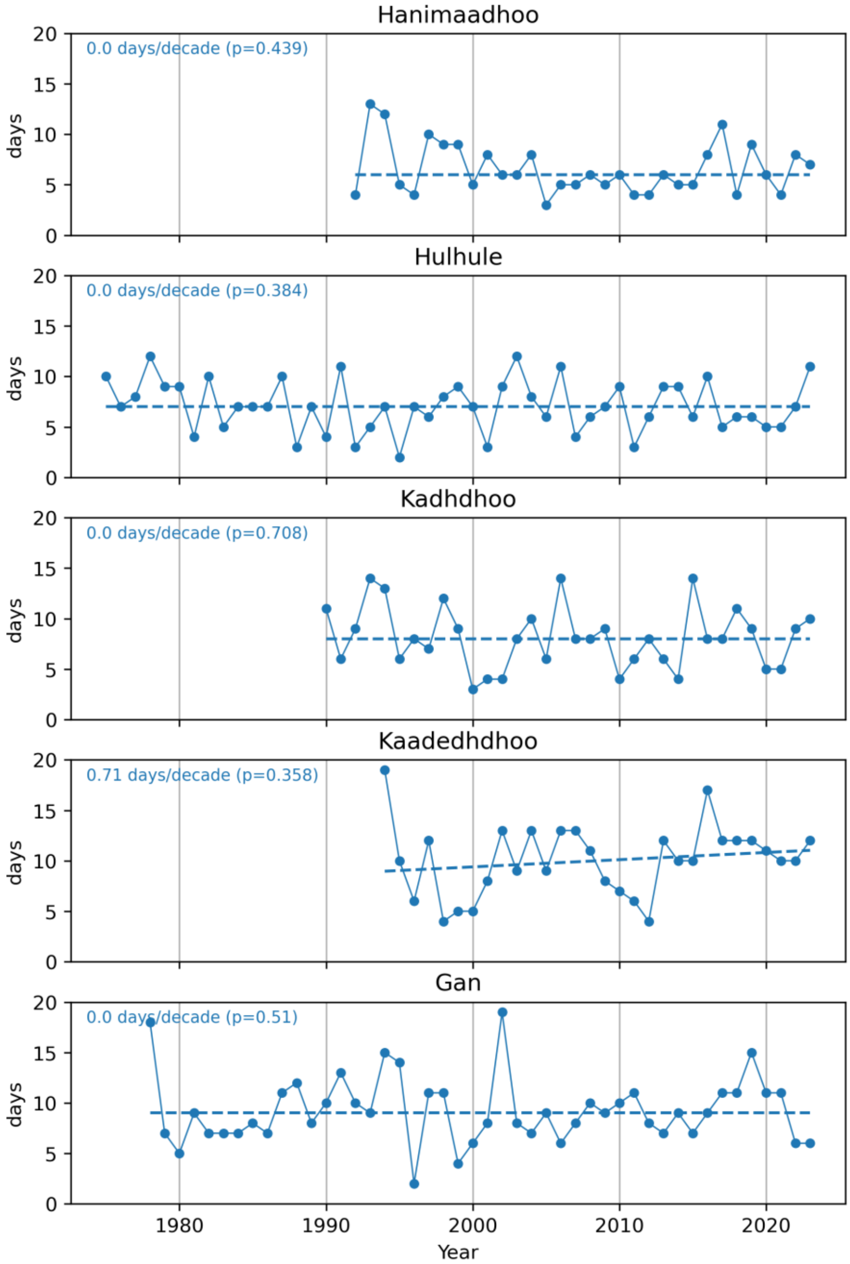

Figure 16. The number of days reaching 50 mm of rainfall, for the five stations with long high-quality records. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). See Figure 5a for locations. Data provided by MMS (Table 2).

The number of flood events caused by rain and the number of islands impacted by these events is extremely variable but increased between 1990 and 2013 (Figure 17). This is consistent with population growth and urbanisation (which increase exposure), as well as the increase in extreme rainfall at Gan (Figure 15).

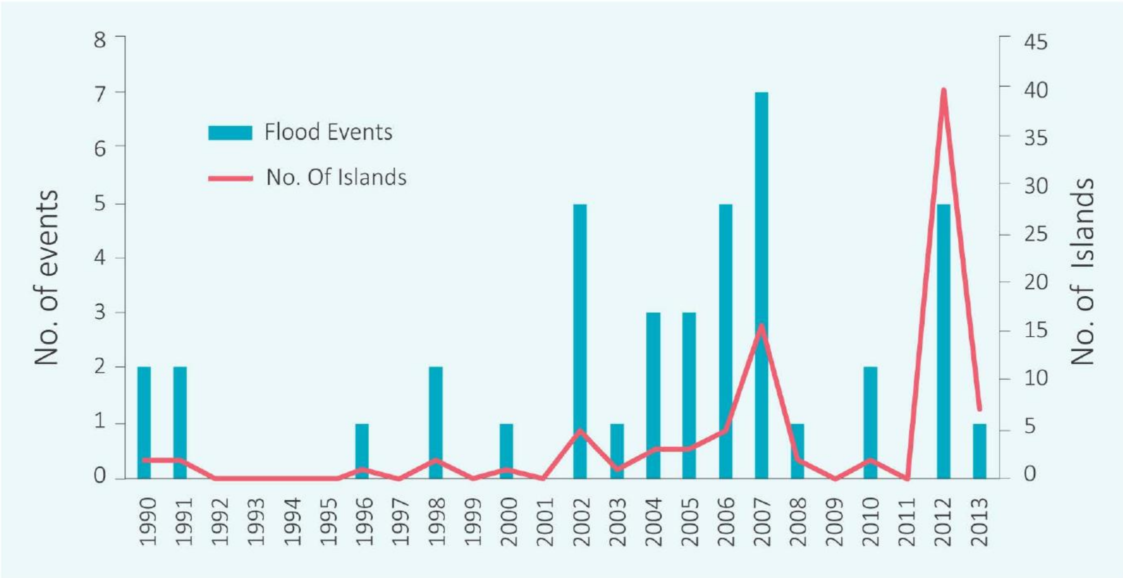

Figure 17. Reported cases of flood events due to rain and number of islands impacted.
Figure taken from the Second National Communication (2016).[114] *Data for years since 2013 have yet to be compiled.*[115]

2.5.3 Tropical cyclones

The proximity of Maldives to the equator means that the landfall of tropical cyclones is rare. Since 1891, 21 tropical cyclones are known to have passed within 60 miles of the Maldives, with all but one classified as a tropical storm or depression and the remaining one as a category one cyclone (Figure 18). The orientation of the Maldives means that tropical cyclones are more likely to pass over the north of the country, however, the whole country feels the effects of cyclones in the region via increases in associated hazards such as swell, wind and rain. Thus, understanding changes in tropical cyclones is important for the Maldives.

[114] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the United Nations Framework Convention on Climate Change: Ministry of Environment and Energy.
[115] Personal communication with National Disaster Management Authority.

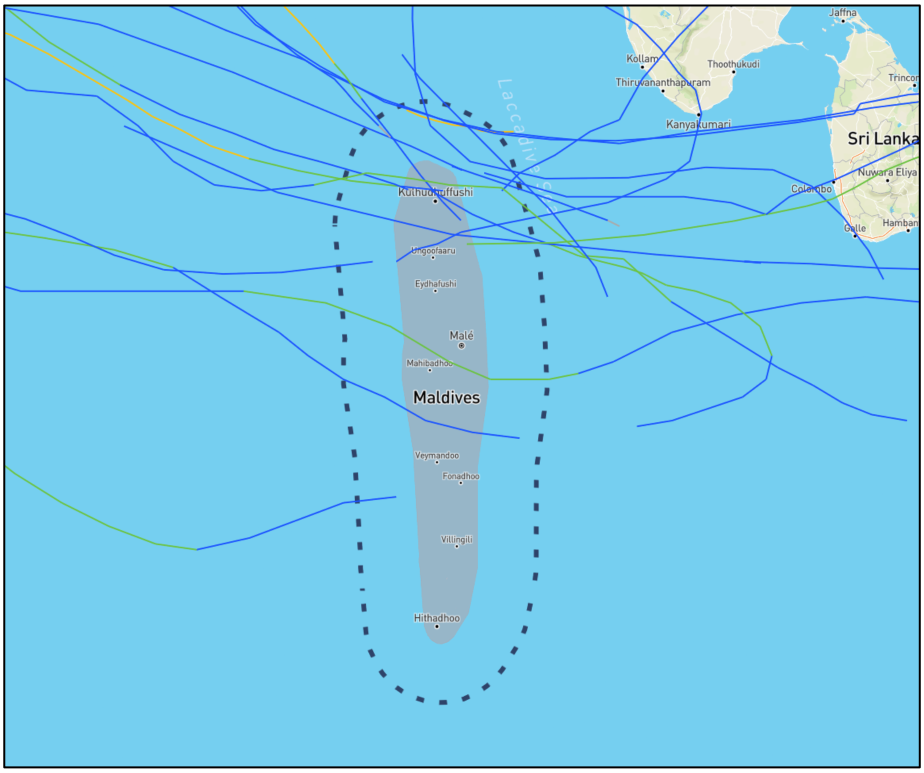

Figure 18. Tropical depressions (blue), tropical storms (green) and category one tropical cyclones (yellow) that have passed within 60 miles (dashed line) of the Maldives since 1891. Data from the IBTrACS database.[116,117]

2.5.4 Drought

Drought is a complex hazard with multiple contributing environmental and meteorological variables (e.g., rainfall, temperature, humidity, geography, vegetation) and can have impacts lasting from months to years. Consequently, there are many definitions of drought[118] with different sectors preferring different definitions. Nonetheless, the Standardised Precipitation-Evapotranspiration Index (SPEI) [119] is a commonly accepted metric of meteorological drought due to its simplicity, limited data requirements, consideration of temperature, characterisation of wet and dry periods, and its ability to evaluate multiple time scales. Therefore, the 12-month SPEI is used here to describe drought in the Maldives, although it is noted that different time scales are relevant for different sectors.

The 12-month SPEI has not changed significantly over the historical record with the exception of Hanimaadhoo, where drought is becoming more intense (Figure 19). However, the short length of this record makes it difficult to attribute this trend to decadal variability or climate change. The timing of drought events is also quite different between Hanimaadhoo and the other four sites. For example, between 2020 and 2023, no significant drought is identified at Hanimaadhoo, while all four other sites experienced drought. Conversely, over 2018 and 2019 drought occurred at Hanimaadhoo but not at the other sites.

[116] Gahtan, J., K. R. Knapp, C. J. Schreck, H. J. Diamond, J. P. Kossin, M. C. Kruk, 2024: International Best Track Archive for Climate Stewardship (IBTrACS) Project, Version 4r01. NOAA National Centers for Environmental Information. doi:10.25921/82ty-9e16. Accessed July to August 2024.
[117] Knapp, K.R., Kruk, M.C., Levinson, D.H., Diamond, H.J. and Neumann, C.J., 2010. The international best track archive for climate stewardship (IBTrACS) unifying tropical cyclone data. Bulletin of the American Meteorological Society, 91(3), pp.363-376.
[118] World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016: Handbook of Drought Indicators and Indices (M. Svoboda and B.A. Fuchs). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.
[119] Vicente-Serrano, S.M., Beguería, S. and López-Moreno, J.I., 2010. A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. Journal of climate, 23(7), pp.1696-1718.

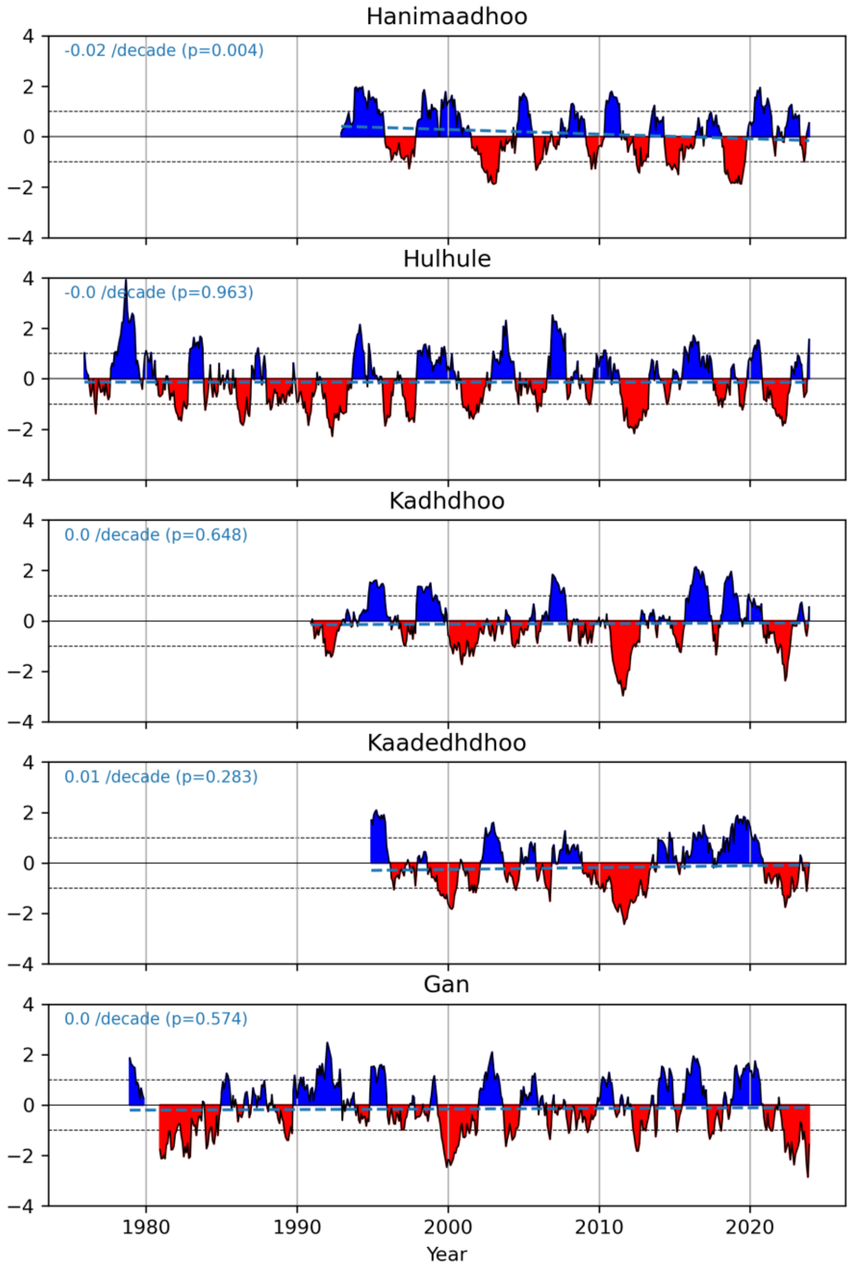

Figure 19. The 12-month Standardised Precipitation-Evapotranspiration Index (SPEI), for the five stations with long high-quality records.
Negative values indicate drier-than-normal conditions and positive values indicate wetter-than-normal conditions. Dashed lines indicate the ±1 standard deviation threshold commonly used for identifying droughts[120]. See Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). See Figure 5a for locations. Data provided by MMS (Table 2).

The maximum number of consecutive days without rain has been decreasing significantly at Hulhule since the 1970s, representing a shortening of the driest part of the year (Figure 20). All other sites have not experienced significant change and currently all five sites experience on average up to 20 to 40 consecutive days without rain annually. Northern sites experience longer periods without rain compared to the south (Figure 20). The large historical variability of this metric should be noted as some locations have experienced over 60 days without rain.

[120] McKee, T.B., Doesken, N.J. and Kleist, J., 1993, January. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology (Vol. 17, No. 22, pp. 179-183).

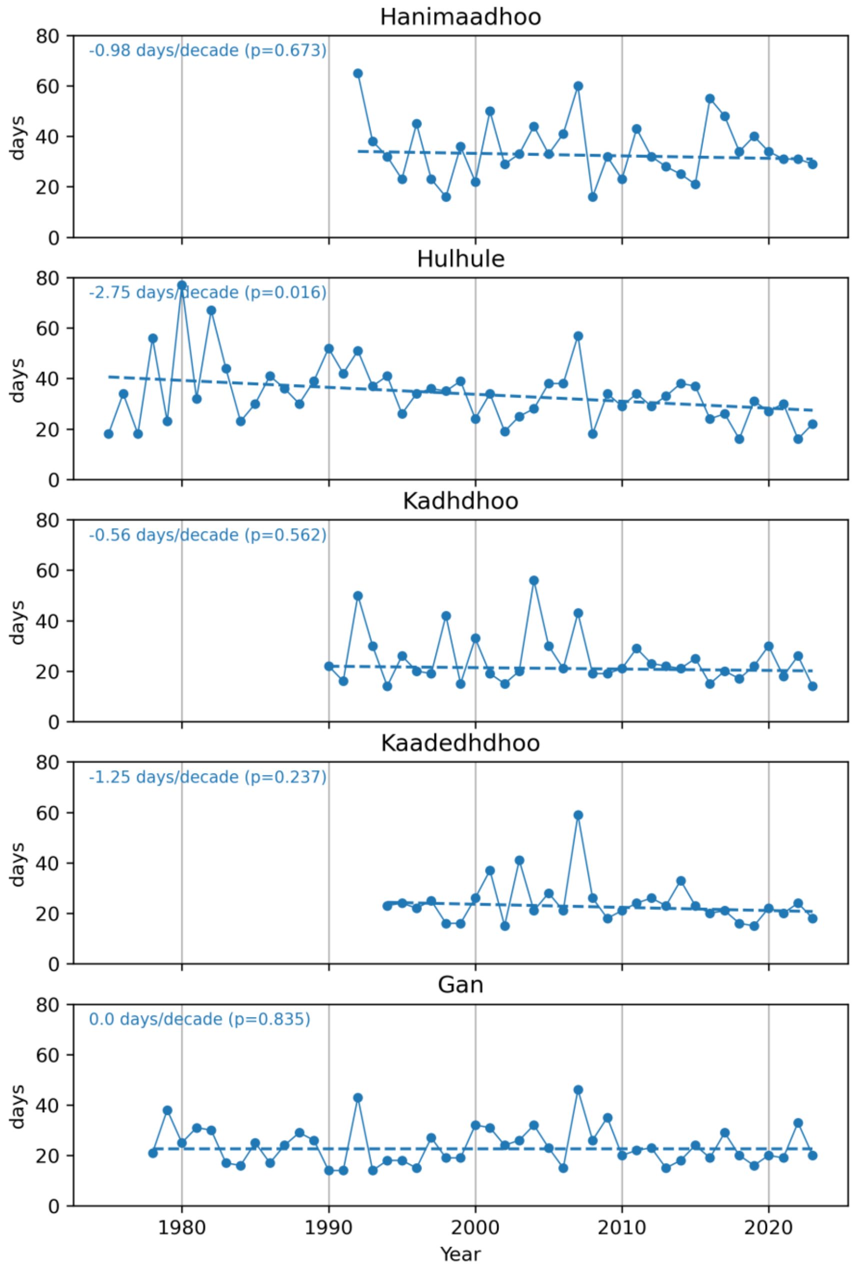

Figure 20. The maximum number of consecutive days without rain, for the five stations with long high-quality records. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). See Figure 5a for locations. Data provided by MMS (Table 2).

2.5.5 Sea-surface temperature

Sea-surface temperatures (SST) are not measured in the Maldives and so a remote sensing product with a ~25km resolution[121] is used to assess changes in the southern versus central and northern Maldives. SST has been increasing at a rate of 0.18 and 0.19 °C/decade, respectively, and is approximately 0.2 - 0.3°C higher in the south than north (Figure 21). The strong El-Niños of 1982-83, 1987-88, 1997-98, 2002-03, 2015-16 and 2023-24 stand out as years of high SST.

Marine heatwaves, similar to their atmospheric counterparts, are defined as prolonged, anomalously warm events and can cause significant coral bleaching and other ecological impacts. Figure 22 shows marine heatwaves have become more frequent in recent decades. These may be increasing at an

[121] Huang, B., Liu, C., Banzon, V., Freeman, E., Graham, G., Hankins, B., Smith, T. and Zhang, H.M., 2021. Improvements of the daily optimum interpolation sea surface temperature (DOISST) version 2.1. Journal of Climate, 34(8), pp.2923-2939.

accelerating pace, unlike the linear increase in SSTs (cf. Figure 21). Here again, the El-Niño years of 1997-98, 2015-16, 2019-20 and 2023-24 stand out as high marine heatwave years.

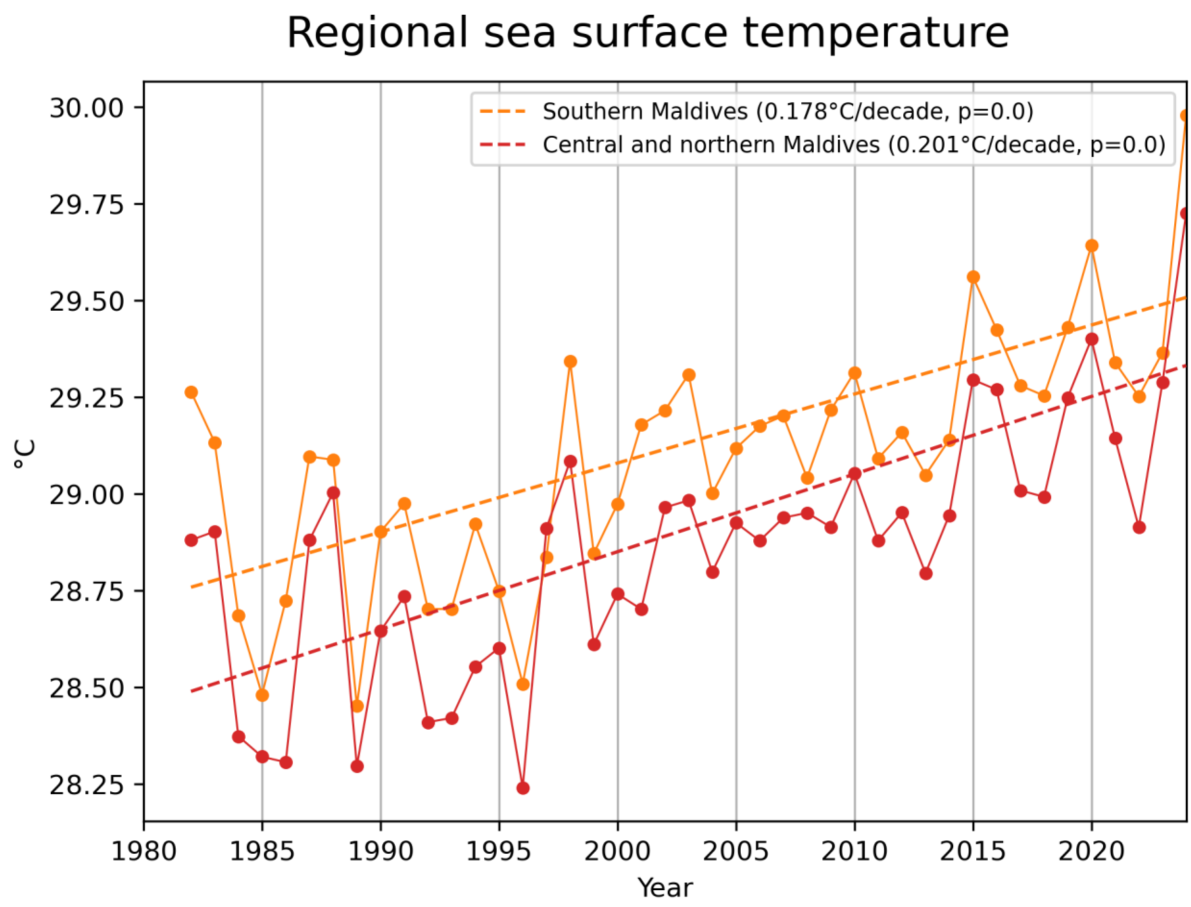

Figure 21. Sea-surface temperature averaged over the southern Maldives (-1°S to 1.5°N; 72.75°E to 73.75°E) and central and northern Maldives (1.5°N to 7.5°N; 72.75°E to 73.75°E).
Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Note that 2024 is only based on data up to and including September, thus the final temperature for this year will differ. Data from the NOAA Physical Science Laboratory.[122]

[122] Huang, B., Liu, C., Banzon, V., Freeman, E., Graham, G., Hankins, B., Smith, T. and Zhang, H.M., 2021. Improvements of the daily optimum interpolation sea surface temperature (DOISST) version 2.1. Journal of Climate, 34(8), pp.2923-2939.

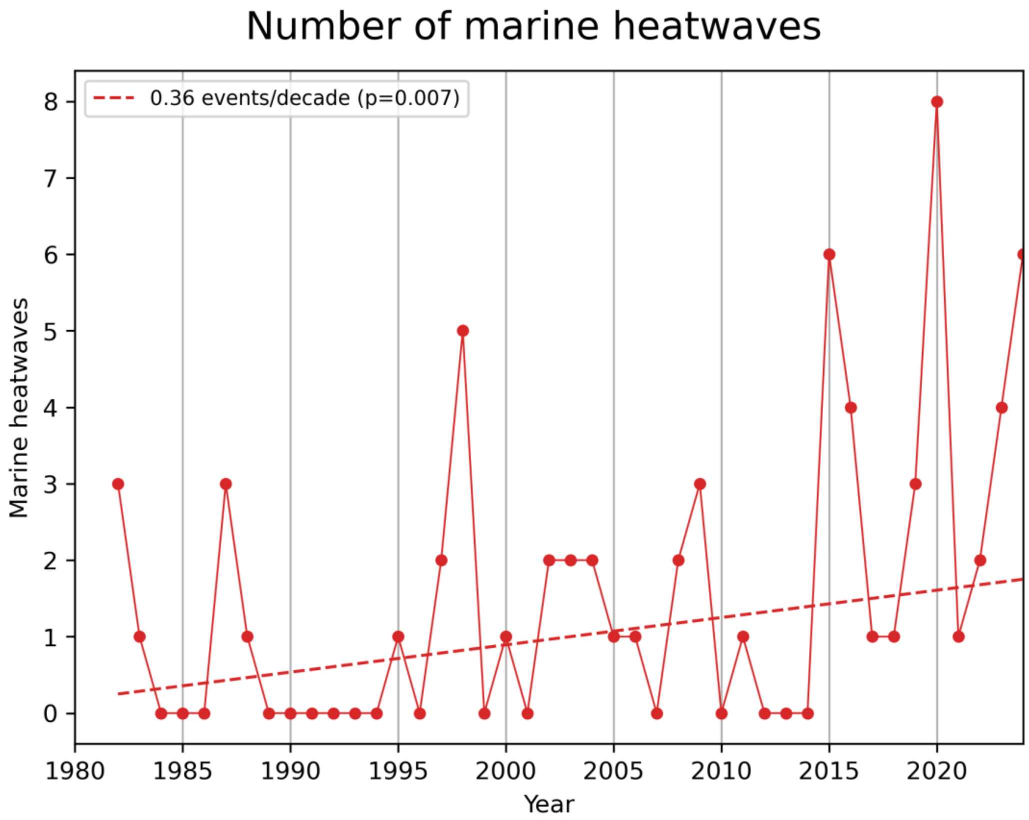

Figure 22. The number of marine heatwaves identified for the central Maldives (4.2°N, 73.5°E). Marine heatwaves are defined according to Hobday et al.[123], where SST's must be greater than the 90th percentile for 5 or more consecutive days and where consecutive heatwaves with a two day or shorter gap are considered one continuous event. Straight dashed line indicates linear trend (size of trend and p-value listed in legend). Note that 2024 is only based on data up to and including September thus the final value may be higher. SST from the NOAA Physical Science Laboratory.[124]

2.5.6 Extreme waves and swell

Locally generated ocean waves and swell from distant weather systems can have significant impacts on the Maldives. No long-term records of wave height exist, therefore gridded data from the ERA5 global reanalysis[125] is used. A reanalysis is a global weather model that integrates observations into its calculations, thus providing more accurate results than traditional weather models along with global coverage, which observation networks by themselves cannot provide. Wave height data for the five sites where long-term weather stations exist is extracted from ERA5 (see Figure 5a for locations). These locations are chosen for consistency, and it should be noted that the islands of the Maldives are not represented in ERA5 due to its relatively coarse spatial resolution (~30 km grid cells). Given the resolution of ERA5 and the importance of local topography and coastlines for local wave height, this data can only provide a broad indication of long-term change.

According to ERA5, the 90th percentile of significant wave height has increased significantly since the 1950's at all sites (Figure 23). The increase in these extreme waves has been two to three times faster

[123] Hobday, A.J., Alexander, L.V., Perkins, S.E., Smale, D.A., Straub, S.C., Oliver, E.C., Benthuysen, J.A., Burrows, M.T., Donat, M.G., Feng, M. and Holbrook, N.J., 2016. A hierarchical approach to defining marine heatwaves. Progress in oceanography, 141, pp.227-238.

[124] Huang, B., Liu, C., Banzon, V., Freeman, E., Graham, G., Hankins, B., Smith, T. and Zhang, H.M., 2021. Improvements of the daily optimum interpolation sea surface temperature (DOISST) version 2.1. Journal of Climate, 34(8), pp.2923-2939.

[125] Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz‐Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D. and Simmons, A., 2020. The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146(730), pp.1999-2049.

at Gan compared to the other sites, with significant wave height in recent years approximately 10% higher than at the beginning of the time series.

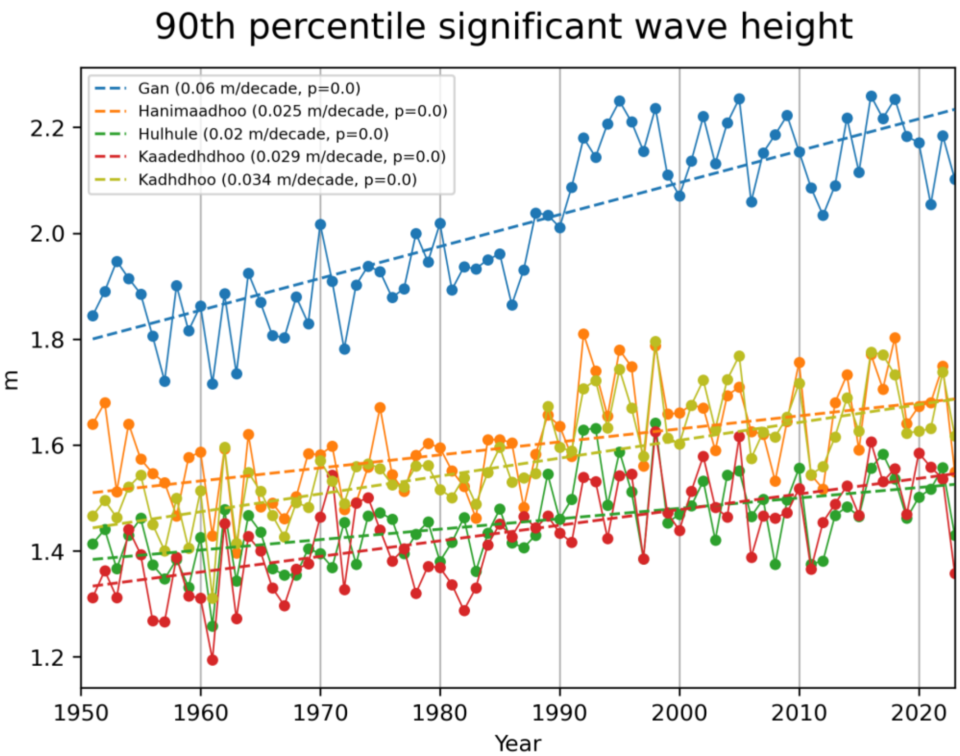

Figure 23. The 90th percentile of significant wave height at five sites used for temperature and rainfall analysis (Table 2). See Figure 5a for locations. Significant wave height is defined as the average height of the highest one third of waves. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Percentiles are calculated on hourly significant wave height taken from the ERA5 reanalysis[126]. A correction to partly mitigate errors due to the coarse resolution of ERA5 is applied[127]. A reanalysis is a global weather model that integrates observations into its calculations, thus providing more accurate results than traditional weather models along with global coverage which observation networks by themselves cannot provide. However, since reanalyses are models, they still contain biases and should only be used when reliable observations are lacking.

A map of 1-in-100-year significant wave heights based on regional wave modelling suggest the southern and northwestern Maldives are the most exposed to extreme wave activity (Figure 24). This is due to wave activity generated by the Indian monsoon and the Southern Ocean, the two dominant contributors of wave activity in the Maldives.[128]

[126] Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz‐Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D. and Simmons, A., 2020. The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146(730), pp.1999-2049.

[127] Fanti, V., Ferreira, Ó., Kümmerer, V. and Loureiro, C., 2023. Improved estimates of extreme wave conditions in coastal areas from calibrated global reanalyses. Communications Earth & Environment, 4(1), p.151.

[128] Amores, A., Marcos, M., Pedreros, R., Le Cozannet, G., Lecacheux, S., Rohmer, J., Hinkel, J., Gussmann, G., van der Pol, T., Shareef, A. and Khaleel, Z., 2021. Coastal flooding in the Maldives induced by mean sea-level rise and wind-waves: From global to local coastal modelling. Frontiers in Marine Science, 8, p.665672.

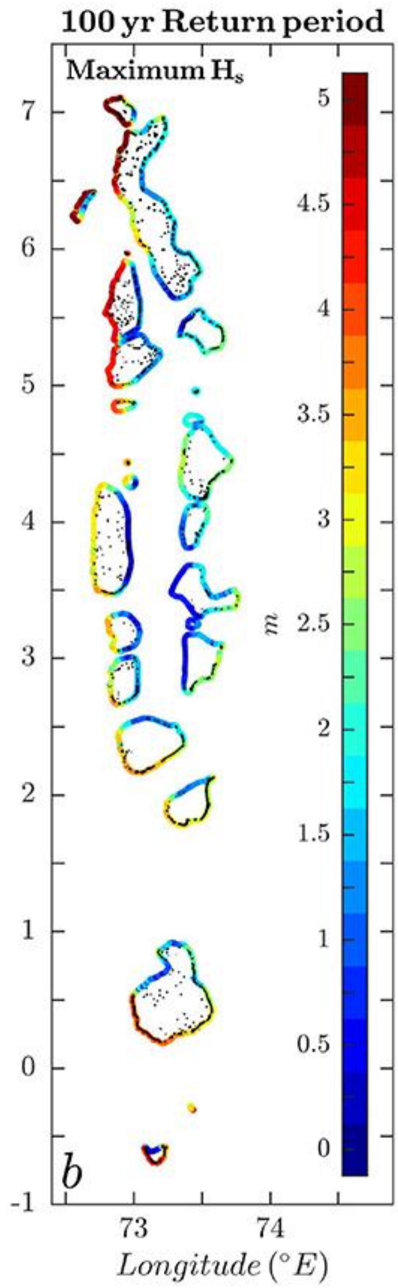

Figure 24. 1-in-100-year significant wave height (Hs) based on regional wave modelling. Figure taken from Amores et al.[129] The largest wave heights occur in the northwestern and southern parts of the Maldives, due largely to wave activity generated by the Indian Monsoon and Southern Ocean, respectively.

The number of islands and frequency of flooding events due to waves increased steadily between 1991 and 2013, with a substantial jump in 2007 due to a large storm in May that occurred over 5,000 km to the southwest of the Maldives (Figure 25; Table 5). This increase in impacts is consistent with an increasing population, higher sea-levels (Figure 8) and increasing wave heights (Figure 23).

[129] Amores, A., Marcos, M., Pedreros, R., Le Cozannet, G., Lecacheux, S., Rohmer, J., Hinkel, J., Gussmann, G., van der Pol, T., Shareef, A. and Khaleel, Z., 2021. Coastal flooding in the Maldives induced by mean sea-level rise and wind-waves: From global to local coastal modelling. Frontiers in Marine Science, 8, p.665672.

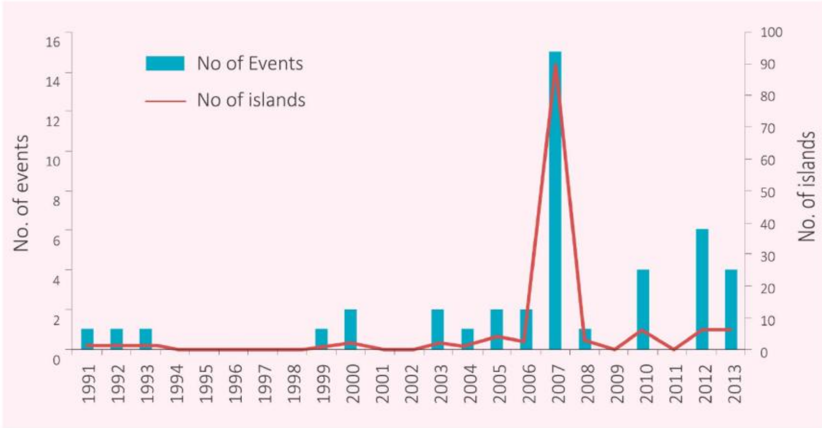

Figure 25. Reported cases of tidal waves and the number of islands flooded due to waves.
Figure taken from the Second National Communication (2016)[130] *Data for years since 2013 have yet to be compiled.*[131]

2.5.7 Strong winds

The Maldives experiences strong winds due largely to the Indian monsoon. The longest records of daily wind speeds are from Hanimaadhoo, Hulhule and Gan. These sites typically experience strong gale-force winds multiple times a year (Figure 26a). Speeds of this magnitude are often associated with high ocean waves and slight structural damage (e.g., slates and chimney pots removed). Events like this may disrupt ocean transportation, which many locals rely on for commuting and for the transportation of goods. While the average wind speed decreased significantly between 2000 and 2019 at all three sites, this reversed from 2020 to 2022 and thus no long-term trend is evident (Figure 26b). The cause of this variability is unclear, and longer records would benefit climate change assessments.

[130] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the United Nations Framework Convention on Climate Change: Ministry of Environment and Energy.
[131] Personal communication with National Disaster Management Authority.

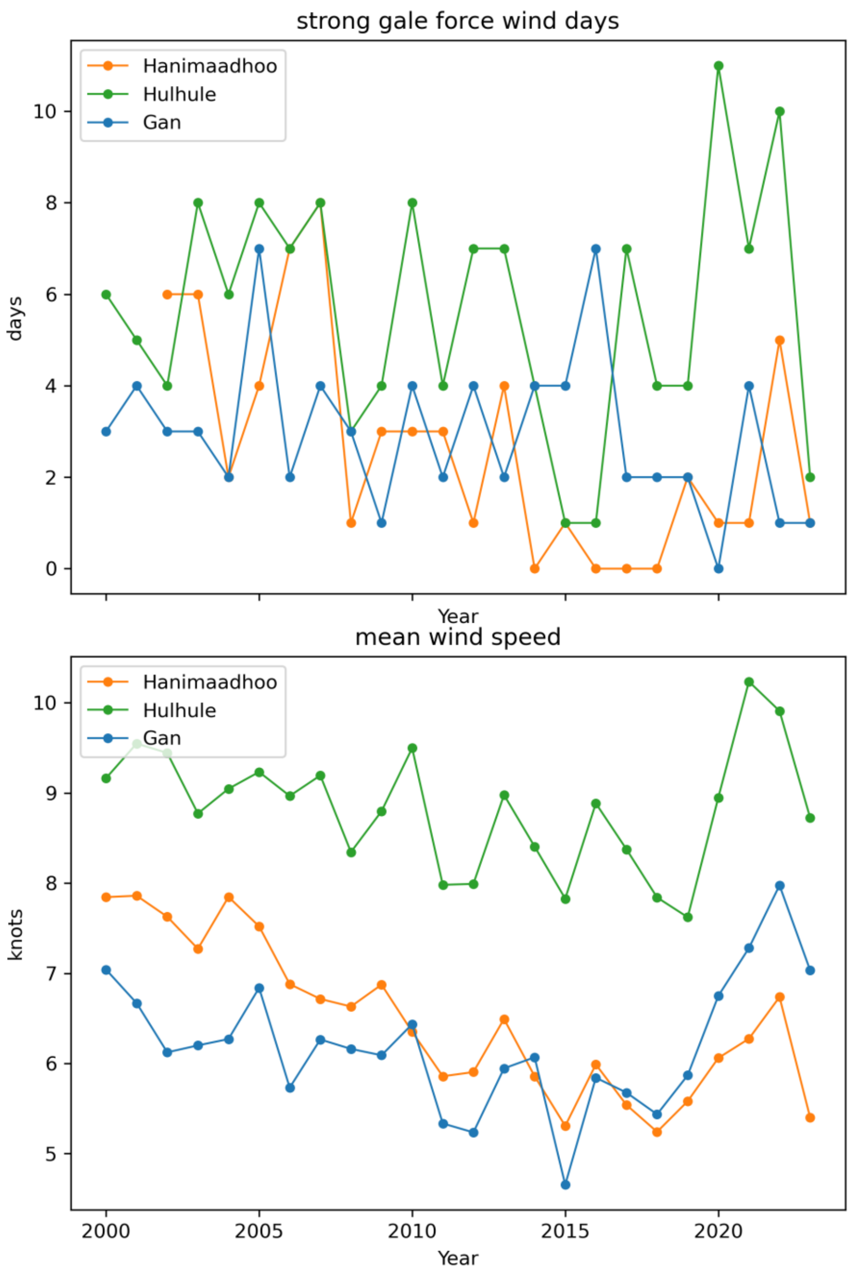

Figure 26. The number of days experiencing strong gales (a; 41-47 knots) and mean surface wind speed (b) at Hanimaadhoo, Hulhule and Gan.
See Figure 5a for station locations. Data provided by MMS.

2.5.8 Recent recorded events

Table 5. Overview of recorded natural hazards affecting the Maldives from 1991 – 2024[132,133,134,135,136, 137]

Date	Location	Disaster event	No. affected	Description and impacts

[132] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the United Nations Framework Convention on Climate Change: Ministry of Environment and Energy.
[133] Wadey, M., Brown, S., Nicholls, R.J. and Haigh, I., 2017. Coastal flooding in the Maldives: an assessment of historic events and their implications. Natural Hazards, 89, pp.131-159.
[134] Asian Disaster Reduction Center, 2018. Republic of Maldives Country Report
[135] Centre for Excellence Disaster Management Reference Handbook, Maldives, 2021.
[136] EM-DAT - The international disaster database, https://www.emdat.be/ (Accessed: October 2024)
[137] Centre for Excellence Disaster Management Reference Handbook, Maldives, 2024.

30 May 1991	Southern atolls	Storm	36,000 people (including 23,849 people forced to evacuate their homes)	Damage to 4081 houses in 13 atolls (13% of all houses in the country) USD 30 million estimated total cost of damage
8 May 1993	Details unavailable	Coastal flood event	Details unavailable	Peak significant wave height of 2.62 m
5 June 1993	Details unavailable	Coastal flood event	Details unavailable	Peak significant wave height of 3.61 m
6 November 1994	Details unavailable	Coastal flood event	Details unavailable	Peak significant wave height of 2.63 m
20 July 2001	Details unavailable	Coastal flood event	Details unavailable	Peak significant wave height of 3.29 m
June-July 2003 (unspecified dates)	Details unavailable	Coastal flood event	Details unavailable	Highest high water level of 2.24 m
3 – 5 May 2004	Details unavailable	Coastal flood event	Details unavailable	Peak significant wave height of 2.83 m
June-July 2005 (unspecified dates)	Details unavailable	Coastal flood event	Details unavailable	Highest high water level of 2.24 m
18 September 2005	Details unavailable	Coastal flood event	Details unavailable	Peak significant wave height of 2.89 m
June 2006 (unspecified dates)	Details unavailable	Coastal flood event	Details unavailable	Highest high water level of 2.19 m
4 September 2006	Details unavailable	Coastal flood event	Details unavailable	Peak significant wave height of 2.2 m
30 November 2006	Details unavailable	Coastal flood event	Details unavailable	Peak significant wave height of 1.26 m
15 – 17 May 2007	Maldives (particularly Gaafu Dhaalu, Dhaalu, Thaa and Laamu atolls)	High waves and coastal flooding	1,649 people evacuated from their homes	• A series of swells (3.0 – 4.5 m) hit an estimated 68 islands in 16 atolls, causing inundation of up to 600 m from the coastline • Damage to 579 houses • Saltwater intrusion on 33 islands, which caused significant damage to crops, agriculture farms, home gardens and vegetation • Minor damage to harbours and jetties in 17 islands • Damage to waste disposal areas and septic tanks
October – November 2012	Maldives	Cyclone Nilam	33,826 people	• Flooding in 51 islands – including severe flooding in 28 islands and four islands in a ‘critical state’ • USD 133,090 estimated total cost of damage
11-12 August 2015	Malé	Swells, strong winds and flooding	Unknown	Male’ eastern waterfront flooded to 0.5m
27-30 September 2015	Southern islands (Gaafu Alif, Gaafu Dhaal and Meemu atolls)	Flooding	Unknown	Waves combined with high tides caused minor flooding in 5 southern atolls
24 – 25 November 2015	Addu City	Floods	Unknown	• Severe flooding after several hours of torrential rainfall, with storm damage

				described as the worst in 40 years • Addu City experienced 228.4 mm rainfall in a day, the highest in a 24-hour period recorded in Maldives' history • 297 houses flooded • USD 0.3 million estimated total cost of damage
28 December 2015	Northeast Maldives (Komandoo Island)	Swells and flooding	Unknown	Swells hit Komandoo Island and water seeped 91m through the island, reaching 3 homes
May – June 2017	Maldives (particularly Malé, Haa Alif, Haa Dhaal, Gaaf Alif, Faafu, Gaafu Dhaal, Addu atolls)	Heavy rainfall, flooding and cyclonic winds	Unknown	• Torrential rain and strong winds (55 mph or 88.5 km/hour) caused damage in 14 islands • 19 houses affected in Thinadhoo (Gaafu Dhaalu atoll) and damage to 46 houses in Hithadhoo (Addu) • Flooding damaged fields on the northern islands of Uligamu (Haa Alif atoll) and Vaikaradhoo (Haa Dhaal atoll) • 80 homes affected by flooding in Nadella (Gaaf Alif atoll) • 18 houses affected on Nilandhoo island (Faafu atoll)
3 December 2017	Addu, Gaafu Dhaalu, and Gaafu Alif, Haa Alif, Haa Dhall atolls	Cyclone Ockhi	Unknown	• Heavy rainfall caused flooding on 36 islands • Winds tore off roofs and felled trees on 22 islands • Swells reported from 4 islands • Damage to households and property across 62 islands in Maldives
May – June 2019	Haa Dhaal, Gaafy Alifu, Thaa, and Laamu atolls	Heavy rainfall and flooding	1,800 people affected	• 600 homes damaged
11 December 2019	Maldives (particularly Malé, Meemu, Alif Dhaal, Gaa Alif and Alif Alif atolls)	Heavy rainfall and flooding	Unknown	• More than 80mm of rainfall in 24 hours reported in some areas
16-17 May 2021	Maldives	Tropical Cyclone Tauktae	1,320 people affected	• 440 families affected
July 2022	Maldives	Heavy rainfall and sea surges	Unknown	• 277 houses and 110 agricultural fields damaged
August 2024	Maldives (particularly central and northern atolls)	Heavy rainfall, high winds, sea swells	Unknown	• 200 flooded houses in Malé • Damage to households and property estimated to be over USD 70,000

2.6 Projected climate overview

2.6.1 Temperature and rainfall

Monthly temperature and rainfall for 2011-2040, 2041-2070 and 2071-2100 at the five sites where long historical records are available are constructed by scaling historical data with projected changes from climate models. Based on this scaling the Maldives is projected to experience annual mean temperatures between 28.5 and 29°C by 2011-2040 under the SSP2-RCP4.5 scenario, depending on location (Figure 27). This represents ~0.6°C warming compared to 1981-2010. The spread in annual rainfall between locations is projected to increase from the historical range of 1,788 – 2,258 mm to 1,959 – 2,368 mm.

The timing of the wet and dry season is projected to remain the same during 2011 – 2040 under SSP2-RCP4.5 (cf. Figure 27 and Figure 4). However, the dry season is projected to become drier in the north and wetter in the south, while the wet season is projected to become wetter throughout the Maldives (Figure 28). The rate of warming also differs between seasons, with wet season temperatures projected to increase more than dry season temperatures (Figure 29).

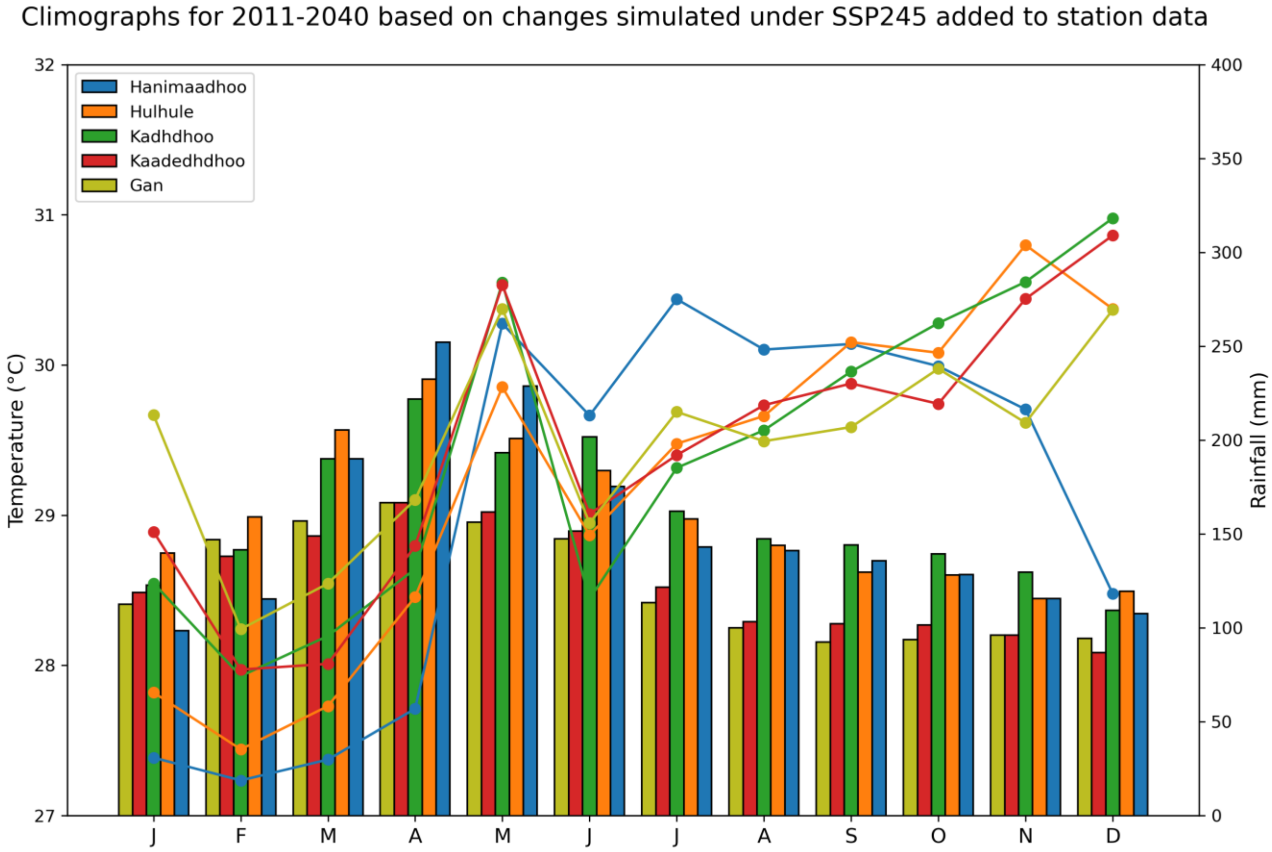

Figure 27. Monthly mean temperature (bars) and rainfall (lines) for the five sites with long high-quality records. Data are based on historical station data scaled by climate projections for 2011-2040 under the SSP2-RCP4.5 scenario from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models[138]. See section 2.3 for more details. See Figure 28a for site locations.

[138] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

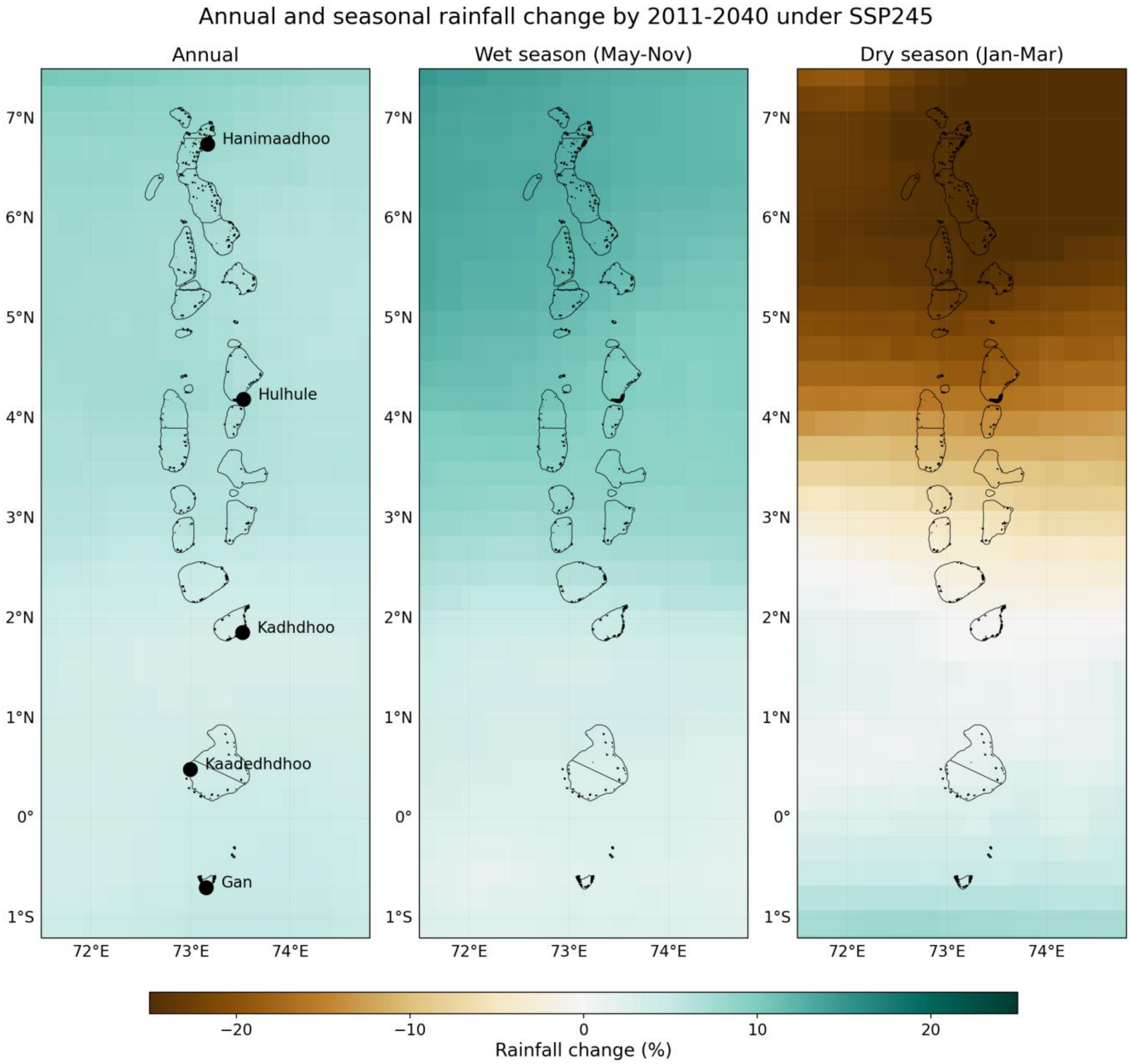

Figure 28. Projected change in rainfall by 2011-2040 for the annual average, wet season and dry seasons under the SSP2-RCP4.5 scenario downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models[139].
Base period for calculating change was 1981-2010. See section 2.3 for more details. Black dots represent sites where historical station data exist (Table 2).

[139] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

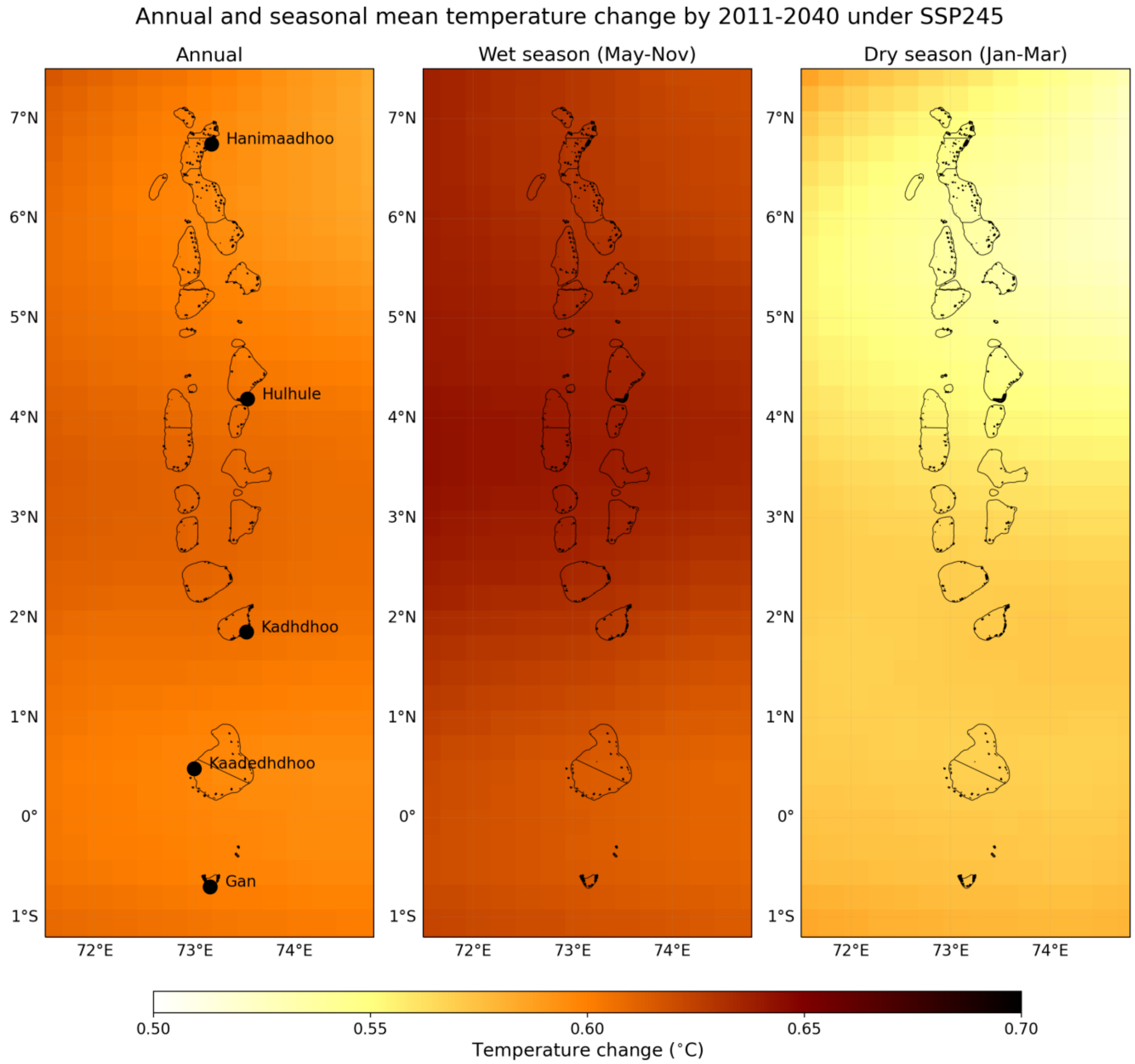

Figure 29. Projected change in temperature by 2011-2040 for the annual average, wet season and dry seasons under the SSP2-RCP4.5 scenario downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models[140].
Base period for calculating change was 1981-2010. See section 2.3 for more details. Black dots represent sites where historical station data exist (Table 2).

Maldives is projected to experience annual mean temperatures between 29.2 and 29.7°C by 2041-2070 under the SSP2-RCP4.5 scenario, depending on location (Figure 30). This represents ~1.3°C warming compared to 1981-2010. The spread in annual rainfall between locations is projected to increase from the historical range of 1,788 – 2,258 mm to 2,039 – 2,359 mm.

The timing of the wet and dry season is projected to remain the same by 2041 – 2070 under SSP2-RCP4.5 (cf. Figure 30 and Figure 4). However, similar to projections for 2011-2041, the dry season is projected to become drier in the north and wetter in the south, while the wet season is projected to become wetter in the central and northern Maldives and experience little change in the south (Figure 31).

[140] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

The rate of warming also differs between seasons, with wet season temperatures projected to increase more than dry season temperatures (Figure 32).

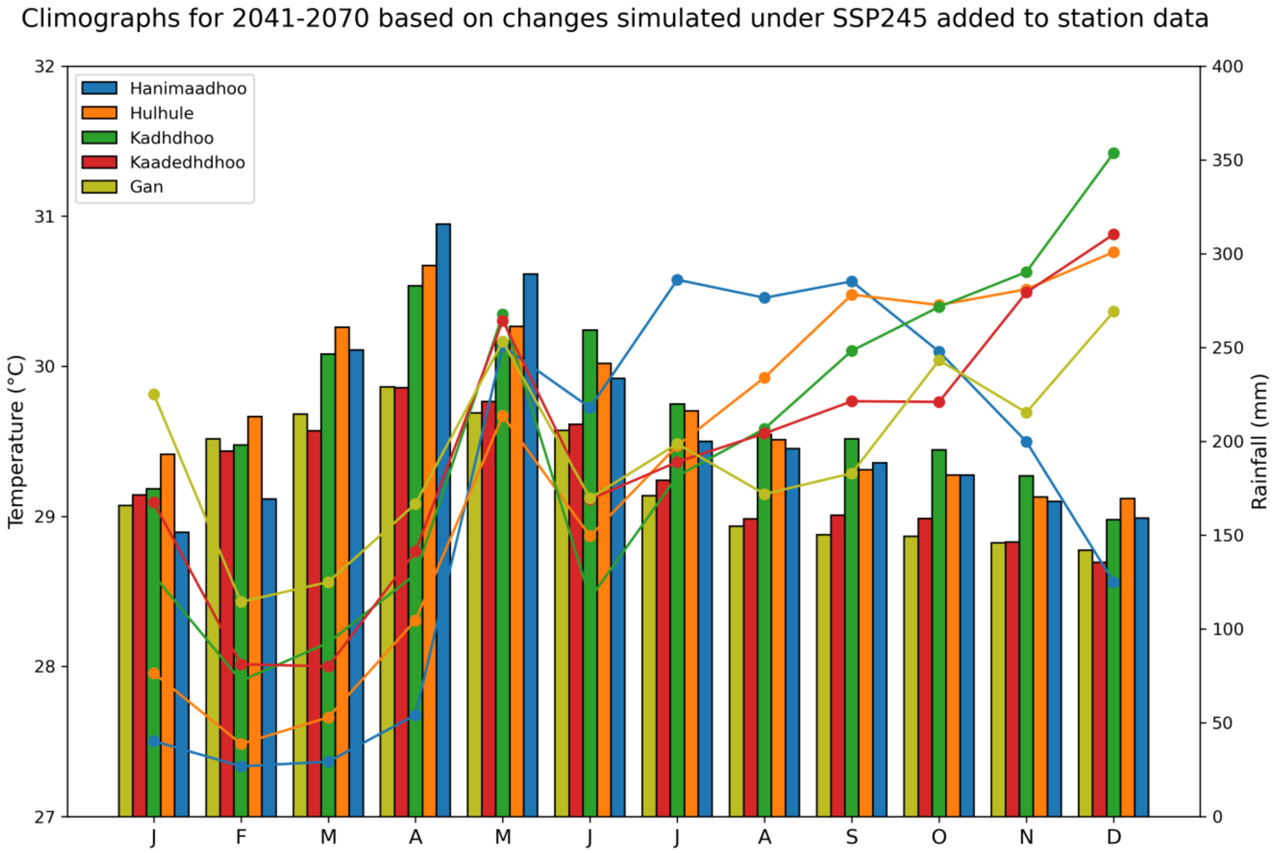

Figure 30. Monthly mean temperature (bars) and rainfall (lines) for the five sites with long high-quality records. Data are based on historical station data scaled by climate projections for 2041-2070 under the SSP2-RCP4.5 scenario from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models[141]. See section 2.3 for more details. See Figure 28a for site locations.

[141] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

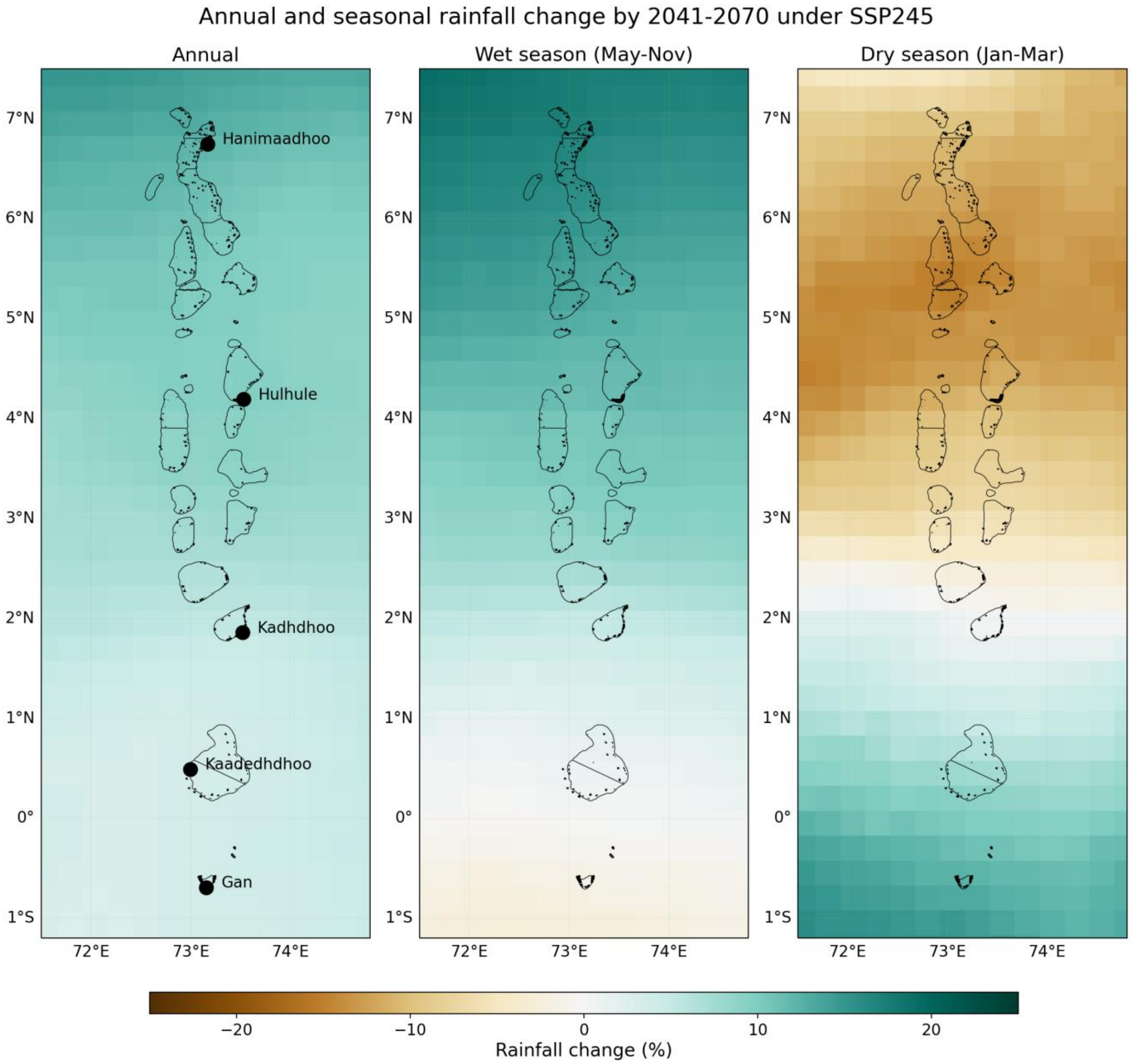

Figure 31. Projected change in rainfall by 2041-2070 for the annual average, wet season and dry seasons under the SSP2-RCP4.5 scenario downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models[142].
Base period for calculating change was 1981-2010. See section 2.3 for more details. Black dots represent sites where historical station data exist (Table 2).

[142] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

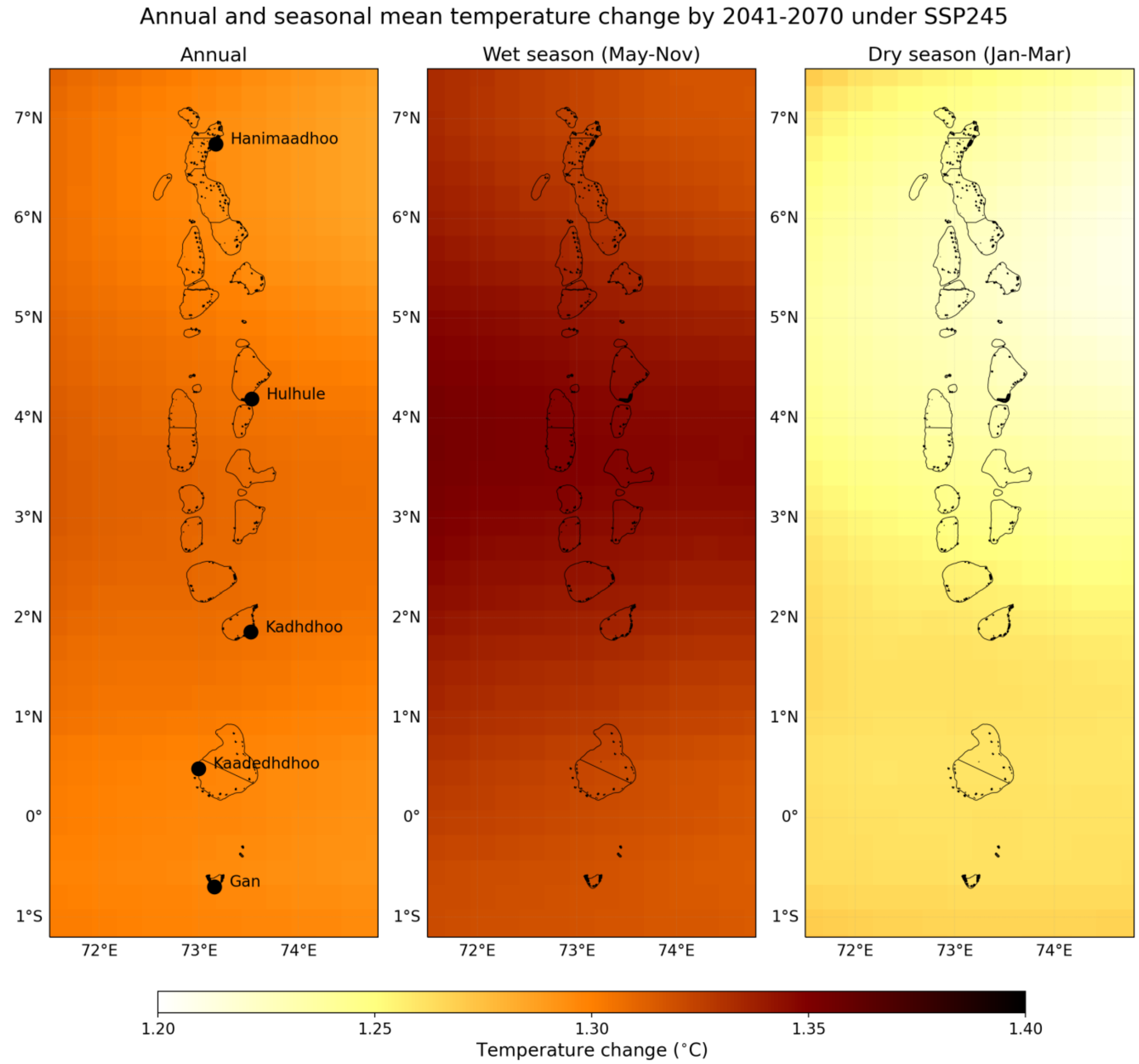

Figure 32. Projected change in temperature by 2041-2070 for the annual average, wet season and dry seasons under the SSP2-RCP4.5 scenario downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models[143].
Base period for calculating change was 1981-2010. See section 2.3 for more details. Black dots represent sites where historical station data exist (Table 2).

[143] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

Maldives is projected to experience annual mean temperatures between 29.7 and 30.1°C by 2071-2100 under the SSP2-RCP4.5 scenario, depending on location (Figure 33). This represents ~1.8°C warming compared to 1981-2010. The spread in annual rainfall between locations is projected to increase from the historical range of 1,788 - 2,258 mm to a future range of 2,105 – 2,407 mm.

The timing of the wet and dry season is projected to remain the same under SSP2-RCP4.5 (cf. Figure 33 and Figure 4). However, the dry season is projected to become drier in the north and wetter in the south, while the wet season is projected to become wetter throughout the Maldives (Figure 34). This is consistent with the conclusion of the IPCC AR6 that South Asian monsoon rainfall will increase by the end of the century (medium confidence).[144] The rate of warming also differs between seasons, with wet season temperatures projected to increase more than dry season temperatures (Figure 35).

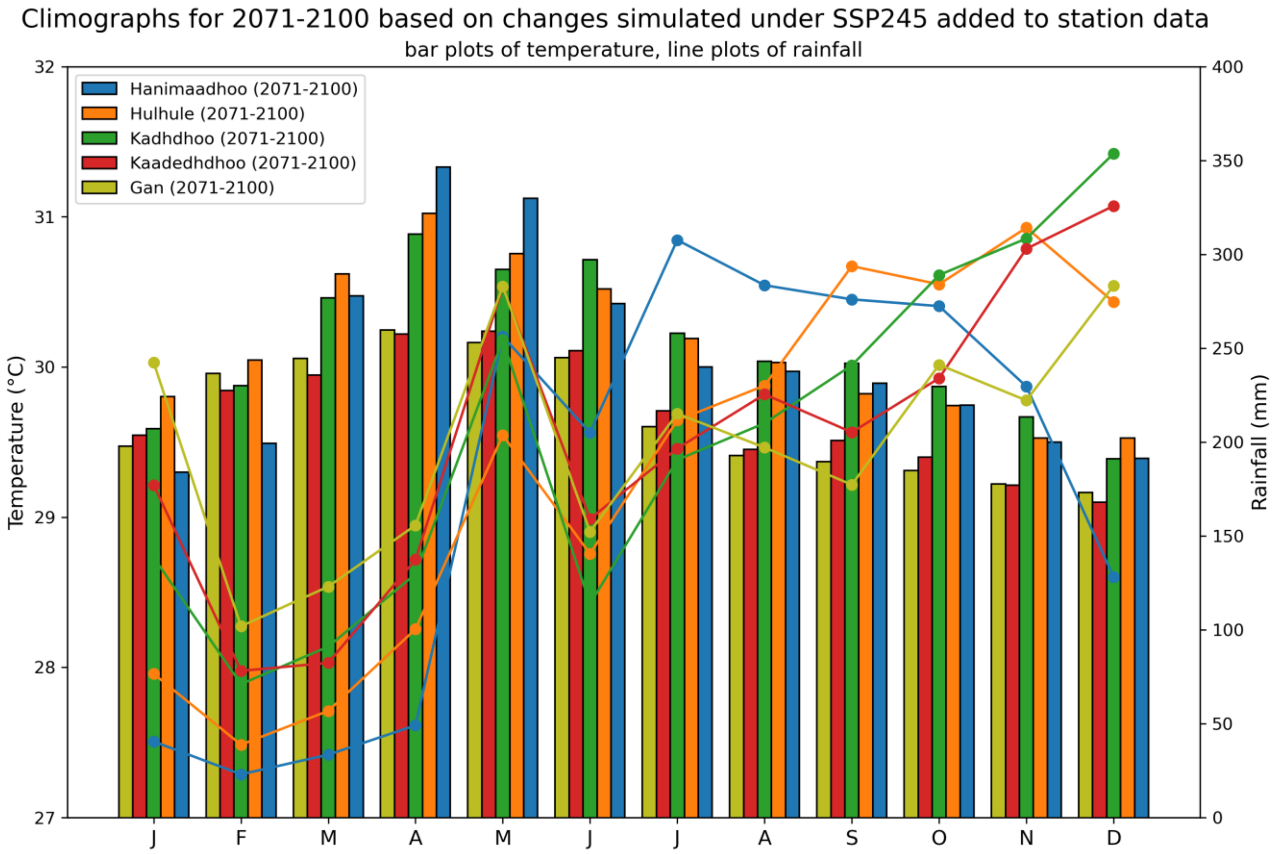

Figure 33. Monthly mean temperature (bars) and rainfall (lines) for the five sites with long high-quality records. Data are based on historical station data scaled by climate projections for 2071-2100 under the SSP2-RCP4.5 scenario from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models[145]. See section 2.3 for more details. See Figure 28a for site locations.

[144] Douville, H., K. Raghavan, J. Renwick, R.P. Allan, P.A. Arias, M. Barlow, R. Cerezo-Mota, A. Cherchi, T.Y. Gan, J. Gergis, D. Jiang, A. Khan, W. Pokam Mba, D. Rosenfeld, J. Tierney, and O. Zolina, 2021: Water Cycle Changes. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1055–1210, doi: 10.1017/9781009157896.010.
[145] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

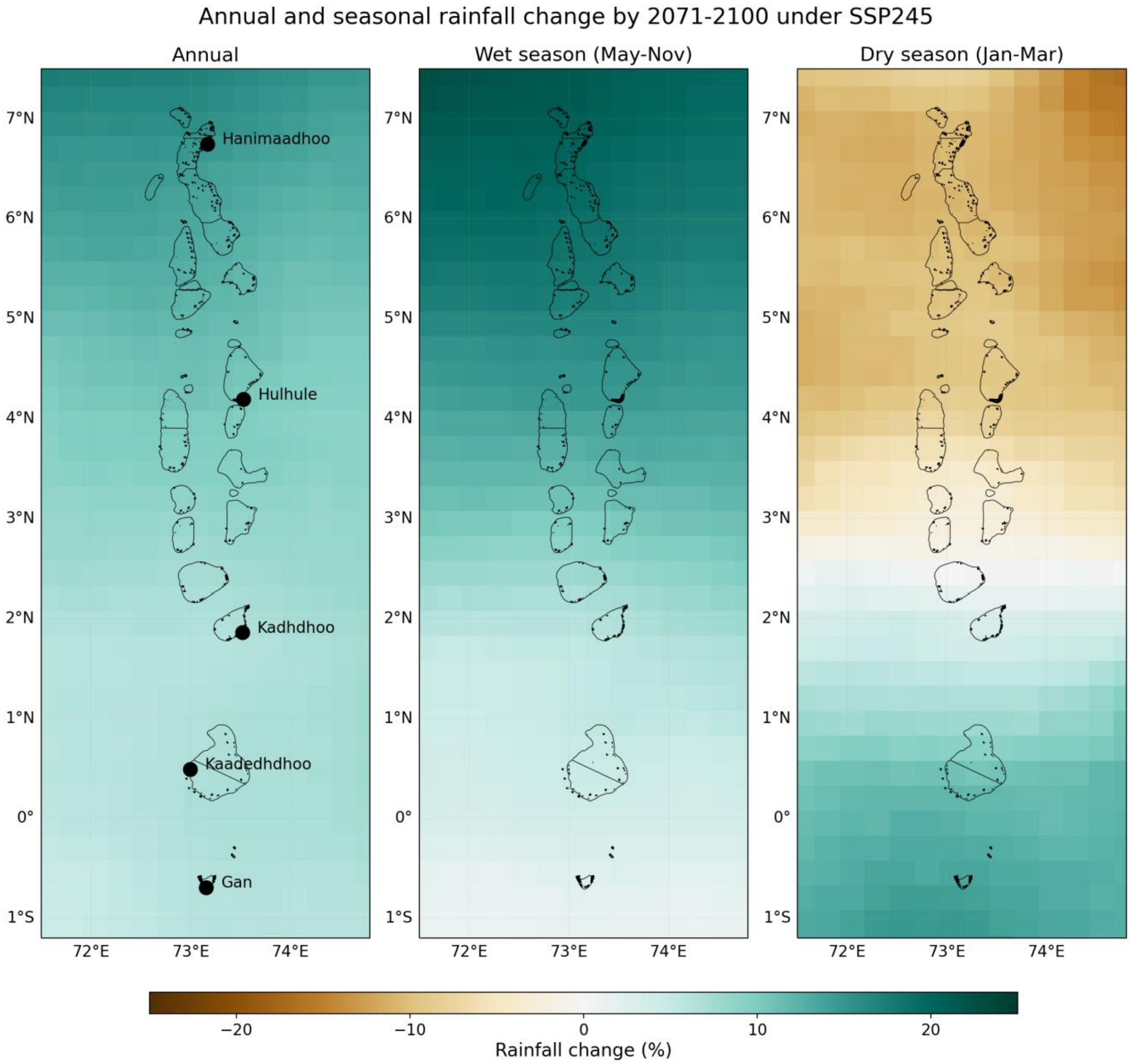

Figure 34. Projected change in rainfall by 2071-2100 for the annual average, wet season and dry seasons under the SSP2-RCP4.5 scenario downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models[146].
Base period for calculating change was 1981-2010. See section 2.3 for more details. Black dots represent sites where historical station data exist (Table 2).

[146] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

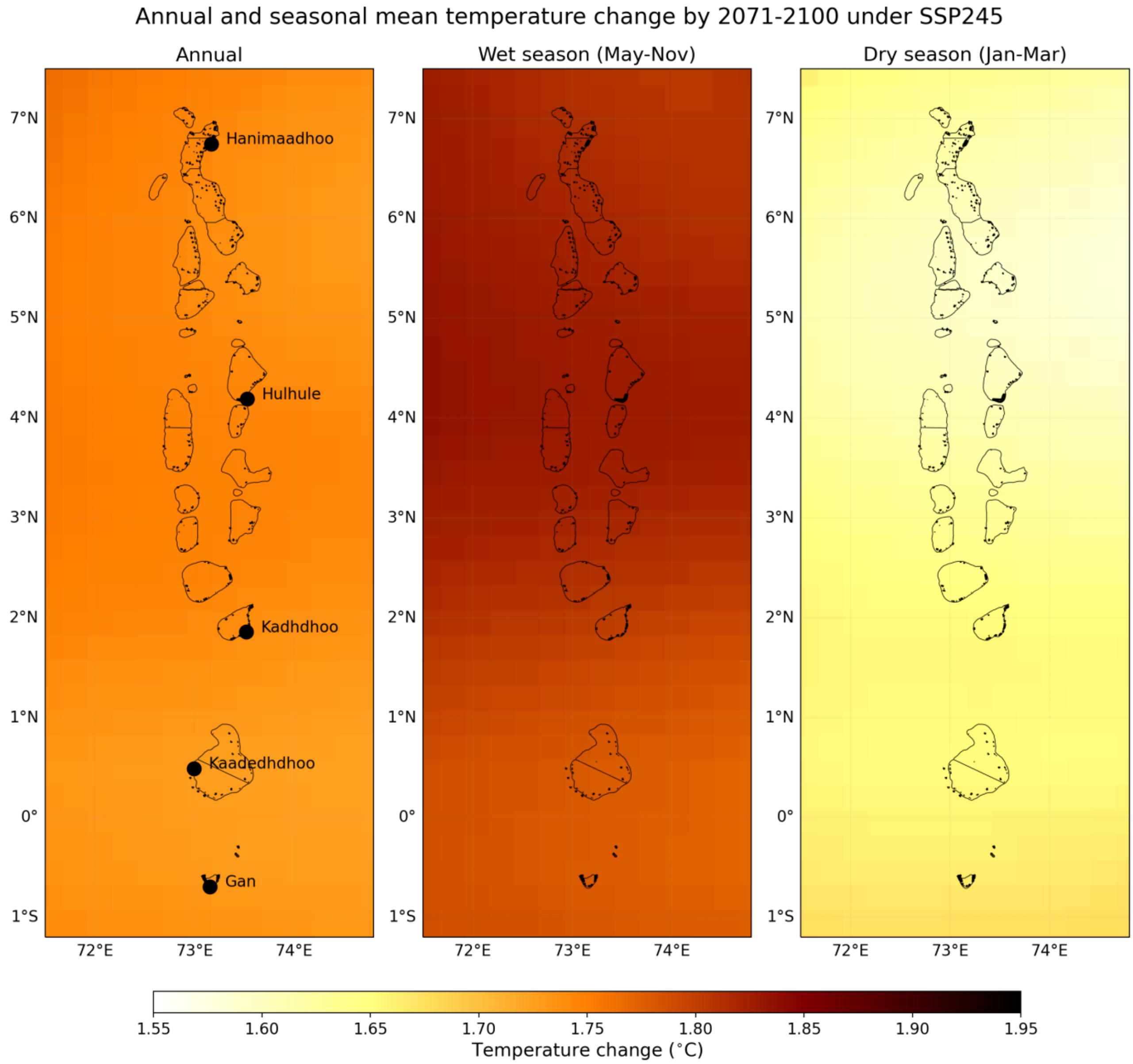

Figure 35. Projected change in temperature by 2071-2100 for the annual average, wet season and dry seasons under the SSP2-RCP4.5 scenario downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models[147].

Base period for calculating change was 1981-2010. See section 2.3 for more details. Black dots represent sites where historical station data exist (Table 2).

2.6.2 Sea-level rise and waves

There is an extremely large spread in projected sea-level rise for the Maldives by the end of the century (Figure 36). This spread reflects the differences between models and climate change scenarios and is increased by the presence of low confidence simulations (black line and grey shading) that include highly uncertain physical processes. Excluding the low confidence simulations, sea-level is projected to rise by 0.19 – 1.44 m by the end of the century. Including the low confidence simulations extends the upper estimate to 2.6 m, which is higher than virtually every island in the Maldives. Despite the potentially large rises that may occur, sea-level rise will not manifest first with a submersion of islands but with more

[147] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

frequent flooding due to combinations of storm surge, waves, swell and tides, which may have only infrequently caused flooding historically.

An ensemble of eight global wave simulations forced by CMIP6 simulations indicate a slight decrease in significant wave height over the northern Maldives by the end of the century under SSP5-RCP8.5, and no significant change under SSP1-RCP2.6.[148] The projected decrease under SSP5-RCP8.5 is opposite to the historical trend produced by the ERA5 reanalysis (Figure 23).

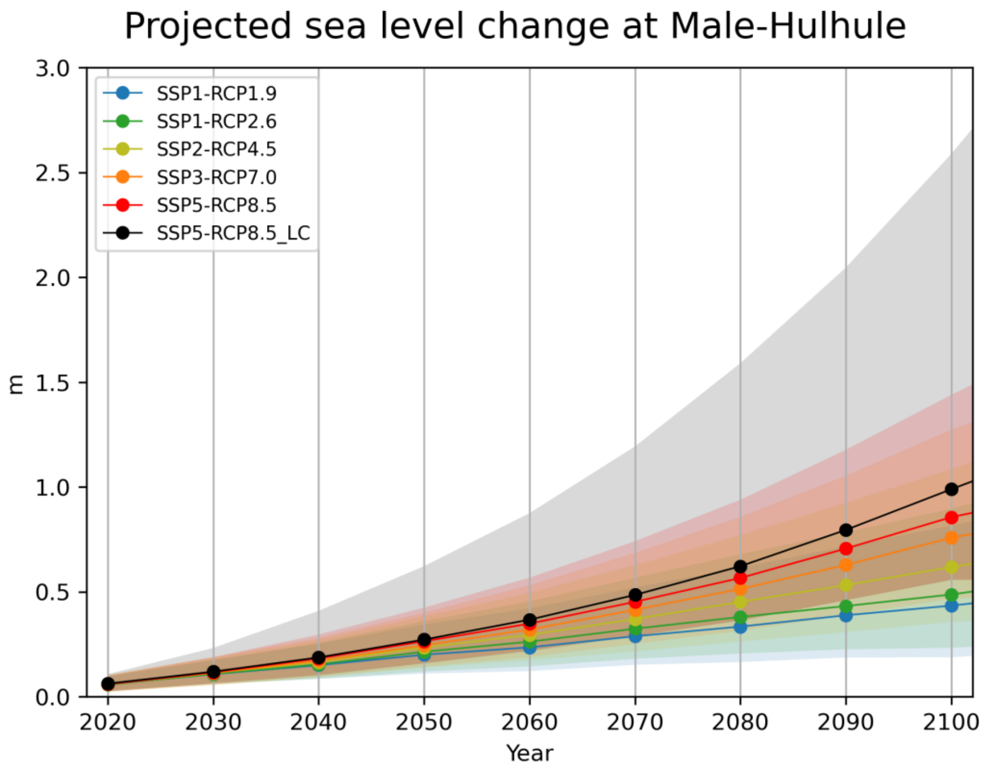

Figure 36. Sea level projections for central Maldives based on the IPCC AR6. Data is relative to 1995-2014. Shaded ranges represent the 17th - 83rd percentile range of ensemble projections. SSP5-RCP8.5_LC refers to low confidence simulations that cannot be ruled out and which include processes related to marine ice cliff instability. Data obtained from NOAA Sea-level projection tool.[149]

2.6.3 Ocean acidification

Projected pH change for the equatorial Indian Ocean by the end of the century ranges between -0.2 and -0.4, based on SSP1-RCP2.6 and SSP5-RCP8.5, respectively (Table 6). These changes represent a faster rate of acidification than has been observed historically for the global ocean (-0.017/decade; Figure 9), though pH decline is projected to begin reversing by the end of the century under SSP1-RCP2.6. Under SSP2-RCP4.5 and SSP5-RCP8.5, the decline in pH will continue beyond the 21st century (not shown).

[148] Meucci, A., Young, I.R., Trenham, C. and Hemer, M., 2024. An 8-model ensemble of CMIP6-derived ocean surface wave climate. Scientific Data, 11(1), p.100.
[149] https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool.

Table 6. Projected surface ocean pH change for the equatorial Indian Ocean from CMIP6, relative to a 1981-2010 base period.
Data from the IPCC interactive atlas.[150,151]

Period	Median change (pH) for SSP1-RCP2.6, SSP2-RCP4.5 and SSP5-RCP8.5
Near Term (2021-2040)	-0.1 / -0.1 / -0.1
Medium Term (2041-2060)	-0.1 / -0.1 / -0.1
Long Term (2081-2100)	-0.1 / -0.2 / -0.4

2.6.4 Modes of variability

The IPCC AR6 concluded that there is no consensus on the projected change in amplitude of ENSO, but that rainfall associated with ENSO events is very likely to increase.[152] Therefore, even without a change in ENSO variability the rainfall changes that accompany ENSO events are projected to be more severe. Similarly, the future state of the Indian Ocean Dipole (IOD) is uncertain, however, there is some evidence that under SSP5-RCP8.5 extreme positive IOD events will become more frequent,[153] which may lead to more significant rainfall extremes.[154]

2.7 Projected high impact events

2.7.1 Temperature extremes

Annual maximum temperatures are projected to increase significantly at all five sites under both the SSP2-RCP4.5 and SSP5-RCP8.5 scenarios (Figure 37). The projected rate of warming is extremely similar across the Maldives. Temperatures are projected to increase by such a large amount that by the end of the century the entire year will be considered a single long heatwave by historical standards. This is reflected by the fact that by the 2060s under both scenarios virtually all days are projected to be hotter than the 90th percentile of historical temperatures, a typical threshold used for defining heatwaves (Figure 38). This result is influenced by the low climate variability in the tropics, which makes small temperature increases capable of exceeding the 90th percentile threshold.

[150] Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I.V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon, 2021: Atlas. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L.Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K.Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/.
[151] Iturbide, M., Fernández, J., Gutiérrez, J.M., Bedia, J., Cimadevilla, E., Díez-Sierra, J., Manzanas, R., Casanueva, A., Baño-Medina, J., Milovac, J., Herrera, S., Cofiño, A.S., San Martín, D., García-Díez, M., Hauser, M., Huard, D., Yelekci, Ö. (2021) Repository supporting the implementation of FAIR principles in the IPCC-WG1 Atlas. Zenodo, DOI: 10.5281/zenodo.3691645. Available from: https://github.com/IPCC-WG1/Atlas.
[152] Lee, J.-Y., J. Marotzke, G. Bala, L. Cao, S. Corti, J.P. Dunne, F. Engelbrecht, E. Fischer, J.C. Fyfe, C. Jones, A. Maycock, J. Mutemi, O. Ndiaye, S. Panickal, and T. Zhou, 2021: Future Global Climate: Scenario-Based Projections and Near-Term Information. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672, doi: 10.1017/9781009157896.006.
[153] Ibid.
[154] Foley, A. and Kelman, I., 2020. Precipitation responses to ENSO and IOD in the Maldives: Implications of large-scale modes of climate variability in weather-related preparedness. International Journal of Disaster Risk Reduction, 50, p.101726.

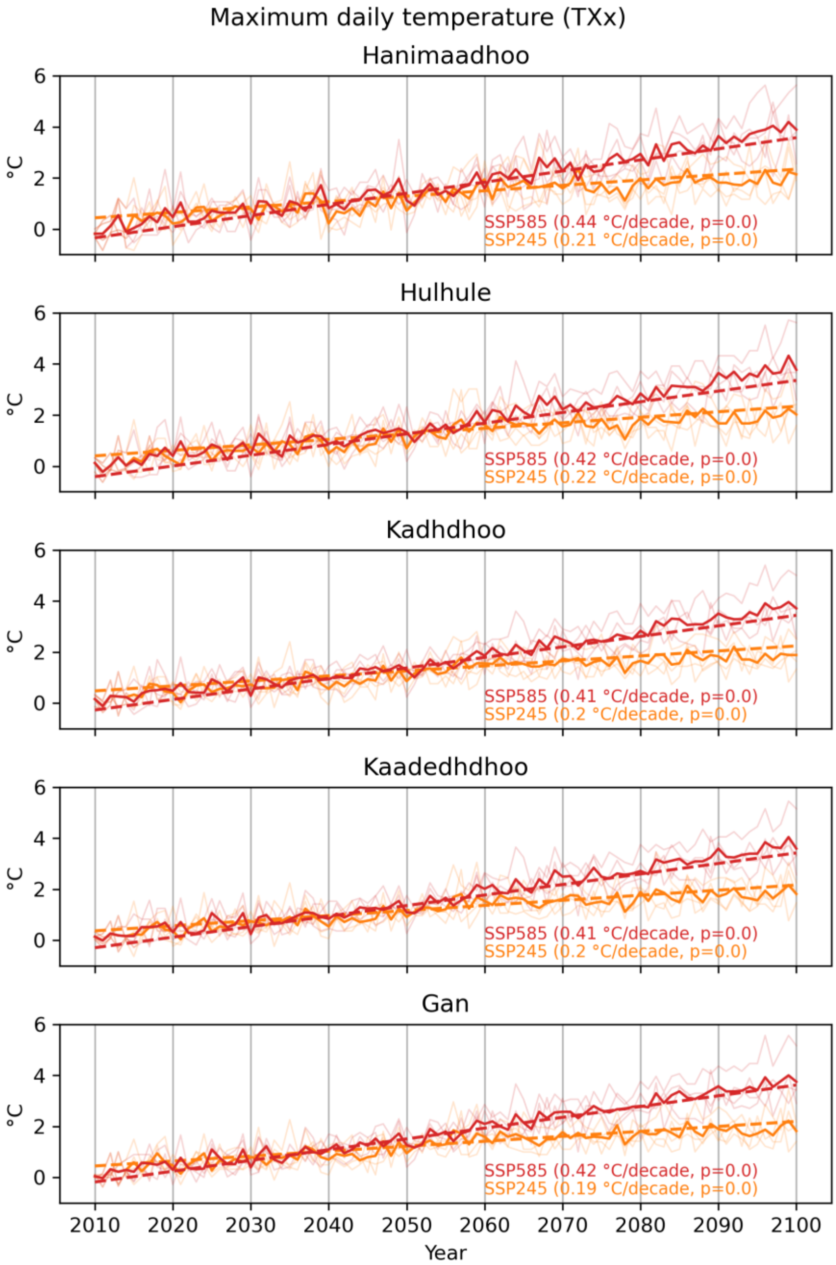

Figure 37. Projected change in maximum daily temperature at the five sites with long high-quality records. See Figure 28a for site locations. Data is downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models for the SSP2-RCP4.5 (orange) and SSP5-RCP8.5 (red) scenarios[155]. Bold lines represent multi-model averages. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Base period for calculating change was 1981-2010. See Section 2.3 for more details.

[155] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

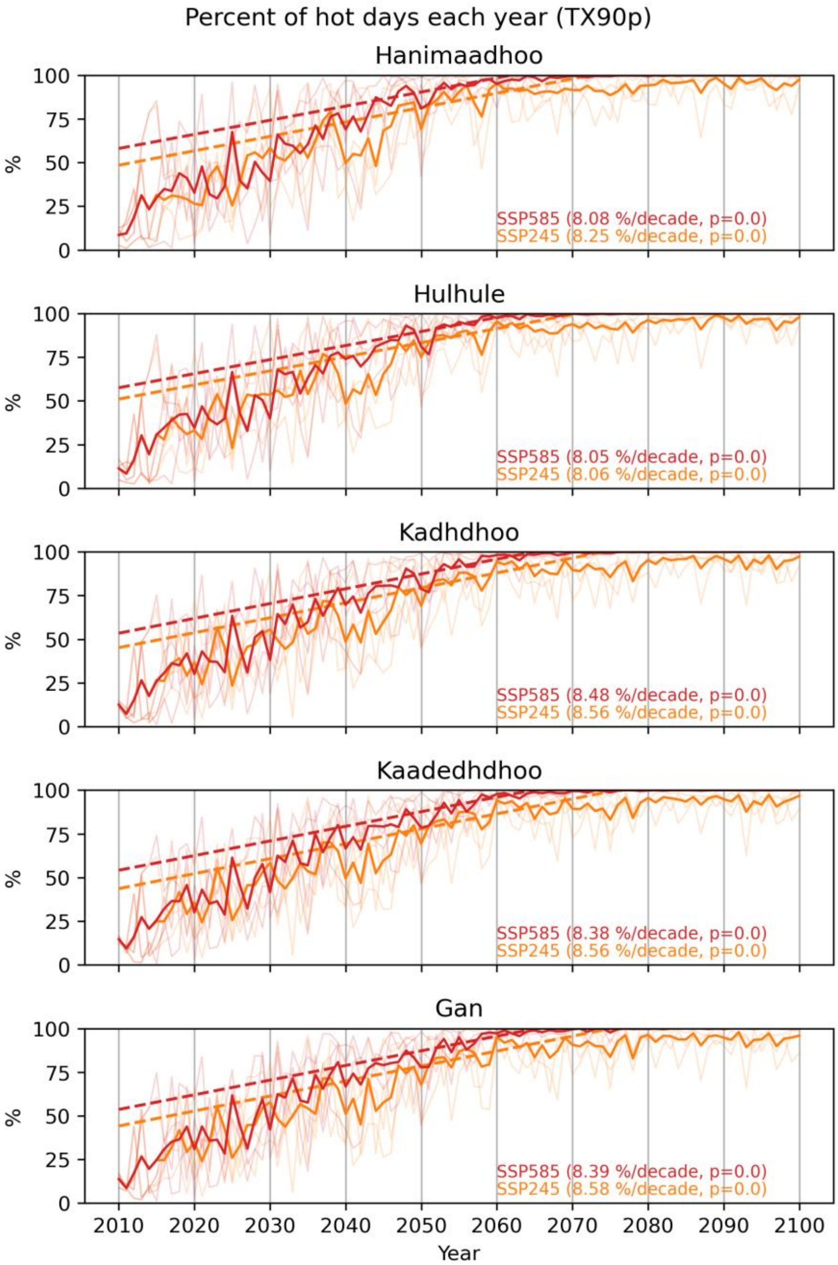

Figure 38. Projected change in the percent of hot days each year (defined by the 90th percentile for 1981-2010) at the five sites with long high-quality records.
See Figure 28a for site locations. Data is downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models for the SSP2-RCP4.5 (orange) and SSP5-RCP8.5 (red) scenarios[156]. Bold lines represent multi-model averages. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). See Section 2.3 for more details.

2.7.2 Rainfall extremes

Under the SSP2-RCP4.5 climate change scenario, maximum daily rainfall is projected to increase significantly at Hanimaadhoo (Figure 39). Under the SSP5-RCP8.5 scenario maximum daily rainfall is projected to increase at Hanimaadhoo, Hulhule and Kadhdhoo. Kaadedhdhoo and Gan are not projected to experience significant increases in maximum daily rainfall under either scenario.

[156] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

In contrast to maximum daily rainfall, the proportion of rain falling on extremely wet days (defined as the top 5% of rainy days) is projected to increase at each site under both scenarios, with the exception of Kaadedhdhoo under SSP5-RCP8.5 (Figure 40).

The above results suggest that by the end of the century the proportion of rain falling on the rainiest days will increase, but that the maximum daily rainfall will only change in the north, and mostly only under SSP5-RCP8.5. Maximum daily rainfall is often used to characterise peak rain events in flood studies.

Considering the importance of flood design for adaptation and the dependence of flood design on extreme rainfall projections, several issues should be considered when interpreting these projections. First, global climate models do not explicitly represent the processes responsible for rainfall due to the small scale at which these processes take place, relative to the large grid cell size of climate models. While downscaling alleviates this, it does so only partially and any change in these processes under climate change will not be reflected in downscaled data. Consequently, rainfall is simulated with far more uncertainty than variables such as temperature. Second, there is large uncertainty in the representation of tropical cyclones (and their changes under global warming) in global climate models, and so any change in future cyclone activity and the subsequent effect on rainfall may not be reflected accurately in the data used here. Third, it is well known that the atmosphere holds ~7% more moisture per degree of warming (known as the Clausius-Clapeyron relationship[157]), and this has been generally observed in historical maximum daily rainfall rates.[158] Warming is virtually certain over the entire globe by the end of the century and so a more moisture-laden atmosphere is expected. This contradicts results showing no significant increase in maximum daily rainfall (e.g. Figure 39) but is qualitatively consistent with the projected increase in mean annual rainfall (Figure 34a). Lastly, the future state of ENSO and IOD is uncertain (see Section 2.6.4) and there are known relationships between extreme rainfall in the Maldives and these modes.[159] If global climate models do not accurately capture the future state of ENSO and IOD then this adds more uncertainty in the projected change in rainfall extremes for the Maldives.

In summary, there are large uncertainties in rainfall extremes simulated by climate models, but there is a strong theoretical expectation that the atmosphere will hold more moisture in a warmer climate. Given this, it is often considered prudent to base expectations of future extreme rainfall on projected changes in temperature through the Clausius-Clapeyron relationship. This same approach may be justified for the Maldives. This has been done in flood design guidelines in several countries as a practical measure for addressing the large uncertainties in extreme rainfall.[160] It should be noted that this approach addresses the thermodynamic component of changing rainfall while leaving the dynamic component (related to changes in atmospheric circulation) unaccounted for.

[157] Trenberth, K.E., Dai, A., Rasmussen, R.M. and Parsons, D.B., 2003. The changing character of precipitation. Bulletin of the American Meteorological Society, 84(9), pp.1205-1218.
[158] Westra, S., Alexander, L.V. and Zwiers, F.W., 2013. Global increasing trends in annual maximum daily precipitation. Journal of climate, 26(11), pp.3904-3918.
[159] Foley, A. and Kelman, I., 2020. Precipitation responses to ENSO and IOD in the Maldives: Implications of large-scale modes of climate variability in weather-related preparedness. International Journal of Disaster Risk Reduction, 50, p.101726.
[160] Martel, J.L., Brissette, F.P., Lucas-Picher, P., Troin, M. and Arsenault, R., 2021. Climate change and rainfall intensity–duration–frequency curves: Overview of science and guidelines for adaptation. Journal of Hydrologic Engineering, 26(10), p.03121001.

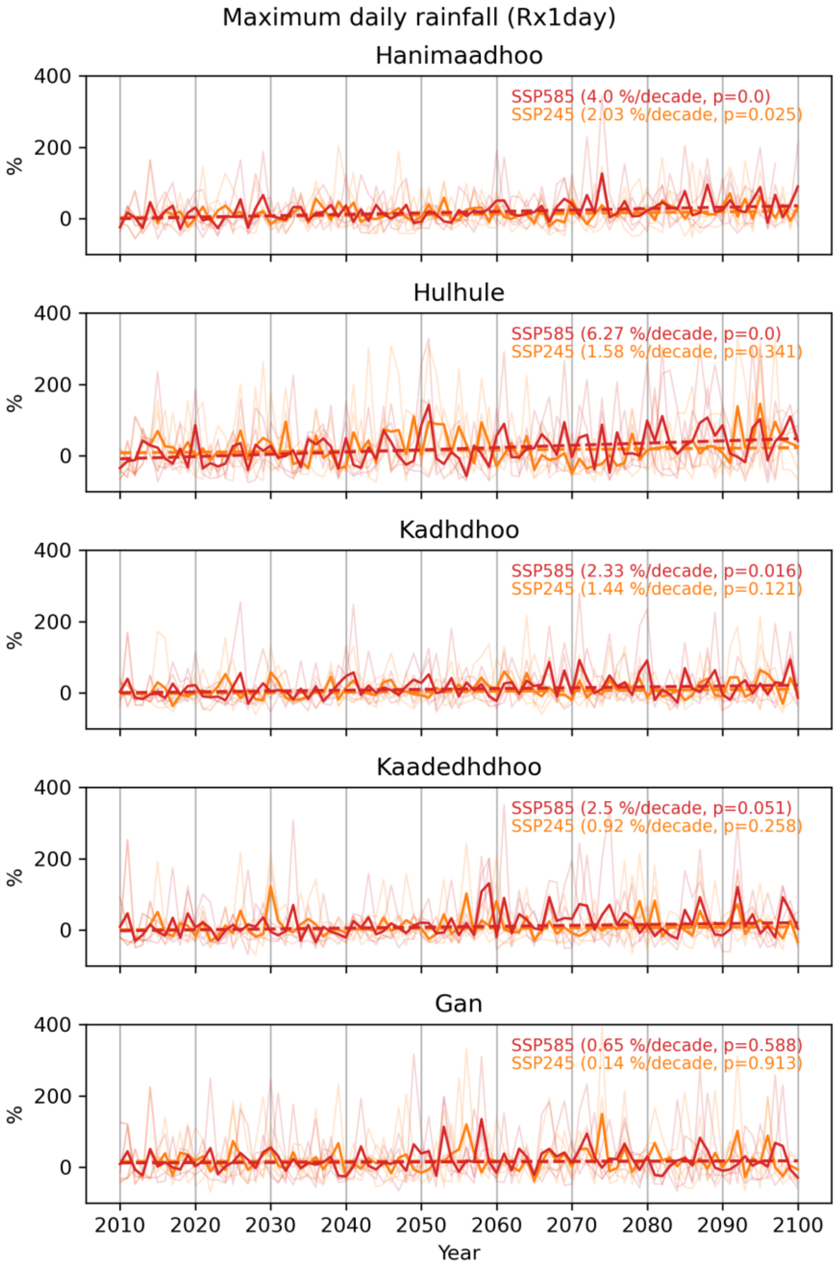

Figure 39. Projected change in maximum daily rainfall (as a percentage) at the five sites with long high-quality records. See Figure 28a for site locations. Data is downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models for the SSP2-RCP4.5 (orange) and SSP5-RCP8.5 (red) scenarios.[161] Bold lines represent multi-model averages. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Base period for calculating change was 1981-2010. See Section 2.3 for more details.

[161] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

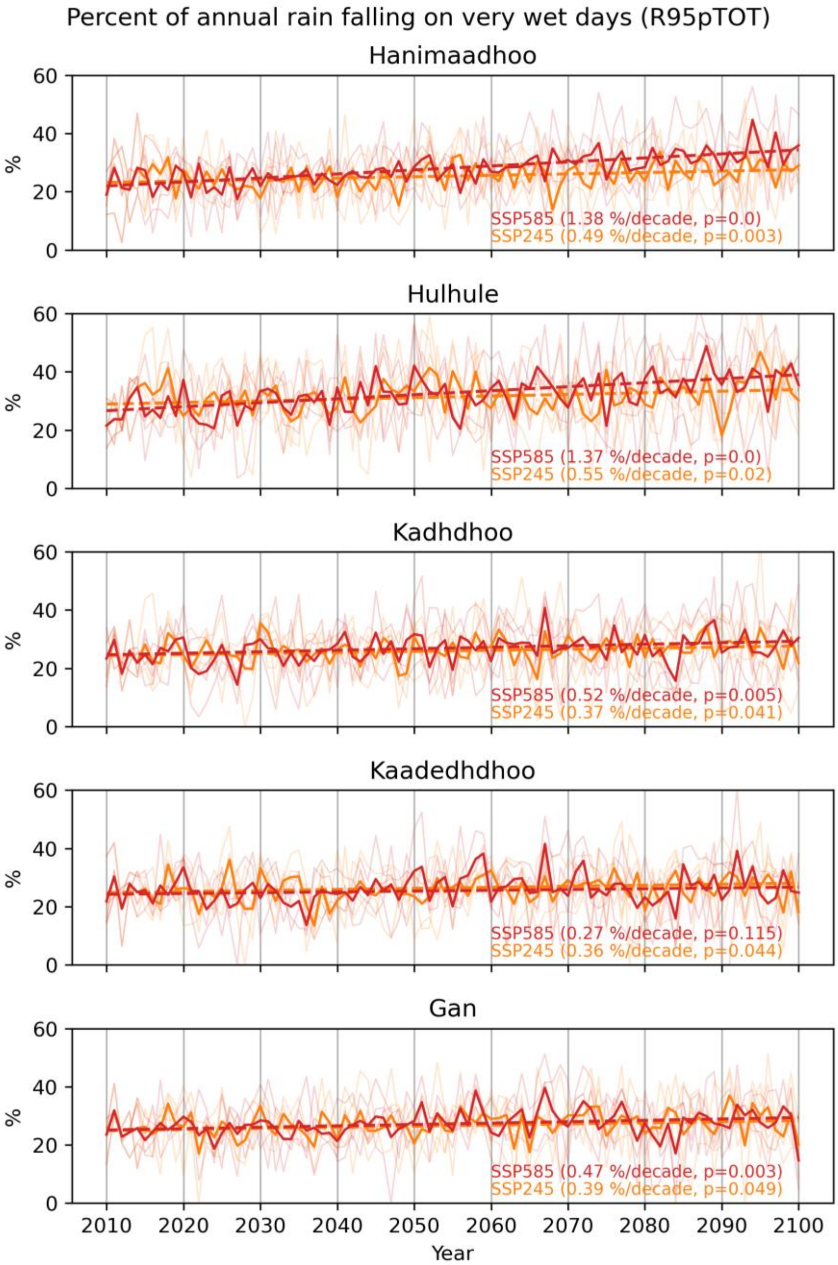

Figure 40. Projected change in the percentage of total rain falling on extreme rainfall days at the five sites with long high-quality records.
See Figure 28a for site locations. Data is downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models for the SSP2-RCP4.5 (orange) and SSP5-RCP8.5 (red) scenarios.[162] Bold lines represent multi-model averages. Straight dashed lines indicate linear trends (size of trend and p-value listed in legend). Base period for calculating change was 1981-2010. See Section 2.3 for more details.

2.7.3 Tropical cyclones

Understanding how the characteristics of tropical cyclones will change in a warming world is an active area of research and as such periodic review of the literature is recommended. Due to inconsistent studies, the short historical record and the rarity of tropical cyclones (compared to other climate extremes), changes in tropical cyclones can only be discussed at the regional level. Based on an analysis of tropical

[162] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

cyclone studies[163] and the latest IPCC assessment report (AR6)[164] tropical cyclone frequency and intensity in the north Indian Ocean is expected to remain similar to the present under climate change (Figure 41). However, the rainfall associated with tropical cyclones is expected to increase by approximately 13 – 20% per two degrees of warming (Figure 41). This is consistent with – and in large part attributable to – the 7% increase in atmospheric moisture per degree of warming dictated by the Clausius-Clapeyron relationship. Under the ~2.9°C of global warming projected for the end of the century in a SSP2-RCP4.5 scenario, this translates to a 19 – 29% increase in rainfall associated with tropical cyclones. Therefore, even in a world where tropical cyclone frequency and intensity remain the same, the rainfall associated with tropical cyclone activity is expected to increase significantly.

Tropical Cyclone Projections (2°C Global Warming)

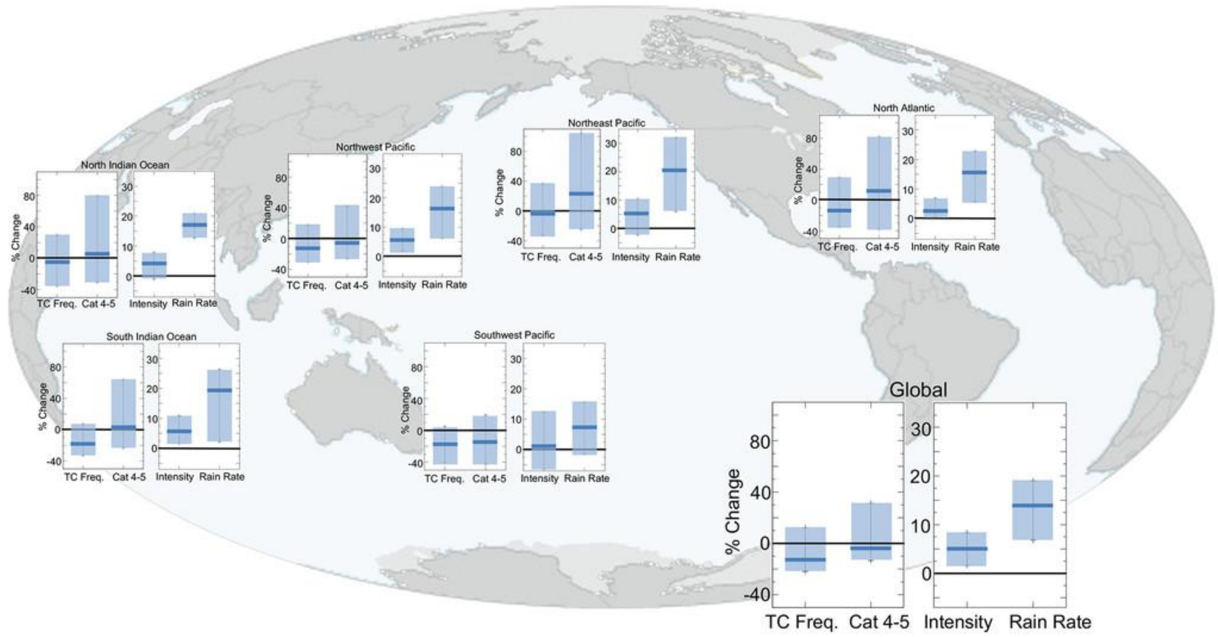

Figure 41. Estimated changes in tropical cyclone frequency, intensity and associated rain rate under two degrees of global warming.
Estimated changes are based on meta-analysis of published simulations and expert opinion from a WMO expert team. Figure from Knutson et al.[165]

2.7.4 Drought

Drought as defined by the 12-month SPEI is projected to become less frequent at the central and northern sites of Hulhule and Hanimaadhoo under both SSP2-RCP4.5 and SSP5-RCP8.5 (Figure 42). This is consistent with the projected increase in mean annual rainfall across the Maldives (Figure 34a). Under SSP5-RCP8.5 the more southern sites of Kadhdhoo, Kaadedhdhoo and Gan are projected to see a small but significant increase in drought, while under SSP2-RCP4.5 results are more mixed (Figure 42). Hanimaadhoo exhibits the strongest change of all sites, with a large reduction in drought over time, however, this is the opposite to observed drying at this site (Figure 19). This suggests either that the current drying is related to climate variability or that the climate models used here do not accurately

[163] Knutson, T., Camargo, S.J., Chan, J.C., Emanuel, K., Ho, C.H., Kossin, J., Mohapatra, M., Satoh, M., Sugi, M., Walsh, K. and Wu, L., 2020. Tropical cyclones and climate change assessment: Part II: Projected response to anthropogenic warming. Bulletin of the American Meteorological Society, 101(3), pp.E303-E322.
[164] Seneviratne, S.I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, I. Iskandar, J. Kossin, S. Lewis, F. Otto, I. Pinto, M. Satoh, S.M. Vicente-Serrano, M. Wehner, and B. Zhou, 2021: Weather and Climate Extreme Events in a Changing Climate. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1513–1766, doi: 10.1017/9781009157896.013.
[165] Ibid, 163.

capture the current trend. It should be noted that by the end of the century multi-model variability increases substantially, reducing the confidence in these results.

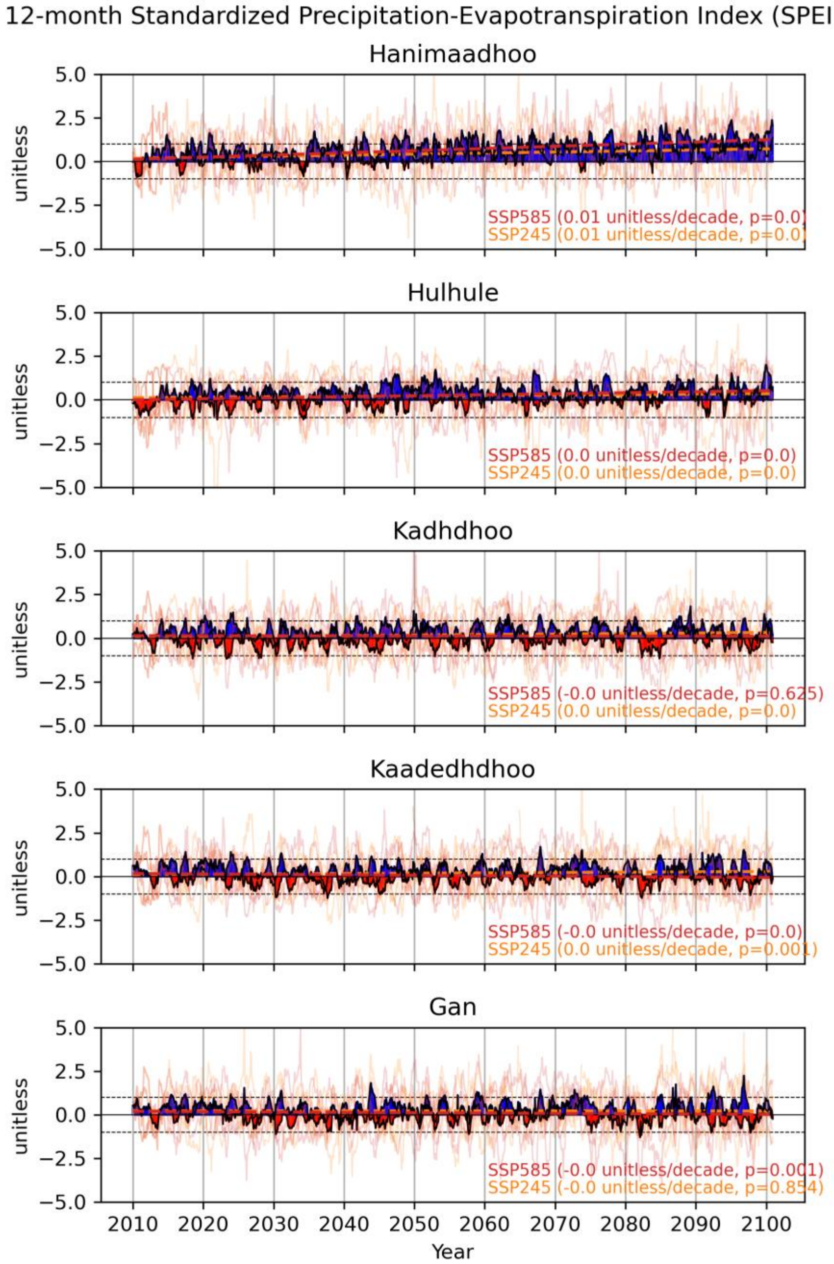

Figure 42. The projected 12-month Standardised Precipitation-Evapotranspiration Index (SPEI) at the five sites with long high-quality records.
See Figure 28a for site locations. Data is downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models for the SSP2-RCP4.5 (orange) and SSP5-RCP8.5 (red) scenarios.[166] Negative values indicate drier-than-normal conditions and positive values indicate wetter-than-normal conditions. Dashed black lines indicate the ±1 standard deviation threshold commonly used for identifying droughts.[167] Dashed orange and red lines indicate linear trends (size of trend and p-value listed in legend).

[166] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

[167] McKee, T.B., Doesken, N.J. and Kleist, J., 1993, January. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology (Vol. 17, No. 22, pp. 179-183).

2.7.5 Sea-surface temperature

The projected warming of equatorial Indian Ocean SSTs by the end of the century ranges from 1.0 – 3.3°C, based on SSP1-RCP2.6 and SSP5-RCP8.5 respectively (Table 7). This warming will increase the number of marine heatwaves that occur. These temperatures represent changes in the open ocean, and it is unclear how rates of warming inside lagoons will differ, though the lower heat capacity of lagoons suggests they will warm faster.

Table 7. Projected sea-surface temperature (SST) change from CMIP6 for the equatorial Indian Ocean, relative to a 1981-2010 base period.
Data from the IPCC interactive atlas.[168,169]

Period	Median SST change for SSP1-RCP2.6, SSP2-RCP4.5 and SSP5-RCP8.5 (°C)
Near Term (2021-2040)	0.7 / 0.7 / 0.8
Medium Term (2041-2060)	1.0 / 1.2 / 1.5
Long Term (2081-2100)	1.0 / 1.8 / 3.3

2.7.6 Strongs winds

No significant changes in maximum daily wind speed are projected under SSP2-RCP4.5 (Figure 43). While significant decreases are projected at four of the five station locations under SSP5-RCP8.5, these changes are very small, with the largest corresponding to a 0.6% decrease per decade (Kadhdhoo). Stronger decreases are projected for average wind speed, and under both climate change scenarios, however the largest of these still only corresponds to a 1.15% decrease per decade (Figure 44). Gan is the only location where neither maximum nor average wind are projected to change under either scenario. Projected decreases are larger in the north than south. The projected decreases are consistent with the decrease in observed wind speed seen up until 2019, though not with the rise afterwards (Figure 26).

[168] Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I.V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon, 2021: Atlas. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L.Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K.Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/.

[169] Iturbide, M., Fernández, J., Gutiérrez, J.M., Bedia, J., Cimadevilla, E., Díez-Sierra, J., Manzanas, R., Casanueva, A., Baño-Medina, J., Milovac, J., Herrera, S., Cofiño, A.S., San Martín, D., García-Díez, M., Hauser, M., Huard, D., Yelekci, Ö. (2021) Repository supporting the implementation of FAIR principles in the IPCC-WG1 Atlas. Zenodo, DOI: 10.5281/zenodo.3691645. Available from: https://github.com/IPCC-WG1/Atlas.

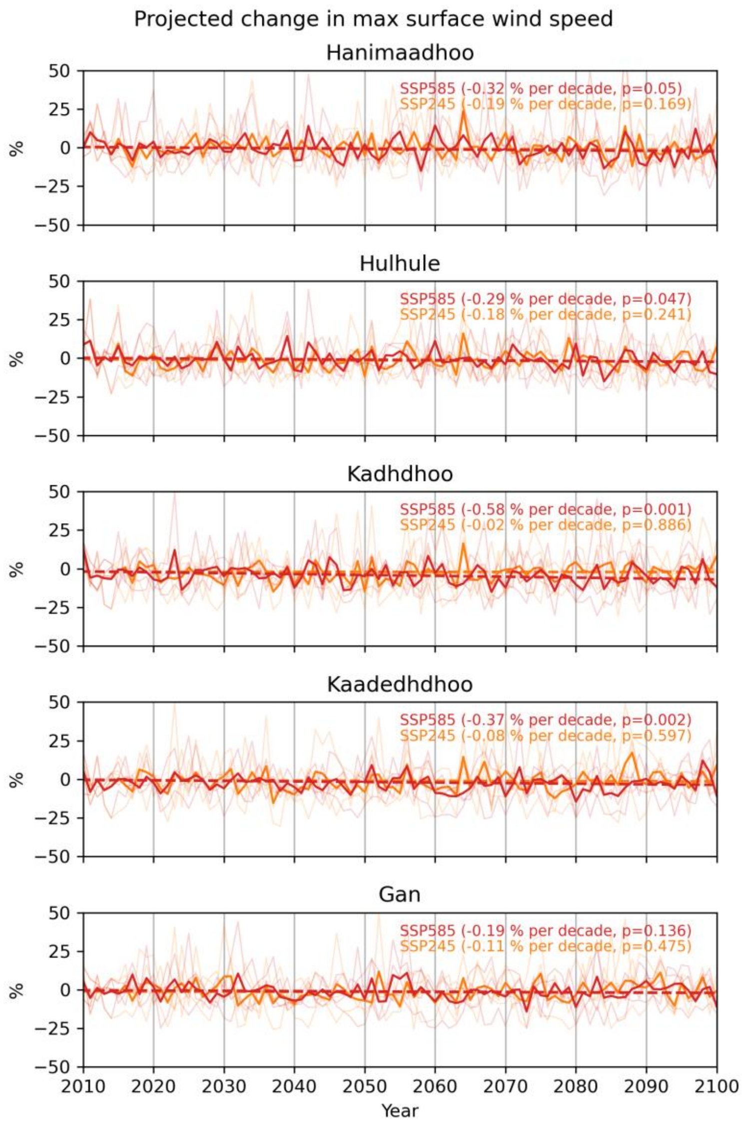

Figure 43. Projected change in maximum daily surface wind speed (as a percentage) at the five sites with long high-quality records.
See Figure 28a for site locations. Data is downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models for the SSP2-RCP4.5 (orange) and SSP5-RCP8.5 (red) scenarios.[170] Dashed orange and red lines indicate linear trends (size of trend and p-value listed in legend).

[170] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.

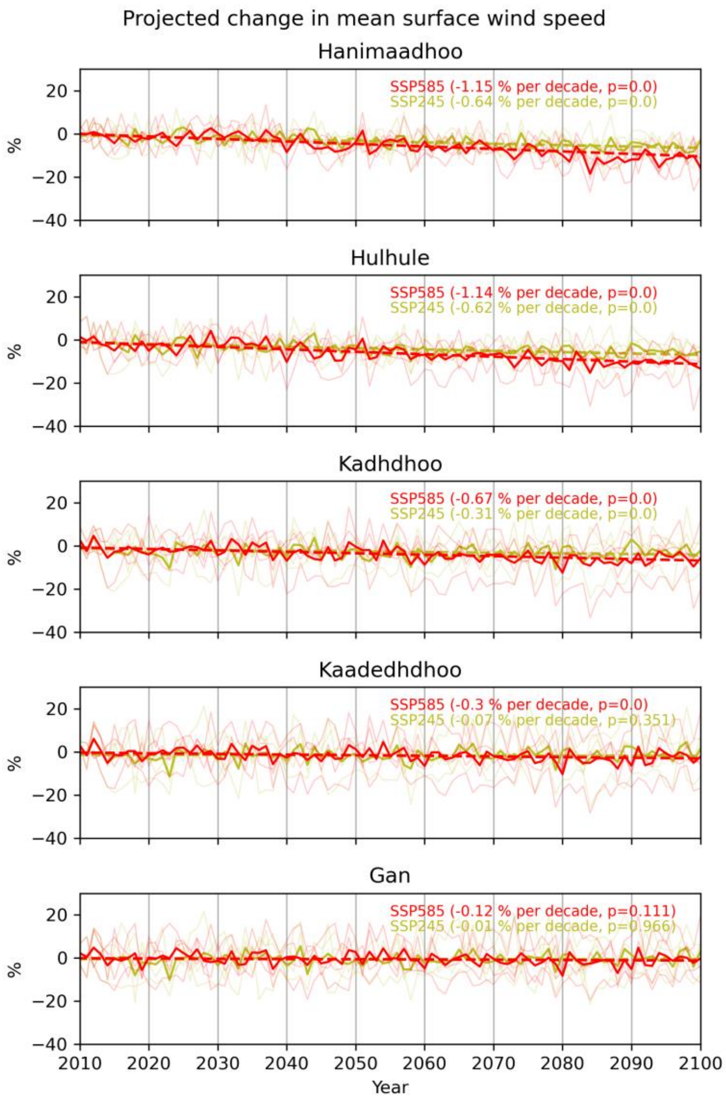

Figure 44. The projected change in average surface wind speed (as a percentage) at the five sites with long high-quality records.
See Figure 28a for site locations. Data is downscaled from the GFDL-ESM4, ACCESS-CM2, MRI-ESM2-0 and NorESM2-MM global climate models for the SSP2-RCP4.5 (orange) and SSP5-RCP8.5 (red) scenarios.[171] Dashed orange and red lines indicate linear trends (size of trend and p-value listed in legend).

2.8 Sector impacts

The impact of extreme weather in the Maldives is discussed considerably in the grey literature (e.g. [172,173]) and to a lesser extent in published literature (see references throughout this annex for examples) and the reader is referred to these for summaries of these impacts. Unfortunately, little quantification of sector impacts from climate change exists, likely due to the scale of this task and the lack of long-term homogeneous sector data. This section describes some current trends in sector productivity and provides initial identification and quantification of relationships between interannual climate variability and sectors. This may provide a first order understanding of the impact of projected climate change on these sectors.

[171] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.
[172] International Federation of Red Cross and Red Crescent Societies (IFRC), 2021, Climate Change Impacts on health and livelihoods: Maldives assessment.
[173] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the United Nations Framework Convention on Climate Change: Ministry of Environment and Energy.

However, more in-depth statistical analysis requires improved sector data curation and assessments from sector experts.

2.8.1 Agriculture

The limited land available in the Maldives severely constrains agricultural productivity and consequently most consumed food is imported. Rainfall and crop data indicate that on average vegetable production is lower in years when the maximum number of consecutive dry days is high, with a statistically significant negative correlation of –0.58 (Figure 45). The impact of extended dry periods on rain-fed agriculture is clear but this relationship is also consistent with the fact that much of the freshwater supply comes from rainwater harvesting and wells, and thus years with long stretches of dry days could lead to a limited ability to irrigate (up to 2 months without rain can occur depending on location; see Figure 20). However, such causality needs to be corroborated with evidence on the ground. This relationship suggests that even with a projected increase in annual rainfall (Figure 34a) and reduced drought intensity in the north (Figure 42), rainwater storage capacity needs to be sufficiently high to sustain agricultural activities over the dry season, and must adjust with population and other non-climatic changes. The maximum number of consecutive dry days under future climate change was not assessed in this report due to insufficient confidence in climate models to simulate rain-free days (the 'drizzle effect' of climate models). However, projected further drying of the dry season in the northern part of the Maldives (Figure 28, Figure 31, Figure 34) suggests that the number of consecutive dry days may increase.

It should be noted that the results in Figure 45 represent a relationship between climate averaged over all five long term weather stations (see Figure 28a for locations) and national agricultural data. Other significant and stronger relationships are likely to be identified if co-located crop and weather data is examined.

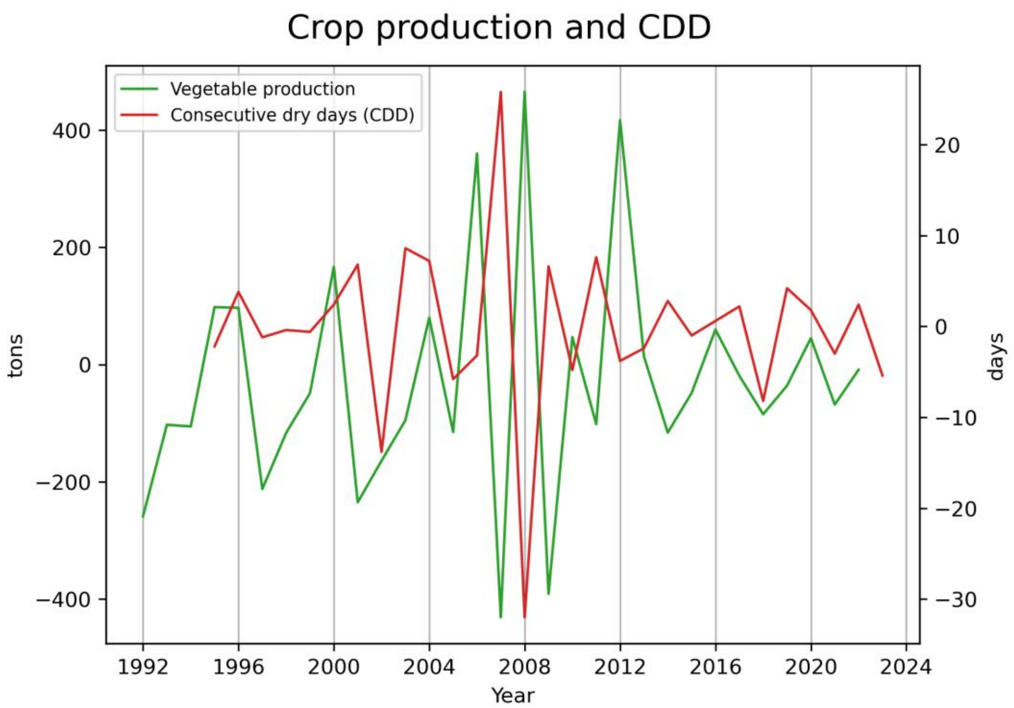

Figure 45. Vegetable production (left axis) and maximum number of consecutive dry days (CDD; right axis) are significantly negatively correlated (correlation coefficient=-0.58, p-value=0.001).
Both times series are detrended. Vegetable production is national and is taken from Food and Agriculture Organization of the United Nations.[174] The CDD index is an average of CDD over the five long term stations available from MMS (Table 2).

[174] Food and Agriculture Organization of the United Nations, 2024, FAOSTAT website, https://www.fao.org/faostat/, accessed July 2024.

2.8.2 Human health

Climate change will affect human health in multiple ways. Mortality due to heat stress under climate change is well documented globally[175] and heatwaves in the Maldives have increased in frequency (Figure 13). Climate change will also increase morbidity and decrease labour productivity[176] and given the Maldives' equatorial location there may be little capacity for acclimatisation before physiological limits are exceeded. Anecdotally this may already be happening, with some fishermen reporting having fainted due to heat.[177] While Maldivians are accustomed to high temperatures, the low seasonality of the tropics predisposes the Maldives to a more rapid increase in hot days under climate change.[178]

Vector-borne diseases such as dengue fever can also be affected by climate change. High humidity as well as stagnant water – commonly present following flood events – provide favourable conditions for mosquitoes to breed. Combining health data from the Maldives Bureau of Statistics with climate data reveals statistically significant relationships between out-patient visits due to dengue fever and rainfall conditions in the Addu, South Huvadhu and Hadhdhunmathi atolls (Figure 46). Regression analysis suggests that, for the South Huvadhu and Hadhdhunmathi atolls, each 10 mm increase in the annual maximum 3-day rainfall corresponds to 10 and 8 more dengue out-patients, respectively (Figure 46); and that at Addu atoll every extra consecutive dry day (i.e. increase in severe dry spell length) corresponds to a reduction of 4.5 out-patients due to dengue fever. While the above relationships are statistically significant and consistent with the moist conditions favoured by vectors, it should be noted that only 11 years of dengue data were available, and thus little confidence should be placed in the specific numbers reported. Nonetheless, given temperatures across the Maldives are increasing (Figure 7) and are projected to continue increasing (Figure 35), that annual mean rainfall is projected to increase (Figure 34), and that coastal flooding will likely increase due to rising sea-levels (Figure 8; Figure 36) and increasing wave height (Figure 23), breeding grounds for vectors may proliferate. These lines of evidence suggest that, all else being equal, dengue cases will increase in the future. Shifts in seasonal dengue fever peaks due to shifts in monthly rainfall are also already suspected to have occurred.[179]

[175] Lüthi, S., Fairless, C., Fischer, E.M., Scovronick, N., Armstrong, B., Coelho, M.D.S.Z.S., Guo, Y.L., Guo, Y., Honda, Y., Huber, V. and Kyselý, J., 2023. Rapid increase in the risk of heat-related mortality. Nature communications, 14(1), p.4894.
[176] Cissé, G., R. McLeman, H. Adams, P. Aldunce, K. Bowen, D. Campbell-Lendrum, S. Clayton, K.L. Ebi, J. Hess, C. Huang, Q. Liu, G. McGregor, J. Semenza, and M.C. Tirado, 2022: Health, Wellbeing, and the Changing Structure of Communities. 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. 1041–1170, doi:10.1017/9781009325844.009.
[177] International Federation of Red Cross and Red Crescent Societies (IFRC), 2021, Climate Change Impacts on health and livelihoods: Maldives assessment.
[178] Herold, N., Alexander, L., Green, D. and Donat, M., 2017. Greater increases in temperature extremes in low versus high income countries. Environmental Research Letters, 12(3), p.034007.
[179] Ibid, 177.

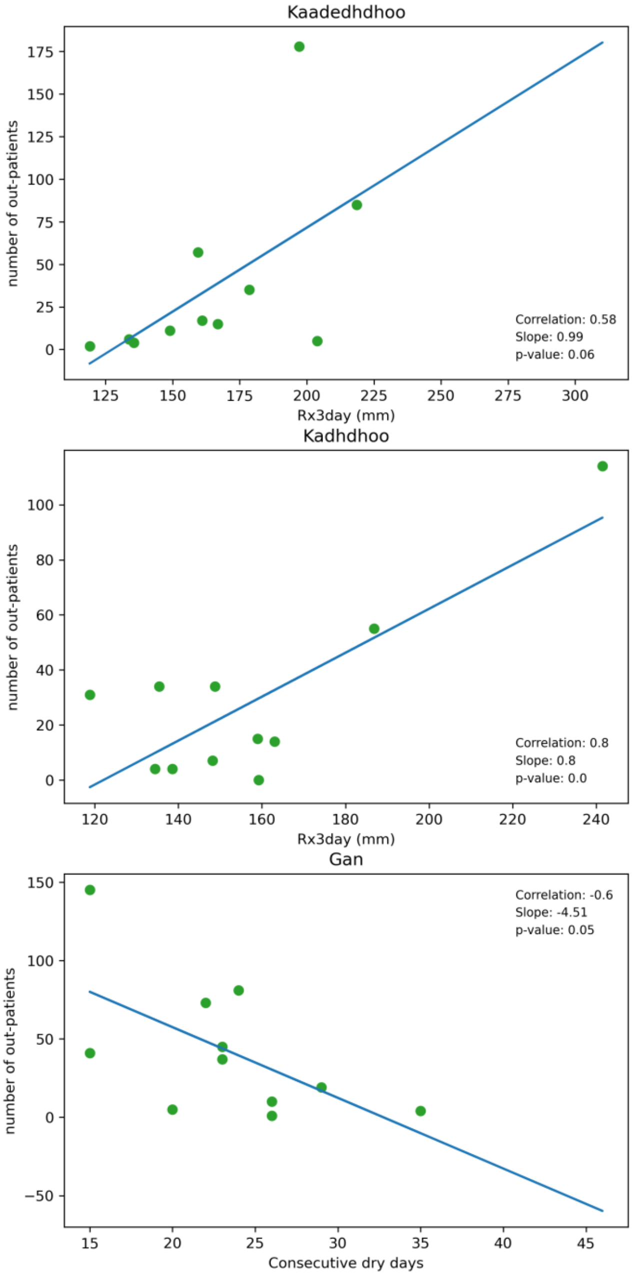

Figure 46. Scatter plots of out-patient visits for dengue fever and a) maximum 3-day rainfall at Kaadedhdhoo (South Huvadhu Atoll), b) maximum 3-day rainfall at Kadhdhoo (Hadhdhunmathi atoll), and c) maximum number of consecutive dry days at Gan (Addu atoll).
The correlation coefficient, slope of regression and p-value for the slope are printed on each panel. Out-patient data taken from the Maldives Bureau of Statistics.[180] Rainfall data are taken from corresponding stations (Table 2).

2.8.3 Marine resources

The marine ecosystem of the Maldives underpins the tourism and fisheries sectors, and coral reefs often reduce coastal flooding by diminishing the energy of waves before they reach the shore. Coral bleaching in the Maldives has become more frequent since the year 2000 (Figure 47). No significant correlation is observed between bleaching events and marine heatwaves or SST in central Maldives (Supplementary Figure 1). While this is counter-intuitive – as there is a direct physical relationship between SST and bleaching – large reporting biases in the coral bleaching record (for example due to gradual improvements in monitoring) and the effects of area averaging on bleaching records, SSTs and marine heatwaves very likely affect this statistic. Nonetheless, coral bleaching, marine heatwaves and SSTs are

[180] https://statisticsmaldives.gov.mv/yearbook/statisticalarchive/, accessed July 2024.

all increasing significantly (Figure 47; Figure 22; Figure 21) and the IPCC AR6 has medium confidence that projected ocean temperature and acidification changes will result in some small island states experiencing severe coral bleaching every year.[181] Therefore, it should be expected that coral bleaching continues increasing in frequency, and potentially, that recovery times between bleaching events will also increase.[182] If global warming exceeds 2°C, mass coral cover could be lost and this in turn will compound coastal flooding, amongst myriad other impacts.

Atolls in the Maldives form part of coral reef systems that have extremely high species diversity and that are fundamental to a variety of ecosystem services. Both tourism and fisheries rely heavily on coral reefs, the former is centred around coral reefs with activities such as diving and snorkelling being major attractions for tourists, whilst reef fishing remains a source of food and income for local fishermen. Continuous reef degradation would result in adverse effects for both sectors and impact economic development in the Maldives.

SST and marine heatwaves exhibit significant positive relationships with ENSO and IOD (Supplementary Figure 1), suggesting that projected changes in the interannual variability of bleaching will be influenced by changes in these modes of variability. This is supported by the high rates of bleaching (Figure 47) and the decline in live coral cover in the central Maldives during the very strong El Niño events of 1997 and 2015 (Figure 48). Therefore, while the underlying trend in bleaching may be driven by increases in SST, bleaching events will likely continue to be modulated by modes of variability such as ENSO.

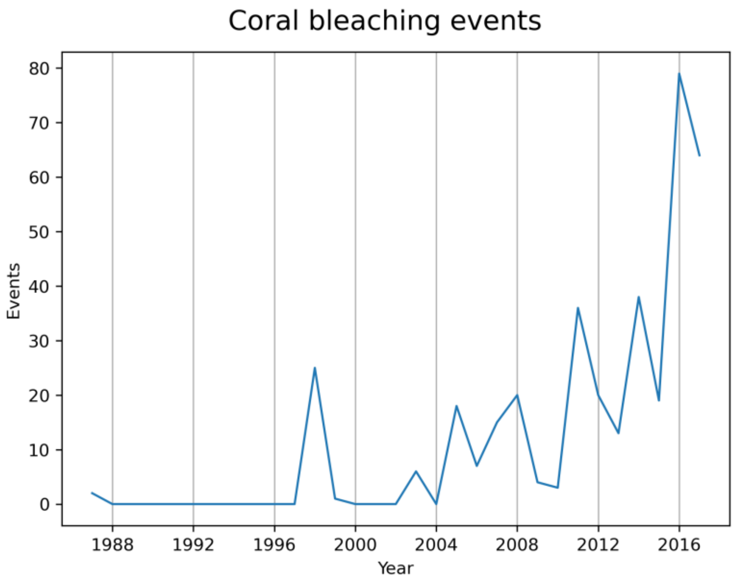

Figure 47. Coral bleaching events in the Maldives recorded in the Global Coral Bleaching Database.[183]

[181] 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.
[182] Pisapia, C., Burn, D., Yoosuf, R., Najeeb, A., Anderson, K.D. and Pratchett, M.S., 2016. Coral recovery in the central Maldives archipelago since the last major mass-bleaching, in 1998. Scientific Reports, 6(1), p.34720.
[183] Spady, Blake L.; Devotta, Denise A.; De La Cour, Jacqueline; Gomez, Andrea M.; Morgan, Jessica A.; Donner, Simon D.; Liu, Gang; Skirving, William J.; Vasile, Roxana; Geiger, Erick; Marsh, Benjamin; Eakin, C. Mark; Manzello, Derek P. (2022). Global Coral Bleaching Database (NCEI Accession 0228498). NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.25921/9xfa-0v97. Accessed July 2024.

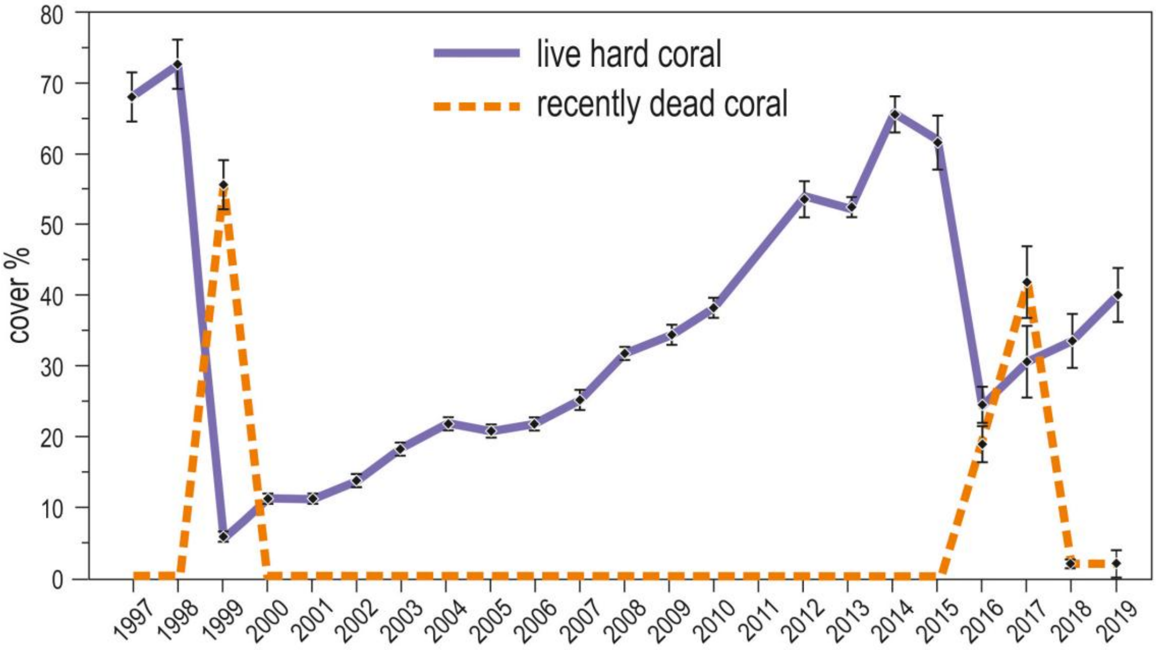

Figure 48. Percentage of live coral from shallow reefs (5±1 m) surveyed in the central atolls. The two prominent drops in live coral reflect the impact of the 1997/98 and 2015/16 El Niño events. Figure from Montefalcone et al.[184]

2.8.4 Freshwater resources

Freshwater comes from four sources in the Maldives: rainwater harvesting, aquifer extraction, desalinisation and imports from other countries. In remote islands, 90% of drinking water comes from rainwater.[185] Current trends indicate no imminent change in drought severity or annual rainfall, with the exception of Hanimaadhoo where drought has been intensifying (Figure 19). Projections show an increase in annual rainfall but with a drier dry season in the northern half of the country (Figure 28; Figure 31; Figure 34). A more severe dry season could have serious impacts as currently some locations can already experience up to 2 months without rain (Figure 20). Furthermore, sea-level rise is projected to cause an 11-36% reduction in fresh ground water in small atoll islands over the coming decades, while larger islands are projected to experience reductions between 8-24%.[186] Thus, in the future, the northern half of the Maldives may experience more severe dry seasons with less fresh groundwater to rely on, despite annual rainfall increasing.

2.8.5 Tourism

Tourism is the largest source of Government revenue in the Maldives and accounted for 22% of GDP in 2022.[187] The tourism sector is directly exposed to several climate change impacts including coastal erosion and flooding from rising seas (Figure 8) and higher waves (Figure 23), heat-health impacts due to rising temperatures (Figure 12), flash flooding from increased extreme rainfall (Section 2.7.2) and coral bleaching from warming oceans (Figure 21). In addition, climate-related events can also contribute to infrastructure damage (e.g., resort facilities). A recent survey of resorts indicates beach erosion as the most pressing concern (Figure 49).

Tourist arrivals have been increasing non-linearly for several decades with the only notable reductions following the 2004 Indian Ocean Tsunami, the 2007-2008 global financial crisis, and the COVID19 pandemic (Figure 50). A recent tourist survey found the top three reasons for visiting the Maldives were

[184] Montefalcone, M., Morri, C. and Bianchi, C.N., 2020. Influence of local pressures on Maldivian coral reef resilience following repeated bleaching events, and recovery perspectives. Frontiers in Marine Science, 7, p.587.
[185] International Federation of Red Cross and Red Crescent Societies (IFRC), 2021, Climate Change Impacts on health and livelihoods: Maldives assessment.
[186] Alsumaiei, A.A. and Bailey, R.T., 2018. Quantifying threats to groundwater resources in the Republic of Maldives Part II: Recovery from tsunami marine overwash events. Hydrological Processes, 32(9), pp.1154-1165.
[187] Bureau of Statistics, 2024, Statistical Yearbook of Maldives 2023, https://statisticsmaldives.gov.mv/yearbook/2023/, accessed August 2024.

the beach, underwater beauty, and the weather.[188] While research from over 20 years ago indicates 68% of tourists who visited the Maldives in 1998-99 were not aware of the large-scale bleaching events of the 1997-98 El Niño,[189] this awareness could be higher today given the more frequent bleaching over the last 20 years (Figure 47) and the increased public awareness of climate change.

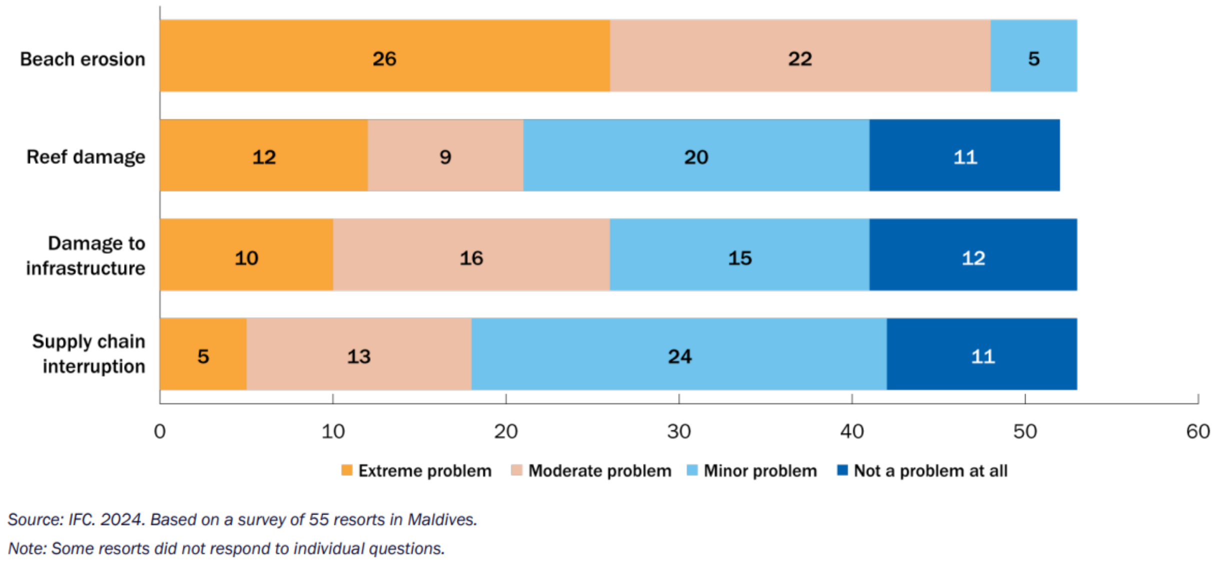

Figure 49. The severity of different climate change problems reported by 55 resorts. Figure from World Bank.[190]

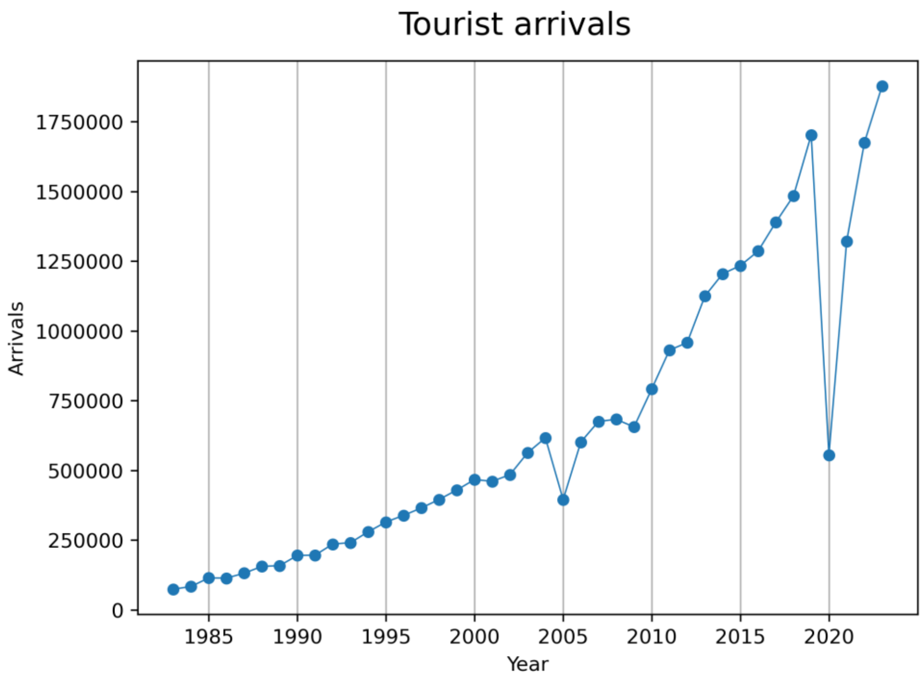

Figure 50. Tourist arrivals into the Maldives. Data from Bureau of Statistics[191] and Ministry of Tourism.[192]

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[188] Ministry of Tourism, 2021. Maldives Visitor Survey. https://www.tourism.gov.mv/dms/document/d8a19fde2b0395aaff05edbf204c041e.pdf.
[189] Westmacott, S., Cesar, H.S., Pet-Soede, L. and Lindén, O., 2000. Coral bleaching in the Indian Ocean: Socio-economic assessment of effects. Essays on the Economics of Coral Reefs. HSJ Cesar (ed.), pp.94-106.
[190] World Bank Group. 2024. Maldives Country Climate and Development Report. © Washington, DC: World Bank. http://hdl.handle.net/10986/41729 License: CC BY-NC-ND 3.0 IGO.
[191] https://statisticsmaldives.gov.mv/yearbook/statisticalarchive/, accessed July 2024.
[192] https://www.tourism.gov.mv/statistics/publications/, accessed July 2024.

2.8.6 Fisheries

Skipjack and Yellowfin tuna constitute the dominant catch by the Maldives fisheries sector (calculated from Indian Ocean Tuna Commission Best Scientific Estimates). The Indian Ocean Dipole (IOD) affects where tuna is caught as well as the effort required per catch,[193] however, at the national and annual scale the IOD has not significantly impacted the amount of catch brought in (tonnes) (Skipjack and Yellowfin tunas have a correlation coefficient with the IOD of -0.07 and 0.09 respectively). However, further data exploration and curation may be required to discern sector-climate relationships (Figure 51; e.g. a large drop in Skipjack Tuna occurs after 2007).

Future changes in the IOD are uncertain although the projected change in the average state of the Indian Ocean resembles a positive IOD, which could potentially lead to a reduction in the amplitude of IOD events.[194] The most extreme positive events could also become more frequent under an SSP5-RCP8.5 scenario.[195] Furthermore, current warming is increasing ocean stratification, which in turn is limiting chlorophyll and the food supply of tuna.[196] This may lead to feeding grounds moving poleward and farther from the Maldives. If these trends continue, the resources needed to maintain the fisheries industry may increase and adaptive measures will need to be considered such as the use of longline fishing techniques and catch diversification.

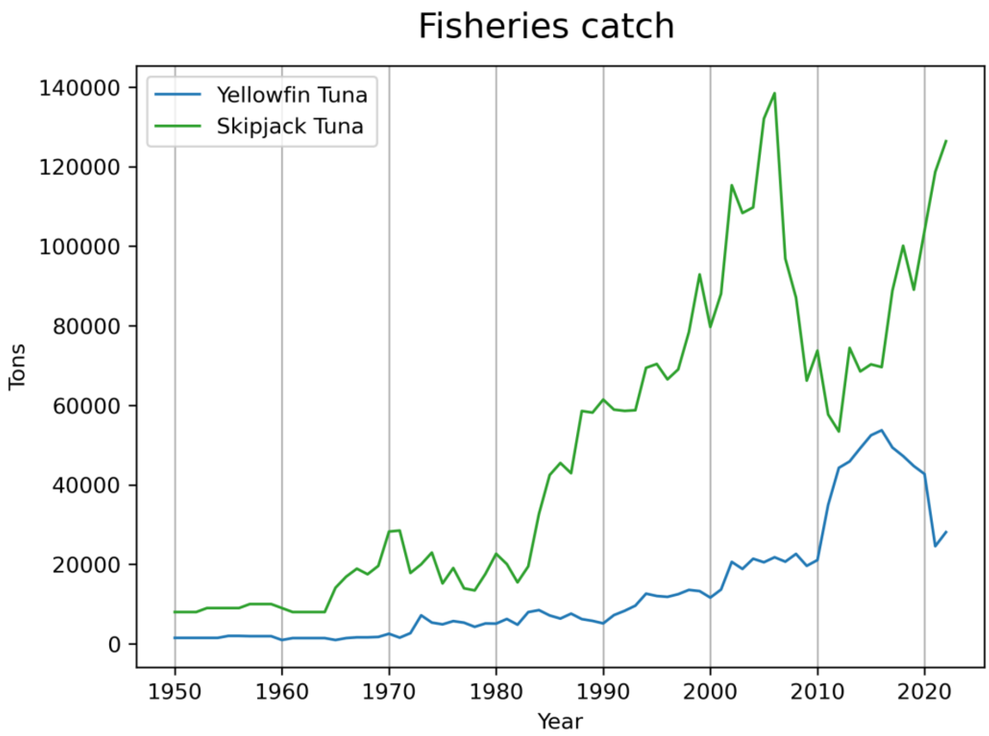

Figure 51. Yellowfin and Skipjack tuna catch by Maldives fisheries. Data from the Indian Ocean Tuna Commission Best Scientific Estimates.[197]

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[193] Lan, K.W., Evans, K. and Lee, M.A., 2013. Effects of climate variability on the distribution and fishing conditions of yellowfin tuna (Thunnus albacares) in the western Indian Ocean. Climatic Change, 119, pp.63-77.
[194] Lee, J.-Y., J. Marotzke, G. Bala, L. Cao, S. Corti, J.P. Dunne, F. Engelbrecht, E. Fischer, J.C. Fyfe, C. Jones, A. Maycock, J. Mutemi, O. Ndiaye, S. Panickal, and T. Zhou, 2021: Future Global Climate: Scenario-Based Projections and Near-Term Information. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672, doi: 10.1017/9781009157896.006.
[195] Ibid.
[196] Roxy, M.K., Modi, A., Murtugudde, R., Valsala, V., Panickal, S., Prasanna Kumar, S., Ravichandran, M., Vichi, M. and Lévy, M., 2016. A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean. Geophysical Research Letters, 43(2), pp.826-833.
[197] https://iotc.org/data/datasets/latest/NC/SCI, accessed August 2024.

3 VULNERABILITY ASSESSMENT

3.1 Agriculture and food security

Traditionally Maldives have been self-reliant on food production, with taro, cassava, sweet potato, breadfruit, corn, finger millet, as well as tropical fruits and vegetables being the main staples, and fish being the main source of protein.[198] However, the agricultural sector of Maldives has been severely limited due to lack of cultivable land area (approximately 27 km^2 throughout the archipelago), poor soil quality[199] and limited freshwater for irrigation.[200] As a result, local production is now insufficient to meet the demands of an increasing population, and around 90% of food in Maldives is imported[201] (now the country imports all food items except fresh tuna and coconut).[202] The high import dependency of Maldives presents a challenge to its food security. This has[203] and will be further threatened by climate change: both as a result of direct impacts on food production and food transport disruption due to extreme weather events.[204]

The impacts of climate-related events on agriculture are already being felt. A large area of land is believed to be inundated, which is hampering already fragile agricultural activities through saltwater intrusion in freshwater aquifers and loss of farming land.[205] For example, in 2007 a series of storms hit 68 islands in 16 atolls leading to inundation up to 600 m from the coastline.[206] In addition, in the past the sector has been stressed by climate-induced extreme weather events, especially storms and floods. In 2007, strong winds reportedly led to agricultural damage due to fruit tree felling in 12 out of 20 atolls.[207] More recently, in 2022 the onset of the monsoon has caused sea transport interruptions leading to food (and energy) shortages in several islands.[208]

Moving forward, climate change is expected to influence crop production through a range of direct (alteration to precipitation and temperatures) and indirect factors (reduced water availability, increased heat stress on plants, loss of land through sea-level rise, salinization of aquafers, changes in moisture and temperature of soil, changes in underground water levels, altered pest and disease profiles, arrival of invasive species etc.)[209,210,211]. As a result of these impacts, 5% and 6% declines in wheat and maize yields respectively are estimated even in the case of the goals of the Paris Agreement being met and global temperature increase is limited to 1.5 °C.[212] In addition, it is expected that the optimal spatial range of various crops will also be altered, though the exact impacts will depend on the degree of climate change.[213]

Given the high import dependency of Maldives, transportation disruption caused by extreme weather events is expected to remain a crucial challenge to food security. The entire food import supply chain, from airports and seaports to loading and transport routes, is reported to be highly exposed to climate

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198 Ministry of Tourism and Environment, 2016. Maldives Second National Communication to the UNFCCC
199 Ministry of Tourism and Environment, 2016. Maldives Second National Communication to the UNFCCC
200 Ministry of Tourism and Environment, 2016. State of the Environment
201 Shabau, I. 2006. Food fuel crisis and climate changes in the Maldives, A MMSll Island State Perspective. Ministry of Fisheries and Agriculture, Government of Maldives.
202 Ministry of Tourism and Environment, 2015. Maldives Climate Change Policy Framework
203 IFRC, 2021. Climate change impacts on health and livelihoods: Maldives assessment.
204 Shabau, I. 2006. Food fuel crisis and climate changes in the Maldives, A MMSll Island State Perspective. Ministry of Fisheries and Agriculture, Government of Maldives.
205 FAO, 2012. Maldives Country Programming Framework 2013-2017
206 Ahmed, M. & Suphachalasai, S., 2014. Assessing the Costs of Climate Change and Adaptation in South Asia. Available at: https://www.preventionweb.net/files/38999_assessingcostsclimatechangeandadapt.pdf
207 JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
208 The Times of Addu, 2022. N. Lhohi faces food shortage amid sea transport disruption
209 IFRC, 2021. Climate change impacts on health and livelihoods: Maldives assessment.
210 JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
211 Asian Development Bank & World Bank Group, 2021. Climate risk country profile. Maldives. Available at: https://www.adb.org/sites/default/files/publication/672361/climate-risk-country-profile-maldives.pdf
212 Tebaldi, C., & Lobell, D., 2018. Differences, or lack thereof, in wheat and maize yields under three low-warming scenarios. Environmental Research Letters: 13: 065001. Available at: https://iopscience.iop.org/article/10.1088/1748-9326/aaba48
213 Asian Development Bank & World Bank Group, 2021. Climate risk country profile. Maldives. Available at: https://www.adb.org/sites/default/files/publication/672361/climate-risk-country-profile-maldives.pdf

change impacts.[214] Moreover, there is no long-term and emergency food storage capacity in Maldives, except for warehousing in Male' and nine other islands,[215] which are reported to be inadequate for handling national emergencies.[216]

3.2 Energy

Over the last four decades Maldives have experienced robust economic growth driven by tourism, fishery industry, sea transport and construction. This growth has been accompanied by an exponential increase in energy demand. Projected demand growth is 10% until 2027 and 6% until 2030 for Male', and 9% until 2027 and 6% until 2030 for other inhabited islands.[217] Since the country does not possess any fossil fuel resources, nearly the entire energy demand has been met by imported liquid fossil fuels (99% in 2016),[218] half of which have been used for electricity generation.[219] Due to the isolated nature of the islands, each of them operates individual power generation facilities. Electricity has been mostly generated using small diesel generators.[220] Dependency on fossil fuel imports has made the country extremely vulnerable to fuel price fluctuations, as well as to disruptions in supplies caused by extreme weather events. The latter is particularly critical for the smaller islands that do not have sufficient fuel storage capacity.[221] As such, reducing the need for fossil fuel imports through increases in renewable energy capacity is one of the key strategic objectives for the energy industry in Maldives to increase energy security. Over the last decade the share of renewable energy in the total electricity capacity has significantly increased from 1.9% (2012) to 6.6% (2022),[222] and the country is now working towards the target of meeting 70% of the daytime peak on inhabited islands with renewable energy.[223] Still, due to the geography of Maldives, the energy sector remains vulnerable to climate change impacts.

Eighty percent of all power sources and a large share of other critical infrastructure in Maldives is located within 100 m of the coastline,[224] which makes energy infrastructure highly vulnerable to the effects of climate change, including sea-level rise, sea swells, and coastal erosion. Historically, there have been multiple instances of above-ground transmission lines being unable to withstand extreme weather conditions, which has sometimes led to the loss of life. Power interruptions have been common in times of heavy rain, due to negative impacts on powerhouse infrastructure. Recent examples in 2019 include power cuts in Dhigurah and Maamendhoo. For protection against future climate change-induced damage, transmission lines in Maldives are now being laid underground, which incurs additional costs, and powerhouses must be stationed at a particular height.[225]

The 2004 Indian Ocean Tsunami severely damaged the energy infrastructure in Maldives resulting in USD 4.65 million in asset losses. Damaged facilities included 24 powerhouses,104 generators, 652 streetlights, 34 switchboards, 632 distribution boxes, and more than 121 kilometres of cable. Though tsunamis are not a climate-induced hazard, this case is relevant for the current assessment since it demonstrates the vulnerability of the energy infrastructure in the face of natural hazards. According to assessments, energy infrastructure in Maldives still lacks robustness and ability to withstand the effects

[214] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[215] Ministry of Tourism and Environment, 2015. Maldives Climate Change Policy Framework
[216] FAO. Maldives Country Programming Framework 2013-2017
[217] ADB. A brighter future for the Maldives powered by renewables. Roadmap for the energy sector 2020-30. Available at: https://www.adb.org/sites/default/files/publication/654021/renewables-roadmap-energy-sector-maldives.pdf
[218] Ministry of Tourism and Environment, 2016. Maldives Second National Communication to the UNFCCC
[219] ADB. A brighter future for the Maldives powered by renewables. Roadmap for the energy sector 2020-30. Available at: https://www.adb.org/sites/default/files/publication/654021/renewables-roadmap-energy-sector-maldives.pdf
[220] Ministry of Housing and Environment, 2010. National Economic Environment Development Studies. Available at: https://unfccc.int/files/adaptation/application/pdf/maldivesneeds.pdf
[221] ADB. A brighter future for the Maldives powered by renewables. Roadmap for the energy sector 2020-30. Available at: https://www.adb.org/sites/default/files/publication/654021/renewables-roadmap-energy-sector-maldives.pdf
[222] IRENA Renewable Capacity Statistics 2023. Available at: https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Mar/IRENA_RE_Capacity_Statistics_2023.pdf?rev=d2949151ee6a4625b65c82881403c2a
[223] Maldives Ministry of Environment, 2019. Maldives First Biennial Update Report to the UNFCCC
[224] IFRC, 2021. Climate change impacts on health and livelihoods: Maldives assessment.
[225] ADB. Dimensions of energy insecurity on small islands: the case of Maldives. 2019. Available at: https://www.adb.org/sites/default/files/publication/543261/adbi-wp1049.pdf

of hazards.[226] In addition, studies have revealed that in general natural disasters that affect SIDS are more likely to destroy distribution infrastructure, which then takes a long time to rebuild.[227] Therefore, in the future, similar damage could also be caused by climate-related hazards, such as cyclone-driven storms in the Indian ocean (there is *high confidence* that the proportion of intense tropical cyclones, average peak tropical cyclone wind speeds, and peak wind speeds of the most intense tropical cyclones will increase with global warming). There is also *high confidence* that average and maximum rain rates associated with tropical cyclones will increase due to global warming,[228] which means that in the future there could be more power cuts due to damage caused by heavy rainfall. Furthermore, as long as Maldives remains dependent on fossil fuel imports, and energy demands increase even further in line with projections, transportation disruptions caused by storms and other extreme weather events will remain a significant risk. Energy storage capacity remains limited, especially in the northern islands.[229]

3.3 Fisheries

Though only contributing to 3.5% of GDP, fisheries are an important part of the Maldivian economy and lifestyle, accounting for 20% of domestic employment and being the main export of the country. Fish is also the main source of protein for the population. Mostly based on tuna and tuna-related species, fisheries are largely dependent on coral reefs as a source of baitfish.[230] In addition, reef fish is extracted for export and resorts.[231] While the population of skipjack tuna is reported to be stable, yellowfin tuna has been seriously affected by overfishing. Though in recent years the government has successfully introduced sustainable practices for management of tuna fisheries, illegal, unreported and unregulated fishing still puts significant pressure on fish populations and reef ecosystems.[232] Climate change poses additional risks to fisheries through increased sea surface temperatures (SST) and ocean acidification.

Coral reefs are very sensitive to increasing ocean temperatures and acidification. Rising temperatures lead to expulsion of symbiotic food-producing algae which can cause coral bleaching, while a drop of pH as a result of increases in dissolved CO_2 in sea water reduces availability of calcium for building coral skeletons.[233] Evidence from the past suggests that sea warming combined with the impacts of El Niño Southern Oscillation (ENSO) events, which include changes in wind-driven water mixing and increase in sunlight, has led to multiple coral bleaching and mortality events (in 1977, 1983, 1987, 1991, 1995, 1997, 1998, 2010, and 2016).[234] This, in its turn, poses risks for entire reef ecosystems, including availability of reef fish. Tuna fishery has also been found to be dependent on large-scale El Niño / La Niña events. It has been reported that during the El Niño years catch rates of skipjack tuna (which accounts for two-thirds of the catch)[235] significantly decreased and those of other tuna species increased. Meanwhile, during the La Niña events an opposite pattern was observed. However, the exact reasons behind these processes and severity of these impacts are still unknown. In addition, it has been observed that tuna catch rates are associated with the Indian Ocean Dipole (IOD) – a pattern of sea surface and sub-surface temperatures that affects the climate of the Indian Ocean – but the exact environmental mechanisms are yet to be studied.[236] It should be noted that the IPCC AR6 reported that there is “low confidence in projected changes in ENSO variability in the 21st century due to a strong component of internal variability”. As such, potential changes in ENSO due to global warming and the impact on fisheries in Maldives are not considered further in this analysis. The IPCC AR6 also reported that there is no evidence of a trend

[226] ADB. A brighter future for the Maldives powered by renewables. Roadmap for the energy sector 2020-30. Available at: https://www.adb.org/sites/default/files/publication/654021/renewables-roadmap-energy-sector-maldives.pdf
[227] ORF Online. What does energy security mean for Maldives? Available at: https://www.orfonline.org/expert-speak/what-does-energy-security-mean-maldives/
[228] IPCC, 2021. Climate Change 2021: The Physical Science Basis
[229] ADB. Dimensions of energy insecurity on small islands: the case of Maldives. 2019. Available at: https://www.adb.org/sites/default/files/publication/543261/adbi-wp1049.pdf
[230] Ministry of Tourism and Environment, 2016. Maldives Second National Communication to the UNFCCC
[231] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[232] Jaleel, A. & Smith, H., 2022. The Maldives Tuna Fishery: An Example of Best Practice. Ocean Yearbook Online.
[233] NOAA, 2018. No safe haven for coral from the combined impacts of warming and ocean acidification. Available at: https://www.climate.gov/news-features/featured-images/no-safe-haven-coral-combined-impacts-warming-and-ocean-acidification#:~:text=Severe%20heat%20stress%20causes%20bleaching,Catch%2D22%20for%20coral%20reefs.
[234] Asian Development Bank & World Bank Group, 2021. Climate risk country profile. Maldives. Available at: https://www.adb.org/sites/default/files/publication/672361/climate-risk-country-profile-maldives.pdf
[235] Jaleel, A. & Smith, H., 2022. The Maldives Tuna Fishery: An Example of Best Practice. Ocean Yearbook Online.
[236] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study

in the IOD mode and associated anthropogenic forcing.[237] Nevertheless, the report also notes that climate extremes such as those associated with the extreme positive IOD event of 2019 are expected to occur more frequently under continued global warming.[238]

Increased SST and ocean acidification can impact Maldivian fisheries in several other ways. Higher temperatures could influence migration patterns and distribution of tuna.[239] Due to geographic shifts of tuna, it is possible that more fishing will have to be done in the international waters,[240] which could induce political risks.[241] In addition, high seas fishing in Maldives requires obtaining special permits, as per the Fisheries Act of the Maldives.[242] Higher temperatures could also negatively influence the survival of tuna larvae. Similarly, changes in pH levels could lead to organ damage (e.g., hamper development of ear bones which are important for orientation and hearing[243]) and even death of juveniles.[244] Reduced tuna availability would directly affect food security in Maldives, with tuna being the main source of protein for the local population, as well as pose a threat to the livelihoods of residents that rely on fisheries.[245]

3.4 Health

The geographical isolation of Maldives' islands poses challenges to delivering health services across the country.[246] Although the entire Maldivian population is covered by the national health insurance scheme (Husnuvaa Aasandha)[247] and each inhabited island has a primary healthcare facility, delivery of health services at the rural level is complicated due to lack of human resources, supplies and poor management. There are only four tertiary hospitals in the country, two of which are privately owned.[248] The dispersed nature of the islands makes it difficult to manage logistics and supplies, assure quality services, as well as administer regular service delivery at the peripheries. Despite the challenges, the health system in Maldives has been able to operate and substantially expand access to health care.[249]

However, emergency medical services are not well established in the country. The sea ambulance service was established in 2014 under the Maldives National Defence Force to facilitate emergency transportation between the islands.[250] However, according to some sources, the vessels provided were not in a good condition and there was insufficient budget available to purchase new ones.[251] Climate change is increasing the frequency, severity and impacts of extreme weather and other hazardous events, which makes accessibility and quality of emergency healthcare critical for achieving and maintaining universal health coverage and optimal health outcomes.[252]

The main direct health impacts of climate change in Maldives that are already being observed are caused by extreme weather events.[253] In 2021, Maldives suffered a loss of 3.0 disability-adjusted life years

[237] IPCC, 2021. Climate Change 2021: The Physical Science Basis
[238] Cai, W. et al., 2021: Opposite response of strong and moderate positive Indian Ocean Dipole to global warming. Nature Climate Change, 11(1), 27–32. DOI:10.1038/s41558-020-00943-1
[239] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[240] Asian Development Bank & World Bank Group, 2021. Climate risk country profile. Maldives. Available at: https://www.adb.org/sites/default/files/publication/672361/climate-risk-country-profile-maldives.pdf
[241] PSM News, 2019. Fishing vessels cautioned on operating outside Maldivian waters. Available at: https://psmnews.mv/en/57978
[242] Fisheries Act of the Maldives 14/2019, 34 (a). Available at: https://www.gov.mv/en/files/fisheries-act-of-the-maldives.pdf
[243] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[244] Frommel, A. et al., 2016. Ocean acidification has lethal and sub-lethal effects on larval development of yellowfin tuna, Thunnus albacares. Journal of Experimental Marine Biology and Ecology, Volume 482, September 2016, Pages 18-24. Available at: https://doi.org/10.1016/j.jembe.2016.04.008
[245] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility Study
[246] Maldives - WHO Country Cooperation Strategy 2018-2022. Available at: https://www.who.int/publications/i/item/3670902292978
[247] Aasandha Company, 2023. Husnuvaa Aasandha - Scheme Overview. Available at: https://aasandha.mv/en/scheme/overview
[248] Republic of Maldives. Ministry of Health. Available at: https://health.gov.mv/en/ministry-of-health
[249] Maldives Ministry of Health, 2016. Health Master Plan 2016-2025
[250] Maldives Ministry of Health, 2016. Health Master Plan 2016-2025
[251] Avas. No budget to purchase new sea ambulances: Defence Minister. Available at: https://avas.mv/en/108680
[252] WHO, 2019. Health Emergency and Disaster Risk Management Framework. Available at: https://apps.who.int/iris/bitstream/handle/10665/326106/9789241516181-eng.pdf
[253] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study

(DALYs)[254] per 100,000 population due to heatwaves and 1.2 DALYs per 100,000 population due to tropical cyclone impacts.[255] Indirect impacts include increases and/or changes in distribution of vector-borne diseases, including dengue, chikungunya and scrub-typhus. It has been found that in the past dengue outbreaks have been associated with ENSO events, coming with a time lag after the actual event.[256] In addition, dengue episode peaks have been found to coincide with rainfall seasons and to be associated with extreme weather events.[257] Climate change is already changing the frequency and severity of these weather events and is influencing proliferation of vector-borne diseases in Maldives. There is evidence that dengue outbreaks are becoming more frequent.[258] In 2019, Maldives saw a 200 percent increase in dengue outbreaks compared to the previous year, as well as increase in chikungunya cases.[259] In the same year, dengue reached an all-time high in the world with continuous growth in 2022-21, which researchers associated with the climate change impacts (rising temperatures, changing precipitation patterns, etc.).[260]

Though no assessment has been done to estimate the exact relationship between climate change and health, it is expected that in the future higher temperatures and more frequent extreme weather events will have increasing direct health impacts in Maldives.[261] Proliferation of climate-related disasters would disrupt healthcare services, putting additional pressure on the emergency services. Establishing capacity for health and medical response in national disasters and emergencies is one of the strategic goals under the Health Master Plan 2016-25.[262] As well as health impacts due to physical injury, the IPCC concluded that "heat-related mortality increases in countries with limited adaptive capacities and large exposed populations".[263] Health concerns of the population related to climate change include dehydration, eye and skin irritation, increase in dust, respiratory diseases etc., which was revealed through interviews.[264] Prevalence of vector-borne diseases is also expected to increase due to changing temperatures and precipitation patterns. Though currently malaria is not highly prevalent in Maldives, towards 2050, under both high and low emissions scenarios, around 23,000 people are projected to be at risk of contracting malaria.[265] Capacity for dengue fever transmission is also expected to increase under both emissions scenarios.[266] Proliferation of food- and water-borne diseases (primarily acute gastrointestinal diseases) could increase as a result of poor sanitation and groundwater contamination exacerbated by heavy rain flooding.[267] Flooding could also damage healthcare logistics in the short run, as well as lead to large-scale population displacements in the long run, disrupting the overall healthcare ecosystem.[268] Other health risks associated with climate change include malnutrition, especially among children, as a result of threats to agriculture, fisheries and food imports.[269]

3.5 Tourism

The tourism sector is the single largest contributor to the Maldivian economy, accounting for 30% of GDP, 90% of government revenue and one third of employment.[270] The country is a tourism vulnerability hotspot for marine biodiversity loss, sea level rise and increased travel costs due to mitigation policies.

[254] Disability-adjusted life year (DALY) is used as a proxy to related health-hazard, whereby one DALY represents the loss of the equivalent one year of full health.
[255] UNESCAP, 2021. Asia Pacific Risk and Resilience Portal – Maldives. Available at: https://rrp.unescap.org/country-profile/MDV
[256] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[257] IFRC, 2021. Climate change impacts on health and livelihoods: Maldives assessment.
[258] Ministry of Tourism and Environment, 2015. Maldives Climate Change Policy Framework
[259] Reliefweb, 2019. Maldives records sharp rise in dengue cases.
[260] Bhatia, S. et al., 2022. A Retrospective Study of Climate Change Affecting Dengue: Evidences, Challenges and Future Directions. Front Public Health. doi: 10.3389/fpubh.2022.884645
[261] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[262] Republic of Maldives: Health Master Plan 2016-2025. Available at: https://www.aidsdatahub.org/sites/default/files/resource/maldives-health-master-plan-2016-2025.pdf
[263] IPCC, 2007. Climate Change Synthesis Report
[264] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[265] WHO, 2015. Climate and Health Country Profile 2015 – Maldives
[266] Asian Development Bank & World Bank Group, 2021. Climate risk country profile. Maldives. Available at: https://www.adb.org/sites/default/files/publication/672361/climate-risk-country-profile-maldives.pdf
[267] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[268] Maldives - WHO Country Cooperation Strategy 2018-2022. Available at: https://www.who.int/publications/i/item/3670902292978
[269] Ministry of Tourism and Environment, 2015. Maldives Climate Change Policy Framework
[270] UNDP, 2013. Climate Risk Management in Maldives

Major climate change impacts on the tourism industry include increasing temperatures, resulting in heat stress and increased prevalence of disease; sea level rise, resulting in loss of beach area and coastal infrastructure; increased frequency of extreme events, resulting in increased insurance costs; and rising sea surface temperatures (SST), resulting in coral bleaching and marine resource degradation.[271]

Climate impacts on the tourist area in Maldives can already be seen. Already 45% of tourist resorts have reported various degrees of beach erosion[272] (though erosion cannot be entirely attributed to climate change as it also originates from other factors such as environmental degradation due to land reclamation and various infrastructure projects). Resorts on the smaller islands where tourism is often the main source of income for the population have already been affected by sea level rise, increased storm frequency and intense tidal patterns.[273] Coral bleaching caused by increase in SST is a threat to the diving sector of tourism in Maldives. During the El Niño event of 1997-1998, 80% of corals in Maldives were bleached. Though the number of tourists arriving to the country did not decrease after this event, researchers argue that the event led to a decrease in growth rates of the tourist industry by approximately 1%, leading to around USD 1 million financial loss in 1998 and USD 2 million financial loss in 1999.[274] However, economic costs could be higher. Based on surveys conducted at Maldivian airports, researchers found that seeing bleached corals was the main disappointment for tourists, and people would be willing to pay an average of USD 87 more to see unbleached corals. Extrapolating this number, researchers estimated a real economic loss of a coral bleaching event to be USD 19 million.[275]

In the long run, climate change is expected to have a range of adverse effects on the tourist industry in Maldives. Sea level rise combined with further coastal erosion could increase costs for beach maintenance and strengthening, lead to water pollution, and overall reduce attractiveness of Maldives as a tourist destination. Increased SST and ocean acidification can lead to more frequent coral bleaching and mortality events. Though in the past coral bleaching events only had a mild impact on the industry, further coral mortality in the future could cause more marine biodiversity loss, which in turn could have negative impact on recreational diving and snorkelling. Increases in air temperatures might lead to higher demand in air conditioning and raise the operational costs for the industry, while proliferation of vector-borne diseases could result in fewer tourists being willing to go on excursions. Increases in the frequency and/or intensity of extreme events such as storms, wave swells and heavy rains might lead to transport disruptions, flooding of coastal zones and higher risk of property and infrastructure loss (since the islands are quite small, most infrastructure is located close to the shore). Other potential adverse effects include contamination of groundwater and coastal vegetation, as well as higher insurance costs.[276] According to estimates, climate change could lead to 15-18% revenue loss from the tourist industry by 2050 and 27-32% by 2100.[277]

3.6 Water resources

Due to the geological formation of the coral islands, Maldives lacks surface water resources (rivers, lakes, streams) except for a few wetlands.[278] The population of Maldives mainly depends on groundwater and rainwater as a source of freshwater. While historically mostly groundwater was used, currently rainwater accounts for 90% of water supply, which makes the water supply vulnerable in dry seasons.[279] After the Indian Ocean Tsunami in 2004, desalination was widely introduced as an additional source of freshwater on densely populated islands, where there is little space for rainwater storage. In 2012, 48% of the population was catered by desalinated water.[280] However, desalination is expensive for the

[271] Ministry of Tourism and Environment, 2016. Maldives Second National Communication to the UNFCCC
[272] Ministry of Tourism and Environment, 2015. Maldives Climate Change Policy Framework
[273] IFRC, 2021. Climate change impacts on health and livelihoods: Maldives assessment.
[274] Cesar, H. et al., 2000. Assessing the Impacts of the 1998 Coral Bleaching on Tourism in the Maldives and Sri Lanka. Available at: http://www.broffice.gov.mv/en/files/coral_bleachin.pdf
[275] Hosterman, H. & Smith, J., 2015. Economic costs and benefits of climate change impacts and adaptation to the Maldives tourism industry. Ministry of Tourism
[276] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[277] Hosterman, H. & Smith, J., 2015. Economic costs and benefits of climate change impacts and adaptation to the Maldives tourism industry. Ministry of Tourism
[278] Ministry of Environment and Energy, 2016. Maldives Second National Communication to the UNFCCC
[279] JICA, 2020. Building Climate Resilient Safer Islands in Maldives. Feasibility study
[280] Ministry of Tourism and Environment, 2016. Maldives Second National Communication to the UNFCCC

government.[281] Water shortages are already a chronic problem in Maldives, with many islands in the northern part of the country running out of water annually between April and May.[282] Water resources have also been affected by overharvesting and extensive pollution.[283] On some islands, groundwater has been found to be largely contaminated by faecal coliforms (B. Hithaadhoo, Gn. Fuvahmulah, Ga. Dhekanbaa – 100% samples, Hithadhoo, Addu city – 60% samples), which is linked to poor sanitation and lack of proper wastewater management systems. Furthermore, collected rainwater has been found to be contaminated with bacteria (such as E. Coli) and faecal coliforms, reportedly due to unsafe harvesting methods, as well as by air quality pollutants (SOx, NOx and ammonium).[284] Still, according to World Bank data, in 2020, 100% of the population used at least basic drinking water services.[285] However, climate change is posing additional challenges to water supply.

Water shortages in dry seasons have become a norm in many islands, incurring significant costs. There is data that at least for several years in the 2000s, due to prolonged dry periods, the National Disaster Management Centre (now the National Disaster Management Authority) was transporting potable water to many islands, which cost USD 2 million per year.[286] During the dry seasons in 2009-10, the supply of desalinated water to over 90 islands cost around USD 640,000.[287] In 2014, failure of a desalination system in Male' due to the fire outbreak led to a 10-day water crisis, which cost the country USD 20 million in relief operations.[288] Though the incident itself was not climate-induced, it revealed vulnerability of the system and the extent of potential negative impacts of water shortages on the economy. Climate change is already exacerbating these challenges, with longer dry periods and higher frequency of emergency water requests being reported.[289] In addition, groundwater resources, which are already pressured due to overharvesting and pollution, are facing salinisation as a result of sea level rise.[290]

In the future, climate change is expected to further challenge freshwater supply in Maldives. With rainfall patterns becoming less predictable and stable, people might not be prepared to capture the rainwater, while increases in dry days could lead to water shortages.[291] Although model predictions indicate that increased precipitation could lead to thickening of the freshwater lens,[292] rising sea levels are expected to further force saltwater intrusion into the freshwater aquifers leading to their degradation. According to the IPCC AR6, the volume of fresh groundwater lens of the small atoll islands (area <0.6 km²) of the Maldives is expected to reduce by 11-36% due to sea-level rise.[293] Furthermore, the energy-intensive process[294] of desalination, which has been one of the key sources of freshwater, conflicts with the climate mitigation targets in Maldives - although it should be noted that some hybrid solar-diesel and waste to energy desalination plants have been proposed.[295]

[281] Hosterman, H. & Smith, J., 2015. Economic costs and benefits of climate change impacts and adaptation to the Maldives tourism industry. Ministry of Tourism
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4. LEGAL AND INSTITUTIONAL FRAMEWORK

4.1 International and regional policies, strategies, conventions and treaties

The project is aligned with several international and regional policies, strategies, conventions and treaties, as outlined below.

Early Warnings for All

The Early Warnings for All (EW4All) initiative aims at ensuring that everyone on Earth is protected from hazardous weather, water and climate events through early warning systems by the end of 2027. The project will strengthen climate services and impact-based multi-hazard early warning in Maldives, directly contributing to the EW4All goal.

Sendai Framework for Disaster Risk Reduction 2015-2030

The Sendai Framework for Disaster Risk Reduction – adopted in 2015 – highlights the need to "substantially increase the availability of and access to multi-hazard early warning systems and disaster-risk information and assessments to the people by 2030." It urges efforts to make forecasting and CIEWSs more efficient, integrated and sustainable, which aligns with the outcomes of the project. The project contributes to progress towards all four identified priorities for action: 1. Understanding disaster risk; 2. Strengthening disaster risk governance to manage disaster risk; 3. Investing in disaster risk reduction for resilience; 4. Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

Asia-Pacific Action Plan for Implementation for the Sendai Framework for Disaster Risk Reduction

Following the call for the development of regional action plans and strategies of the Sendai Framework, the national governments of the Asia-Pacific region and partners agreed to develop a joint plan for preventing disaster risk to protect sustainable development. The 2015-2030 Plan for Implementation defines actions to be taken at the regional, national, and local levels for the achievement of the four priorities outlined in the Sendai Framework:

- Priority 1 – Understanding disaster risk: the Asia-Pacific Action Plan includes making risk, forecast, early waning and disaster impact information publicly available and accessible by everyone;
- Priority 2 – Strengthening disaster risk governance to manage disaster risk: the Implementation Plan calls for actions to adopt and promote coherent planning and implementation of disaster risk reduction and climate change adaptation strategies that also promote gender equality;
- Priority 3 – Investing in disaster risk reduction for resilience: this priority area ensures that countries allocate the necessary resources for the development and implementation of disaster risk reduction and climate change adaptation.
- Priority 4 – Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction: the Action Plan for Implementation includes actions at national and local level regarding prevention, preparedness, and recovery.

The project contributes to progress towards all four identified priorities for action at the national and local level in Maldives.

Asia-Pacific Ministerial Conference on Disaster Risk Reduction 2024

The Ministerial Conference drew insights from the mid-term review of the Sendai Framework and highlighted the goal of the Early Warnings for All initiative. The co-chairs issued a statement summarizing the highlights of the Conference and underscoring remaining gaps for the Asia-Pacific region's efforts to align with the four priority areas of the Sendai Framework. The project directly supports the conference's key calls to action by broadly supporting progress towards Disaster Risk Reduction efforts in Maldives.

SAMOA Pathway

The SAMOA Pathway addresses unique challenges faced by SIDS and supports their sustainable development. Key priorities outlined within the SAMOA Pathway are climate change adaptation and resilience, disaster risk reduction, and strengthening infrastructure and capacity building. The project directly contributes to these areas and supports the improvement of Maldives' resilience to climate-related disaster risks.

Paris Agreement on Climate Change

The project contributes to advancing the objectives of the Paris Agreement on Climate Change by consolidating Maldives' positioning in the following key areas:

- Article 7:
    - Art 7.7(c): *Strengthening scientific knowledge on climate, including research, systematic observation of the climate system, and early warning systems, in a manner that informs climate services and supports decision-making.*
    - Art 7.9: *Each Party shall, as appropriate, engage in adaptation planning processes and the implementation of actions, including the development or enhancement of relevant plans, policies and/or contributions*
- Article 8:
    - Art 8.1: *Parties recognize the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events, and the role of sustainable development in reducing the risk of loss and damage*.
    - Art 8.4: *Accordingly, areas of cooperation and facilitation to enhance understanding, action and support may include: a) early warning systems […]*

Sustainable Development Goals

The project will support national progress towards the SDGs, in particular

- SDG 3 – Good Health and Well-being: by reducing the health impacts of extreme weather- and climate events, the strengthening of Maldives' EWS contributes to SDG 3.
- SDG 5 – Gender Equality: the project will promote, enforce and monitor equality and non-discrimination on the basis of sex as a cross-cutting priority in line with SDG 5.
- SDG 13 – Climate Action: strengthening EWS helps Maldives to adapt to climate-related hazards, directly supporting SDG 13 which calls for action to combat climate change and its impacts.

4.2 National legislation, policies and strategies

At the national level, coherent legal and policy frameworks are needed to create an enabling environment for uptake and investment in climate services and early warning systems (EWS). Legislation can play a critical role in mandating institutional responsibilities and the authorisation to act. Relevant national legislation, policies and strategies for climate services and EWS in Maldives are outlined below.

National Emergency Operations Plan, Volume I and II

The National Emergency Operations Plan (NEOP) Volume I serves as a framework for disaster response in the Maldives. It outlines the roles, responsibilities, and coordination mechanisms between national and local councils, agencies, and stakeholders during emergencies, including providing a framework for integrating EWS into disaster response and management. The NEOP Volume I provides legal operational guidance and institutional arrangements for the disaster response phase. It does not cover long-term recovery or post-disaster reconstruction.

The NEOP Volume II outlines operating procedures for response to disasters, focusing on 13 Emergency Support Functions (ESFs): Logistics and Transportation; Communications; Public Works, Water and Sanitation; Firefighting, Search and Rescue; Emergency Management and Relief Operations; Mass Care, Shelter, Public Assistance, Housing and Relief Services; Resource Support and Finance; Public Health and Medical Services; Public Safety and Security; Haz-Mat and Environment; Agriculture and Natural Resources; Energy; and External Affairs. Each procedure defines the lead agencies, mission, scope, objectives, and actions to be undertaken before, during, and after a disaster. The NEOP Volume II includes the operational aspects of EWS integration.

National Disaster Management Authority Strategic Plan (2024-2029)

The National Disaster Management Authority (NDMA) Strategic Plan outlines five main strategic focuses of NDMA. The importance of establishing and maintaining robust EWS is explicitly stated in the Strategic

Focus (1): *Enhancing emergency response and preparedness*. The Strategic Plan also reaffirms the need to increase national resilience to disasters and to improve the way in which authorities, media, private sector, and civil society coordinate to manage disasters and climate-related risks.

<u>Disaster Risk Reduction Strategy (2024-2030)</u>

The Disaster Risk Reduction (DRR) Strategy was endorsed by the National Disaster Management Council in December 2024 and it outlines an approach to develop resiliency in Maldives.[296] The Strategy identifies seven key priorities for DRR in Maldives: (1) Strengthen governance and legal frameworks; (2) Enhanced multi-hazard risk assessment; (3) Building resilience through infrastructure and nature; (4) Empowering communities for effective response; (5) Strengthening EWS and preparedness; (6) Promoting comprehensive recovery and livelihood resilience; and (7) Cultivating a culture of safety and climate resilience. The DRR Strategy is aligned with the Sendai Framework for DRR, and it recognises that EWS are crucial to improving disaster preparedness and response, ultimately increasing the resiliency of the country.

<u>Education Sector Emergency Preparedness and Response Plan (2022)</u>

The Education Sector Emergency Preparedness and Response Plan (ES-EPRP) recognises that education is a fundamental right that should be protected at all times, including in emergencies. The ES-EPRP outlines a preparedness strategy and response strategy, as well as preparedness and response activities for five selected hazards (including flooding due to heavy rainfall and storm surge as the priority climate-related hazard). Under the preparedness strategy, the main actions of relevance to the proposed project are as follows:

- *Structural and organisational preparedness*
    - Adopting and integrating lessons learnt during previous disasters to build a culture of safety and resilience
    - Strengthening partnerships, corporate social responsibility and multi-agency coordination
    - Clarifying and adherence to disaster management laws, policies and frameworks
    - Emergency response mechanisms, including stand-by resources, trained staff, equipment and supplies
    - Addressing capacity building needs at sectoral level, island/atoll level, and school level
    - Utilising risk assessments, especially child-centred risk assessments.

- *Information preparedness*
    - Baseline information (e.g., maps, census data, enrolment, socioeconomic data, logistical information and procurement information)
    - Early warning information that alerts decision-makers to prepare for or respond to a crisis
    - Public information preparedness to enable quick communication about what is happening and what is being done
    - Information management (e.g., systems, systematic and regular, credible data collection)

The ES-EPRP includes information on the early warning system activation structure in the education sector, as well as a proposed communication tree for the Ministry of Education (MoE) during an emergency. It also proposes to form an Education in Emergency (EiE) Steering Committee, MoE Emergency Response Team and three Working Groups on EiE.

<u>Climate Emergency Act (Act no. 9/2021)</u>

The Climate Emergency Act was passed by the Parliament of Maldives on 29 April 2021. The Act stipulates actions to address the climate emergency and defines the legal structure and guidelines for climate policy. The Act required the Minister to constitute an office under the Ministry as 'Climate Change Directorate', mandated with leading the country's interests in the international realm to address the urgent issue of climate change.

<u>Update of Nationally Determined Contribution of Maldives (2020)</u>

The updated Nationally Determined Contribution (NDC) of Maldives clearly states that "climate change remains an existential threat to the Maldives" and stresses the need for urgent and immediate adaptation

[296] <u>Council endorses Maldives' disaster risk reduction strategy | Atoll Times</u>

actions and building climate resilience. The adaptation priorities outlined in the NDC are economy-wide and target all sectors. The following priority adaptation actions are of particular relevance to the proposed project:

- *Early Warning and Systematic Observation* – including continue strengthening and expansion of the meteorological network and early warning systems to cover the entire archipelago; improve climate and weather forecasting tools for decision making; strengthen the early warning system and risk management tools.
- *Disaster Risk Reduction and Management* – including strengthen the existing databases on disaster risk management; strengthen collaboration with island communities to understand and obtain information on local impacts; enhance mechanisms for collection of information on losses and damages.
- *Climate Governance and Capacity Building* – including mainstream climate considerations into national development planning processes; develop and promote appropriate technologies to address climate change impacts with support from the international community; implement appropriate policies and strategies to address the impacts of climate change on vulnerable groups.

Maldives Strategic Action Plan (2019-2023)

The Strategic Action Plan (SAP) of Maldives is the overarching policy framework and planning document to guide the country's development direction from 2019-2023. The SAP presents five priority sectors for development: i) Blue Economy; ii) Caring State; iii) Dignified Families; iv) Jazeera Dhiriulhun[297]; and v) Good Governance. Each sector encompasses several sub-sectors with associated policies, targets and strategic actions. The *Jazeera Dhiruilhun* sector includes the 'Resilient Communities' sub-sector, which prioritises the following policy areas:

1) Strengthen adaptation actions and opportunities and build climate-resilient infrastructure and communities to address current and future vulnerabilities.
2) Promote environmentally sound technologies and practices towards building sustainable climate resilient island communities.
3) Foster strategic partnerships and enhance national and international cooperation and advocacy in climate change.
4) Enhance island, atoll and city level preparedness, response and recovery capacities to manage recurring hazards.
5) Strengthening national level disaster management information, communication and coordination systems.
6) Ensure and integrate sustainable financing into climate change adaptation opportunities and low emission development measures.
7) Strengthen aeronautical meteorology and multi-hazard early warning capacity.

Actions to improve capacity to deliver on all four elements of an effective, people-centred multi-hazard early warning system are a cross-cutting priority for Maldives to ensure the resilience of its communities. Key strategic actions outlined under the various policy areas of relevance to the proposed project are identified in Table 8 below.

Table 8. Key strategies and actions under the 'Resilient Communities' sub-sector of the Strategic Action Plan 2019-2023 relevant to delivering a holistic, people-centred multi-hazard early warning system

Strategy	Action No.	Description
1.3: Integrate disaster risk reduction and climate change risk management into local planning processes	**1.3c**	Conduct climate-informed island level hazard, vulnerability and capacity assessments.
4.2: Increase community understanding of hazards	**4.2a**	Implement the Community Based Disaster Risk Management (CBDRM) programme in communities that are most vulnerable to hazards and climate-induced emergencies.

[297] The term 'Jazeera Dhiriulhun' literally translates to 'island life'. It represents a development model in which citizen engagement, inclusivity and sustainability are at the core.

and local level preparedness	**4.2d**	Carry out a nationwide public awareness campaign for disaster risk reduction, early warnings and response actions.
5.1: Enhance and ensure that disaster risk information management systems are up to date and ready to use for preparedness and response coordination	**5.1b**	Establish a GIS-integrated disaster risk management information system that captures island-level hazards and vulnerability maps, safe shelters, disaster loss and damage database, etc.
	5.1c	Establish an emergency communication and coordination system that provides situational awareness and incident coordination during emergencies and disasters.
5.2: Establish and strengthen national level early warning mechanisms to efficiently disseminate early warning information to the public	**5.2a**	Develop regulatory frameworks to mandate telecommunication service providers to develop uninterrupted early warning capacities to efficiently disseminate mass early warning messages to island communities.
7.1: Ensure the quality management system is in place as per ISO 9001:2015	**7.1a**	Conduct refresher trainings for Weather Observers, Forecasters and Technicians.
	7.1b	Conduct competency assessment for recertification of all technical staff (within Maldives Meteorological Service) every two years.
7.2: Enhance weather observation, forecasts and warnings dissemination to ensure safety of national and international air transportation	**7.2a**	Expand the radar network to cover the whole country.
	7.2b	Calibrate all the meteorological equipment as per ISO quality manual.
	7.2c	Develop a comprehensive maintenance regime to repair and maintain all equipment as per the ISO standards.
7.3: Strengthening observation network, data automation and integration	**7.3b**	Establish a marine meteorological observatory.
	7.3c	Develop an ocean weather prediction modelling and forecasting system.
	7.3d	Improve existing communication networks.

<u>Maldives First Biennial Update Report under the UNFCCC (2019)</u>

The first Biennial Update Report (BUR) of Maldives under the UNFCCC identifies climate change as a cross-cutting development issue for the country. The BUR recognises “limited availability and access to low-cost financial resources” as the key barrier for implementation of climate change adaptation and mitigation efforts in Maldives. Furthermore, it highlights several capacity building and technology transfer needs. With regard to adaptation and building climate resilience, the specific technology transfer needs are: i) Enhancing weather and climate monitoring in the Maldives and developing human resource capacity at Maldives Meteorological Service; and ii) Establishing a GIS integrated national level system for disaster management information, communication, and coordination.

<u>Second National Communication of Maldives to the UNFCCC (2016)</u>

The Second National Communication (SNC) of Maldives builds on the First National Communication submitted to the UNFCCC in 2001 and outlines the developments in efforts made to address climate change in Maldives. Most relevant in the context of the proposed project, the SNC includes a discussion of the country’s vulnerability to climate change (Chapter 7) and identifies current practices and further needs for climate change adaptation (Chapter 8).

The SNC lists a number of gaps and constraints, particularly in relation to data availability and quality, including: i) lack of institutional arrangements for data collection and data sharing; ii) inconsistent data formats; iii) lack of proper methods in data acquisition, analysis and management; iv) lack of means for data quality control; v) reluctance by the private sector in provision of their data; and vi) lack of necessary infrastructure for collection of data on atmospheric, ocean and coastal conditions and geomorphological change.

<u>Maldives Climate Change Policy Framework (2015)</u>

The Climate Change Policy Framework of Maldives is an essential policy document that recognises climate change as a central player in sustainable development. Key policy goals of relevance to the proposed project and associated strategies are as follows:

- *Policy Goal 3. Strengthen adaptation actions and opportunities and build climate-resilient infrastructure and communities to address current and future vulnerabilities.*
    - Prepare adaptation vulnerability assessments for key vulnerable sectors identified in NAPAs and subsequent plans and strategies.
    - Incorporate climate change scenarios and projections into the urban and rural planning sector.
    - Prepare detailed island risk assessments, plans, tools and guides for selected islands.
    - Analyse and evaluate poverty, health and food security issues to determine vulnerability to climate change and consider these vulnerabilities in future policies and initiatives.
    - Foster the use of local and traditional knowledge in climate adaptation.
- *Policy Goal 4. Inculcate national, regional and international climate change advocacy role in leading international negotiations and awareness in cross-sectorial areas in favour of the most vulnerable and small island developing states.*
    - Provide technical and scientific guidance to policymakers through appropriate means.
    - Use available communication tools to spread awareness and advocate for climate change adaptation and opportunities (and LED measures)
    - Establish an effective communication and networking mechanism on climate change issues among various stakeholders.
    - Develop locally appropriate awareness materials for distribution and display across the nation.
    - Include and update climate change elements within the secondary school curriculum as well as in tertiary and vocational education courses.
    - Encourage student research around the issue of local climate change and its significance to Maldivian communities.
    - Strengthen capacity building for atoll, island and city councillors to promote awareness of climate change issues.
    - Develop appropriate training tools on climate change awareness for government officers involved in awareness and training programmes in all relevant government institutions.
- *Policy Goal 5. Foster sustainable development while ensuring security, and economic, social and environmental sustainability and sovereignty, from the negative consequences of changing climate.*
    - Establish climate spatial data mechanisms to make well-informed decisions and climate sensitive reporting.

Disaster Management Act (2015)

The Act indicates the responsibility of the State to “protect its people, their health and well-being, their property, and the natural and built-up environment they live in from natural and man-made disasters, and hazards”. It requires the State not only to respond to disasters, but also to mitigate risks, establish emergency response guidelines, ensure disaster preparedness, assist in disaster relief, and coordinate all related matters.

Maldives’ Intended Nationally Determined Contribution (2015)

The Intended Nationally Determined Contribution (INDC) of Maldives recognises that the country is a minimal contributor to global greenhouse gas emissions and hence places a significant priority on adapting to the adverse impacts of climate change. ‘Early Warning and Systematic Observation’ is identified as a key adaptation contribution, with associated activities as follows:

- Expand and strengthen the meteorological network and weather-related early warning system to cover all the communities of the Maldives.

- Improve climate forecasting using climate modelling and provide information to support decision making of sectors affected by weather and climate variability.
- Develop appropriate early warning systems and risk management tools.

National Climate Change Research Strategy (2015)

The National Climate Change Research Strategy of Maldives aims to ensure the provision of relevant and useful research results to enable government, private sector and community stakeholders to make the best possible decisions to manage climate change-related trends, risks and impacts. The Strategy outlines three major focus areas: i) Building Knowledge; ii) Enabling Research; and iii) Linking Decision Making and Facilitating Change. Key research priorities under Area 1: *Building Knowledge* of relevance to the proposed project are identified below:

- Understanding climate change: *Knowing about past climate patterns, current trends and projected future changes to climate*
- Understanding implications of climate change: *Accurately identifying the impacts on physical environment, infrastructure, economy and society*
- Living with climate change – towards climate resilient islands: *Understanding practical and cost-effective measures towards a climate resilient pathway*
- Understanding how we can communicate risks: *Knowing what, who, how and when to communicate climate information for a climate resilient pathway.*

National Community Based Disaster Risk Reduction (CBDRR) Framework (2014)

The National CBDRR Framework outlines the enabling environment required to mainstream disaster risk reduction for effective, efficient and sustainable development at community level in Maldives. It provides a tool for communities to mainstream disaster risk reduction into their local development planning process. In addition, the Framework focuses on strengthening the key elements that enabling a conducive environment for large scale CBDRR activities. The Framework identifies the expectation for UN agencies to support government departments through building human capacity and strengthening institutional arrangements and technical capacity in relation to CBDRR. It also identifies the need for donor agencies to contribute financial resources for CBDRR implementation.

Strategic National Action Plan (SNAP) for Disaster Risk Reduction and Climate Change Adaptation (2010-2020)

Maldives' SNAP aims to build resilience and promote collaboration among policy makers, experts and practitioners of disaster risk reduction and climate change adaptation for the development of a comprehensive risk management approach. The SNAP identifies four strategic areas and ten areas for strategic action, as outlined below.

- Enabling Environment Towards Good Governance:
  - Institutional framework, institutional alignment and decision-making
  - Capacity building for disaster preparedness and recovery at all levels
- Empowered and Capable Communities:
  - End-to-end early warning system
  - Community-based disaster risk management
- Resilient Communities with Access to Technology, Knowledge, and Other Resources:
  - Knowledge management capacity building
  - Awareness raising
  - Connecting island communities to technology, knowledge, and resources
- Risk-Sensitive Regional and Local Development:
  - Regional development focused on vulnerable communities
  - Risk-sensitive policy and regulations in construction and industry
  - Disaster-resilient community housing and infrastructure.

Maldives National Strategy for Sustainable Development (2009)

The National Sustainable Development Strategy (NSDS) establishes specific goals, objectives and targets to achieve long-term sustainable development in Maldives. The NSDS identifies '*Adapt to climate* *change*' as the foremost national sustainable development goal. Key objectives of relevance under this goal are: i) Make the inhabited islands resilient against the threats posed by global climate change; and ii) Strengthen human, technical, regulatory, and institutional capacity for coastal zone management.

National Adaptation Program of Action (2007)

The National Adaptation Program of Action (NAPA) presents a framework for climate change adaptation in Maldives aimed at enhancing resilience of natural, human and social systems and ensuring their sustainability in the face of predicted climate hazards. The NAPA identifies key vulnerabilities and sustainable development challenges of Maldives – which are being exacerbated by climate change – and proposes 12 priority adaptation projects. Several of the NAPA projects were not realised as a result of financial limitations and inadequate technology transfer and capacity building. A GCF Readiness project *"Advancing the National Adaptation Plan (NAP) of the Maldives"* is currently underway to update the NAP by strengthening the scientific and economic basis for the adaptation strategies, whilst also ensuring a focus on medium to long-term climate change risks.[298]

4.3 National stakeholders relevant to the project

The Republic of Maldives has a demonstrated commitment to addressing the climate emergency and has fully engaged with international frameworks governing issues related to climate change. Government, sectors, communities and NGOs are already implementing actions to increase their resilience and adapt to climate change, but are constrained by limited institutional, financial, technical and human resource capacities – as well as significant data limitations – rather than the willingness and impetus to act. There are a number of institutions and organisations whose mandated roles and functions are relevant to the proposed project and who represent potential partners for project implementation. These institutions are involved, to varying degrees, in the weather and climate services value chain and/or in the dissemination of warnings to the population of Maldives. In addition, several of these entities are involved in disaster risk reduction and emergency response in Maldives.

Maldives Meteorological Service (MMS)

The MMS is responsible for providing hydrometeorological, climatological, aeronautical meteorological, and seismological services in Maldives. Its vision is to provide accurate, timely and reliable information to minimise impacts on life and property, whilst supporting the country's sustainable socio-economic development.

Under the Government of Maldives Strategic Action Plan (SAP) 2019-2023, MMS is the lead implementing agency responsible for *Policy 7: Strengthen aeronautical meteorology and multi-hazard early warning capacity* under the 'Resilient Communities' sub-sector. In addition, the SAP stipulates the involvement of MMS in actions related to the following:

- Maritime safety information, forecasts and warnings
- Data collection, monitoring and climate modelling for natural water resources
- Strengthening national institutional frameworks and planning for climate change adaptation and disaster risk management
- Vulnerability assessments for sectors and communities
- Mechanisms to efficiently disseminate early warning information to the public.

MMS is the national lead for Pillar 2 of the Early Warnings for All (EW4All) initiative, which focuses on observations and forecasting.

National Disaster Management Authority (NDMA)

The NDMA is the main coordinating body responsible for disaster management activities at the national level. It was established in December 2018 – as per the 2015 Disaster Management Act – and assumed all operations of the preceding National Disaster Management Centre (NDMC). The NDMA is responsible for mainstreaming disaster risk reduction at the national level. This includes planning processes, establishing agreed standards, and developing procedures and policies. This work is guided by the National Community-Based Disaster Risk Reduction Framework. The NDMA is divided into three units:

[298] UNEP, 2021. GCF Readiness Proposal – Advancing the National Adaptation Plan of the Maldives

- *Early Warning and Emergency Operations* – The National Emergency Operations Centre (NEOC) is responsible for conducting emergency management functions and ensuring the continuity of relief and recovery operations during emergencies.
- *Disaster Preparedness and Risk Reduction* – The Disaster Risk Reduction (DRR) unit is responsible for conducting national and local-level programs to prepare for and mitigate disaster risks. This includes the implementation of disaster awareness and Community-Based Disaster Risk Management (CBDRM) programs.
- *Corporate Affairs* – Provides all administrative support (e.g., HR, procurement, logistics, budget and finance) to the NEOC and DRR unit in implementing programs and strategies.[299]

NDMA is the national lead for Pillar 1 of the EW4All initiative, which focuses on disaster risk knowledge.

Maldivian Red Crescent (MRC)

The MRC is the largest humanitarian organisation in Maldives, with more than 320 members and 2200 volunteers. The MRC was established in 2009 on the basis of the Maldivian Red Crescent Law (Law 7/2009) and was recognised as a fully-fledged member of the International Federation of Red Cross and Red Crescent Societies (IFRC) in November 2011. The MRC is mandated by law to act as an auxiliary to the state in Emergency Response, which forms a key part of the organisation's disaster risk management work. It responds to emergencies and disasters in collaboration with the NDMA and other relevant stakeholders.[300] The MRC Strategic Plan 2019-2030 outlines six strategic priorities, which are as follows:

1. Strengthen Emergency Response
2. Strengthen First Aid and Psychosocial Support Services
3. Facilitate Planning for Resilience
4. Promote Health and Wellbeing in a Changing Environment
5. Foster Humanitarian Values and Volunteerism
6. Organisational Development and Sustainability

MRC is the national lead for Pillar 4 of the EW4All initiative, which focuses on preparedness and response capabilities.

SME Development Finance Corporation (SDFC)

SDFC is a state-owned specialised financial institution that provides financial products and ancillary services to micro, small and medium enterprises (MSMEs) and entrepreneurial start-ups, with the primary purpose of easing access to finance for Maldivian MSMEs. In October 2022, the Government of Maldives nominated SDFC for accreditation as a GCF Direct Access Entity (DAE). The USAID Climate Adaptation Project is currently providing financial assistance to support the capacity development activities required for SDFC to achieve GCF accreditation.

Communications Authority of Maldives (CAM)

CAM is the regulatory body responsible for overseeing and managing the telecommunications, broadcasting, and postal services in Maldives. It oversees licensing and ensures compliance with relevant laws. CAM plays a key role in fostering connectivity and advancing the country's communications infrastructure. It is a national co-lead for Pillar 3 of the EW4All initiative, which focuses on warning dissemination and communication.

National Centre for Information Technology (NCIT)

NCIT is a government agency that aims at strengthening information and communication technology (ICT) in Maldives. It provides ICT infrastructure and supports other government institutions in developing digitalised public services. Together with CAM, NCIT is a national co-lead for Pillar 3 of the EW4All initiative, which focuses on warning dissemination and communication.

Business Center Corporation (BCC)

BCC is a state-owned corporation focused on supporting entrepreneurship and the development of MSMEs in Maldives. As the implementing body for MSME development projects initiated by the Ministry

[299] NDMA, 2016. About National Disaster Management Authority. Available at: http://ndmc.gov.mv/about/
[300] MRC, 2019. Maldivian Red Crescent Strategic Plan 2019 – 2030

of Economic Development and Trade, BCC provides business advisory services, facilitates access to finance, and offers training and mentorship programs. BCC is crucial for strengthening Maldives' economy and for empowering local businesses.

5 PRIVATE SECTOR ANALYSIS

5.1 Overview

Maldives has an open economy, with a narrow export base and high dependence on imports for its economic activities. Imports account for around 61 percent of GDP, whereas exports – consisting predominantly of fish and fish products – represent around 11-15 percent of GDP.[301]

Tourism accounts for almost one-third of the economy[302] and had a projected indirect contribution of 79 percent of GDP in 2022. Heavy reliance on tourism makes Maldives particularly vulnerable to macroeconomic and external shocks, such as climate-induced disasters, political instability, and global health crises (such as the COVID-19 pandemic). Economic diversification has been identified as a key need to enhance the country's economic resilience, as well as contribute to a more sustainable and inclusive economy by promoting growth across a range of sectors.[303]

5.2 Micro, Small and Medium Enterprises (MSMEs)

Micro, Small and Medium Enterprises (MSMEs) constitute the backbone of the Maldivian economy, representing around 94 percent of total businesses in the country.[304] MSMEs are critical to achieving inclusive growth in Maldives through their role in job creation and improving livelihoods in small island communities. Whilst tourism is the main driver of employment in the central region (containing the capital Male'), the fisheries, agriculture and trade sectors tend to prevail amongst MSMEs in other locations.

MSMEs in developing countries face a number of constraints to growth, particularly stemming from lack of finance, lack of market information, low expenditure on research and development, and insufficient use of information technology. Key impediments to (M)SME growth in Maldives are outlined below:[305, 306]

- **Lack of access to finance** resulting from a risk-averse financial system and geographical barriers that hinder the delivery of financial services. The SME Development Finance Corporation (SDFC) is expected to play a key role in reducing financial barriers for SMEs.
- **Under-developed local transport infrastructure** resulting in limited market access and increased transport costs for businesses located in remote atolls.
- **Limited economic diversification** – mainly due to lack of natural resources – resulting in limited opportunities for income generation. Climate change is exacerbating this issue due to negative impacts on the fisheries sector, which is an important source of income particularly in the southern regions of Maldives.
- **Lack of protective legislation** to support micro-entrepreneurs – although recent reforms to public procurement regulation are expected to create a fairer environment for SMEs to compete and access bidding opportunities.
- **Lack of business knowledge, awareness, and other social issues**, including cultural norms beliefs that limit women's engagement in entrepreneurial activities.

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301 UK High Commission of the Republic of Maldives, 2020. Maldives Economic Profile. Available at: https://www.maldiveshighcommission.uk/index.php/business/economic-profile (Accessed: 12 January 2024)

302 The World Bank, 2024. The World Bank in Maldives – Overview – Country Context. Available at: https://www.worldbank.org/en/country/maldives/overview (Accessed: 12 January 2024)

303 ADB, 2023. Beyond Tourism: Diversifying the Maldivian Economy for a Sustainable Future

304 The World Bank Group, 2024. Maldives Financial Sector Assessment Program. Technical Note: Access to Finance for MSMEs. Available at: https://documents1.worldbank.org/curated/en/099060624144517678/pdf/P18010016f22fd0b918bd21f7a1062ad47b.pdf (Accessed: 10 December 2024)

305 Maldives Monetary Authority, 2019. Research and Policy Notes. Impediments to SME Growth in Small Island Developing States – The Case of the Maldives

306 Ismail, F. P-Ed. Building an inclusive ecosystem for SMEs. Available at: http://saruna.mnu.edu.mv/jspui/bitstream/123456789/13644/1/Building%20and%20inclusive%20eco%20system%20for%20SME%27s.pdf (Accessed: 12 January 2024)

Although the SME sector in Maldives has historically been overlooked, the SME Act passed in 2013 aimed to provide a framework to promote and support micro, small and medium-sized enterprises. The Ministry of Economic Development and Trade (MEDT) provides technical support to SMEs through business centres covering every inhabited island of the country.[307] The Business Center Corporation (BCC) is a state-owned enterprise established in 2017 to serve as the implementing body of MSME development projects initiated by MEDT. Amongst others, BCC provides consultancy and advisory services, trade facilitation, outreach, and entrepreneurial development.[308]

5.3 Implications of climate change

Climate change represents a major risk to the economic and financial stability of Maldives. In addition to infrastructure damage and loss of human lives and livelihoods, extreme climate events are expected to exacerbate supply chain disruptions and inflationary pressures. In turn, this could lead to food and water shortages and weaken debtor capacity to repay obligations.

Analysis by the IMF highlighted the need for detailed climate risk analysis, supported by better coverage and granularity of climate data, to improve understanding of climate change implications for the economy and financial sector. Currently, financial institutions in Maldives lack both the analytical skills needed for complex climate risk analyses, as well as specialised knowledge for the management of climate-related financial risks.[309] Strengthening climate change risk analysis and management capacity within the financial sector will thus be an important contributor to long-term stability.

[307] Maldives Monetary Authority, 2019. Research and Policy Notes. Impediments to SME Growth in Small Island Developing States – The Case of the Maldives
[308] Business Center Corporation, 2024. Available at: https://bcc.mv/ (Accessed: 12 January 2024)
[309] IMF, 2023. Maldives: Financial System Stability Assessment

6 NEEDS ASSESSMENT FOR CLIMATE INFORMATION AND EARLY WARNING SYSTEMS

6.1 Baseline climate information and early warning systems

This section provides an analysis of the current capacity of Maldives to provide reliable climate information and early warning systems (CIEWS). This analysis draws on i) primary data collection including in-country consultations and survey responses with key stakeholders across the CIEWS value chain in Maldives; and ii) comprehensive desk review of existing literature, reports and assessments conducted by Maldives, regional organisations, academia, and international partners.

Table 9 provides an overview of the current strengths, weaknesses, opportunities and threats that can affect the further development of CIEWS in the Maldives.

Table 9: SWOT analysis for CIEWS in Maldives.

Strengths	Weaknesses
• Strong partnerships with organisations like the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES), the World Meteorological Organization (WMO) and the Green Climate Fund (GCF) contribute funding, access to information and technical expertise, and capacity-building opportunities. • Five existing weather stations managed by the Maldives Meteorological Service (MMS) provide a foundation for meteorological data collection. • The Systematic Observations Financing Facility (SOFF) is financing the enhancement and maintenance of weather observation systems in Maldives, ensuring the long-term sustainability of five stations meeting the requirements of the Global Basic Observing Network (GBON). • Mobile network coverage of 100% has the potential to enable efficient dissemination of early warnings within Maldives.	• Limited existing observational networks and outdated weather monitoring systems reduce the accuracy and reliability of forecasts. • Insufficient human resources and technical expertise at MMS impede the effective operation and maintenance of systems. • Outer atolls face challenges in receiving timely warnings due to inadequate communication infrastructure and coordination mechanisms. • More isolated and less connected islands might face delays in the deployment of response teams and/or supplies. • High degree of reliance on international donors for financial and technical support.
Opportunities	**Threats**
• Membership of WMO facilitates access to weather, water and climate data and information and related capacity development to optimise the production of hydrometeorological services. • Commitment towards the Paris Agreement and the achievement of the Sustainable Development Goals (SDGs) at national and institutional level presents the opportunity to accelerate the further development of CIEWS. • The Government of Maldives recognises the need to strengthen early warning systems (*e.g.*, 2024-2030 Disaster Risk Reduction Strategy[310], 2020 Updated Nationally Determined Contribution[311] and 2019-2023 Strategic Action Plan[312]).	• Near-term and evolving vulnerability to extreme weather events and climate-related hazards, including sea-level rise and ocean acidification. • Degradation of natural buffers (*i.e.*, coral reefs and mangroves) exacerbates Maldives' climate vulnerability, increasing and making more immediate the demand for effective warning systems. • Limited in-country financial capacity to implement climate change adaptation interventions, and to procure, operate and maintain hydrometeorological and early warning systems infrastructure. • Low public awareness and capacity to act based on early warning systems may reduce their effectiveness in mitigating disaster risks.

[310] Disaster Risk Reduction Strategy, 2024-2030. Available at: https://ndma.gov.mv/storage/uploads/50wNZewA/mixvv4ks.pdf
[311] Maldives Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[312] Government of Maldives, 2019. Strategic Action Plan 2019-2023

• Maldives has been selected as one of the first thirty countries to receive support under the Early Warnings for All initiative (EW4All), providing access to resources for enhancing CIEWS.	

The baseline status of CIEWS in Maldives is presented below, in alignment with the four key elements of early warning systems identified in the WMO Checklist on Multi-Hazard Early Warning Systems (MHEWS)[313] and accordingly the four pillars under the Early Warnings for All initiative.

The information presented draws on the findings of the self-assessed *Core Capability Checklist for Early Warning Systems*, which was completed in advance of the first National Consultation on Early Warnings for All (EW4All) in Maldives in July 2023. The findings of the self-assessment are complemented by further information garnered from stakeholder consultations and documents collected and analysed via desk review.

6.1.1 Disaster risk knowledge

Identification of key hazards and related threats

Hazard assessments have been conducted but are outdated or limited in spatial resolution. For example, a comprehensive disaster risk profile for Maldives was developed with the support of UNDP in 2006. Detailed island risk assessments are available for nine islands but were completed in 2006/2007. The Multi-hazard Risk Atlas of Maldives (2020) prepared by the Asian Development Bank provides a country-level overview of climate-related hazards but lacks specificity at the atoll/island level. Hazard Vulnerability and Capacity Assessments (HVCAs) have been conducted through the community-based disaster risk management (CBDRM) programme in local communities. The HVCAs are less holistic than VCAs (see Section 8.1.3) and are limited in coverage (7 out of 187 inhabited islands covered). There is no standardised risk assessment methodology, which represents a key gap in supporting the production of risk knowledge in Maldives.

With regard to hazard mapping, the National Disaster Management Authority (NDMA) is generating single hazard GIS-based maps with the support of UNESCAP and UNDP.[314] Dynamic and multi-hazard risk maps are not currently generated.

There is limited analysis of the socio-economic and environmental impacts of climate change. Sectoral impacts are discussed, for example, in the updated Nationally Determined Contribution (2020) and the Second National Communication (2016). A detailed assessment on climate change impacts on health and livelihoods in Maldives was published in 2021, with the support of the Red Cross Red Crescent Climate Centre and IFRC.[315] However, there is no systematic analytical process undertaken and available analyses are generally limited to the national level. Estimating economic losses from disasters and climate change processes remains a challenge.

NDMA tracks and collects damage assessment data on all household-level emergencies. Data collected by NDMA are uploaded to DesInventar (updated in 2022). However, data disaggregation (e.g., by sex, age, disability, sector, and geography) is highly limited. Damage and loss data through DesInventar provides information on previous events from the 1990s to the present day.

Assessment of exposure, vulnerabilities, and capacities

The latest population and housing census for Maldives was conducted in September 2022. The census results provide information on the population at the atoll and island level by basic demographic characteristics, such as age, sex, nationality, population distribution, and household size. Information on vulnerability factors such as migration, education, prevalence of disability, economic activity, marriage and fertility, and household type is also available. Based on the census results, the number of exposed

[313] WMO, 2018. Multi-Hazard Early Warning Systems: A Checklist
[314] UN Joint Programme “Strengthening National and Subnational Capacity for Sustainable Disaster Risk Reduction, Climate Change Adaptation and Mitigation in Maldives” (2022-2024)
[315] RCCC, 2021. Climate Change Impacts on Health and Livelihoods: Maldives Assessment

people can be inferred. However, exposure quantification in relation to specific climate-related hazards is not routinely conducted.

Detailed island risk assessments for nine islands (2006/2007) contain information on environmental exposure and structural vulnerabilities, but these are outdated and limited in coverage. There are no dedicated inventories or databases of exposed infrastructure, agricultural land and assets, critical services, or ecosystem services. Assessment and quantification of exposure to compounding risks is also not undertaken.

Data on disaster impacts and risk assessments for the agri-food sector (crops, livestock, forestry, fisheries, aquaculture) is lacking. For example, NDMA has limited data on damage to agricultural fields. AgroNAT[316] has limited data on damage to crops due to weather events. Impact assessments for critical infrastructure and secondary risks associated with these impacts are not conducted. There is no analysis undertaken on potential impacts and stress-testing of critical infrastructure, or on cascading risks to critical infrastructure and secondary impacts to the socio-economic system. Vulnerabilities of key economic sectors at national to local levels are not systematically assessed.

Local and traditional knowledge is incorporated into risk assessments to some degree. For example, NDMA collects local and community-level data for hazardous event reporting. In addition, HVCAs conducted by NDMA incorporate community and traditional knowledge. Stakeholders have identified the need to conduct risk and early warning system perception studies,[317] which could be used to identify gaps that may increase vulnerability.

The (outdated) disaster risk profile for Maldives broadly describes drivers of disaster risk. However, no specific identification and evaluation of risk drivers (including urbanisation, food production, infrastructure, demographics, land use patterns) is undertaken.

The results of HVCAs are integrated into local Island Disaster Management Plans (IDMPs). As of December 2023, IDMPs are available for 72 islands; however, only seven incorporate HVCAs.[318] Vulnerability and Capacity Assessments (VCAs), which are broader in scope that HVCAs, are used in the preparation of Island Development Plans. Whilst risk assessment outcomes are integrated into local risk management plans, there is a lack of integration of hazard, vulnerability, and exposure data in early warning generation.

Stakeholder coordination

The NDMA has the official mandate on risk information, as per the Disaster Management Act (2015). The Act also stipulates the role of Maldives Meteorological Service (MMS) in providing up-to-date information on hazards. Guidelines on hazardous event logging and damage assessments are provided through regulation by NDMA.

The Strategic Action Plan (2019-2023) requires climate-informed island-level hazard, vulnerability, and capacity assessments to be conducted in all islands (Action 1.3c) with NDMA as the lead implementing agency. Other identified implementing agencies are the Ministry of Tourism and Environment[319], Maldives Marine Research Institute, Local Government Authority, and the National Bureau of Statistics.

There is no standardised process for scientific and technical experts to assess and review the accuracy of risk data and information. In addition, no experts have been trained in the collection, production, verification, use, and dissemination of risk information.

Consolidation of and access to risk information

There is no central standardised repository, database or knowledge platform established to store all hazard event and disaster/risk information at the national level. There are also no national statistical standards for collection, management, analysis, use and dissemination of risk data and information.

[316] The Agro National Corporation (AgroNAT) is a State-Owned Enterprise with the overall mandate to assist in developing the agricultural sector in Maldives.
[317] National Consultation on Early Warnings for All in Maldives, 4-5 July 2023
[318] This is due to the limited coverage of HVCAs.
[319] Formerly known as the Ministry of Environment, Climate Change and Technology and, subsequently, the Ministry of Climate Change, Environment and Energy

Maldives conducts reporting under the Sendai Framework for Disaster Risk Reduction. However, no data for the country is available on the Sendai Framework Monitor[320] as of October 2023.

Up-to-date risk information is not easily available and accessible by relevant stakeholders at the national level. There are datasets available, but access is limited due to the siloed nature of working between agencies. For example, MMS has limited access to impact information from various sectors and post-disaster analytics. Local level risk information is not consolidated at the national level.

Use of risk knowledge for emergency response

Information on the geographical extent of hazards is used to some extent to define safe areas and evacuation zones. The Island Disaster Management Plans developed for 72 islands, seven of which were informed by HVCAs, have evacuation plans, routes, and centres. However, the maps are not digitalised.

Innovation for risk knowledge

New or advanced technologies (e.g., remote-sensing technologies, open-source satellite information, *in-situ* data collection, digital-based data collection technology and storage, cloud-based computing, digital communication tools and web or mobile-based apps) for the collection, production, analysis, dissemination, or use of risk information have not been utilised in the Maldives. Although, MMS leverages satellite data from multiple sources for hazard monitoring (see Section 6.1.2).

Environmental dimensions of risk knowledge

Assessment and quantification of exposed species in relation to climate hazards is highly limited. The Ministry of Environment, Climate Change and Technology has conducted studies on vulnerable species, but no mapping of environmental vulnerabilities and exposure has been undertaken. The National Climate Change Research Strategy (2015) recognises the need to improve understanding on the environmental dimensions of climate change impacts.

Data on the environmental impacts of hazardous events is not collected. Local knowledge about environmental vulnerabilities may be referred to in the development of Island Disaster Management Plans. However, there is no system in place to enable communities to collect and report environmental data.

The Disaster Management Act (2015) includes provision for environmental protection in the context of disaster risk reduction, but mandates, roles, responsibilities, and technical focal points in this regard have not been assigned.

6.1.2 Observations and forecasting

Country Hydromet Diagnostics

The Country Hydromet Diagnostics (CHD) provides a maturity assessment of National Meteorological Services, their operational environment, and their contribution to high-quality weather, climate, hydrological, and environmental information services and warnings. The CHD evaluation focuses on the ten key elements of the hydromet services value chain, which have been grouped into four categories: i) enablers; ii) observation and data processing system; iii) service and product development and dissemination; and iv) user and stakeholder interaction.

The CHD uses peer review as its overarching approach, whereby advanced National Meteorological and Hydrological Services (NMHSs) from developed and developing countries undertake the Diagnostics, strictly following the tool. The CHD document for Maldives was initially written by the India Meteorological Department (IMD) in 2021. The Finnish Meteorological Institute (FMI) and Agency for Meteorology, Climatology, and Geophysics of Indonesia (BMKG), as Peer Advisors under the Systematic Observations Financing Facility (SOFF) program in Maldives, have reviewed and updated the document in close collaboration and consultation with Maldives Meteorological Service (MMS).

The CHD results show that most of the assessed elements for Maldives have maturity level at 3. Some exceptions include Element 8 (Contribution to Hydrology), which received a rating of 1. This is primarily explained by the geography of Maldives and lack of water resources (rivers, lakes, glaciers), making hydrology mostly irrelevant to MMS operations. This factor should be taken into account when evaluating the CHD document. Another element with a low maturity level is Element 7 (Contribution to Climate

[320] https://sendaimonitor.undrr.org/

Services), which received a maturity level score of 2. This is because MMS does not have dedicated staff to provide climate services. To address this gap, it is recommended that well-trained staff be recruited to enhance the capabilities of the climate division. Similarly, Element 10 (Use and national value of products and services) received a score of 2 due to MMS service development currently drawing on informal stakeholder input and feedback. It is recommended to improve customer/client feedback and its involvement in institutional strategies, enhancement and service provision, as well as expanding Quality Management System (QMS) implementation to NMHS operations. An overview of the results of the CHD maturity assessment is shown in Figure 52 below.

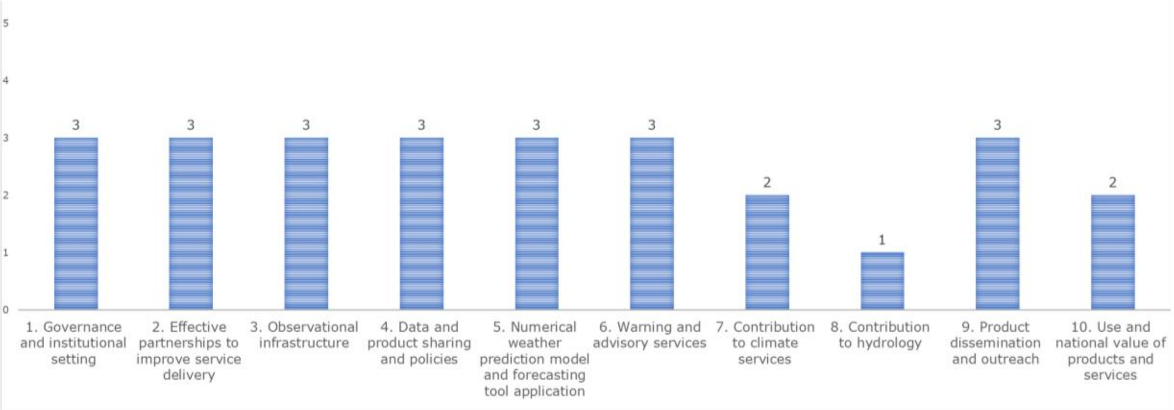

Figure 52. Overview of the CHD peer review results for MMS (Source: FMI and BMKG, 2023)

Early Warnings for All (EW4All) Rapid Assessment

In 2023, WMO conducted a Rapid Assessment of the hazard monitoring and forecasting capacity of the 30 countries selected for initial support under the EW4All initiative. Quantitative and qualitative data was collected through structured interviews and the responses were then weighted and analysed to determine capacity levels for each of eight elements of the hydrometeorological value chain. These levels were ranked on a scale of 1 to 5, where 5 represents advanced capacity and 1 represents no or less than basic capacity. In addition to assessing the general hazard monitoring and forecasting capacity of the 30 countries, the Rapid Assessment examined the countries' preparedness to address the top five self-identified hazards from a hydrometeorological perspective.[321]

[321] WMO, 2023. Early Warnings for All in Focus: Hazard Monitoring and Forecasting. Results of the Pillar 2 Rapid Assessment. Analytical Brief

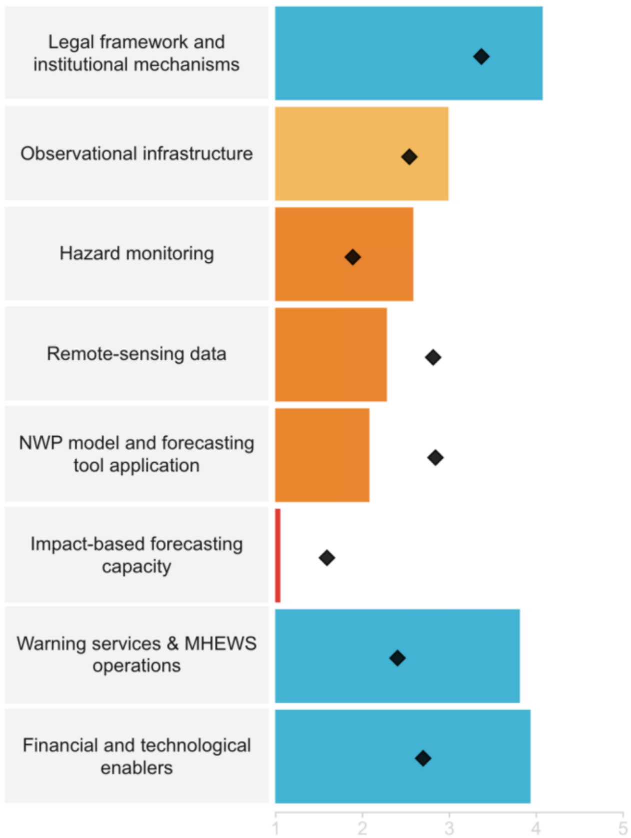

Figure 53. Element Maturity Scores for Maldives as determined by the EW4All Pillar 2 Rapid Assessment. The colours of the bars represent the degree of attainment of each element as quantified by the Rapid Assessment. The • indicates the global average based on the currently assessed National Meteorological and Hydrological Services. (Source: WMO Monitoring System, 2023)

The results of the EW4All Rapid Assessment show that Maldives relies on basic (Level 2) monitoring and forecasting capacity to support its early warning system. Although the observational infrastructure in Maldives is deemed to be moderate (Level 3), capacities within MMS for hazard monitoring, use of remote-sensing data, and application of Numerical Weather Prediction (NWP) models and forecasting tools are all deemed to be basic. The most significant gap for Maldives is the near complete lack of impact-based forecasting (IBF) capacity. The exception to this is that a few forecasters have been trained on IBF for tropical cyclones; however, no impact-based forecast and warning services are produced for any hazards. Despite these capacity gaps, the Rapid Assessment found that MMS has adequate (Level 4) capacity to implement (non-impact-based) warning services and multi-hazard early warning system (MHEWS) operations. Similarly, Maldives has adequate capacity in terms of its legislation, governance mechanisms, and financial and technological enablers to support implementation of EW4All Pillar 2.[322] These results suggest that whilst major technical capacity gaps remain, there exists sufficient readiness and enabling conditions for MMS to advance its hazard monitoring and forecasting capabilities to underpin the national MHEWS, if the relevant support is provided.

Governance and institutional setting

Maldives Meteorological Service holds the designation as a government agency under the Ministry Tourism and Environment, with the primary areas of responsibility encompassing hydrometeorology, climatology, aeronautical meteorology, and seismology. As the National Meteorological and Hydrological Service (NMHS) of Maldives, MMS is officially recognised as the national alerting authority for hydrometeorological hazards in the country or territory.

A draft legislative Act related to meteorology and hydrology (Maldives Meteorology Act, 2016) was prepared in 2016. However, it needs to be revised and updated with later developments in the field of

[322] WMO, 2023. Early Warnings for All Dashboard – Maldives. Available at: https://wmo.int/activities/monitoring-and-evaluation-merp/early-warnings-all-dashboard. (Accessed: 10 January 2024)

meteorology. The main focus of the Act is to strengthen the legal framework and cost recovery for some services. At present, MMS does not have the legal status required to formally engage in partnerships with the private sector. The Act would also provide the legal mandate for MMS to act independently and implement more adaptive management measures.

Currently, the legal mandate and scope of MMS are outlined in the presidential decree, as stipulated in Act No.3/68 dated 11 November 1968. Accordingly, MMS is mandated by the Government to carry out the following activities (un-official translation, as only available in Dhivehi):

- Plan, administer and develop activities related to meteorology in the Maldives.
- Maintaining the data on climate, earthquake, and tsunami, required for economically and socially sustainable development. Develop and maintain such a knowledge base and facilitate access to this information to those who require it.
- Conduct research activities on meteorology and seismology in the Maldives.
- Provide aeronautical meteorological services to international and domestic aviation requirements as per the required standards of the International Civil Aviation Organization (ICAO) and World Meteorological Organization (WMO).
- Monitor weather, earthquake, and tsunami over the region.
- Issue impact-based forecast and early warning alerts to concerned authorities and general public.

MMS operates in accordance with a Service Charter, which serves as a guiding document that outlines the service standards, commitments, and expectations for MMS' interactions with its stakeholders, clients, and the general public. It aims to ensure transparency, accountability, and the delivery of high-quality hydrometeorological services in line with established benchmarks and best practices.

In total, MMS employs 107 personnel, comprising 77 males (72%) and 30 females (28%). The current human resources situation is outlined in Table 10 below. Crucially, MMS has no human resource capacity to deliver climate services.

Table 10. Human resources capacity in Maldives Meteorological Service

Role	Number of staff
Management Staff	7
Meteorologists	10
Meteorological Technicians	60
Hydrologists	0
Hydrological Technicians	1
Climate Services	0
Researchers	0
Other	29

Observation infrastructure

MMS maintains a network of five manned synoptic weather stations, providing essential surface observations. These stations exhibit an average horizontal resolution ranging from 150 to 300 km. There is one upper-air observation station within the country, with a horizontal resolution of 1000 km. However, this station is obsolete.[323] At present, none of the stations are compliant with the WMO Global Basic Observing Network (GBON) technical regulations. However, this is proposed to be addressed under the Systematic Observations Financing Facility (SOFF).

The SOFF will support the upgrade and automation of four of the existing stations, as well as installation of one additional station to comply with horizontal resolution requirements for GBON stations. The upper-air station will also be upgraded. The SOFF Investment Phase Funding Request was approved on 28 November 2023 and the implementation period will run from 2024-2028.

[323] SOFF, 2023. GBON National Gap Analysis – Maldives

Table 11. Location of surface-based observation stations to be improved under SOFF

Name	Latitude	Longitude	Variables
Hanimaadhoo	6°44’53.7” N	73°10’10.3”	• Sea-level pressure • Temperature • Humidity • Wind • Precipitation
Hulhule (Male’)	4°11’34.0” N	73°31’39.4”	
Kadhdhoo	1°51’36.3” N	73°31’12.8”	
Gan	0°41’24.4 “S	73°08’59.3”	

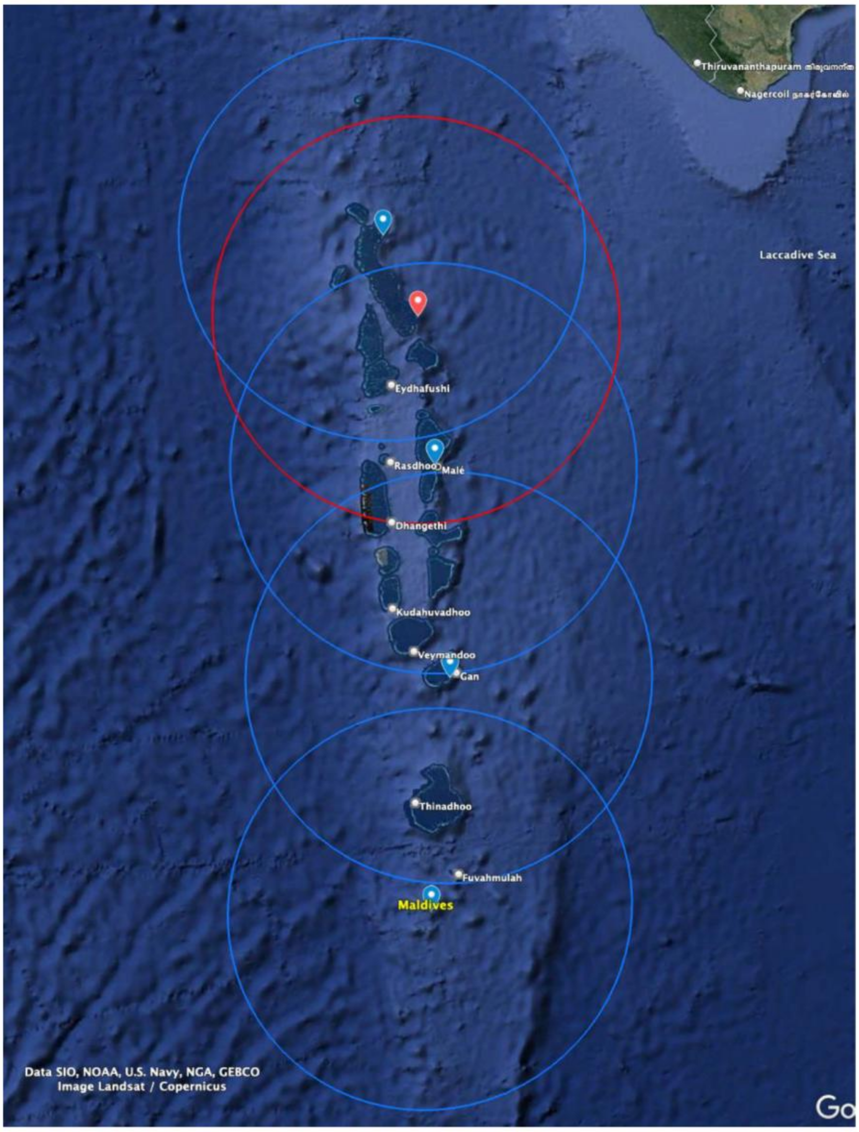

Figure 54. Geographical visualisation of the distribution of proposed GBON stations to be supported by SOFF. Blue markers indicate existing surface-based stations. The red marker indicates the proposed location of the new station (in Maafaru). Circles indicate 500 km diameter. (Source: SOFF, 2023)

The upper-air sounding station is located in Gan, with the following coordinates: 0°41’24.4” S, 73°08’59.3”.

In addition to the abovementioned stations, MMS’ network contains 45 automatic weather stations (AWS). Frequent data gaps and maintenance issues are experienced despite the AWS being just three years in operation. Over half of the stations are not fully functioning. As such, these stations are not currently proposed for inclusion in the GBON network.

Table 12: Existing network of Automatic Weather Stations and status as of 8. September 2024

Order of urgency for repair and maintenance	AWS island	Manufacturer	Status as of 8 September 2024
1	Sh. Kanditheemu	Cae	Not Working
2	R. Dhuvaafaru	Cae	Not Working
3	R. Maduvvari	Cae	Not Working
4	B. Thulhaadhoo	Cae	Not Working
5	Lh. Olhuvelifushi	Cae	Not Working
6	K. Guraidhoo	Cae	Not Working
7	Dh.Kudahuvadhoo	Cae	Not Working
8	Th. Buruni	Cae	Not Working
9	Ga. Kolamaafushi	Cae	Not Working
10	Gdh. Faresmaathoda	Cae	Not Working
11	AA.Himandhoo	Cae	Not Working
12	S.Hulhumeedhoo	Cae	Not Working
13	Ha. Hoarafushi	Cae	need attention
14	Thimarafushi Airport	Jics	need attention
15	Ga. Gemanafushi	Cae	need attention
16	K. Gaafaru	Cae	need attention
17	F. Bilehdhoo	Cae	need attention
18	Adh. Mahibadhoo	Cae	need attention
19	K. Dhiffushi	Cae	need attention
20	HDh.Makunudhoo	Cae	need attention
21	L. Maavah	Cae	need attention
22	Kadhdhoo Airport	Jics	need attention
23	Gdh. Thinadhoo	Cae	need attention
24	R. Alifushi	Cae	Working
25	Sh. Komandoo	Cae	Working
26	AA. Thoddoo	Cae	Working
27	Sh. Funadhoo	Cae	Working
28	M. Muli	Cae	Working
29	B. Goidhoo	Cae	Working
30	HDh. Kulhudhufushi	Cae	Working
31	Kaadehdhoo Airport	Jics	Working
32	Fuvahmulah Airport	Jics	Working
33	F. Nilandhoo	Cae	Working
34	Ha. Kelaa	Cae	Working
35	N. Maafaru	Cae	Working
36	K.Kaashidhoo	Cae	Working
37	Villa International Airport	Jics	Working
38	Ifuru Airport	Jics	Working
39	Hanimaadhoo	Jics	Working
40	V.Rakeedhoo	Cae	Working

41	Dharavandhoo Airport	Jics	Working
42	Koodoo Airport	Jics	Working
43	S.Hithadhoo	Cae	Working
44	Gan International Airport	Jics	Working
45	Velana International Airport	Jics	Working

Hazard-based observation capacity

Geographical, financial, and logistical constraints have resulted in areas of the country where observations are missing. This hinders the ability of MMS to undertake comprehensive hazard monitoring.

For various hazards, MMS monitors key variables, including wind speed and direction, pressure, precipitation, temperature, radar reflectivity, and remote sensing images. However, there are identified gaps in monitoring capacity and the need for additional variables. For instance, for wind-related hazards, improved data quality control is required. In the case of flash floods and thunderstorms, there is a lack of observation stations, insufficient automation, limited access to real-time data, and inadequate data quality control. Similarly, for high seas and rogue waves, challenges include the absence of observation stations, insufficient automation, limited access to real-time data, a lack of remote sensing data, and insufficient data quality control. Additionally, for tropical cyclones, data quality control issues persist, and there is a need to enhance monitoring capacity for additional variables. MMS collaborates with the Regional Specialised Meteorological Centre (RSMC) in New Delhi to receive observations relevant to tropical cyclone monitoring.

Remote-sensing data

There is one S-band Doppler weather radar installed in Maldives, which is used for monitoring and tracking weather phenomena such as thunderstorms and squall lines. The radar is quite old and has frequent maintenance issues. Due to the high downtime, the radar is not effectively used on a continuous basis. There is a project in the pipeline (with the support of the Government of Italy) to install four new X-band radars covering the territory of Maldives.

In addition, MMS uses a variety of satellite data sources to enhance its observational capabilities for monitoring and forecasting. For flash floods, MMS relies on data from the FY-2E and G satellites from the China Meteorological Administration (CMA), as well as data from the INSAT 3D and 3DR satellites, made available by the Indian Meteorological Department (IMD). For monitoring high seas and rogue waves, MMS utilises open-source altimeter data and products from satellites like ASCAT METOP-B and ASCAT METOP-C, provided by the National Oceanic and Atmospheric Administration (NOAA). In the context of thunderstorms and squall lines, MMS uses the FY-2E and G satellites from CMA and the INSAT 3D and 3DR satellites from IMD. Satellite data is not used for monitoring wind-related hazards.

MMS has established several means for accessing satellite data. This includes maintaining a CMACast reception station and accessing INSAT 3D and 3DR satellite images through web-based platforms. In addition, MMS obtains open-source Altimeter, ASCAT METOP-B and ASCAT METP-C satellite products (NOAA) via the internet. These multiple channels ensure a diverse and robust data stream for hazard monitoring. However, it should be noted that the heavy reliance on external satellite data is an issue for nowcasting in the tropics, due to delays in receiving the information.

Data sharing and data management

MMS faces certain challenges in data sharing and interagency cooperation. At present, there is no established national agreement within the WMO Integrated Global Observing System (WIGOS) framework for the integration and open sharing of observations from both NMHS and non-NMHS sources. This absence of a formalised partnership agreement may limit the seamless exchange of vital observational data.

Within MMS, there are no specific data policies and practices for sharing observation data. While data generated by MMS can be provided to users upon request free of charge, there is no comprehensive data sharing policy or established practices in place. This may impact the accessibility and consistency of data sharing. Despite this, MMS has some established agreements and interagency protocols for data exchange related to monitoring systems and baseline data necessary to produce data products for various hazards. For example, MMS has a memorandum of understanding (MoU) established with the Civil Aviation Authority and Maldives Airports Company Limited. Under the Disaster Management Act (2015), MMS is also mandated to provide hazard data to the National Disaster Management Authority (NDMA). Although these agreements are in place, they are described as being only partially effective, suggesting that further enhancements and clarifications may be required for more robust and seamless data exchange, particularly in the context of priority hazards such as wind, flash floods, high seas, thunderstorms, and tropical cyclones.

Furthermore, MMS does not currently possess a system for quality control, archiving, and sharing of observational data. The absence of such a system may affect data management and the long-term preservation of critical meteorological information. In addition, the presence of multiple data platforms presents a challenge – for example, forecasters must refer to many different platforms to make an informed decision. MMS is currently involved in an integration project so that all climate data is available on a single platform (COROBOR). Once materialised, this should solve issues relating to equipment compatibility.

General forecasting capacity

MMS actively utilises forecast products from various World Meteorological Centres (WMCs) and Regional Specialized Meteorological Centres (RSMCs) to support its service delivery. These sources include the Korea Meteorological Administration (KMA), China Meteorological Administration (CMA), European Centre for Medium-Range Weather Forecasts (ECMWF), India Meteorological Department (IMD), Regional Integrated Multi-Hazard Early Warning System (RIMES), and the UK Met Office (UKMO). MMS generally experiences reliable access to products provided by global and regional centres, ensuring a continuous flow of critical meteorological information.

The types of forecast products obtained encompass a range of formats, including charts, images, texts, and gridded data, with the latter primarily sourced from ECMWF. The gridded data is employed by the MMS for generating spatial plots, enhancing their ability to visualize and understand meteorological phenomena. While MMS staff have acquired proficiency in accessing and utilising the available resources, they have not received any official training in this regard.

Since February 2023, MMS has collaborated with ECMWF through the WMO scholarship scheme, which is part of a wider programme designed by WMO to expand its international network of cooperation opportunities between weather forecasters from different countries.[324] This is a good example of international training opportunities aimed at increasing the capacity of MMS staff in Numerical Weather Prediction (NWP).

MMS releases forecasts and warnings based on deterministic NWP. To achieve this, MMS utilises a diverse set of NWP models, each with its own unique capabilities and attributes. These models include the following:

- **ECMWF:** This model offers a maximum lead time of 10 days, with a spatial resolution of 9 km and a temporal resolution of 6 hours.
- **WRF:** The Weather Research and Forecasting model provides a maximum lead time of 3 days, with a spatial resolution of 27 km and a temporal resolution of 1 hour.
- **UM-UKMO:** Utilising the Unified Model from the UK Met Office, this model offers a maximum lead time of 7 days, with a spatial resolution of 27 km and a temporal resolution of 3 hours.
- **IMD model output (WRF):** The MMS relies on output from the India Meteorological Department (IMD) model, which has a maximum lead time of 5 days, a spatial resolution of 3 km, and a temporal resolution of 3 hours.
- **CMA model output:** Output from the China Meteorological Administration (CMA) model is used, offering a maximum lead time of 144 hours, a spatial resolution of 0.5 degrees, and a temporal resolution of 6 hours.

[324] ECMWF, 2023. Maldives Meteorological Service and ECMWF collaborate through the WMO Fellowship Scheme. Available at: https://www.ecmwf.int/en/about/media-centre/science-blog/2023/maldives-meteorological-service-and-ecmwf-collaborate

- **JMA model output:** Data from the Japan Meteorological Agency (JMA) model is incorporated into their forecasting efforts, providing a maximum lead time of 10 days with a 6-hourly temporal resolution.
- **Oceanic model:** The MMS also utilises oceanic models, including those from the Indian National Centre for Ocean Information Services (INCOIS) and the WAVE4M model, which is supported by Italy and, in the near future, by USAID.

The WRF model is the only one run in-house by MMS. However, data assimilation and verification methods need to be developed for the model. Lack of ground-truthing of NWP model outputs (in part, due to insufficient observational data) means that the reliability of NWP predictions is not assessed, and on-the-ground meteorological significance cannot be confirmed.

Weather forecasts provided by MMS are very regionalised (i.e., broadly refer to the north, central, or south areas), meaning that information has limited practicality for the island context. The 9 km resolution ECMWF products perform reasonably well on average, especially over relatively larger islands such as Male' City, a high miss rate is likely over smaller islands. Whilst some research has been undertaken to validate ECMWF weather forecasts for the Maldives,[325] further studies are required in this area and there is a need for universities and academia to fill this gap.

While MMS does not directly release forecasts and warnings based on probabilistic NWP, it should be noted that probabilistic NWP (from global NWP and climate prediction centres) is used as a valuable reference in the forecasting process. This means that while probabilistic forecasts may not be published as standalone products, they play a role in enhancing the overall accuracy and reliability of MMS' weather predictions.

MMS currently lacks the capacity to post-process NWP data, including Ensemble Prediction System (EPS) products. The absence of post-processing capabilities means that MMS does not perform additional statistical or numerical operations on the NWP data to generate ensemble forecasts or other probabilistic products.

In terms of NWP equipment, MMS employs a range of hardware and software resources to support their forecasting activities. Hardware includes mini server PCs and desktop PCs, while software tools such as Python, QGIS, and ArcGIS are used to facilitate data analysis, visualisation, and other critical tasks related to weather forecasting and monitoring.

Impact-based forecasting capacity

While MMS provides traditional forecasts and warnings, it does not currently have capacity to produce impact-based forecasts and warnings. Incorporation of impact-based forecasting (IBF) principles represents a major opportunity for MMS to enhance its service provision. To bolster IBF capabilities, it is essential that forecasters receive training in IBF principles, methods, and application. Currently, few staff members within MMS have received such training, indicating room for expansion in this area.

A key limiting factor for IBF is that whilst MMS has thresholds set from a meteorological perspective, alert thresholds must also account for ground realities (e.g., city islands can flood more quickly due to having large amounts of infrastructure). There is a need for inter-agency dialogue on the practicality of thresholds (considering factors such as population and geography), which should include MMS, NDMA and MRC.

Access to impact information from various sectors and post-disaster analytics is currently limited for MMS. The incorporation of such information into impact-based forecasts could significantly improve the quality and relevance of warnings. In addition, it should be noted that the use of hazard-specific impact models is not a current practice within MMS, and responsibility for impact modelling lies primarily with other agencies or ministries.

MMS lacks sufficient resources for producing impact-based forecasts and warnings. There is a need for investment in appropriate software tools to enable MMS to develop more sophisticated and impactful

[325] ECMWF, 2023. Maldives Meteorological Service and ECMWF collaborate through the WMO Fellowship Scheme. Available at: https://www.ecmwf.int/en/about/media-centre/science-blog/2023/maldives-meteorological-service-and-ecmwf-collaborate (Accessed: 8 August 2024)

forecast and warning products. This includes investing in enhanced computation capacity to enable NWP models to be run at higher resolution.

Warning services and MHEWS operations

MMS operates its warning and alert service 24/7 throughout the year, ensuring that it is consistently available to provide timely and critical information to the public. As part of this, MMS has established multi-hazard early warning system (MHEWS). This system is based on the Common Alerting Protocol (CAP), which provides a standardised approach to disseminating alerts and warnings for various hazards.

MMS has defined categories of severity for the issuance of alerts and warnings, which run on a scale of “minor” (white), “moderate” (yellow), “severe” (orange), and “extreme” (red), as illustrated in Table 13. The warning messages issued by MMS include a description of the hazard, but no instructions or guidance on specific actions that could be taken to reduce risks are provided. Incorporating actionable guidance in warning messages could empower the public and authorities to make informed decisions during hazardous events.

Table 13. Common Alerting Protocol (CAP) categories of severity and thresholds for alerts issued by Maldives Meteorological Service (MMS) for various hazards (Source: MMS)

Hazard	**CAP categories of severity**			
	Minor ***Alert level 1*** ***WHITE***	**Moderate** ***Alert level 2*** ***YELLOW***	**Severe** ***Alert level 3*** ***ORANGE***	**Extreme** ***Alert level 4*** ***RED***
Heavy Rain and Flood	50 mm in 1 hour or 80 mm in 6 hours	70 mm in 1 hour or 100 mm in 6 hours	90 mm in 1 hour or 120 mm in 6 hours	180 mm in 6 hours
Thunderstorms	Significant thunderstorm reported and evidence from Satellite/ Radar/ Lightning Detection Network (LDN)	Moderate thunderstorm observed and evidence from Satellite/ Radar/ LDN	Severe thunderstorm observed or evidence from Satellite/ Radar/ LDN	-
Wind and Seas	19-24 mph (past 3 hrs) or 22-27 mph (past 1hr), or forecast to meet this condition	25-30 mph (past 3 hours) or 28-35 mph (past 1 hour), or forecast to meet this condition	34-40 mph (past 3 hours) or 36-42 mph (past 1 hour), or forecast to meet this condition	> 40 mph (past 3 hours) or > 42 mph (past 1 hour), or forecast to meet this condition
Squalls (Frequent Gusts)	50 mph	55 mph	63 mph	70 mph
Swell and Tidal Waves (Observed or forecast)	Observed or forecasted (minor impact)	Observed or forecast (affect at least five islands)	Observed or forecast (affect at least ten islands)	Observed or forecast (extreme impact based)
Tropical Cyclone (TC)	Regional Specialised Meteorological Centre for TC over North Indian Ocean declare TC centre within latitude 5°S - 12°N, longitude 66°E - 81°E box	TC track towards Maldives and expect to cross Maldives atolls in next 24 hours	TC track towards Maldives and expect to cross Maldives atolls in next 12 hours	TC track towards Maldives and expect to cross Maldives atolls in next 6 hours
Earthquake (Occurred)	Richter magnitude > 6 within 400 km of Maldives Exclusive Economic Zone (EEZ). Or Richter magnitude > 7 in Indian Ocean within 4000 km of Maldives EEZ	Richter magnitude > 7 within 400 km of Maldives EEZ. Or Richter magnitude > 8 in Indian Ocean within 4000 km of Maldives EEZ	Richter magnitude > 8 within 400 km of Maldives EEZ. Or Richter magnitude > 9 in Indian Ocean within 4000km of Maldives EEZ	Richter magnitude > 9 within 400 km of Maldives EEZ
Tsunami	Magnitude > 8 in Indian Ocean within 4000km of Maldives EEZ. Or confirmation of Indian ocean wide	Magnitude > 9 in Indian Ocean within 4000 km of Maldives EEZ. Or confirmation of Indian Ocean wide	Confirmation of Indian Ocean-wide Tsunami of high impact to Maldives	Confirmation of Indian Ocean-wide Tsunami of extreme impact to Maldives

	Tsunami of low impact to Maldives	Tsunami of moderate impact to Maldives		

MMS disseminates advisory information that alerts the public to the potential hazard. No information is provided about potential impacts, although MMS intends to develop this capability in the future. Currently, alerts are at atoll level. As its core systems are strengthened, MMS aims to reach every community in the country with information, alerts, and early warnings.

Existing warning services cover a range of priority hazards, including tsunami, tornado, storm surge/coastal flood, wind, tropical cyclone, thunderstorms/squall lines, high seas/rogue waves, rain/wet spells, lightning, and flash floods. In some cases, MMS relies on Regional Specialised Meteorological Centre (RSMC) advisories as the basis for issuing local warnings, ensuring alignment with international standards. The use of a Flash Flood Guidance System for issuing flash flood warnings is not currently implemented by MMS. However, MMS maintains a warning and forecast archival system for all priority hazards, ensuring that historical data is accessible for reference, research, and verification processes.

Climate services

Maldives has established national governance mechanisms to facilitate coordination for climate services. These mechanisms align with climate change adaptation and mitigation efforts outlined in the National Determined Contribution (NDC). Maldives has also embraced an open data policy, reinforced by a presidential instruction to respond to data requests within three days. These governance structures provide a foundation for coordinating and integrating climate services into national adaptation planning.

MMS maintains basic fundamental climate systems, including observing networks, data management, and forecasting systems. These systems support the production and delivery of climate information and services. This includes time series plots of temperature, rainfall, sunshine, and wind. MMS also provides seasonal climate outlooks and generates monthly climate reports, which are distributed through the Global Telecommunication System (GTS) and the MMS website. Seasonal and sub-seasonal forecasts are made available on the website and discussed during the South Asian Seasonal Climate Outlook Forum (SASCOF).

It is important to note that there are no dedicated staff specifically allocated to climate service provision, which may affect the depth and customisation of services. Maldives is also yet to establish formal technical advisory services and training programs to address capacity development needs related to climate service provision and use.

Mechanisms for user interaction and engagement in climate services are present. The annual Monsoon Forum serves as a platform for dialogue and feedback. Additionally, MMS offers a dedicated email and maintains an informative website to facilitate communication between climate service users and providers.

The implementation of a robust climate database management system with end-user production capabilities is imperative but currently lacking. Such a system would enable the efficient collection, management, and dissemination of climate data and information, fostering accessibility and usability. In terms of data rescue, efforts have been undertaken across various variables. However, there are still records that are unavailable and scattered in other institutions.

There is no structured mechanism for monitoring and evaluating the socio-economic benefits of climate services. While climate data is available, its direct translation into quantifiable socio-economic impacts remains an area for further development.

Hydrological services

The relevance of hydrological services to Maldives is low due to its geographical characteristics (mainly lack of rivers, lakes, and glaciers). MMS is mandated by the government to carry out activities related to meteorology, tsunamis, and earthquakes. There is no single authority responsible for carrying out tasks related to hydrology. Hence, standard products such as quantitative precipitation estimation and forecasts (QPE/QPF) are not made ready and produced on a routine basis within MMS. The QPE is produced based on demand from the hydrological research community.

There is no SOP for the exchange of information between MMS and hydrological agencies, as the state tasks for hydrology in the Maldives is not carried out by a single organisation. There is also no clear flood management plan currently established in the Maldives. Although accessible for flood prediction, QPE/QPF data is yet to be verified to evaluate the longer-term effects of climate change or the availability of hydrological groundwater.

MMS does not currently share hydrological data. However, it has committed to responding to any data requests from local and national agencies or across international borders within three days. This is a regulation related to open data policy regulating government institutions under the instructions of the President's Office of the Maldives.

6.1.3 Dissemination and communication

Organisational and decision-making processes

Maldives Meteorological Service (MMS) delivers warnings in the Common Alerting Protocol (CAP) format, ensuring that alert messages are aligned with international standards and can be effectively disseminated to the public and relevant authorities. There are four alert levels:

- *Alert Level 1*: Low/White. It is used for low-impact disaster events that can be managed locally without the need for emergency declaration; the National Disaster Management Authority (NDMA) and the National Emergency Operations Centre (NEOC) are in normal duty status.
- *Alert Level 2*: Serious/Yellow. It is declared for events affecting 10-20% of households in a community, city, or atoll. Typically, one or more islands within an atoll are impacted, requiring the activation of atoll or city-level resources and emergency systems. Community Emergency Response Teams (CERTs) are deployed; NDMA and NEOC may be activated.
- *Alert Level 3*: Significant/Orange. It is issued when multiple islands within an atoll or multiple atolls within Maldives report a disaster event, with at least 20-50% households of the atoll or country being affected. Support from the NDMA is requested; CERTs and National Emergency Response Force (NERF) are likely to be deployed.
- *Alert Level 4*: Catastrophic/Red. Occurs when at least half of the country's population may be affected by a major incident. It requires immediate action from the central government. The NEOC is activated; CERTs and NERF are deployed. Regional and international assistance may also be requested.

MMS has established standard operating procedures (SOPs) in coordination with registered authorities and stakeholders. MMS' SOPs are synergised with those of other stakeholders in order to help streamline communication and response efforts. Such stakeholders include NDMA, Airport Emergency Operation, Education Sector Schools, Government Ferry Transport, Coast Guard, and Marine Police. These SOPs are tailored to different hazard types, including wind, flash floods, high seas/rogue waves, thunderstorms/squall lines, and tropical cyclones. The flow of alert messages and warnings from MMS is shown in Figure 55 below.

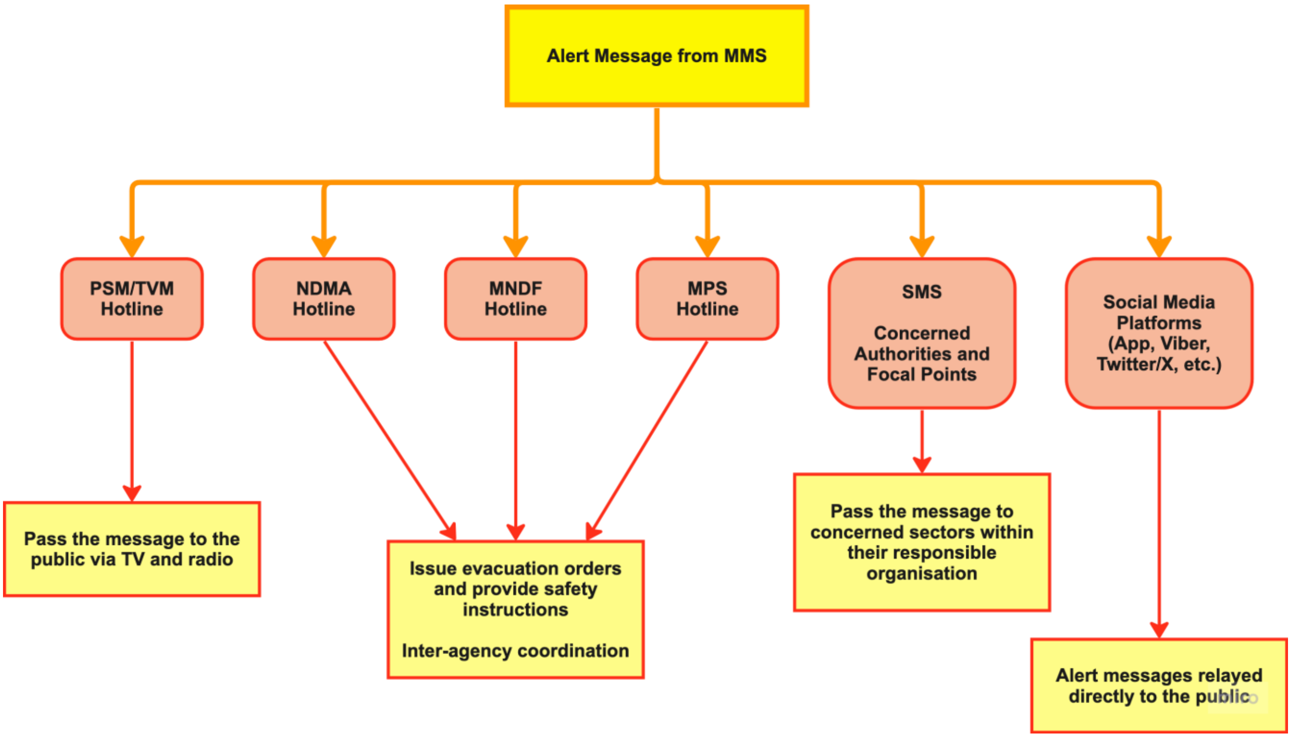

Figure 55. Flow of alert messages and warnings from Maldives Meteorological Service (MMS)

Communication systems and equipment

MMS employs a range of communication channels to disseminate weather information and products, including television, radio, web applications developed in-house, social media platforms, mobile phone applications (both in-house and third-party), as well as SMS text messaging and push notifications. MMS operates a weather studio that functions 24/7, providing continuous monitoring and updates on weather conditions and forecasts. Radio channels are utilised as a primary means to review and disseminate up-to-date weather information.

Terrestrial Trunked Radio (TETRA)

The Terrestrial Trunked Radio (TETRA) is a mobile radio communication system designed for public safety, military, and other emergency services. It ensures secure and reliable connectivity during disasters and provides voice and data communication services. The existing TETRA network is operated by the Maldives Police Services (MPS).[326]

TETRA systems have the following key components:

- Base stations: act as radio towers providing coverage and relaying calls and data;
- Switching and control systems: ensure network functionality through call setup, handovers, and overall system management;
- User devices: include mobile radio and desktop consoles used for field communications; and
- Encryption and security features: essential to protect sensitive communications.

Currently, 17 base stations are operational across Maldives, with plans to install an additional 4 stations in 2025.

Table 14: Islands with existing and planned TETRA base stations.

Existing TETRA network	TETRA network expansion in 2025
1. HA. Dhidhdhoo 2. HDh. Kulhudhuffushi 3. Lh. Naifaru	1. S. Gan 2. N. Manadhoo 3. R. Maduvvari

[326] Communication Authority of Maldives, 2012: Project Brief – Strengthening National Early Warning System and establishing Emergency Telecommunication System in the Maldives. Prepared for National Disaster Management Center.

4. B. Eydhafushi 5. K. Malé 1 6. K. Malé 2 7. K. Hulhumalé 8. K. Dhoonidhoo 9. L. Fonadhoo 10. K.Vilimalé 11. L. Gan 12. GA. Viligili 13. GDh. Thinadhoo 14. Gn. Fuvahmulah 15. S. Hithadhoo 16. S. Maradhoo 17. S. Hulhumeedhoo	4. GDh. Gadhdhoo

In 2018, the company DAMM Cellular Systems was selected to expand the network of TETRA base stations in Maldives. The aim was to cover the entire territory; no further updates on the status of implementation could be found.[327]

Effectiveness of warning communication

There is no end-to-end early warning message dissemination system in Maldives and no mechanism to reach out to differently abled population groups. Current alert messages are hazard based and need to be improved to incorporate impact-based forecasts (for which capacity within MMS is currently lacking). Alerts are currently issued at the atoll level. Investment in enhanced computation capacity is needed for MMS to run Numerical Weather Prediction (NWP) models at higher resolution, which would facilitate more localised forecasting and warning capacity. Currently it is assumed that laypersons can understand the information disseminated by MMS. However, no field-testing has been undertaken to confirm this. There is a need to translate scientific terminology into layperson terms, which could be supported through development of a glossary and training warning disseminators to provide background information to explain forecasts.[328]

There is no formal user feedback mechanism to evaluate the effectiveness of warning communication. However, MMS has conducted (limited) surveys to verify the timeliness and relevance of warnings. A key means of collecting stakeholder feedback is during the annual Monsoon Forum, where MMS engages with all of its major stakeholders. Functionality to obtain user feedback is also established in the MMS mobile app (Moosun). Whilst MMS conducts internal evaluations on its performance and role within the national MHEWS, the country does not have a specific mechanism in place to evaluate the overall performance of the EWS.

6.1.4 Preparedness and response

Institutional arrangements

Maldives has 17 administrative atolls and four city councils across 187 administrative islands. The roles and responsibilities of atoll and island councils were formalised in the Decentralisation Act (2010). Local Councils at the island, atoll and city level are responsible for immediate response actions in the event of emergencies in their jurisdictions. The Local Councils and Disaster Management Committees (DMCs) liaise with both national entities and local volunteer groups to disseminate information to vulnerable communities and to response and coordinating agencies.[329] At the island level, Community Emergency Response Teams (CERTs) conduct response operations in the immediate aftermath of an emergency event. The CERTs are comprised of around 15-20 local volunteers who receive training from national entities such as the Maldivian Red Crescent, Maldives National Defence Force (MNDF), MNDF's Fire Service and Coast Guard, and the Police.[330] The lines of coordination for emergency response are shown in Figure 56. Whilst the Decentralisation Act and its recent amendments have supported empowerment of Local Councils in relation to disaster risk management activities, the formal systems for coordination

[327] dammcellular.com/news/damm-wins-maldives-nation-wide-public-safety-network/
[328] Based on consultations with MMS and MRC
[329] ADRC, 2018. Republic of Maldives – Country Report
[330] Centre for Excellence in Disaster Management & Humanitarian Assistance, 2021. Maldives Disaster Management Reference Handbook

of such activities require further strengthening through standard setting, improved practices, and guidance.[331]

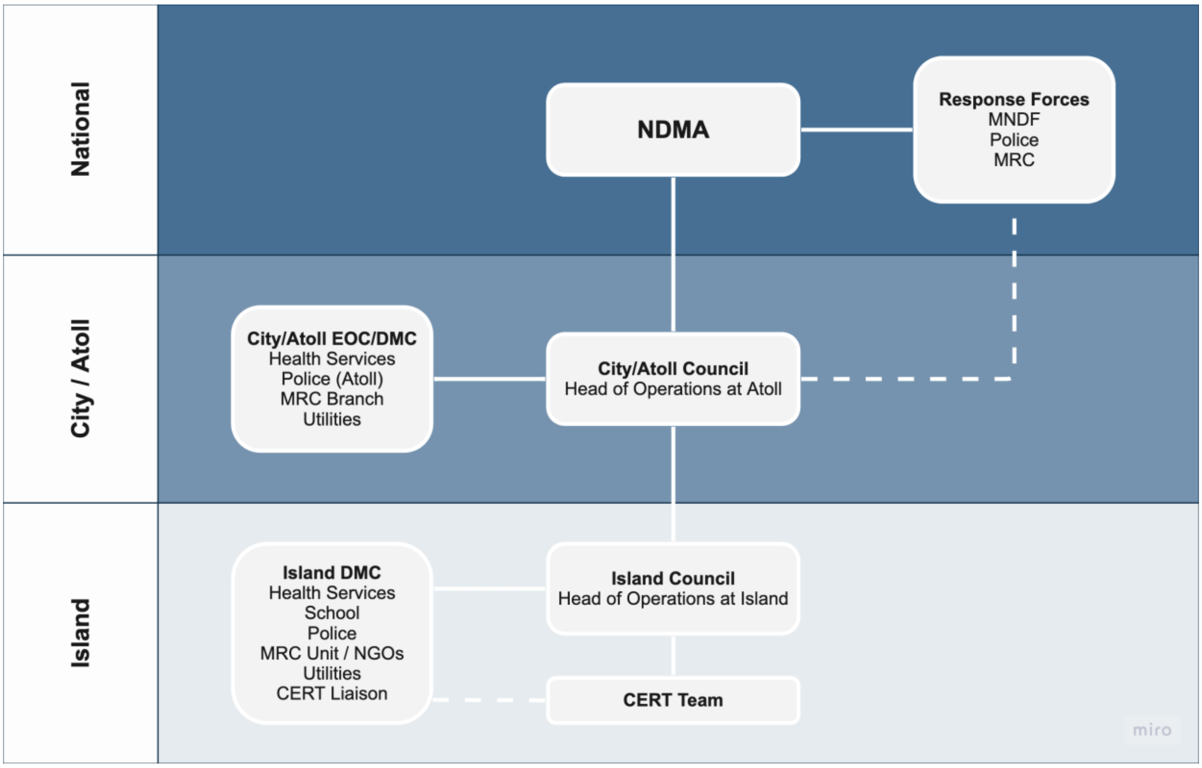

Figure 56. Lines of coordination for emergency response (Adapted from: ADRC, 2018)

Comprehensive Risk Management Policy, Laws, and Strategy

MMS uses the Common Alerting Protocol (CAP) standard for issuing alert messages. There are no standard operating procedures in place in relation to Impact-Based Forecasting and Warning Services (IBFWS) or the Global Multi-hazard Alert System (GMAS).

There are no policies, plans or strategies in relation to forecast-based financing or anticipatory action established. Social protection systems that integrate anticipatory action or preparedness are also lacking.

Institutional preparedness capacities

There is a lack of a "culture of preparedness" and Maldivians generally take it for granted that high impact events occur at low frequency.[332] There is a need for greater consideration of back-up and contingency mechanisms. For example, whilst MMS has SOPs in place for disaster risk management, there is a need to undertake simulations and drills to test the effectiveness of SOPs. At present, backstop drills at MMS are limited to annual testing of the communications line on World Tsunami Awareness Day (5 November).

Local preparedness capacities

At the island, city and atoll levels, Community Emergency Response Teams (CERTs) act as first emergency responder teams. CERTs consist of trained community members who are tasked with assisting the most affected and vulnerable, preventing further loss and damage, conducting initial field assessment, and coordinating relief efforts.[333]

Island Disaster Management Plans (IDMPs) are available for 72 out of the 187 inhabited islands and are used to activate community-level response mechanisms.[334] MMS-issued alert messaging and thresholds are incorporated into the IDMP response structure. The IDMPs aim to reflect understanding of differential

[331] UN Maldives, 2021. UN Joint Programme Document: Sustainable Disaster Risk Reduction, Climate Change Adaptation and Mitigation in Maldives
[332] Based on consultations with MMS, NDMA and MRC
[333] Centre for Excellence Disaster Management Reference Handbook, Maldives, 2024.
[334] Centre for Excellence Disaster Management Reference Handbook, Maldives, 2024.

needs, risks, and capacities (i.e., how sex, gender, identity, age, physical ability, ethnicity, nationality, or other factors can influence how a person is affected, and how they can respond and recover). This is in part facilitated by community-level Hazard Vulnerability and Capacity Assessments (HVCAs).

There is no formal contingency planning undertaken based on forecasts across different timescales (short-term, seasonal, long-term) or informed by climate projections and scientific research.

Sectoral plans are available to facilitate the responses of critical services. These include the Health Emergency Operations Plan (2018) and the National Emergency Operations Plan (NEOP). It should be noted that whilst NDMA continues to use and update the NEOP, it has not been officially endorsed; NEOP is also not mentioned in the Maldives Disaster Risk Reduction Strategy 2024-2030, which was endorsed in December 2024.[335,336] There are no established protocols to evacuate last-mile operators (e.g., local police, firefighters, volunteers, health services) involved in disaster response.

Public awareness and education

Public awareness and education on hazards, vulnerabilities, exposure, and how to reduce disaster impacts is limited. Awareness programs, interviews with facilitators, and visibility campaigns (including radio spots) are used to promote and disseminate information. MMS collaborates with island communities, MRC, local government officials, and disaster management actors to organise outreach activities. College students frequently visit MMS or outer island observation stations as part of a community awareness program. NDMA publishes disaster advisories in moderate impact emergencies.

There is no public education on recognising hydrometeorological and geophysical hazards, and limited education on how warnings will be disseminated, which sources and reliable, and how to respond. MMS has undertaken some initiatives with CSOs (mostly MRC) to reach vulnerable and marginalised groups. However, in general, awareness and education campaigns are not tailored to the specific needs of vulnerable groups (e.g., women, children, older people, illiterate people, and persons with disabilities) and no leadership of awareness and education campaigns by women's organisations or other organisations representing the interests of vulnerable groups.

Testing and evaluation

Drills and simulations are undertaken to test the effectiveness of response mechanisms. However, there is little understanding of the effectiveness and reach of early warning dissemination or preparedness measures. Public awareness strategies and programmes are not evaluated regularly or updated as required. Testing and optimisation of the inclusiveness and accessibility of warning dissemination, preparedness and response measures is also lacking.

The HVCAs use seasonal and past events to understand likely emergency scenarios, which can then inform the development of IDMPs. In general, post-impact analyses and incorporation of lessons learned into preparedness and response plans remains limited.

Financing and delivery mechanisms for preparedness and anticipatory action

Anticipatory action mechanisms or response options linked to the provision of funding to support them have not been established. There are also no strategies available/implemented to maintain preparedness for longer return periods or during cascading hazard events. Investments in forecast-based actions, preparedness/anticipatory actions, and operational capacity development are lacking.

Some level of funding exists in the national budget and/or other pre-arranged and reliable funding sources for specific preparedness and response actions – e.g., CERT trainings and provision of response equipment to island communities. The national budget does not include any funding allocation for the development of anticipatory action plans.

6.1.5 Cross-cutting

Governance, policy, and legislation

Maldives has a national legal and institutional framework in place in the form of the Disaster Management Act (2015) that provides the basis for the implementation of early warning systems (EWS). Part V, clauses

[335] CFE-DM, 2021. Maldives Disaster Management Reference Handbook
[336] NDMA, 2024: Disaster Risk Reduction Strategy, Maldives.

(U) to (W) of the Act states: “Establish and maintain multi-hazard early warning systems, disseminate disaster warnings to the public, and ensure information availability in multiple languages during disaster situations.” Whilst the Act states that an end-to-end EWS should be established, Maldives lacks a national policy that provides comprehensive guidance for the development and operation of EWS. In addition, no specific legislation on EWS exists.

The Act stipulates the establishment of a national Disaster Management Steering Committee (DMSC), which includes members appointed from the NDMA, MMS, Ministry of Health, Ministry of Finance (MoF), Ministry of Infrastructure, Local Government Authority, Maldives Police Service and Maldives National Defence Force. The DMSC can appoint experts of various sectors as members of the committee. It can also form sub-committees and nominate experts to provide advice. Experts are regarded as academia and scientific and technical actors. The Act also outlines roles and responsibilities of the private sector and civil society organisations. It should be noted that whilst the DMSC has been established through the Disaster Management Act, it has not yet been operationalised in practice.

Maldives does not have any formal agreements or interagency protocols for data exchange in relation to hazard monitoring. However, there are bilateral and multi-lateral agreements in place to facilitate cross-border exchange of warnings with neighbouring countries. National warnings are shared in Common Alerting Protocol (CAP) format through the WMO Alert Hub and within the Intergovernmental Oceanographic Commission of UNESCO (IOC/UNESCO) framework. Regional warnings on tsunamis are coordinated through the Regional Specialised Meteorological Centre (RSMC) in Delhi for tropical cyclones. Maldives is also a member of the Indian Ocean Tsunami Warning and Mitigation System (IOTWS) and the WMO/ESCAP Panel on Tropical Cyclones. MMS receives regional warning information from the abovementioned sources.

Regarding gender equality and social inclusion, whilst no specific EWS policies and legislation exist, the Constitution of the Maldives as the supreme law of the country promotes gender equality and non-discrimination through its bill of rights. The Disaster Management Act stipulates that the State should not discriminate against anyone in matters relating to disaster management. However, the Act does not include provisions relating to women or gender and it does not make reference to the representation or participation of women within the institutional arrangements.[337]

Coordination

Limited stakeholder mapping has been undertaken in areas related to disaster risk management and climate change. There is no overarching institutional framework that clearly defines the roles and responsibilities of government agencies, civil society organisations, and other stakeholders involved in the implementation of EWS. Nevertheless, the government-approved mandates of MMS and NDMA recognise their roles in hazard information provision and disaster risk management, respectively.

There is no operational multi-stakeholder platform dedicated to facilitating coordination and collaboration among stakeholders in EWS. However, the DMSC is recognised for its potential to serve this purpose. There is also no formal multi-sector consultative platform specifically dedicated to meteorological and hydrological services in Maldives, although MMS does engage with stakeholders from various sectors, including agriculture, fisheries, gender, and local government.

There is limited/no representation of key communities (including women, persons with disabilities, youth, rural communities) as stakeholders in the development and implementation of EWS. The views and perspectives of these communities are reportedly not taken into account in decision-making processes.

Communication and advocacy

There is no national communication plan or strategy in place to promote the benefits of EWS. No specific awareness-raising activities or campaigns are conducted to inform the public, relevant stakeholders, or decision-makers about the importance of EWS and their benefits. However, the community-based disaster risk management (CBDRM) programmes conducted by NDMA, and the Maldivian Red Crescent include awareness-raising components.

There is limited engagement of key stakeholders (including government agencies, civil society organisations, private sector, local communities, and volunteers) to build consensus and support for the

[337] IFRC, 2021. IFRC Disaster Law – Maldives Disaster Management Act 2015. Available at: https://disasterlaw.ifrc.org/dmi/dmi_country/61

implementation of EWS. However, the level of engagement has increased in conjunction with the launch of the EW4All initiative in Maldives. Media engagement workshops/activities have been undertaken. However, further capacity building is required to promote the role of the media in awareness raising, disaster risk reduction and preparedness.

Planning and finance

Existing financial resources are inadequate to support the development and implementation of an end-to-end, impact-based multi-hazard early warning system and early action in Maldives. National actors are highly reliant on donor funding, particularly for new investments. National budget allocations are insufficient to fully cover the operation and maintenance of existing equipment.

There is no sustainable financing mechanism in place to ensure long-term continuity of EWS. There is also no mechanism (i.e., public-private partnerships or other innovative financing approaches) for mobilising financial and other resources for the development and implementation of EWS. Moreover, MMS lacks the legal status to formally engage in partnerships with the private sector.

The MoF has made steps to track climate-related expenditures and Climate Budget Tagging has been proposed. However, there is currently no specific mechanism to track finance for anticipatory action in the national budget. Whilst the MoF publishes budget-related statistics and data, transparency and accountability in the planning and financing of EWS is limited.

Monitoring and Evaluation

There is no clear mechanism for monitoring and evaluating the effectiveness of EWS in Maldives. This includes a lack of clear and well-defined objectives or performance indicators. There is no reliable and consistent system for collecting data on EWS activities and no feedback mechanisms in place covering the effectiveness of EWS across different sectors and stakeholders.

6.2 Gaps and needs for climate information and early warning systems

6.2.1 GBON National Gap Analysis

Under the Readiness Phase of the Systematic Observations Financing Facility (SOFF) for Maldives (April – September 2023), the Finnish Meteorological Institute (FMI) conducted an analysis of the Global Basic Observing Network (GBON) gap. The key recommendations for actions to be undertaken during the SOFF investment and compliance phases are summarised below.

- Renewal of the upper-air sounding station in Gan
- Renewal of thermometers and wind sensors in all GBON stations, and automation of the stations for GBON variables (sea-level pressure, temperature, humidity, wind, precipitation)
- Installation of one new surface observation station (in Maafaru)
- Commencement of one-hour observation/data sharing cycle in all GBON stations
- Implementation of WIS2.0 compliant data sharing
- Establishment of spare part stock, design of calibration procedures, and training of staff.

6.2.2 GBON National Contribution Plan

As part of the Readiness Phase of the SOFF project for Maldives, FMI also developed a GBON National Contribution Plan, which identifies key required activities for achieving sustained GBON compliance. While most of the identified needs will be addressed through the SOFF investment, several recommended activities are beyond the scope of the SOFF project and thus should be considered for inclusion under the proposed GCF project. These activities are outlined below:

- Strengthen partnerships and collaboration with various stakeholders, such as:
  - Civil Aviation Authority (CAA) – on providing Aeronautical Meteorological Services
  - National Disaster Management Authority (NDMA) – on providing early warning information and development of impact-based forecasts
  - Velana International Airport - on providing weather and climate information and warning to support airport operation
  - Island Councils – on disseminating information to communities

- Water management authority – on providing weather predictions related to the harvesting rainwater.

- Develop a cost recovery mechanism and update it regularly to include targeting of more sectors, should new opportunities arise.
- Develop and implement a data sharing policy with established data pricing procedure, which could also contribute to cost recovery.
- Support MMS to provide improved services and greater accuracy of alerts and warning information for various sectors (sector-based and impact-based forecasting).
- Improve the timeliness, accuracy, and ease of comprehension of alerts and warning information from MMS and contextualise information locally.

6.2.3 Country Hydromet Diagnostics

The Country Hydromet Diagnostics (CHD)[338] identified several key needs and recommendations for improving MMS capabilities according to the ten key elements of the hydromet services value chain. These are detailed in Table 15 below.

Table 15. Key needs and recommendations for MMS identified through the Country Hydromet Diagnostics

Element	Maturity Level[339]	Key needs and recommendations for MMS
1. Governance and institutional setting	3	• Finalise the Meteorological Act and commence cost recovery activities to ensure sustainable funding for crucial services • Initiate strategic planning processes with annual monitoring and clearly defined responsibilities to provide a structured framework for organisational development • Develop mid- and long-term strategic plans for capacity development
2. Effective partnerships to improve service delivery	3	• Develop a comprehensive partnership strategy to strengthen the position of MMS in resource allocation and financial decision-making • Increase coordinated stakeholder consultation mechanisms, building on the Monsoon Forums, to facilitate more structured and inclusive dialogue • Develop a strategic plan and development roadmap to guide MMS' growth and strengthen partnerships
3. Observational infrastructure	3	• Achieve compliance with GBON requirements • Improve station operational rates through enhanced maintenance efforts and calibration capacity • Recruit additional staff to support maintenance of observational infrastructure (potentially supplemented by trained local community members) • Explore options for sub-contracted calibration procedures with other countries and/or Regional Instrument Centre(s) • Invest in stock of spare parts to fill gaps in instruments under calibration • Establish a national governance mechanism within the WMO Integrated Global Observing System (WIGOS) framework • Establish a process for acting on data quality issues received from the WMO Information System (WIS) Data Quality Monitoring System (WDQMS)
4. Data and product sharing and policies	3	• Establish a centralised data collection, management and dissemination system with capacity for stakeholder data dissemination • Expand international data sharing practices • Migrate to the use of WIS 2.0 protocols for data transfer • Establish coordination mechanisms with other ministries, institutions and local governments that have potential to conduct hydrometeorological observations

338 Further details on the CHD are provided in Section 6.1.2
339 Assessed on a scale of 1-5 (5 being the highest) and collectively agreed upon by the Finnish Meteorological Institute (FMI), Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) and MMS

5. Numerical weather predication model and forecasting tool application	3	• Invest in improved resources, including strengthening technical capacity of staff and training of IT and modelling experts • Install a High-Performance Computing (HPC) system (alongside adequate training of staff to manage the HPC) • Implement post-processing methods, such as Model Output Statistics (MOS), to enhance forecast accuracy • Expand the forecast range and improve the spatial resolution of existing Weather Research and Forecasting (WRF) model outputs • Conduct data assimilation covering surface observation stations, soundings and radars • Archive raw model data in a centralised storage system to enabling building of model climatology and development of time-lagged ensemble forecasts • Consider using cloud computing for heavy model post-processing • Implement a centralised data management system capable of integrating both internal and external model data and conducting post-processing operations; the data management system should include or be integrated into the forecaster workstation tool and automated forecast production system
6. Warning and advisory services	3	• Conduct regular evaluations on the performance and accuracy of warnings • Initiate continuous operational verification of warnings • Establish user feedback mechanisms to ensure that warnings are timely, relevant and reliable; conduct user surveys on warning services • Implement a Quality Management System (QMS) tailored to warning services • Include instructions/statements for action in communications to empower the public and authorities to take appropriate measures in response to weather-related hazards • Implement impact-based forecasting (IBF) • Identify and develop sectoral-based and locally contextualised warnings • Develop weather radar-based nowcasting algorithms (e.g., MAPLE or PySTEPS) to improve the accuracy and timeliness of short-term weather predictions • Use satellite-based products (e.g., GSMAP RIKEN NOWCAST) for nowcasting references
7. Contribution to climate services	2	• Recruit dedicated staff members specifically tasked with climate services provision and capacity building • Implement a climate database management system (CDMS) with end-user production capabilities • Improve coordination and communication efforts among relevant institutions and stakeholders to facilitate creation of more specific and tailored climate information, and enhancement of observation and data sharing • Conduct impact-based analyses and/or loss and damage assessments for weather and climate services across various sectors
8. Contribution to hydrology	1	• Increase interaction with the hydrological sector • Provide climate information and services considering the long-term impact of climate change on hydrological ground water availability
9. Product dissemination and outreach	3	• Enhance the level of information provided on the MMS website • Expand sector-based warnings (beyond aviation and tourism) to cover health, agriculture, water resources, and climate change • Conduct more awareness-raising and capacity building activities with the end-user community • Increase the number of end-user products • Implement automated forecast production processes and forecast production tools to enable implementation of more dissemination methods

10. Use and national value of products and services	2	• Establish a continuous user engagement process that encompasses all service fields of MMS; facilitate user feedback through various channels (e.g., website, mobile application) • Expand implementation of QMS to cover all operational fields of MMS

6.2.4 Recommendations from WMO climate analysis

Below are modelling and data-related recommendations arising from the climate analysis conducted by WMO (see Section 2). They are listed in no particular order.

Climate analysis

- **Comparison of CMIP6 downscaled products over the Maldives:** At least two statistically downscaled CMIP6 products exist that are freely accessible[340,341] (though note the problem identified with *Thrasher et al.* in Section 2.3.2). The next phase of CORDEX is also dynamically downscaling CMIP6 data. Downscaled CMIP6 products should be compared with each other as well as with their host CMIP6 models, and a subset of these should be recommended for use in future climate adaptation projects in the Maldives. This selection should then be publicised. This will reduce duplication of effort between adaptation projects, avoid instances where model selection is made blindly, and provide consistency of results and assumptions between climate assessments. This is not an activity required to justify current requests for climate finance but is a worthy pursuit for any potential climate service that may be established.
- **Investigate statistical downscaling of MMS climate stations:** Related to the above recommendation, methods exist to statistically downscale climate projections to climate station locations. Given the good quality and reasonable length of the five MMS stations (Table 2), this activity is likely feasible and would provide climate projections that are consistent with historical data. Open-source software is available that can perform such downscaling. This downscaled data would be computationally inexpensive to produce and would complement gridded downscaled projections produced by other methods[342].
- **Compound events:** This analysis has assessed historical and projected changes in multiple climate extremes individually. The increasing frequency of climate extremes and the multiplicative effect of extremes occurring at the same time makes assessing changes in the likelihood of compound events necessary (e.g. a simultaneous heatwave and drought). This could be a useful activity for a climate service.
- **Submit MMS climate station data to GHCNd:** The GHCNd database is the primary source of global daily station data and is used in many global products such as reanalyses and blended products that combine remote sensing and stations. The current data held by GHCNd for the Maldives is of extremely poor quality and it would be beneficial for the global community and for the Maldives if the high-quality data held by MMS was submitted to GHCNd. This would improve the performance of future global products over the Maldives.

Data curation and rescue

- **Homogenisation and spatial disaggregation of existing sector data:** Some sector data was sourced from global databases for this analysis. The quality of the data and their homogeneity is uncertain, though clear instances of inhomogeneity exist (e.g. on agriculture data). To allow high-quality statistical comparisons with climate data it is recommended that key time series for each sector are quality controlled and homogenised by sector experts. Which time series these should be requires discussion between sector and climate experts but data with long time series, that are of societal importance and that have known or suspected relationships with weather and

[340] Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P.J., Bennett, G.L., Boothroyd, R., Cloke, H., Delorme, P., Griffith, H. and Hardy, R., 2023. A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), p.611.
[341] Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T. and Nemani, R., 2022. NASA global daily downscaled projections, CMIP6. Scientific data, 9(1), p.262.
[342] Ibid, 340 and 341.

climate should be prioritised. Spatial disaggregation of sector data should also be considered in order to better identify relationships between climate and the sectors. For example, crop data available per atoll would allow local climate data to be used and improve the likelihood of identifying significant relationships.

- **National Disaster Management Authority (NDMA) data curation:** The NDMA is a good example of an organisation with relevant hazard impacts data that could be used to quantify relationships between large scale climate and local impacts. Several examples of this are reported in the Second National Communication[343], including flood events due to rain, number of islands flooded due to waves, reported cases of strong winds and reported tornadoes. However, extension of the datasets published in that document to the present day has not occurred due to the significant human resources required (two to three decades of records required approximately three months of effort from multiple staff[344]). Maintenance of such datasets has obvious benefits for the monitoring and evaluation of adaptation activities but also allows relationships between climate and local impacts to be quantified to demonstrate the need for – and prioritisation of – adaptation activities.
- **Climate data rescue:** MMS have advised that there is approximately ~10-15 years of additional data for each of the five long term stations that requires digitisation. This would significantly increase the utility of the existing time series', which start at the earliest in the 1970's. There would be follow-on benefits for the quality of global datasets that incorporate this data (e.g., climate reanalyses such as ERA5 that assimilate station data). An extra activity could include the scanning of all field logbooks for posterity.

6.2.5 Early Warnings for All Pillar Gap Analysis

In preparation for the development of an action plan on for Early Warnings for All (EW4All) in Maldives, a technical discussion was held to identify technical, financial, policy, and other gaps across the four key elements of multi-hazard early warning systems in Maldives. Key identified gaps and needs are presented below.

Table 16. Gaps and needs in the four pillars of Early Warnings for All identified through technical discussion

Pillar	Gaps and needs
Pillar 1: Disaster Risk Knowledge	• Development/update of risk information to ensure the availability of comprehensive national climate and disaster risk information for Maldives • Update of the national disaster database, incorporating climate-related disasters, including disaster impacts • Development of a standardised disaster risk assessment and methodology, which can be used at national and sub-national levels • Development and mapping of high-resolution bathymetry and specific information/monitoring of coral reef status • Extensive training on climate and disaster risks of NDMA and other relevant ministries/institutions at both national and sub-national levels • Mainstreaming of disaster risk reduction and incorporation of risk information into policies and plans • Public awareness and education on hazards, with supporting materials in Maldivian language, targeted to primary and secondary schools • Strengthened national loss and damage accounting, multi-hazard risk mapping, and capacity building to address risk knowledge gaps relevant to EWS (including infrastructure vulnerability) • Improved access to and use of risk data for impact-based forecasting • Sectoral risk assessments for highly climate-sensitive sectors, such as tourism, food security and telecommunications • Economic impact forecasts for future events (especially for sectors) • Alignment of disaster risk reduction and environmental management

[343] Ministry of Tourism and Environment, 2016. Second National Communication of Maldives to the United Nations Framework Convention on Climate Change: Ministry of Environment and Energy.
[344] Personal communication with the National Disaster Management Authority.

	• Scale up risk education, particularly in remote atolls • Collection of exposure and vulnerability data, particularly targeting persons with disabilities and older people
Pillar 2: Observations and Forecasting	• Achievement of GBON compliance • Expansion of coverage of weather stations (need for individual island coverage; considerations for engagement of tourism sector private actors is encouraged) • Training in operation and maintenance of weather stations (significant proportion of existing stations are not operational) • Increase radar coverage (currently one radar exists with maintenance issues) • Investigate rain cell technology with ICT and the two mobile network operators (estimation of rainfall intensity based on real-time mobile network operations data) • Development of ocean and wave monitoring capacity • Capacity to manipulate big data and ingest it into predictions • Improvement of the warning system, building on optimal access to and usage of available forecast data, resolving infrastructure issues with local computing facility (procurement issues are preventing the setup of the full suite of servers and software already acquired) • Development of impact-based forecasting, in connection with Pillar 1, and its rollout in each island/atoll • Sustain implementation of Common Alerting Protocol (CAP) by MMS (using locally developed CAP editor) • Significant training effort is needed due to insufficient government budget allocation
Pillar 3: Dissemination and Communication	• Development of a dissemination and communication plan/strategy for all islands and atolls, including satellite communication strategy • Appointment of a communication focal point for every island, with responsibility to coordinate regular drills and simulation • Adoption of one emergency number and integration into the NDMO • Adoption of cell broadcasting (noting that there are around ~700,000+ mobile phones, corresponding to an average of 1.4 per person in Maldives) • Development of CAP usage by stakeholders to allow for consistent dissemination across all of society (TV Broadcasters, radios, digital signage systems, sirens and loudspeakers, as appropriate, building on various stakeholder support – including faith-based and tourism sectors) • Establishment of a two-way feedback mechanism (e.g., through a digital platform, providing opportunity to utilise citizen science) • Explore potential to use the National Digital Identity system (recently launched) to disseminate warnings
Pillar 4: Preparedness and Response	• Regular maintenance and update of preparedness and response plans established by local community councils • Ensure that drills and simulations are conducted in each island and atoll • Financial commitment to preparedness and response at both national and local council levels (including consideration to link social protection with EWS and risk transfer) • Technical support and capacity development for Forecast-based Financing / Anticipatory Action • Urban disaster risk management, especially in densely populated communities in Male' and other small islands' capitals • Accelerate behavioural change through better monitoring of how advisories and early warnings are currently crafted and how people respond (including gender analysis)
Cross-Cutting	• Revitalisation of Disaster Management Steering Committee • Monitoring and evaluation of the effectiveness of national MHEWS • Adoption of the Meteorological Act in consistency with other regulatory material • Ensure continuous in-country technical coordination (by UNCT, NDMA and MMS) linked to regional coordination mechanisms

6.2.6 Sector needs assessment for climate information and early warning systems

Key gaps and needs for climate information and early warning systems in priority sectors in Maldives, as reported through national and international policies, plans and assessments, are outlined below.

Agriculture and Food Security

Table 17. Identified gaps and needs for climate information and early warning systems in the agriculture and food security sector

Pillar	Gaps and needs
Pillar 1: Disaster Risk Knowledge	• Prepare adaptation vulnerability assessments for key sectors identified in the National Adaptation Programme of Action (NAPA) (including agriculture and food security)[345] • Analyse and evaluate poverty, health, and food security issues to determine vulnerability to climate change and consider these vulnerabilities in future policies and initiatives for Maldives[346]
Pillar 2: Observations and Forecasting	• Strengthen utilisation of weather and climate data in agriculture[347] • Obtain highly localised agrometeorological data to prepare crop calendars[348] • Develop a roadmap and accelerate efforts towards providing operational hydrological services, which are critical for the agriculture and water management sectors[349] • Incorporate sector-specific risk information to issue impact-based forecasts[350]
Pillar 3: Dissemination and Communication	• Improve quality of early warning messages and alerts distributed through existing applications and establish Common Alerting Protocol (CAP) to enable the best use of information by various industries including agriculture[351]
Pillar 4: Preparedness and Response	• Develop and implement sectoral disaster management plans for critical sectors to ensure business continuity of provision of basic services at national and island level[352] • Strengthen existing climate risk insurance mechanisms for building resilience against the loss of assets and livelihoods due to extreme events • Enhance relief efforts in the post-disaster period taking into account national food and nutrition security[353]
Cross-Cutting	• Develop interagency protocols/SOPs for data exchange, including guidelines for data sharing, data storage, and data access[354] • Strengthen and formalise partnerships with relevant stakeholders, including in data collection and sharing, consultation, and interpretation of results, to assess potential impact of disasters on the industry and improve impact-based forecasting[355]

Education

Table 18. Identified gaps and needs for climate information and early warning systems in the education sector

Pillar	Gaps and needs
Pillar 1: Disaster Risk Knowledge	• Ensure data is fully disaggregated to enable better targeted responses. Data should be disaggregated into meaningful units – e.g., island/school level, gender, urban/rural differences, age, disability needs[356]

[345] Ministry of Environment, Energy and Water, 2006. National Adaptation Programme of Action.
[346] Ministry of Environment and Energy, 2015. Maldives Climate Change Policy Framework
[347] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[348] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[349] FMI, 2023. Country Hydromet Diagnostic for Maldives
[350] FMI, 2023. Country Hydromet Diagnostic for Maldives
[351] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[352] Government of Maldives. Strategic Action Plan 2019-2023.
[353] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[354] Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
[355] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[356] Ministry of Education, 2022. Education Sector Emergency Preparedness and Response Plan

	• Mainstream the collection, management and dissemination of data related to disaster risk reduction and disaster risk management[357] • Identify the key hazards and their potential impacts to school children[358]
Pillar 2: Observations and Forecasting	• Incorporate sector-specific risk information to issue impact-based forecasts[359]
Pillar 3: Dissemination and Communication	• Prepare and disseminate early warning information that alerts decision-makers to prepare for or respond to a crisis[360] • Develop "communication trees" to enable effective delivery of warnings in emergency situations[361]
Pillar 4: Preparedness and Response	• Strengthen education sector-wide risk-informed preparedness and response capacity[362] • Identify organisations or units within organisations that are required to prepare to respond to emergencies[363] • Develop emergency response mechanisms, including stand-by resources, trained staff, equipment, and supplies[364] • Develop disaster risk management plans for all schools[365] • Develop a Climate Literacy Education Programme focusing on hydrometeorological and geophysical hazards and warnings systems and roll it out as a part of school curricula targeted at students, teachers, and parents[366] • Strengthen public information preparedness to enable quick communication about the situation and required actions[367] • Develop a digital platform with online resources, educational messaging on hydrometeorological and geophysical hazards and warnings systems[368]
Cross-Cutting	• Develop interagency protocols/SOPs for data exchange, including guidelines for data sharing, data storage, and data access[369] • Strengthen and formalise partnerships with relevant stakeholders, including in data collection and sharing, consultation, and interpretation of results, to assess potential impact of disasters on the industry and improve impact-based forecasting[370]

Energy

Table 19. Identified gaps and needs for climate information and early warning systems in the energy sector

Pillar	Gaps and needs
Pillar 1: Disaster Risk Knowledge	• Prepare adaptation vulnerability assessments for key sectors identified in the NAPA (including critical infrastructure, e.g. powerhouses and utilities) [371] and subsequent plans and strategies[372]

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[357] Ministry of Education, 2022. Education Sector Emergency Preparedness and Response Plan
[358] Ministry of Education, 2022. Education Sector Emergency Preparedness and Response Plan
[359] FMI, 2023. Country Hydromet Diagnostic for Maldives
[360] Ministry of Education, 2022. Education Sector Emergency Preparedness and Response Plan
[361] Ministry of Education, 2022. Education Sector Emergency Preparedness and Response Plan
[362] Ministry of Education, 2022. Education Sector Emergency Preparedness and Response Plan
[363] Ministry of Education, 2022. Education Sector Emergency Preparedness and Response Plan
[364] Ministry of Education, 2022. Education Sector Emergency Preparedness and Response Plan
[365] Government of Maldives. Strategic Action Plan 2019-2023.
[366] Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
[367] Ministry of Education, 2022. Education Sector Emergency Preparedness and Response Plan
[368] Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
[369] Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
[370] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[371] Ministry of Environment, Energy and Water, 2006. National Adaptation Programme of Action
[372] Ministry of Environment and Energy, 2015. Maldives Climate Change Policy Framework

	• Undertake mapping of critical infrastructure[373] • Develop a Hazard and Risk Index of critical infrastructure and services in major populations[374] • Analyse cascading risks to critical infrastructure and secondary impacts to the socio-economic system[375]
Pillar 2: Observations and Forecasting	• Collect high-quality data on renewable energy resources availability to improve planning[376] • Develop and implement basic climate services (climate database management system, preparation of climate data products based on sectoral needs, alerts and advisories at extended and medium scales) for various sectors, including energy[377] • Incorporate sector-specific risk information to issue impact-based forecasts[378]
Pillar 3: Dissemination and Communication	• Improve quality of early warning messages and alerts distributed through existing applications and establish CAP to enable the best use of information by various industries[379]
Pillar 4: Preparedness and Response	• Develop and implement sectoral disaster management plans for critical sectors to ensure business continuity of provision of basic services at national and island level[380] • Develop guidelines to support integration of disaster risk reduction elements and climate change related risk management strategies into infrastructure development projects[381]
Cross-Cutting	• Develop interagency protocols/SOPs for data exchange, including guidelines for data sharing, data storage, and data access[382] • Strengthen and formalise partnerships with relevant stakeholders, including in data collection and sharing, consultation, and interpretation of results, to assess potential impact of disasters on the industry and improve impact-based forecasting[383]

Health

Table 20. Identified gaps and needs for climate information and early warning systems in the health sector

Pillar	Gaps and needs
Pillar 1: Disaster Risk Knowledge	• Promote research to understand the nexus between climate change and health, such as its impacts on vector-borne diseases, mental health, and air quality[384] • Prepare adaptation vulnerability assessments for key identified in the NAPA (including human health) [385] • Develop a Hazard and Risk Index of critical infrastructure and services in major populations[386]

373 Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
374 Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
375 Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
376 IRENA, 2015. Renewable Energy Roadmap: The Republic of Maldives
377 IMD, 2021. Country Hydromet Diagnostic for Maldives.
378 FMI, 2023. Country Hydromet Diagnostic for Maldives
379 USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
380 Government of Maldives. Strategic Action Plan 2019-2023.
381 Government of Maldives. Strategic Action Plan 2019-2023.
382 Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
383 USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
384 Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
385 Ministry of Environment, Energy and Water, 2006. National Adaptation Programme of Action
386 Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027

	• Analyse cascading risks to critical infrastructure and secondary impacts to the socio-economic system[387]
Pillar 2: Observations and Forecasting	• Incorporate sector-specific risk information to issue impact-based forecasts[388]
Pillar 3: Dissemination and Communication	• Establish an Emergency Communications Framework, which should describe the communication and IT protocols and coordination procedures between response functions during public health emergencies[389] • Develop an effective risk communication plan, and identify and train a focal point to lead communication during emergencies[390] • Collaborate with weather services, disaster management authorities and local administration to disseminate impact-based early warnings on peak temperatures affecting health, WASH, DRR and livelihoods[391]
Pillar 4: Preparedness and Response	• Enhance public health advocacy and awareness activities to reduce vector-borne and other noncommunicable diseases including those driven by heat stress and poor air quality[392] • Monitor health impacts of climate change and develop strategies for reorienting programmes to address the emerging health issues[393] • Provide training to agencies and committees to ensure effective and efficient emergency management when an emergency occurs[394] • Establish a partnership with the Maldivian Red Crescent to develop health sector preparedness and responses in provision of relief, rehabilitation and mitigation in disasters and emergencies[395] • Strengthen implementation of a health sector response plan and standard operating procedures for disasters and more frequent emergencies in alignment with national disaster management plans[396]
Cross-Cutting	• Facilitate integration of climate change into the national health systems to ensure sustainable and climate resilient adaptation measures[397] • Systematically integrate medium- and long-term climate information in healthcare programming to anticipate, prepare for and reduce the health impacts of climate-sensitive diseases e.g. vector-, water- and food-borne diseases, in high-risk rural and urban areas[398] • Strengthen and formalise partnerships with relevant stakeholders, including in data collection and sharing, consultation, and interpretation of results, to assess potential impact of disasters on the industry and improve impact-based forecasting[399] • Develop interagency protocols/SOPs for data exchange, including guidelines for data sharing, data storage, and data access[400]

Marine and Fisheries

Table 21. Identified gaps and needs for climate information and early warning systems in the marine and fisheries sector

Pillar	Gaps and needs

[387] Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
[388] FMI, 2023. Country Hydromet Diagnostic for Maldives
[389] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[390] Ministry of Health, UNICEF & WHO, 2018. Health Emergency Operations Plan.
[391] IFRC, 2021. Climate Change Impacts on Health and Livelihoods: Maldives assessment
[392] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[393] Ministry of Health, 2014. Maldives Health Master Plan 2016-2025.
[394] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[395] Ministry of Health, 2014. Maldives Health Master Plan 2016-2025.
[396] Government of Maldives. Strategic Action Plan 2019-2023.
[397] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[398] IFRC, 2021. Climate Change Impacts on Health and Livelihoods: Maldives assessment
[399] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[400] Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027

Pillar 1: Disaster Risk Knowledge	• Improve the system of collection and analysis of scientific and statistical data, in order to design appropriate reef fisheries management plans[401] • Prepare adaptation vulnerability assessments for key sectors identified in the NAPA (including fisheries) [402]
Pillar 2: Observations and Forecasting	• Strengthen the existing coral reef monitoring program by engaging partners and stakeholders and developing tools (such as remote sensing and projections) for predicting, measuring, and monitoring effects of climate variabilities and changes on reefs, marine ecosystems, and vulnerable species[403] • Collect island-specific data (e.g., coastal dynamics, reef characteristics, hazard exposure) to build a long-term dataset that can inform coastal dynamic modelling exercises in future coastal projects[404] • Establish citizen science-based programmes for monitoring the health of coral reef ecosystems and other marine ecosystems[405] • Incorporate sector-specific risk information to issue impact-based forecasts[406]
Pillar 3: Dissemination and Communication	• Obtain and disseminate reliable weather information from MMS among fishermen to improve planning of fisheries operations and avoidance of adverse conditions[407]
Pillar 4: Preparedness and Response	• Enhance resilience of coral reefs and ecosystems by developing policy tools, incorporating into development plans, promoting best practices, increasing advocacy and through management actions[408] • Strengthen insurance schemes to enhance resilience of small-scale fishers and fishing industry to cover against losses due to extreme events and anomalies[409]
Cross-Cutting	• Collaborate with authorities and research institutes, such as the Maldives Marine Research Institute, to involve communities in initiatives to protect and rehabilitate coral reefs and mangroves for augmenting marine life[410] • Strengthen and formalise partnerships with relevant stakeholders, including in data collection and sharing, consultation, and interpretation of results, to assess potential impact of disasters on the industry and improve impact-based forecasting[411] • Develop interagency protocols/SOPs for data exchange, including guidelines for data sharing, data storage, and data access[412] • Facilitate fisheries research and development initiatives considering sectoral resilience building towards managing the changing of fish stocks and their migration patterns, adapting to efficient technologies, and investing in national capacity needs[413]

Tourism

Table 22. Identified gaps and needs for climate information and early warning systems in the tourism sector

Pillar	Gaps and needs
Pillar 1: Disaster Risk Knowledge	• Facilitate a way to improve availability and access to high quality information for businesses to understand their climate risks and climate adaptation investment opportunities[414]

[401] Ministry of Fisheries, Marine Resources and Agriculture & FAO, 2019. National Fisheries and Agricultural Policy 2019-2029
[402] Ministry of Environment, Energy and Water, 2006. National Adaptation Programme of Action
[403] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[404] Ministry of Tourism & USAID, 2023. Maldives Tourism Climate Action Plan.
[405] Ministry of Tourism, 2023. Maldives Fifth Tourism Master Plan 2023–2027: Goals and Strategies
[406] FMI, 2023. Country Hydromet Diagnostic for Maldives
[407] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[408] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[409] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[410] Ministry of Tourism & USAID, 2023. Maldives Tourism Climate Action Plan.
[411] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[412] Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
[413] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[414] Ministry of Tourism, 2023. Maldives Fifth Tourism Master Plan 2023–2027: Goals and Strategies

	• Prepare adaptation vulnerability assessments for key sectors identified in the NAPA (including tourism) [415]
Pillar 2: Observations and Forecasting	• Obtain detailed, reliable, and timely weather information from MMS to plan trips[416] • Incorporate sector-specific risk information to issue impact-based forecasts[417]
Pillar 3: Dissemination and Communication	• Provide timely weather alerts about potential hazards, particularly storms, for planning tourist trips and safety of tourists[418]
Pillar 4: Preparedness and Response	• Set up the digital services necessary for emergency preparedness and response[419] • Develop industry guidelines for insurance policies on climate change, natural disasters, and other extreme events[420] • Establish an insurance mechanism to reduce the impacts on the tourism sector through risk sharing and risk management[421]
Cross-Cutting	• Mainstream climate change risks into tourism sector policies to enhance the resilience and sustainability of the sector[422] • Join and contribute to global tourism initiatives to enable more effective sharing of lessons learnt and collection of important data relevant to climate adaptation[423] • Strengthen and formalise partnerships with relevant stakeholders, including in data collection and sharing, consultation, and interpretation of results, to assess potential impact of disasters on the industry and improve impact-based forecasting[424] • Develop interagency protocols/SOPs for data exchange, including guidelines for data sharing, data storage, and data access[425]

Water Resources Management

Table 23. Identified gaps and needs for climate information and early warning systems in the water sector

Pillar	Gaps and needs
Pillar 1: Disaster Risk Knowledge	• Improve overall understanding of impacts of climate change on natural water resources based on the latest science[426] • Prepare adaptation vulnerability assessments for key sectors identified in the NAPA (including water resources)[427]
Pillar 2: Observations and Forecasting	• Develop a roadmap and accelerate efforts towards providing operational hydrological services which are critical for the agriculture and water management sectors[428] • Conduct climate modelling under different emission scenarios for natural water resources[429] • Incorporate sector-specific risk information to issue impact-based forecasts[430]
Pillar 3: Dissemination and Communication	• Collaborate with weather services, disaster management authorities and local administration to disseminate impact-based early warnings on peak temperatures affecting health, WASH, DRR and livelihoods[431]

[415] Ministry of Environment, Energy and Water, 2006. National Adaptation Programme of Action
[416] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[417] FMI, 2023. Country Hydromet Diagnostic for Maldives
[418] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[419] Ministry of Tourism, 2023. Maldives Fifth Tourism Master Plan 2023–2027: Goals and Strategies
[420] Ministry of Tourism, 2023. Maldives Fifth Tourism Master Plan 2023–2027: Goals and Strategies
[421] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[422] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[423] Ministry of Tourism & USAID, 2023. Maldives Tourism Climate Action Plan.
[424] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[425] Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027
[426] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[427] Ministry of Environment, Energy and Water, 2006. National Adaptation Programme of Action
[428] FMI, 2023. Country Hydromet Diagnostic for Maldives
[429] Ministry of Environment, 2020. National Water and Sewerage Strategic Plan 2020-2025
[430] FMI, 2023. Country Hydromet Diagnostic for Maldives
[431] IFRC, 2021. Climate Change Impacts on Health and Livelihoods: Maldives assessment

Pillar 4: Preparedness and Response	• Develop and test an emergency protocol for service providers to ensure that sufficient drinking water is stored, and water treatment plant is secured, in various disaster scenarios[432] • Implement policies, standards, regulations to pre-emptively protect natural water resources from future climate change impacts[433]
Cross-Cutting	• Strengthen and formalise partnerships with relevant stakeholders, including in data collection and sharing, consultation, and interpretation of results, to assess potential impact of disasters on the industry and improve impact-based forecasting[434] • Develop of interagency protocols/SOPs for data exchange, including guidelines for data sharing, data storage, and data access[435]

[432] Ministry of Environment, 2021. Water and Sewerage Master Plan (2021-2035).
[433] Ministry of Environment, 2020. Update of Nationally Determined Contribution of Maldives
[434] USAID, 2023. Potential for Impact Based Forecasting in the Maldives to mitigate climate risks
[435] Ministry of Tourism and Environment; National Disaster Management Authority; Maldives Meteorological Service, Early Warning for All Initiative & Maldivian Red Crescent, 2023. Scaling Up Early Warning Systems Implementation Roadmap: Maldives 2023-2027

7 RELEVANT PROJECTS AND INITIATIVES

An overview of existing and previous projects and initiatives related to climate change adaptation and resilience building is provided in Table 24 below.

Table 24. Relevant existing and previous projects and initiatives

Project	Supporting Entity / Donor	Total Funding (USD)	Timeline	Description
Strengthening Climate and Risk Data Ecosystem in the Maldives for Early Warning	UNDRR, UNEP / CREWS	242,950	2024-2025	The CREWS Accelerated Support Window (ASW) project focuses on i) enhancing understanding of the status of risk knowledge and related tools in Maldives; and ii) strengthening disaster data collection mechanisms, aggregation, and analysis with a focus on early warning systems. The ASW project will lay the foundation for the use of a new tracking system for hazardous events and losses and damages under development by WMO, UNDRR and UNDP.[436] The GCF TRACT project will build on the CREWS investments by supporting the establishment and strengthening of Maldives' national disaster loss database as part of the roll-out of the global tracking system.
Systematic Observations Financing Facility (SOFF)	UNEP, Finnish Meteorological Institute (FMI) / SOFF	4,876,526 (Investment Phase)	Readiness Phase: 2023 Investment Phase: 2024-2028 Compliance Phase: 2029 onwards	The SOFF will provide long-term technical and financial support for the installation, operation and maintenance of the basic surface-based weather and climate observing network in Maldives to company with the WMO Global Basic Observing Network (GBON) technical regulations. The SOFF will operate in three phases: 1) Readiness Phase (6 months): FMI as the Peer Advisor provides technical assistance to Maldives Meteorological Service (MMS) to complete a GBON Gap Analysis and National Contribution Plan and update the Country Hydromet Diagnostics (CHD), which was piloted in Maldives in 2021. 2) Investment Phase (3-5 years): SOFF will provide funding for the observing network infrastructure and developing the human and institutional capacity needed to implement the GBON National Contribution Plan. 3) Compliance Phase: SOFF will provide results-based finance and peer advisors' technical assistance to MMS to operate and maintain the surface-based observation network and the international sharing of data. This phase will last for as long as Maldives is an ODA-eligible SIDS. Whilst the GBON Gap Analysis and National Contribution Plan focus on achieving GBON compliance. The CHD takes a broader approach to assess MMS and its contribution to high-quality weather, climate, hydrological and environmental information services and warnings. The CHD

[436] The new disaster losses and damages tracking system will replace the existing DesInventar with a more comprehensive and interoperable tracking system that will cover both hazardous events, as well as disaggregated losses and damages at localised scales. The new system will be synergised with the WMO-approved Cataloguing Hazardous Events (CHE) methodology. Further information is available here: https://www.undrr.org/disaster-losses-and-damages-tracking-system (Last accessed: 9 January 2024)

				analyses the ten most critical elements of the hydromet value chain. Its aim is to inform policy and hydromet investment decision-making by providing the analytical foundation needed for better targeted and more coherent investments. As such, the CHD will provide key baseline information and identify gaps and needs that can be addressed through the current proposal. The SOFF Investment Phase will support the upgrade and automation of four existing surface-based observation stations and install one additional station (in Maafaru). The (currently obsolete) upper-air station will also be upgraded. The SOFF will also provide funding for additional ICT infrastructure to support data collection and management. In addition, the SOFF will fund five new technicians, three ICT staff, and two management staff to ensure the availability of sufficient human capacity for operations and maintenance. The GCF TRACT project has been designed to complement the SOFF Investment Phase activities, as well as address gaps identified through the Country Hydromet Diagnostics, which were not eligible to receive financial support through the SOFF.
Advancing the National Adaptation Plan of the Maldives	UNEP / GCF	2,845,709	2022-2025	The UNEP-supported GCF Readiness project aims to reduce the vulnerability of Maldives to climate change impacts through enhanced capacity for planning, implementing and monitoring adaptation interventions. The Readiness project intends to deliver four participatory, gender-responsive and socially inclusive outcomes, focusing on: 1) Enabling national government and non-state actors/stakeholders to advance the NAP process through strengthening institutional arrangements and improved technical capacity. 2) Identifying, analysing and prioritising climate change impact and adaptation information to inform adaptation planning in the Maldives. 3) Developing a funding strategy for the implementation of national adaptation. 4) Enhancing the capacity to monitor, report on, and learn from the NAP process in the Maldives.
Climate Adaptation Project	USAID	10.5 million	2022-2027	The USAID Climate Adaptation Project aims to enhance the adaptive capacities of public and private sectors and local communities in Maldives to climate change impacts through the implementation of activities that contribute to the following objectives: • Identify and scale up innovative solutions to climate-related risks through market-driven private sector and community engagement • Strengthen central and/or local governance to address climate-related risks • Improve the quality of and access to information for decision-making to reduce vulnerability to climate change.

				The USAID project focuses on the three main economic sectors of the country – i.e., tourism, fisheries and agriculture. The project is being implemented through a series of small grant awards (USD 50,000 – 200,000) for activities aligned with the above objectives. The Climate Adaptation Project is currently supporting MMS through the procurement and installation of a High-Performance Computing (HPC) system, which is due to be installed before the end of 2023. The project will also support development of an impact-based forecasting (IBF) model for Maldives and conduct a pilot demonstration of IBF in one location (tentatively identified to be Fuvamulah City, Gnaviyani Atoll). The pilot IBF demonstration process is expected to commence immediately after installation of the HPC system. MMS is working with RIMES as a technical partner for both interventions. Under the Climate Adaptation Project, USAID is also providing grant financing to support the SME Development Financing Corporation (SDFC) in Maldives to be achieve accreditation as the country's first Direct Access Entity (DAE) with the GCF. The GCF TRACT project will scale up support for IBF in Maldives, leveraging and building on the results of the pilot under the USAID project. In addition, the GCF TRACT project aims to build the capacity of SDFC to incorporate climate analytics into the design and delivery of green finance products for SMEs, which are a priority for SDFC to develop as part of its efforts towards achieving accreditation as a GCF DAE.
Strengthening National and Subnational Capacity for Sustainable Disaster Risk Reduction, Climate Change Adaptation and Mitigation in Maldives	UNDP, UNESCAP / Joint SDG Fund	957,390	2022-2024	The UNDP/UNESCAP Joint Programme (UNJP) aims to strengthen the integration of disaster risk reduction (DRR) and climate change adaptation (CCA) with national and sub-national development planning. This will be achieved through the establishment of new implementing regulations, national-subnational institutional coordination mechanisms, and island-level standard operating procedures and capacities to sustain DRR/CCA planning and execution. The UNJP includes several interventions of high relevance to the proposed project, which are as follows: • Analysis of national disaster and climate laws and regulations to map the current DRR/CCA mandates at all levels of government • Development of a gender-sensitive baseline to understand gendered impacts of climate change and disasters • Technical advisory to NDMA to build a systematic, homogeneous and compatible record of disaster typologies • Update of the Maldives risk profile by capitalising on advances in high-resolution geospatial and climate modelling • Enhancement of MMS institutional capacity to upgrade and scale up the Monsoon Forums with better customised climate and weather

				risk reduction services, in partnership with RIMES • Support to MMS to establish a formal coordination mechanism for sharing critical data and information among national and sub-national agencies. As of August 2023, the UNJP has collected and combined most of the freely available bathymetry, mapped vulnerabilities of critical infrastructure locations from available data sources and conducted vulnerability assessments in some locations. These datasets will be available for MMS to use in its operational activities, including within the impact-based forecasting to be supported under the GCF TRACT project.
Strengthening Preparedness and Resilience through Inclusive Community Governance (SPRING)	ADPC / USAID BHA	TBC	2022-2024	The objective of the SPRING program is to enhance community preparedness and resilience through a focus on locally led actions to mitigate and prepare for disasters. The lead national partners are MRC and NDMA. The program interventions are centred around four areas: • Community awareness and mobilisation • Capacity development • Knowledge management, sharing and dissemination • Promoting private sector engagement in disaster risk reduction. The SPRING program is being implemented in seven localities: Finey (Haa Dhaalu Atoll), Komandoo (Shaviyani Atoll), Kendhoo and Maalhos (Baa Atoll), Dhiffushi and Male' City (Kaafu Atoll), and Dhevvadhoo (Gaafu Alifu Atoll). The GCF TRACT project will build on and replicate several interventions implemented under the SPRING project by expanding support for vulnerability and capacity assessments, public awareness campaigns, community-level disaster preparedness in additional target islands, as well as expand the reach of MRC's support to SMEs to formulate business continuity plans.
Building Climate Resilient Safer Islands in the Maldives (FP165)	JICA / GCF	66.0 million	2021-2027	The overall aim of the JICA-led GCF project FP165 is to establish and realise integrated coastal zone management (ICZM) in Maldives and implement coastal conservation measures, supported by the delivery of disaster warnings and information. The project includes small-scale support for coastal early warning services through the following interventions: • Deployment of wave and sea-level monitoring equipment in three selected sites • Coastline, coral reef, and land use monitoring using satellite, GIS and UAV technologies • Installation of digital terrestrial television broadcasting (DTTB) equipment for live broadcasting of weather forecasts and warnings • Development of an operational manual for an Early Warning Broadcast System (EWBS) using DTTB and associated training

				• Evacuation drills with test transmission of EWBS in pilot sites. The GCF TRACT project includes several interventions that will synergise with and/or build on the JICA-led GCF project, as follows: • Multi-hazard risk assessments and mapping and impact-based forecasting will, where relevant, use coastline, coral reef and land use monitoring data collected under FP165 • Expansion of the ocean observation and monitoring system by deploying equipment in new sites not targeted under FP165 • Strengthening of warning communication systems to reach 'last mile' communications will synergise with the DTTB system supported under FP165 through the use of additional channels to ensure redundancy.
Preparation of Technology Needs Assessment (TNA) under UNFCCC for the Republic of Maldives	UNEP, UNEP-CCC / GEF	TBD	2020-2023	The purpose of the TNA is to assist Maldives to identify and analyse priority technology needs, which can form the basis for environmentally sound technology (EST) projects and programmes to facilitate the transfer of, and access to, ESTs and know-how in the implementation of Article 4.5 of the UNFCCC Convention. The TNA includes the following activities: • Identify barriers hindering the acquisition, deployment, and diffusion of prioritised technologies. • Develop Technology Action Plans (TAPs) specifying activities and enabling frameworks to overcome the barriers and facilitate the transfer, adoption, and diffusion of selected technologies. • Develop Concept Notes for attracting funding to implement selected technologies in priority areas of national relevance. The TNA for Adaptation (2022) identified several adaptation technology options that the GCF TRACT project will contribute to delivering on: • Coastal data collection and mapping (TRACT will enhance climate-related data collection and hazard mapping in coastal areas) • Weather radar systems for improved weather forecasting (TRACT will support the procurement of spare parts to facilitate the continued operation of existing radar systems)
Supporting vulnerable communities in Maldives to manage climate change-induced water shortages (FP007)	UNDP / GCF	28.2 million	2017-2022	The overall aim of the UNDP-led GCF project FP007 is to deliver safe and secure freshwater to 105,000 people in the islands of Maldives in the face of climate change risks. This is being achieved through a scaled-up integrated water supply system and introduction of decentralised dry season water supply system, as well as support to improve groundwater quality through better regulation and ongoing monitoring. The main activity of relevance to the proposed project is the installation of six new automatic weather stations (AWS). The GCF TRACT project will complement the FP007 investments through further expansion of the weather and climate monitoring network, as well as support the development of a multi-year Operation and

				Maintenance Plan covering existing and new infrastructure.
CAP on a Map	Sahana Foundation, WMO / UN ESCAP Trust Fund	300,000	2014-2016	The “CAP on a Map” project aimed to operationalise a Common Alerting Protocol (CAP)-enabled Multi-Agency Situational Awareness (MASA), Sahana Alerting and Messaging Broker (SAMBRO), to provide location-specific alerts and warnings. The project introduced the SAMBRO platform and strengthened awareness on CAP. However, support for CAP implementation did not advance beyond the project implementation period. The GCF TRACT project will provide training on CAP usage for a range of stakeholders to ensure consistent warning dissemination and communication practices. It will also support upgrade of MMS’ existing CAP software to enhance its functionality.
Community Based Disaster Risk Reduction (CBDRR) Project	Canadian Red Cross	CND 975,128	2010-2014	The four-year CBDRR project provided technical and financial assistance for MRC to commence implementation of CBDRR in Maldives. The aim of the project was to build resilient communities through enhancing MRC’s long-term advocacy role in disaster risk reduction (DRR) and climate change adaptation (CCA); increasing MRC’s immediate DRR and CCA capacity building; improving immediate disaster management practices in communities; and supporting establishment of long-term mitigation measures at the community level. The CBDRR project targeted six branches of MRC through training and equipping Emergency Response Teams as per the MRC Response Mechanism (Gnaviyani, Haa Dhaalu, Male’, Lhaviyani, Thaa, and Seenu Atolls) and supported resilience-building activities in four communities (HA. Hoarafushi, GDh. Gadhdhoo, LH. Hinnavaru, K. Kaashidhoo). The GCF TRACT project will enable MRC to scale up its support for CBDRR in 48 target islands.

8 PRE-FEASIBILITY ASSESSMENT

8.1 Disaster Risk Knowledge

8.1.1 Disaster Risk Knowledge Platform

The attributes of a successful risk data management platform, as identified by the Asian and Pacific Centre for the Development of Disaster Information Management (APDIM), are outlined below:

- **Platform description** – The platform should advise users on what data and information can be found on the platform and for what geography. Ideally, this should be provided as a simple description on the platform's homepage.
- **Platform ownership and contact details** – The platform should clearly identify who owns and maintains it and provide contact details for users to ask questions or request further information.
- **Data format** – All datasets should be shared in standard, machine-readable formats such as .shp, .xls, .csv, or similar so that users can take advantage of the raw data. Note that most images and PDFs are not considered machine-readable in this context.
- **Metadata** – All datasets should be provided along with standard metadata containing information on the original source, methods, spatial and temporal resolution, and other details required for effective use of the data.
- **Licensing** – All datasets should be provided along with information about the license and copyright information, if any, under which it is shared. Free and unrestricted usage should be encouraged, where possible.
- **URL** – All datasets should have their own unique, permanent URL that does not change when updated and only links to the individual dataset.
- **Regular updates** – Where applicable, datasets should be regularly updated, and the date of the most recent update made easily visible to users.
- **APIs and Federation** – Where possible, data should be delivered through application programming interfaces (APIs) and web-services that enable reliable and regular programmatic use of their datasets by software applications.
- **Ease of Use** – The data platform should have a high-quality interface design that responds to the needs of the intended user group(s) in order to encourage use of risk information.[437]

8.1.2 Hazardous Events and Disaster Losses and Damages Tracking System

Following agreement at UNFCCC COP27 to scale up support for vulnerable countries suffering from the impacts of climate change and recognising the need to improve understanding of disaster losses and damages, a new-generation tracking system to record and analyse hazardous events and disaster losses and damages is currently under development. Led by UNDP, UNDRR and WMO, the new system will replace the existing DesInventar with a more comprehensive and interoperable tracking system covering both hazardous events, as well as disaggregated losses and damages at localised scales. Moreover, the system will be synergised with the WMO-approved Cataloguing Hazardous Events (WMO-CHE) methodology, thereby enabling weather observations and hazardous events to be linked with related losses and damages information and their cascading impacts.

A schematic showing the key elements and foundation for the new system is shown below.

[437] APDIM, 2020. APDIM Preliminary Assessment of the Gaps and Needs for Disaster Risk Information and Data Management Platforms in Asia and the Pacific Region

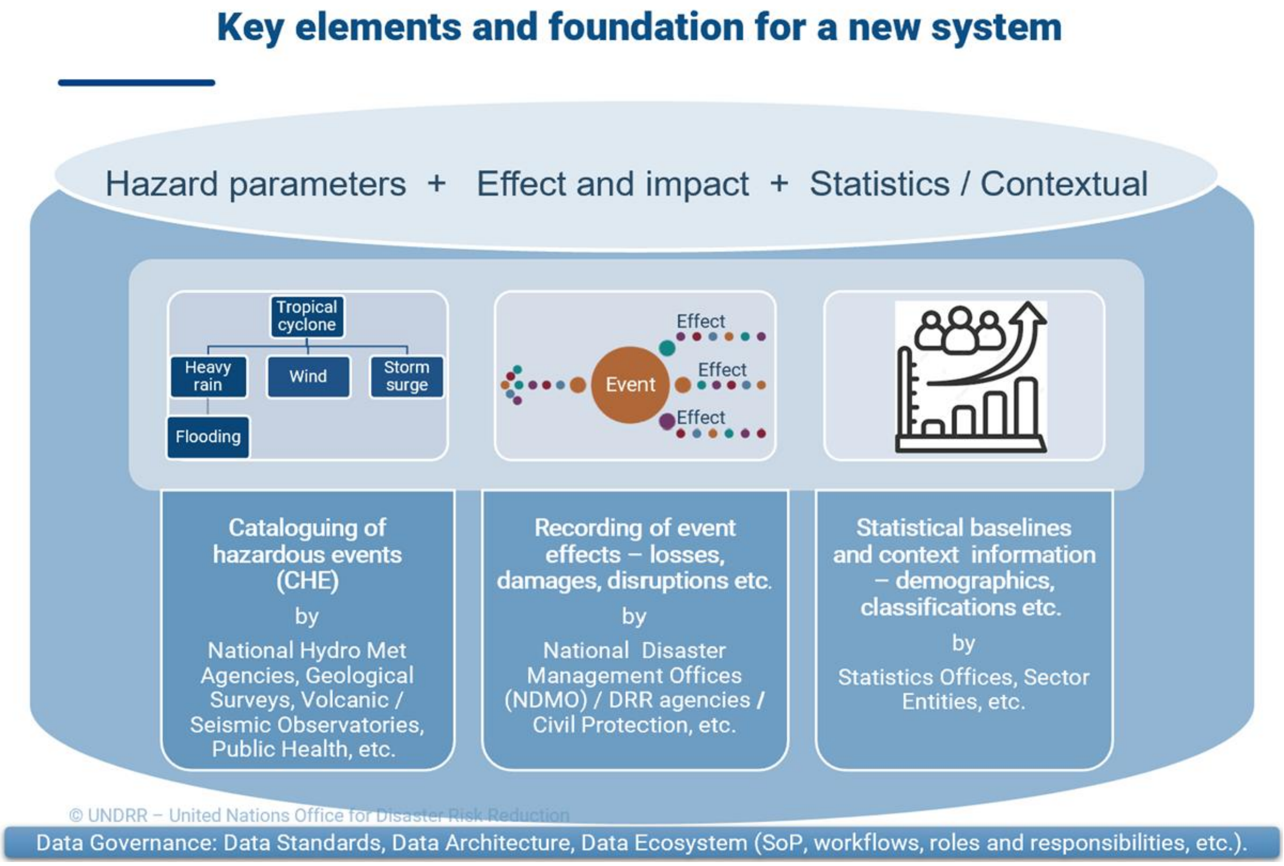

Figure 57. Key elements and foundation for a new tracking system for hazardous events and disaster losses and damages. (Source: UNDRR, 2023)

8.1.3 Enhanced Vulnerability and Capacity Assessment (EVCA)

The Vulnerability and Capacity Assessment (VCA) is a long-standing approach of the Red Cross Red Crescent Movement (RCRC), which serves as a participatory process designed to foster community resilience through the assessment and analysis of the risks they face and the identification of actions to reduce these risks. The enhanced VCA or "EVCA" is an upgraded version of the VCA, which has an improved analysis process, is integrated with the IFRC Roadmap to Community Resilience, and incorporates climate change as well as gender and diversity considerations.[438]

The IFRC identifies four key reasons to conduct an EVCA, which are outlined below:

1. Improve understanding amongst communities on the nature and extent of existing, evolving, and emerging risks that they are and will be facing.
2. Enable communities to identify relevant and practical actions to reduce their risks and strengthen their resilience based on their own priorities.
3. Raise awareness and mobilise resources both within the community and externally, so that the community can implement its risk reduction action plan.
4. Enable National Societies to support communities to reduce their prioritised risks, including by influencing policies, laws and development investments that can benefit those communities.

The step-by-step process to conduct an EVCA is outlined in Figure 58 below.

[438] IFRC, 2018. What is the EVCA? Available at: https://www.ifrcvca.org/what-is-evca

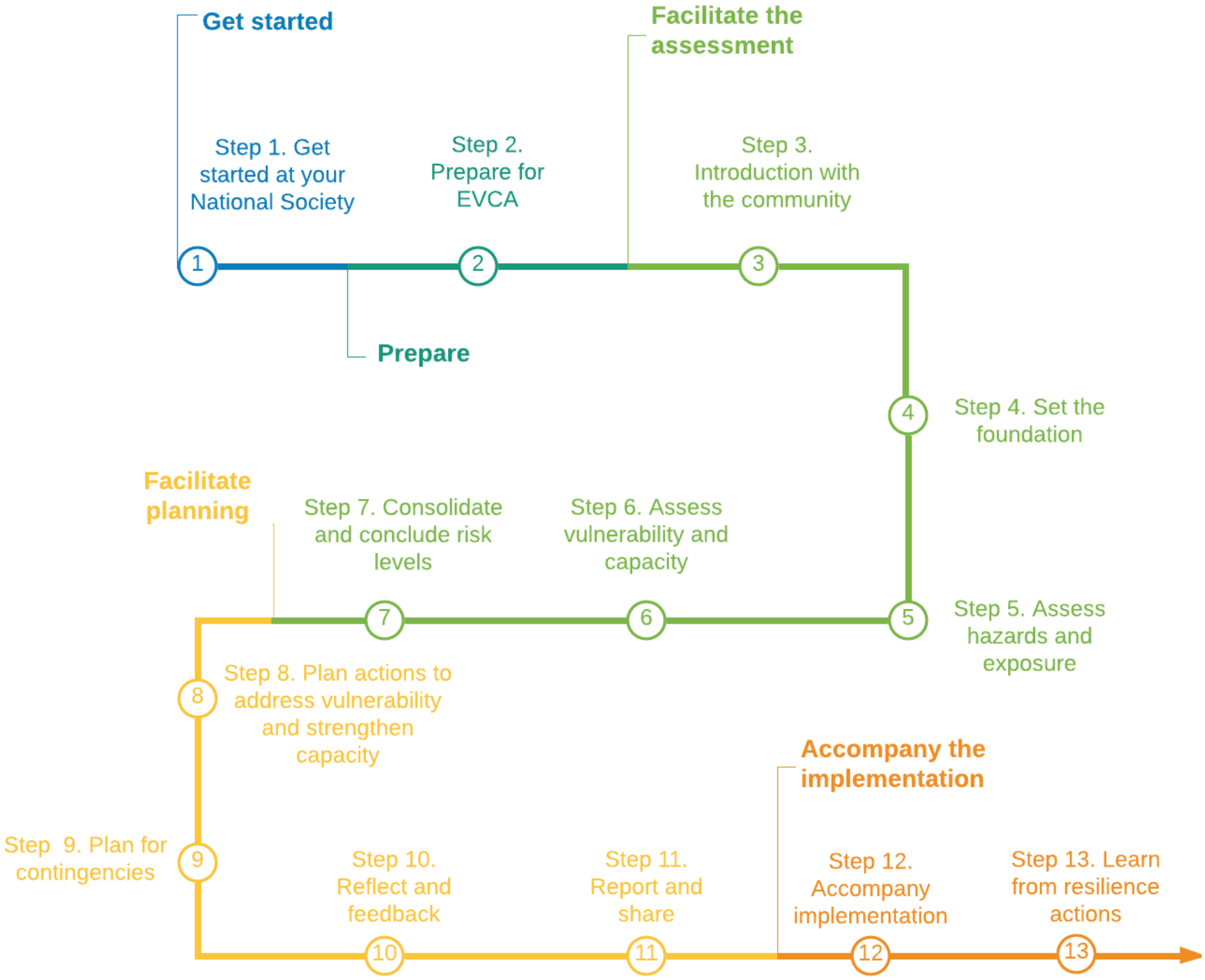

Figure 58. Steps to conduct an EVCA (Source: IFRC, 2023)

EVCA stakeholders[439]

The primary stakeholders in the EVCA process are the National Society (acts as a facilitator of community participation and empowerment) and the community (acts as the driver of the EVCA process). Within the community, the EVCA should involve people from all social and economic groups, particularly those most vulnerable or marginalised. This is important to ensure inclusivity and prevent the reinforcement of unequal power relations or existing vulnerabilities.

There are additional stakeholders that can act as contributors and/or enablers to the EVCA. Such stakeholders can include local government, relevant ministries, national meteorological and hydrological services (NMHSs), NGOs, the private sector, and academic institutions. NMHSs can play an important role in supporting the integration of climate change considerations into the EVCA, by providing weather and climate information covering past, present and future timescales, as well as scientific early warning information and recommendations for early action.

Feasibility Assessment

MRC has experience in using VCAs as a tool to facilitate risk assessments and local level planning for disaster preparedness and risk reduction. In this regard, MRC trains and mobilises local teams and volunteers to facilitate the VCA data collection process. Amongst others, the VCAs are used to inform

[439] IFRC, 2019. Enhanced Vulnerability and Capacity Assessment. Version 1 – for field testing. Available at: https://www.ifrcvca.org/_files/ugd/7baf5b_d87b11d03de245559c36f0a7d756c0f5.pdf

the preparation of Island Development Plans. Currently, existing VCAs are limited in coverage and MRC lacks the resources needed to regularly update the VCAs, which should be done at least every 2-3 years due to evolving climate change hazards.

The need to strengthen risk-based resilience planning at island and city levels is recognised as a key priority in MRC's Strategic Plan 2019-2030. The main strategies to achieve this is through expanding the coverage of risk assessments (using the VCA tool), to increase the use of these assessments and data in local planning, and to advocate for national risk assessment guidelines.

8.2 Observations and Forecasting

8.2.1 WMO Competency Framework for Climate Services

The WMO Executive Council, as its sixty-eighth session (EC-68) in 2016, approved the competency framework for the provision of climate services to help National Meteorological and Hydrological Services (NHMSs) and other institutions to deliver high-quality climate services in compliance with WMO standards and regulations. The competency framework for the provision of climate services approved by EC-68 is divided into the following five top-level competencies:

1. Create and manage climate data sets
2. Derive products from climate data
3. Create and interpret climate forecasts, climate projections, and model outputs
4. Ensure the quality of climate information and services
5. Communicate climatological information to users.

In line with country demand, WMO proposes to offer training in the following areas as part of the proposed project: Co-production of Climate Services; Earth Observations (EO); and Quality Management Systems (QMS) for Climate Services. A description of each proposed training areas, as well as the relevant top-level competencies and learning objectives, is provided below.

Co-production of Climate Services

- *Competency 4 – Ensure the quality of climate information and services*
- *Competency 5 – Communicate climatological information to users*

This training area will focus on how to design and implement co-production, including the required criteria, principles, good practices, and approaches; how to establish effective communication channels and partnerships between producers and users of climate services; and how to comply with the interfacing requirements of the Global Framework for Climate Services (GFCS) and integration with WMO Climate Information Systems.

Main learning objectives:

i. Understand the role of climate science information for the delivery of climate services

ii. Describe how to interact and strengthen linkages and mutual understanding between users of climate information such as sectors or groups, and climate information producers

iii. Discuss how to promote effective partnerships between climate services producers and users for transformative climate action

iv. Recognise best practices for co-producing climate science information for specific sectors, exchanging knowledge and translating climate science into effective national decision-making

v. Identify the role and importance of National Frameworks for Climate Services (NFCS) to support co-development and application of climate science information for climate action.

Earth Observations (EO): Synthesis and interpretation of climate information for various climate applications

- *Competency 2 – Derive products from climate data*
- *Competency 4 – Ensure the quality of climate information and services*
- *Competency 5 – Communicate climatological information to users*

This training area will build skills to interpret, formulate, and effectively articulate climate science analyses for various climate applications. To address climate risk and adaptation, defining climate hazard, exposure, and vulnerability will involve gathering and synthesising a diverse range of information, which will be unique for each climate action intervention. This training area will provide an overview of tools and techniques for synthesising past trends, variability, extremes, and future changes in climatic factors, and classification of different types of information sources with a specific focus on EO. Additionally, it will provide a synthesis of existing approaches and data that can be converted into an easily interpretable and usable form.

Main learning objectives:

i. Develop EO links with climate services notably for multi-hazard early warnings and adaptation

ii. Discern multiple lines of evidence obtained from a variety of sources (country-level climate risk profiling, climate model information platforms, satellite imagery, etc.) and define what is the best available information for specific applications

iii. Identify and apply a range of science-based methods and tools with an emphasis on EO for climate science basis analysis

iv. Explore different data and product management approaches including data sharing policies that can ensure compliance with WMO standards for EO.

Quality Management System (QMS) for Climate Services

- *Competency 4 – Ensure the quality of climate information and services*
- *Competency 5 – Communicate climatological information to users*

This training area will focus on improving MMS' climate services and products through the implementation of a QMS roadmap. The development and implementation of a QMS within an ISO 9001 quality management framework will enhance the capacity of MMS to better integrate weather and climate services for forecasting; generate standardised climate information; establish strong user engagement; and be capable of effectively using global and regional inputs in a national context. This achievement will further facilitate the establishment of a National Framework for Climate Services and enhance the provision of information through tools such as Climpact to serve decision-makers across a wide range of climate-sensitive sectors.

Main learning objectives:

i. Integrate a quality management approach to enable the effective and efficient delivery of climate services

ii. Understand, demystify, and apply the fundamentals of the ISO 9001:2015 requirements for QMS

iii. Prepare the NMHS, and in particular, their climate services, for conformity with WMO standards, or the achievement of Certification of Compliance to the ISO 9001:2015

iv. Define a standardized approach to assess hydrometeorological systems and services.

Target Audience

Each training will target 30-35 national participants. The target audience envisioned for the above trainings will vary based on specific needs and competencies, as well as training area, but can include the following:

- Maldives Meteorological Service
- National Disaster Management Authority
- GCF stakeholders (National Designated Authority – Ministry of Tourism and Environment, and potential Direct Access Entities)
- Sector specialists (e.g., marine, water, health, tourism, agriculture, fisheries)
- UN technical agencies and partners
- Academia
- Island communities (e.g., local councils, women's groups).

8.3 Dissemination and Communication

8.3.1 Cell Broadcasting

Cell Broadcast (CB) is a function of cellular networks for the simultaneous delivery of a single text or binary message to multiple mobile phones within a defined area. Unlike SMS, which uses a point-to-point connection, CB works on a one-to-many basis. Cell Broadcast is an inherently location-based technology, with the possibility to target a single radio cell or up to the entire mobile network.[440]

Cell Broadcast has several key benefits for the implementation of mobile emergency alerting:

- Messages can be displayed automatically with no user interaction
- One message can be sent to millions of devices in seconds
- Differentiated messages can be sent to designated areas
- Dedicated network signalling means that CB is not affected by and will not lead to network congestion, making it ideal for Government nationwide emergency alerts
- Recipients remain anonymous, meaning that there is no violation of citizen privacy
- CB can only be sent from authorised, verified sources.[441]

Whilst location-based SMS (LB-SMS) technology holds some advantages over CB – including full compatibility with all mobile devices with a SIM, alert update capability and situational awareness[442] – the ITU states that CB is usually the recommended option for countries with limited budgets and mobile network operator (MNO) networks of varying maturity.[443] International telecommunication standardisation bodies (3GPP, ETSI, ATIS) also recognise CB as the most suitable technology for implementing mobile emergency alerts in 2G, 3G, 4G and 5G.[444]

How it works

A CB system is composed of (redundant) Cell Broadcast Centres (CBCs) and one or more Cell Broadcast Entities (CBEs). A CBE is any application connecting to a CBC. In the case of public warnings, the CBE is located in the Government environment and integrates to the MNO. Messages are composed on a CBE by authorised parties. The CBE dictates the message text, its destination, and the message scheduling.

A CBC is a network element in the mobile core network that manages the transmission of CB messages to the target cells, through the radio access network (RAN) controllers. RAN controllers are entities in the operator's radio network that manage a group of cells. BSC, RNC, MME and AMF are the RAN controllers for 2G, 3G, 4G and 5G, respectively. The CBC is located within the MNO domain and maintains all relevant information on the radio cell location – the Public Land Mobile Network (PLMN) dataset.

The cell antenna is the component that wirelessly sends the CB message to mobile devices. The end-user device, generally a mobile phone, complies with the CB protocol and thereby receives and presents the CB message on the device. The CBC connects directly to the RAN, meaning that even when the network is congested, emergency alerts are disseminated simultaneously to all mobile devices associated with the cells in the target area.[445, 446]

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[440] one2many, 2020. Why Cell Broadcast is more important than ever for emergency alerting!
[441] GSMA, 2013. Mobile Network Public Warning Systems and the Rise of Cell-Broadcast. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2013/01/Mobile-Network-Public-Warning-Systems-and-the-Rise-of-Cell-Broadcast.pdf; Accessed: 7 Aug 2023
[442] Situational awareness relates to the ability to obtain additional insights on the disaster situation. In the case of LB-SMS, the number of people who received the alert message can be confirmed and the last-known-location feature can be used to generate a population density map (ITU, 2023)
[443] ITU, 2023. Digital transformation and early warning systems for saving lives
[444] one2many, 2020. Cell Broadcast Solution Overview. Available at: https://e54f7065-984c-4ed7-9b39-6fc8266dcf2a.filesusr.com/ugd/8632b1_c180456681b941eda0fee94d5d38da81.pdf?index=true; Accessed: 7 Aug 2023
[445] one2many, 2020. Cell Broadcast Solution Overview. Available at: https://www.one2many.eu/_files/ugd/8632b1_c180456681b941eda0fee94d5d38da81.pdf?index=true
[446] Celltick, 2023. CBC – Cell Broadcast Center. Available at: https://www.celltick.com/cell-broadcast-center/

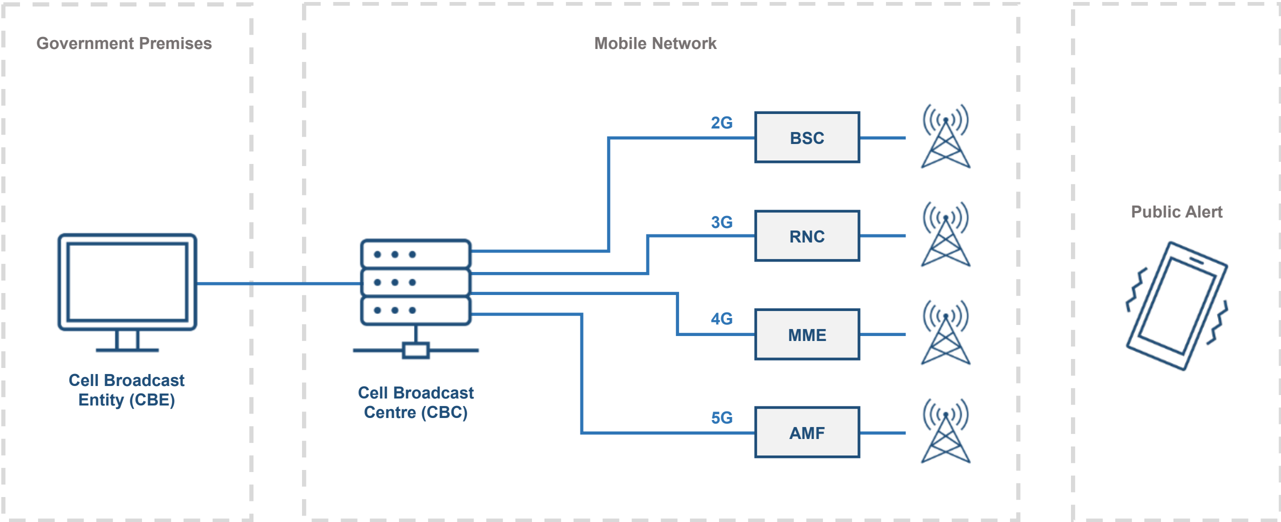

Figure 59. Schematic of a Cell Broadcast system. Adapted from one2many and Mavenir

Key considerations for leveraging CB in early warning systems[447]

The GSMA has identified a number of key factors to consider that can either serve as key enablers of, or barriers to, the successful implementation of CB in early warning systems (EWS). These factors have been categorised as Operational, Financial, Technical, and User-facing. Key questions to be answered in relation to these questions are listed below:

- **Operational**
  - How should partners collaborate?
  - What role do standards and regulations play?
- **Technical**
  - Is CB an appropriate channel?
  - What are the limitations in terms of message dissemination?
  - What are the handset requirements, and are handsets compatible with CB systems?
  - How does CB interact with existing network infrastructure?
  - How resilient is network infrastructure?
  - Is there adequate network coverage?
- **Financial**
  - What are the costs of implementing a CB-enabled EWS?
  - Who pays for the system?
  - Is there a choice between third-party vendors and a DIY approach?
  - Do cost-saving measures exist?
- **User-facing**
  - How can communities be made aware of EWS?
  - How can stakeholders create a culture of risk?
  - How can stakeholders ensure a CB-enabled EWS is accessible?
  - How can stakeholders build and maintain trust in a CB-enabled EWS and messages?

Technical considerations

Maldives has two MNOs – Dhiraagu and Ooredoo – which provide 100% coverage of Maldives.[448, 449] At the start of 2022, there were 810,400 cellular mobile connections in Maldives, which is equivalent to 149.9 percent of the total population. It should be noted that many people use more than one mobile connection,

[447] GSMA, 2023. Cell Broadcast for Early Warning Systems: A review of the technology and how to implement it
[448] ADB, 2022. ADB, Dhiraagu to Expand Internet Access in Maldives Through New Undersea Cable System. Available at: https://www.adb.org/news/adb-dhiraagu-expand-internet-access-maldives-through-new-undersea-cable-system (Accessed: 12 January 2024)
[449] Hotelier Maldives, 2023. Hotelier GM Forum 2023: Ooredoo showcases vision of ‘Powering the Future’. Available at: https://hoteliermaldives.com/hotelier-maldives-gm-forum-2023-ooredoo-showcases-vision-of-powering-the-future/ (Accessed: 12 January 2024)

meaning that it is not unusual for mobile connection figures to significantly exceed total population numbers.[450]

Financial considerations[451]

There are multiple factors that can influence the cost of implementing a CB-enabled EWS, including the number of networks (2G/3G, 4G/5G) to be implemented, type of system (centralised CBC or decentralised), size of the network (number of cell towers), and requirements for infrastructure. In addition to the upfront costs, the costs of training, awareness/sensitisation campaigns, and system maintenance should also be considered.

The following examples can serve as benchmarking for the prospective implementation of CB-enabled EWS in Maldives:

- In the Caribbean, a recent study estimated the average cost per MNO to be between USD 245,000 – USD 480,000 for a single CBC. Considering the additional integration costs per MNO and nationwide system, the upfront investment was estimated at USD 1.2 million – USD 2.5 million for a country with three MNOs. Ongoing maintenance, rent and essential upgrades costs were estimated at USD 245,000 per year.
- In New Zealand, the total cost of the CB-enabled EWS for the country's three-MNO system (including CBCs, CBEs, and software costs) was USD 7.2 million, with estimated annual budget requirements of USD 2 million.
- In Samoa, the estimated cost for the country's CB-enabled EWS, including five-year maintenance and support, was USD 330,000. However, it should be noted that this cost estimate is from 2012.

Innovation in cell broadcasting

Innovative research and new developments in CB are increasing the accessibility, targeting capabilities, resilience, and overall utility of CB-enabled EWS. Two examples are outlined below:

- **Device-Based Geo-Fencing:** Geo-fencing improves the accuracy of warning areas by utilising location technology within mobile devices (e.g., GPS and Wi-Fi) to determine whether a device falls within a target area,[452] rather than using polygons and circles for cell selection. Increased location accuracy enables the delivery of highly-targeted information and helps to avoid panic and alert fatigue, which can impede efficacy and trust in public warnings.[453] Device-based geo-fencing can provide accuracy of metres, equal to that of GPS navigation.[454]
- **Non-Terrestrial Networks:** Non-terrestrial networks (NTNs), such as satellite communication networks and high-altitude platform systems (HAPS), complement terrestrial mobile infrastructure by enhancing coverage and providing redundancy options in the event of a disaster or network outage. Although NTN-based solutions may still require partnership with MNOs, there are some solutions, such as the Galileo Global Navigation Satellite System (GNSS) and other low Earth orbit (LEO) satellites, that do not. Satellite technologies can extend the reach and targeting of early warnings to within 2-3 metres. [455]

[450] DataReportal, 2022. Digital 2022: The Maldives. Available at: https://datareportal.com/reports/digital-2022-maldives (Accessed: 12 January 2024)
[451] GSMA, 2023. Cell Broadcast for Early Warning Systems: A review of the technology and how to implement it
[452] Everbridge, 2024. Enhance emergency alerts with device-based geo-fencing. Available at: https://www.everbridge.com/blog/enhance-emergency-alerts-with-device-based-geo-fencing (Accessed: 16 February 2024)
[453] GSMA, 2023. Cell Broadcast for Early Warning Systems: A review of the technology and how to implement it
[454] One2many, 2020. Cell Broadcast Solution Overview. Available at: https://e54f7065-984c-4ed7-9b39-6fc8266dcf2a.filesusr.com/ugd/8632b1_c180456681b941eda0fee94d5d38da81.pdf (Accessed: 16 February 2024)
[455] GSMA, 2023. Cell Broadcast for Early Warning Systems: A review of the technology and how to implement it

8.4 Preparedness and Response

8.4.1 Y-Adapt

'Y-Adapt' or 'Youth Adapt' is a dynamic and game-based curriculum for young people consisting of seven modules that not only educate but also empower youth to take meaningful action in their communities to combat the effects of climate change. The innovative program addresses a wide range of climate-related challenges, including rapid-onset events such extreme rainfall leading to flooding and slower-onset issues such as extreme heat causing drought. Y-Adapt encourages youth to not only understand the complexities of climate change but also to develop and implement their own climate change adaptation and advocacy plans within their local communities.[456]

In 2023, MRC hosted a regional Y-Adapt training-of-trainers (ToTs) workshops with the support of IFRC and the Italian Red Cross under the project *"Strengthening Urban Youth Climate and Resilience Programming in South Asia".* Through this regional workshop, MRC trained five ToTs who will be able to deliver Y-Adapt workshops within its existing administrative bases across the Maldives. Following up on the ToT workshop, under the same project, MRC is rolling out focused Y-Adapt workshops targeted towards youth volunteers and schools situated in the Greater Male' area, Kulhudhuffushi City (Northern Region), and Addu City (Southern Region). The proposed GCF project would support the establishment of Y-Adapt as a regular program aiming to increase awareness and promote a youth-centred, community-driven approach to building climate resilience.

8.4.2 Forecast-based Action (FbA) and Anticipatory Action (AA)

Forecast-based Action (FbA), or Anticipatory Action (AA), is a proactive approach to disaster risk management where early actions are pre-planned and triggered by reliable forecasts and risk analysis. Resources are allocated and measures are implemented – for example evacuations or infrastructure reinforcement – before a hazard strikes, based on pre-defined thresholds. This minimises losses, reduces the need for post-disaster humanitarian aid, and strengthens community resilience to climate-related hazards.

Considerations for Early Action Protocol (EAP) development[457]

The project proposes to facilitate the process of developing EAPs at both the national and institutional levels. Assuming that the process to kick off the national EAP development will take some time, the initial years of the project will focus on building the internal capacities of the Maldivian Red Crescent (MRC) on FbA/AA and supporting them in the development and approval of their simplified or full EAP for the key priority hazard and geography of interest. IFRC has its own guidance, criteria and approval process set out for the EAP that will enable national societies (including MRC) to access funds up to CHF 500,000 (approx. USD 585,000) for the implementation of each approved protocol. MRC aims to have its first institutional EAP (simplified or full) approved before the end of the second year of the project, allowing them to access resources to lead the implementation of FbA/AA in Maldives, which can ultimately inform the national process (led by the government) for EAP development in successive years. The national EAP would have more coverage, more partners involved, and be mainstreamed in the national disaster management frameworks and operations.

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[456] Red Cross Red Crescent Climate Centre, 2024. Y-Adapt. Available at: https://www.climatecentre.org/priority_areas/youth/y-adapt/ (Accessed: 19 February 2024)
[457] Based on guidance from the Senior Technical Advisor and Asia Pacific Focal Point at the Red Cross Red Crescent Climate Centre in January 2024.

9 KEY BARRIERS

9.1 Institutional and legal barriers

Lack of systematic integration of climate change considerations and disaster risk reduction (DRR) into decision-making and planning

Whilst the Government of Maldives has taken steps to mainstream climate change adaptation (CCA) and DRR into decision-making and planning, current approaches lack consistency and are often based on incomplete or limited data.[458] Weak integration of climate information into national plans and policies can partly be attributed to the absence of a National Framework for Climate Services. CCA and DRR mainstreaming efforts are further impeded by a siloed approach, which limits coordination and synergistic action, particularly at the local level. For example, overlapping mandates in relation to decentralisation and DRR/CCA planning have resulted in unclear roles and responsibilities, which in turn impede relevant agencies from synergising effectively to deliver coordinated DRR and CCA interventions.[459]

Inadequate multi-sectoral and inter-institutional collaboration to deliver an effective, end-to-end multi-hazard early warning system (MHEWS)

Lack of an overarching framework for inter-agency and multi-sectoral engagement, collaboration, and data sharing limits institutional effectiveness in providing a coordinated and integrated MHEWS. There is no operational multi-stakeholder platform to facilitate coordination and collaboration among stakeholders or to facilitate structured and inclusive dialogue. Whilst many sectoral standard operating procedures (SOPs) and plans relating to disaster risk management already exist, there is a need to align and synergise existing emergency management plans in different sectors.

Limited exchange of climate-related data and information between relevant entities

Integration, interoperability, and availability of climate-related information between public agencies (G2G) and public and private agencies (G2B/B2G) is lacking.[460] This in part stems from a lack of inter-agency and cross-sectoral coordination for data sharing and collection, especially at the lower levels of government and in localities, due to insufficient technical capacity, budget, and other resources.[461] Moreover, whilst data and information are sometimes shared on an *ad-hoc* basis[462], there is no data exchange mechanism backed by statutes.[463] There is also no structured procedure for addressing data quality issues, meaning that data and information that is shared is not necessarily usable.

Lack of institutional or legal frameworks for public-private engagement in climate services

There is no legal status or regulation enabling Maldives Meteorological Service (MMS) to formally engage in partnerships with the private sector. As a result, MMS is unable to undertake cost recovery activities, which would contribute towards ensuring sustainable funding for its crucial services. In addition, MMS does not have any formal agreements in place with the private sector for service delivery, operation and maintenance of observational networks, or sharing of observational data.

Lack of clarity in roles and responsibilities for disaster risk management (DRM), particularly at the local level

The current approach to DRM in Maldives is fragmented, with frequent duplication of efforts. Communication and coordination between local councils and the administration in Male' is lacking, including in the event of emergency situations.[464] Whilst the Decentralisation Act (2010) and other regulations outline roles for the Local Government Authority and Island Councils in relation to DRM, in

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[458] UNEP, 2022. GCF Readiness Proposal: Advancing the National Adaptation Plan of the Maldives
[459] Joint SDG Fund, 2022. Joint Programme Document: Sustainable Disaster Risk Reduction, Climate Change Adaptation and Mitigation in Maldives. Available at: https://info.undp.org/docs/pdc/Documents/MDV/SIDs%20proposals%20Maldives%20-%20(26%20October%202021).docx (Accessed: 22 August 2024)
[460] Government of Maldives, 2023. Scaling Up Early Warning Systems Implementation Roadmap. Maldives 2023-2027
[461] ADPC and UNDRR, 2019. Disaster Risk Reduction in Republic of Maldives: Status Report 2019
[462] UNEP, 2022. GCF Readiness Proposal: Advancing the National Adaptation Plan of the Maldives
[463] Government of Maldives, 2023. Scaling Up Early Warning Systems Implementation Roadmap. Maldives 2023-2027
[464] Axisa, G.B., *et al.,* 2023. Island Studies Journal. Vulnerability to Disaster in the Maldives: The Maamigili and Fenfushi Island Communities

practice, formal mechanisms and associated human capacity to coordinate the implementation of DRM activities are limited.

9.2 Technical and technological barriers

Insufficient generation of high-quality and real-time data for timely and reliable monitoring, forecasting and warning of impending hazards

While existing initiatives have invested in observational equipment, coverage at a national scale of surface-based land, marine and upper-air observations is insufficient to enable localised modelling and impact-based forecasting that translates weather, climate and ocean data into understandable and actionable information for users. Limited access to real-time data (particularly in relation to flash floods, thunderstorms, high seas and rogue waves) impedes timely monitoring of rapidly evolving hazards. Inadequate data quality control further limits monitoring capabilities.

Inadequate communication systems to provide timely, accurate and actionable warning information to those at risk

There is no end-to-end early warning dissemination system in Maldives and no mechanism to reach out to differently abled population groups. Whilst Maldives is receiving support to establish digital terrestrial television broadcasting (DTTB), there is still a need to ensure redundancy in communications and that alternative channels are simultaneously utilised according to the needs and preferences of different population groups. There is limited use of the Common Alerting Protocol (CAP), meaning that warning messages are not consistently disseminated over multiple channels. There is a need for full implementation of CAP, such that actionable instructions are provided as part of the warning messaging.

9.3 Capacity barriers

Insufficient technical capacity for data analysis, climate modelling and impact-based forecasting

MMS service provision is constrained due to having too few specialist personnel, including those skilled in the areas of numerical weather prediction (NWP) modelling, data assimilation and verification, and statistical post-processing. There are no dedicated staff within MMS to provide climate services and capacity for impact-based forecasting is almost completely lacking. There is also limited access to formal training opportunities for existing staff. Insufficient computing capacity within MMS further limits data processing capabilities.

Insufficient capacity for targeted communication of climate risk information and warnings tailored to different user needs

Lack of tailoring of information, alerts and advisories to differential risks, needs and vulnerabilities of subpopulation groups remains a key barrier to achieving sustainable ‘last mile’ effectiveness and ensuring that warnings translate into appropriate actions. It is assumed that the general public can understand the information disseminated by MMS, but no field-testing has been undertaken to confirm this. Lack of a formalised feedback mechanism for warning communication means that the timeliness and usability of alerts and warning messages is not evaluated.

Lack of capacity to implement anticipatory or forecast-based actions

Maldives has not received support to develop systems to take action based on forecasts and risk analysis – known as anticipatory or forecast-based action. This is in part due to the current lack of availability of robust climate information and early warning systems (CIEWS) infrastructure at the scale required for effective implementation of forecast-based actions.

Limited capacities at national, sectoral and community levels to use CIEWS to increase resilience and reduce disaster risks

There is a lack of a “culture of preparedness” in Maldives. People generally taking it for granted that high impact events have historically occurred at low frequency and that, in the event of adverse impacts, the State will step in to provide support.[465] Island Disaster Management Plans (IDMPs) are available for less than 40% of the inhabited islands (72 out of 187). However, those that exist are often based on out-dated risk and vulnerability assessments. There is no formal contingency planning undertaken based on

[465] Based on consultations with MMS, NDMA and MRC

forecasts across different timescales or informed by climate projections and scientific research. Stakeholders are often not aware of or familiar with existing plans/protocols and available SOPs/plans relating to disaster risk management are not necessarily tested or put into practice.

9.4 Information barriers

Lack of data and information on climate-related hazards, vulnerabilities, and exposure

There is limited coverage of hazard maps and risk assessments. Those that exist are often outdated and thus limited in their usability. Location-specific vulnerability data is lacking, particularly in relation to socio-economic vulnerabilities. There is also a lack of understanding of cascading risks and impacts, which is especially pertinent given the increasing complexity of climate change impacts and risks, and the potential for compounding risks.[466]

Insufficient awareness and understanding of the severity of climate change risks and potential impacts

This can arise from unavailability of up-to-date risk information and hazard maps. Lack of awareness and understanding of climate-related risks to business operations in key sectors of the economy (e.g., agriculture, fisheries and tourism) constitutes a major barrier to creating market demand for climate services.

9.5 Social and gender barriers

Lack of meaningful engagement of civil society, especially vulnerable groups, in decision-making and planning processes

Lack of meaningful engagement of all relevant stakeholders (notably women and youth) is a systematic barrier to reaching the 'last mile' by limiting consideration of all user perspectives and awareness of the potential contributions of different population groups. Moreover, exclusion of minority groups from climate resilience-building activities can decrease their interest, resulting in lack of ownership and reduced participation in preparedness and response actions.

9.6 Financial barriers

Insufficient funding to enable fully functioning climate services and MHEWS

Operational services in MMS are fully funded by the government, with investments being primarily reliant on donor and project funding. The allocated state budget is insufficient to fully cover operation and maintenance (O&M) of equipment required for hydromet services and disaster risk management. Insufficient funding for O&M is a root cause for data availability issues. Lack of funding has also resulted into the inability to obtain qualified human resources. For example, MMS does not have any staff dedicated to providing climate services.

Inadequate investment in building preparedness and response capabilities

There is no state budget for preparedness, awareness, and vulnerability reduction activities[467] leading to a reliance on non-governmental organisations, such as the Maldivian Red Crescent, which itself is highly dependent on donor funding. Previous investments in building preparedness and response capabilities have been generally *ad-hoc* and small-scale.

9.7 Geographical barriers

Isolated and fragmented geographical context, with many dispersed, small and remote island communities

The geography of Maldives poses a major challenge in terms of ensuring the full reach of climate information and early warnings, as well as leading to higher costs (e.g., for travel and logistics) in comparison to other countries. Geographical, financial and logistical constraints result in areas of the country where observations are missing, which prevents comprehensive hazard monitoring and generation of tailored forecasts and warnings. Effective emergency response is limited by the country's

[466] IPCC, 2022. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Summary for Policymakers
[467] UNDRR, 2019. Disaster Risk Reduction in Republic of Maldives: Status Report 2019

geographical isolation.[468] Similarly, the capacity to undertake coordinated efforts to engage local communities in planning to reduce their vulnerability is limited by Maldives' geographical fragmentation and dispersed communities.[469]

[468] UNDRR and ADPC, 2019. Disaster Risk Reduction in Republic of Maldives. Status Report 2019
[469] Axisa, G.B., *et al.,* 2023. Island Studies Journal. Vulnerability to Disaster in the Maldives: The Maamigili and Fenfushi Island Communities

10 PROPOSED INTERVENTIONS

The transformative goal of the project is to increase resilience and reduce the vulnerability of sectors and communities in Maldives to climate change impacts by ensuring the availability and access to reliable climate services and a people-centred impact-based multi-hazard early warning system (MHEWS) covering the entire country. The project is designed to ensure a holistic and integrated approach to strengthening early warning systems in Maldives as a critical component of climate change adaptation and disaster risk reduction. By addressing a range of cross-cutting adaptation options concurrently – namely, disaster risk management, climate services, *and* early warning systems – the adaptation and risk reduction benefits of the project will be amplified.[470]

The Theory of Change diagram below shows the intervention logic proposed by the project and highlights the causal links and pathways from activities to outputs to project-level outcomes and co-benefits, along with the underlying assumptions, and barriers to be addressed. The proposed outputs, activities, and sub-activities are further detailed thereafter.

The impact of the project is a paradigm shift toward leveraging reliable climate services and people-centred, impact-based MHEWS to enhance the capacity of sectors and communities to implement preparedness and anticipatory actions, ultimately increasing resilience and reducing vulnerability of sectors and communities to climate change impacts.

The project aims to achieve impact via three interlinked outcomes, whereby Outcomes 1 and 2 provide an enabling environment for Outcome 3. The first two project outcomes are aligned with the respective paradigm-shifting pathways for climate information and early warning systems (CIEWS) identified in the corresponding GCF sectoral guide.[471] The project includes several interventions – for instance Sub-Activities 2.2.7 and 4.1.5 – that are designed to deliver on the third paradigm-shifting pathway for CIEWS identified by the GCF. The project outcomes will be achieved via four project outputs, which are designed to deliver on the four interconnected pillars of MHEWS: i) Risk Knowledge; ii) Observations and Forecasting; iii) Warning Dissemination and Communication; and iv) Preparedness and Response Capabilities. The contribution of the project outputs to outcomes is summarised below:

- ***Outcome 1: Reliable climate and disaster risk information is available to support risk-informed, evidence-based decision making –*** The project will work with the government and key climate-sensitive sectors in Maldives to improve collaboration for the collection, management and exchange of climate-related data and information. It will also strengthen capacities for multi-hazard risk and vulnerability assessments and collection and analysis of weather, water, climate and air quality data. This will be delivered through Outputs 1 and 2.
- ***Outcome 2: User-driven climate services and an end-to-end, people-centred impact-based MHEWS are operational and sustained –*** The project will enhance the utilisation of climate information services in decision making for all sectors of the Global Framework for Climate Services at the national level. Reliable climate services will provide the data, forecasts and predictions that underpin effective MHEWS. Investment in early warning systems will go beyond Pillar 2 (Observations and Forecasting) to cover the entire MHEWS value chain. This will be delivered across all four Outputs.
- ***Outcome 3: Sectors and communities implement timely and effective preparedness and anticipatory actions that increase resilience and reduce disaster risks –*** Outcomes 1 and 2 provide an enabling environment for the increase of resilience and the reduction of disaster risks. This Outcome ensures that sectors and communities have the knowledge and capacity to access, use, and act on impact-based forecasts and warnings, and sector-specific climate analytics to reduce disaster risks and avert or minimise climate-related losses and damages, including loss

[470] The IPCC AR6 reported with *high confidence* that "A range of adaptation options, such as disaster risk management, early warning systems, climate services and risk spreading and sharing approaches have broad applicability across sectors and provide greater risk reduction benefits when combined".
[471] GCF, 2022. Sectoral Guide Consultation Version 1: Climate information & early warning systems. Available at: https://www.greenclimate.fund/document/sectoral-guide-climate-information-early-warning-systems (Accessed: 18 December 2024)

of life. Well-functioning early warning systems are also critical to enhancing public health and safety. This will be delivered through Outputs 2 – 4.

In addition to the abovementioned outcomes, increasing gender equality and social inclusion is a cross-cutting priority of the project, which will translate into gender co-benefits. This includes deepening understanding of the root causes of vulnerability and gendered and intersectional risks (Output 3) and promoting and supporting women's full, equal and meaningful participation at all levels (Outputs 1-4).

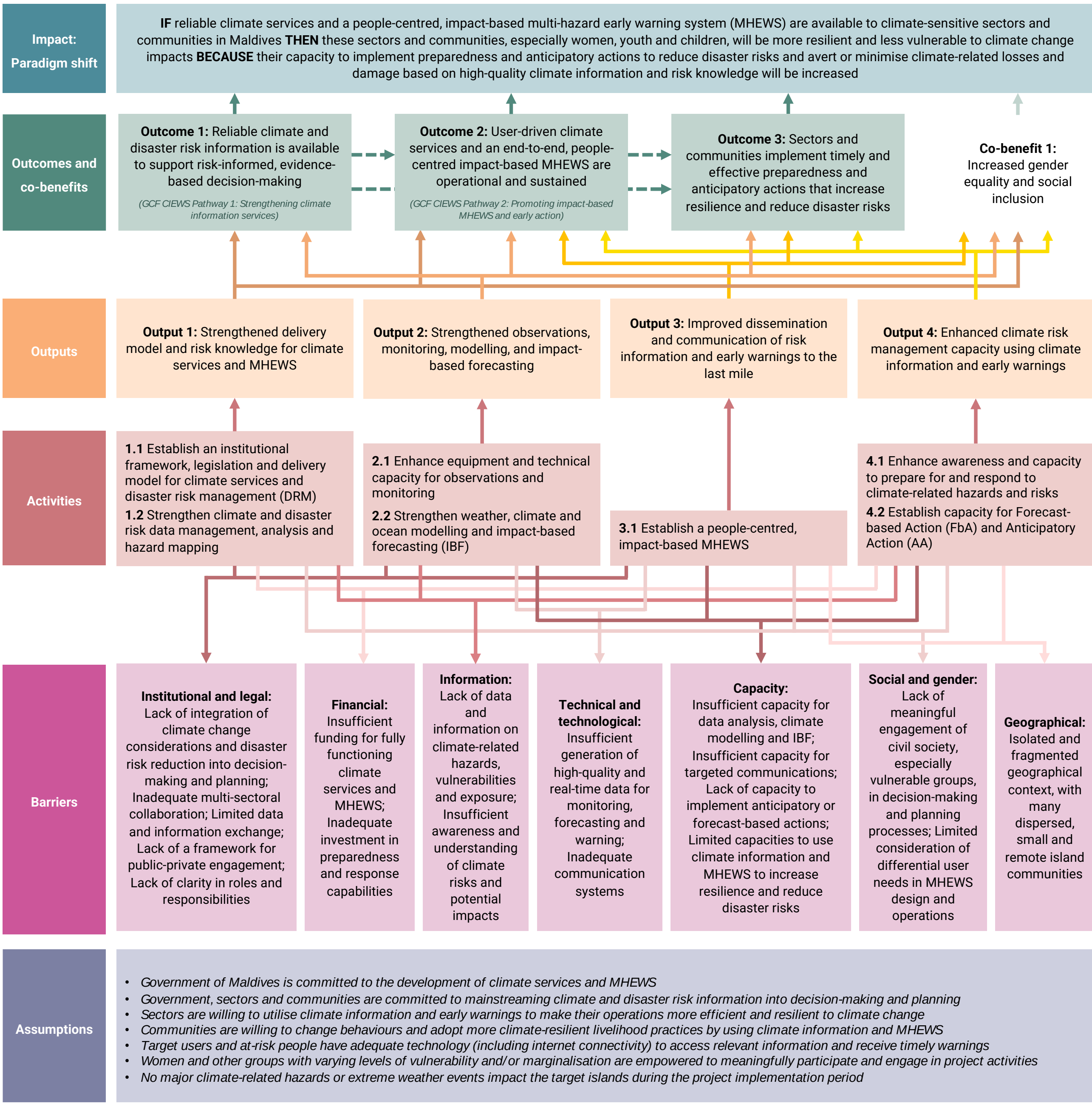

Figure 60. Theory of Change for the TRACT project

Output 1 – Strengthened delivery model and risk knowledge for climate services and a multi-hazard early warning system

Activity 1.1 – Establish an institutional framework, legislation and delivery model for climate services and disaster risk management

<u>Sub-Activity 1.1.1 – Develop a National Framework for Climate Services (NFCS)</u>

The project will support the establishment of a National Framework for Climate Services (NFCS) to coordinate, facilitate and strengthen collaboration among national institutions for enhanced generation and use of science-based climate information and services in Maldives. This will be underpinned by multi-stakeholder consultation workshops, which will bring together all relevant actors to identify the gaps and key elements for developing a national strategic plan and costed action plan to operationalise the NFCS. Informed by the outcomes of the consultations, the project will support the development of a national strategic plan and annexed action plan outlining the costs and timelines for delivering an NFCS and improving the delivery of nationwide climate services. Following a validation workshop, the NFCS will be launched at a high-level event involving all relevant ministries, UN organisations, and development partners.

<u>Sub-Activity 1.1.2 – Enhance inter-ministerial and multi-stakeholder coordination for climate services and disaster risk management</u>

The project will strengthen the government-led delivery of secretariat functions to establish and sustain an inter-ministerial, multi-stakeholder coordination mechanism for climate services and disaster risk management. The mechanism will build on the existing Disaster Management Steering Committee[472], where appropriate, and ensure representation of women and other vulnerable groups. This sub-activity will include support for the following functions: achieve consensus on mandate, functions, and define roles and responsibilities; support for decision-making, follow-up and performance monitoring; define priorities and multi-year plans for joint and sector-specific action by members; progress reporting; and outreach and cooperation with other government-led bodies and committees. The project will also facilitate coordination with the UN Country Team (UNCT) in Maldives to leverage UN-wide support for country-led climate information and early warning systems (CIEWS) and disaster risk management/reduction (DRM/DRR) in the context of One UN.

To complement operationalisation of the coordination mechanism, the project will facilitate peer-to-peer learning and training on global and regional best practices for CIEWS and DRM/DRR through study tours, networking, and development of multi-stakeholder communities of practice. A biennial national summit on CIEWS and DRM/DRR will also be convened to showcase good practices, community-led use of climate services and innovations in EWS and DRR, and technologies for change.

Moreover, the project will support the delivery of a National Platform for DRR. To maximise participation of local government representatives across the country, the Platform will be held through a series of events across four geographical regions (north, north-central, central, and Male')[473]. Key stakeholders to be engaged include island councils,[474] atoll councils, Maldives National Defence Force, Maldives Police Service, MMS, Local Government Authority, Maldivian Red Crescent, and other NGOs.

<u>Sub-Activity 1.1.3 – Enhance the National Climate Outlook / Monsoon Forum</u>

The project will enhance the National Climate Outlook / Monsoon Forum as a platform for multi-stakeholder dialogue and knowledge sharing between MMS and institutional end-users, including stakeholders from all five priority sectors of the Global Framework for Climate Services (agriculture and food security, disaster risk reduction, energy, health, and water).

The Monsoon Forum will serve as a key delivery mechanism of the User Interface Platform (UIP), which is one of the five pillars of the NFCS to be developed under Sub-Activity 1.1.1. The Forums will facilitate delivery of the four intended outcomes of the UIP, as outlined below:

- **Feedback –** The Forums will provide a venue for MMS to obtain feedback on how effectively its products and services are meeting the needs of user communities, as well as respond to forecast information requests from users. Better understanding of sectoral information requirements will support the development of tailored climate information products for specific sector applications.

[472] The Disaster Management Steering Committee was established on paper under the 2015 Disaster Management Act but has not been operationalised.
[473] N.B. National Platforms for DRR in other regions are covered by other initiatives.
[474] The Detailed Budget Plan (Annex 3) includes funding for two participants from each island council with the aim of ensuring 50% female representation

- **Dialogue –** The Forums will enhance dialogue between climate information providers and users, enabling forecasts (particularly seasonal and sub-seasonal) to be discussed for integration into seasonal planning and implementation of preparedness and anticipatory management strategies.
- **Outreach –** The Forums will support improved climate literacy in the user community, as well as improved literacy in the climate community of user needs. As a platform for knowledge sharing, the Forums will support stakeholders to better understand the content and uncertainties in climate forecasting and the meaning and use of probability rankings about likely climate risks. In the long-term, the process of improving understanding of climate change risks and opportunities will contribute to strengthening the country's coping capacities and resilience to weather and climate-related hazards.
- **Evaluation –** The Forums will provide a mechanism to monitor and evaluate the development, delivery and effectiveness of climate services in Maldives to ensure that MMS' products and services meet the needs of its stakeholders. This will facilitate continuous capacity building of MMS to deliver best-practice climate services in the Maldivian context.

The Monsoon Forums will aim to provide a structured means for MMS and user agencies to enhance collaborations and partnerships, as well as strengthen capacities in potential impact assessment, risk analysis, and development of matrices for impact-based forecasting.

<u>Sub-Activity 1.1.4 – Strengthen strategic partnerships and knowledge brokering through regional and international fora</u>

The project will support MMS and key climate services users/sectors to strengthen their engagement in regional and international fora. The aim of this sub-activity will be to reinforce strategic partnerships and knowledge brokering that enhance the ability of MMS to provide high-quality climate services and EWS aligned with international good practices, as well as increase appreciation and understanding amongst sectors on climate services applications. This will include (but is not limited to) support for the following:

- *South Asian Climate Outlook Forum (SASCOF) and Climate Services Users Forum (CSUF)* – The SASCOF is organised annually to prepare consensus seasonal climate information on a regional scale that provides a consistent basis for the preparation of national-level outlooks for nine South Asian countries, including Maldives. The SASCOF is conducted back-to-back with the CSUF, which brings together experts in seasonal prediction and operational users from agriculture, DRR, health, and other climate-sensitive sectors in the region, creating a platform for sharing, understanding, and interpreting seasonal climate outlooks for effective use in climate risk management. Participation of MMS and key sectoral staff in the SASCOF and CSUF promotes South-South cooperation and ensures that staff are kept up to date with regional initiatives on seasonal climate information and its sectoral applications.
- *Orientation and linkage of MMS tools/products with the Global Disaster Alert and Coordination System (GDACS)* – This process will include a scoping of the web-based disaster information systems and related coordination tools in GDACS and identify synergies between the alerts and systems available from MMS and/or to be developed through the proposed project. Data sharing via API and coordination mechanisms will also be explored in this process.

<u>Sub-Activity 1.1.5 – Establish a legal framework for enabling private sector investment in weather and climate services</u>

The project will address the need to establish a legal status for MMS, which is essential for it to function independently and to formally engage in partnerships with the private sector. MMS does not currently have a dedicated legal framework defining its institutional role, authority, and responsibilities. These are defined through a presidential decree (Act No.3/68 dated 11 November 1968), administrative decisions, strategic documents, internal protocols and policies. MMS is unable to undertake cost recovery activities, which would contribute towards ensuring sustainable funding for its crucial services. In addition, MMS does not have any formal agreements in place with the private sector for service delivery, operation and maintenance of observational networks, or sharing of observational data.

Under this sub-activity, the project will support MMS to revise and update the draft Meteorological Act (prepared in 2016) to reflect the latest developments in the field of meteorology and, if deemed feasible, provide a clear legal framework for cost recovery for relevant services.

The Act will define the mission and mandate of MMS and ensure clarity in the definition of its responsibilities, including providing the legal authority for certain duties. This will facilitate that MMS is clearly designated at the national authoritative voice for the provision of information relevant to the management of weather- and climate-related hazards. The Act will also support recognition of MMS' contribution to society, which in turn should promote adequate allocation of resources. The establishment of a legal status for MMS will be key to enabling the formation of public-private partnerships – for which opportunities will be explored under Sub-Activity 1.1.6.

Sub-Activity 1.1.6 – Develop a financial framework and business delivery model for weather and climate services

The project will work with MMS to develop a financial framework and business delivery model to ensure that MMS has the means to sustain and ensure the ongoing operation of its services to mitigate weather- and climate-related risks (including financial risks in both public and private sector markets) beyond the term of the project, as capacity to generate specialised value-added services is developed.

This sub-activity will facilitate a series of dialogues between MMS and target sectors (including aviation, insurance, and tourism sectors), which will focus on:

- Scoping options for private sector actors to utilise specific weather and climate information products
- Identifying viable opportunities for the development of specialised value-added products and services
- Potential for public-private partnerships and private investment in weather and climate services.

Informed by the multi-stakeholder dialogues, the project will support the development of a financial framework and business delivery model for weather and climate services in Maldives, which will cover the following elements:

→ Identification of the components of a sustainable business model for MMS based on the climate services value chain, which identifies two key output streams: basic "public good" services (i.e., public communication of general weather forecasts and warnings) and specialised services (which are tailored to specific users in the public and private sectors). The business delivery model will identify opportunities for MMS to provide specialised value-added services to government agencies and private sector entities, with potential options for cost recovery beyond the term of the project.

→ Opportunities for strategic partnerships to enhance cooperation between the public and private sectors and academia, thereby delivering win-win situations that fulfil public sector responsibility to provide weather and climate services as a public good, and concurrently meet the needs of economic sectors that increasingly require weather and climate analytics for safe, efficient operations and management of financial risks.

→ Opportunities for mobilisation of finance at scale, including innovative financing solutions (e.g., blended finance), enhanced resource mobilisation from global funds, ring-fenced funding, and scale-up of national budget allocation for climate information and early warning systems.

→ Integration of resources mobilised from the Systematic Observations Financing Facility (SOFF)[475], which will provide technical and financial assistance to SIDS and LDCs for the generation and exchange of essential observational data to meet and achieve sustained compliance with the Global Basic Observing Network (GBON)[476] technical regulations.

As part of this sub-activity, the project will support an international study tour for MMS staff to a country where cost recovery for climate services has already been established. Additionally, the project will

[475] In November 2022, Maldives was approved amongst the first batch of beneficiary countries to receive support from the SOFF. UNEP has been selected by Maldives to serve as its SOFF Implementing Entity. The SOFF Readiness Phase for Maldives began in April 2023.
[476] WMO, 2023. GBON – Global Basic Observing Network. Available at: https://community.wmo.int/en/activity-areas/wigos/gbon

engage with MMS and other key stakeholders to analyse the socio-economic benefits of strengthening climate services and multi-hazard early warning systems (MHEWS) for Maldives. The results of the analysis will help identify and communicate the impact and value-for-money of climate services and MHEWS and hence strengthen the business case for further investment.

Sub-Activity 1.1.7 – Establish National Guidelines for Integrating Protection, Gender and Inclusion (PGI) into Disaster Management

The project will support the development of National Guidelines for Integrating PGI into Disaster Management, which will promote the implementation of protective, gender-transformative, and inclusive approaches to disaster risk management at all levels in Maldives. Recognising that sex, gender identity, age, physical ability, race, nationality, and many other factors can influence a person's vulnerability to and impacts from climate-related disasters, the guidelines will aim to ensure that disaster management approaches are appropriately tailored and prioritised to reach all at-risk persons effectively and in a non-discriminatory and equitable manner. To enhance efficiency and ensure that previous efforts are utilised, this sub-activity will build on internal Gender Equality Guidelines for NDMA that were developed in 2022 but have not been officially published or used. Development of the guidelines will be informed by stakeholder consultations and focus group discussions both in Male' and in outer islands.

Activity 1.2 – Strengthen climate and disaster risk data management, analysis and hazard mapping

Sub-Activity 1.2.1 – Develop and implement a National Climate and Disaster Risk Information Strategy

The project will support the formulation of a multi-year National Climate and Disaster Risk Information Strategy and Action Plan for Maldives, ensuring a gender-responsive approach and incorporating findings from multi-stakeholder consultations, diagnostic of relevant e-government policies and regulations, and good practices derived at the global and regional level. As part of the strategy development, the project will deploy expert assistance to the government to co-design standard operating procedures (SOPs) for risk assessments, including delivery of tailored technical assistance to sectors. The overall aim of this sub-activity will be to establish coherent national guidance for the systematic collection, sharing, and assessment of data and information on climate change and disaster risks – including collation and use of existing information and methodologies.

Sub-Activity 1.2.2 – Establish institutional arrangements for data governance and sharing

Under the leadership of the National Centre for Information Technology (NCIT), the project will support the establishment of institutional arrangements for data governance and sharing between MMS, NDMA, and MRC – as well as other key actors across the agriculture, disaster risk reduction, environment, fisheries, health, tourism, and water sectors. This process will be informed by multi-stakeholder consultation workshops, with follow-up assessments and meetings in Years 4-5 to discuss data access and use, and update arrangements as needed. Data governance and sharing mechanisms will be subsumed into the national strategy to be developed under Sub-Activity 1.2.1. Enhancing inter-sectoral data sharing and coordination will strengthen the foundation for implementation and scale up of impact-based forecasting and anticipatory action activities.

Sub-Activity 1.2.3 – Establish standardised multi-hazard risk assessments and mapping

The project will support the establishment of a standardised multi-hazard risk assessment and mapping approach, methodology and process for a range of climate-related hazards, in partnership with key stakeholders including MMS and NDMA. This will include the development/implementation of hazard assessments and maps for storms, strong winds, storm surge, coastal flooding, and drought at various return periods. CMIP6 climate projections will also be developed, and trends in climate extremes established for different scenarios and time periods. In line with a comprehensive risk management approach, the assessments will include consideration of non-climate drivers.

As part of the multi-hazard risk assessment, the project will gather and analyse existing exposure and vulnerability data (including vulnerability curves) and identify gaps where additional data is required. Intersectionality will be considered in this analysis. In consultation with relevant stakeholders, a methodology and questionnaires for further data collection will be developed. Stakeholders will also be engaged in the finalisation of physical vulnerability curves and social and economic vulnerability indicators and ratings. Following this, exposure and vulnerability assessments (including a LiDAR survey, community surveys, focus group discussions, site visits, and associated analysis) will be conducted in select “most-at-risk” inhabited islands with high levels of socioeconomic activity. The exposure and vulnerability data will then be integrated with the hazard assessments and maps, as well as into the decision support system (DSS) for disaster risk management (DRM) to be developed under Sub-Activity 2.2.5. Post-assessment consultations and workshops will be conducted to validate and subsequently update the hazard mapping and assessment results based on feedback from stakeholders. Multi-stakeholder workshops will also serve as platforms to discuss how the results could be utilised and assessment/mapping efforts continued by relevant agencies.

The establishment of standardised assessment and mapping approaches, methodologies, and processes for different hazards and vulnerabilities (physical, social, economic, environmental) aims to ensure sustained updating of multi-hazard risk assessments and maps at regular intervals. This will contribute to improving risk knowledge, ensuring that recent changes in hazard and vulnerability are identified and reflected. Risk assessment and mapping approaches will be aligned with national frameworks and legislation as relevant (e.g., Climate Emergency Act, Disaster Management Act) to add legal weight to support their implementation.

Following the establishment of a standardised approach, methodology, and process, the assessment models, parameters, indicators, and weights will be integrated into the DSS for DRM to ensure that vulnerability information can be linked with hazard forecasts, and therefore contribute to impact-based forecasting. In addition, the availability of high-resolution hazard maps will help to strengthen the existing Island Disaster Management Plan (IDMP) development process, which is currently reliant on the use of publicly available maps of insufficient resolution.

<u>Sub-Activity 1.2.4 – Strengthen local capacities to undertake climate-related risk assessments</u>

The project will deploy targeted training to facilitate that capacity to undertake multi-hazard risk assessments and mapping (Sub-Activity 1.2.3) is embedded within the relevant national institutions to support long-term sustainability and potential for future scale-up. This sub-activity will include the following:

- <u>*Technical training and involvement of MMS representatives in the hazard mapping and assessment process:*</u> MMS staff will be involved in the entire assessment and mapping process for hydrometeorological hazards.
- <u>*Training on GIS and remote sensing, and involvement in the vulnerability mapping and assessment process for NDMA and Maldives Land and Survey Authority (MLSA):*</u> The training will include review of the usefulness/suitability of relevant concepts, indicators, ratings and weight assessments that would define different components (exposure, sensitivity, and capacity) and types (physical, social, economic, environmental) of vulnerability.
- <u>*Training of enumerators:*</u> Enumerators are required for the conduct of surveys that feed into the exposure and vulnerability assessment and mapping. This could include local staff of MLSA and NDMA who can be trained in the conduct of surveys.
- <u>*Training on the hazard and vulnerability assessment/mapping approach, methodology, and process to sustain the risk mapping/assessment exercise:*</u> This training will help to ensure that key representatives from MMS, NDMA and MLSA are capacitated on the standardised hazard mapping and assessment approach, methodology and process established under Sub-Activity 1.2.3. Trained staff should be able to update GIS-based hazard and vulnerability assessments/maps at regular intervals (i.e., between 3-5 years) and upload the outputs in the DSS for DRM (Sub-Activity 2.2.3). Integration of hazard and vulnerability maps will enhance the impact-based forecasting capacity of the DSS.

To complement the above training, the project will strengthen capacity of national and local actors to accelerate adoption of existing analytic frameworks and models that provide the basis for multi-hazard risk mapping and impact-based forecasting, so that the use of existing tools can be sustained. Technical assistance and capacity building will cover the following:

- Risk analysis of climate-driven hazards facing productive economic sectors, social services and social infrastructure, critical assets, supply chains and trade, and options for attenuation of risks through a combination of public and private investment, community action, and risk transfer options, among others.

- Infrastructure stress-testing to enable quantification of contingent liabilities in the face of climate risks and to strengthen national assessment of socio-economic and environmental impacts.
- Qualitative and quantitative annualised loss modelling across multiple sectors, including estimation of economic loss; quantification of direct, secondary and tertiary effects of historical events and forecasted growth of hazard exposure and vulnerabilities; co-identification of risk transfer options with the Ministry of Finance, Maldives Monetary Authority, and NDMA.
- Programming skills and use of languages and tools for processing and visualisation of field data required for impact-based forecasting, including multidisciplinary risk and vulnerability assessments; and analysis of spatial data and hydrological modelling, including through the use of cloud-based technologies.

Sub-Activity 1.2.5 – Conduct Enhanced Vulnerability and Capacity Assessments (EVCAs)

The project will support the implementation of Enhanced Vulnerability and Capacity Assessments (EVCAs) – a participatory process designed to foster community resilience through the assessment and analysis of the risks they face and the identification of actions to reduce these risks.[477] MRC will conduct capacity building workshops in Years 1-2 of the project to establish a pool of EVCA facilitators. This will be followed by implementation of the EVCA process in target island communities across the northern, central and southern regions. The EVCA process will be implemented by MRC under the oversight of NDMA.

The EVCA process will go beyond data collection, analysis and action planning to serve as a means for learning and empowerment for target communities in relation to risk understanding, risk reduction, and resilience building. Inclusive participation will be critical to ensure meaningful empowerment and sustainable impact. In this regard, a gender responsive and socially inclusive approach will be emphasised to ensure that the project engages with and understands the needs, capacities and priorities of all population groups.[478]

This sub-activity will contribute to upscaling and expansion of the Community Based Disaster Risk Management (CBDRM) programme, led by NDMA in coordination with MRC. NDMA and MRC are currently working to integrate the EVCA process into the production of Island Disaster Management Plans (IDMPs) as part of the CBDRM programme. The collated community-level vulnerability and risk data will feed into to the development of multi-hazard maps and community risk profiling, ultimately informing IDMPs.

Sub-Activity 1.2.6 – Establish a national disaster risk knowledge platform

The project will support the design and establishment of a national disaster risk knowledge platform for Maldives, hosted within NDMA. The platform will serve as a ‘one-stop shop’ for all relevant data and information on climate-related hazards and disaster risks at the national level, integrating or scaling up existing databases and portals as relevant. The development of the platform will prioritise a collaborative, user-driven approach and will be informed by a series of multi-stakeholder consultations and co-design workshops, which will facilitate the identification of the requisite features and functionalities based on user needs and capacities.

The platform features and functionalities will be developed using an *Agile* approach, while ensuring interoperability with any relevant existing systems, flexibility in ingesting data in different formats, and scalability with emerging technologies and new technical capacities of target users. The platform will be developed using cost-effective technology and will embed the latest technologies such as machine learning, remote sensing, GIS, and other AI approaches, whenever feasible.

Upon development of the disaster risk knowledge platform, this sub-activity will support the collection, digitisation, and integration of relevant impact data, hazard and risk maps, and vulnerability and capacity assessment (VCA) information. This will include incorporation of all data and outputs from Sub-Activities 1.2.3 and 1.2.5, as well as from the loss and damage tracking system to be established under Sub-Activity 1.2.7. While automatic data ingestion via API will be favoured, manual data uploading is also expected. Moreover, the risk knowledge platform will be designed and developed in such a way that is automatically

[477] IFRC, 2018. What is the EVCA? Available at: https://www.ifrcvca.org/what-is-evca
[478] This includes women, men, boys, girls, elderly persons, persons with disabilities, and individuals from diverse social, cultural, economic and religious groups, including migrant groups.

linked with the decision support system (DSS) for disaster risk management (DRM) (Sub-Activity 2.2.5) to leverage its vast wealth of information. Through a unified system, the DSS for DRM could also contribute to populating impact-based data into the risk knowledge platform.

Technological developments under this sub-activity will be complemented by a series of trainings on data uploads as well as usage of the platform. The trainings will be important in ensuring the usability, manageability, and sustainability of the platform for the data providers and the portal administrators. Data providers, such as MMS, sectoral agencies, and community representatives, will be trained on how to populate the platform, as well as how to use the information and risk analysis for planning and tactical operations. Similarly, the platform administrator from NDMA will be trained to update and manage the platform.

Sub-Activity 1.2.7 – Establish a tracking system for hazardous events and losses and damages

The project will support the establishment and strengthening of Maldives' national disaster loss database in line with the rollout of the Disaster Losses and Damages Tracking System 2.0 under development by UNDRR, WMO and UNDP. At the global level, the new system will replace the existing DesInventar with a more comprehensive and interoperable tracking system covering both hazardous events, as well as disaggregated losses and damages at localised scales.[479] The country-level roll-out will include the deployment of technical assistance to institutionalise the WMO Cataloguing Hazardous Events (WMO-CHE) methodology to better link weather observations and hazardous events with related impacts and loss and damage information.

To complement the system roll-out, a key focus of this sub-activity will be on strengthening national capacities to collect, manage, and utilise data on past and current losses and damages from hazardous events. This will include capacity building on the management and utilisation of loss and damage data for decision making to reduce disaster risks. Additionally, this sub-activity will facilitate peer-to-peer learning between Maldives and other countries in the region with robust risk knowledge platforms and national disaster loss databases in place (e.g., Philippines, Pakistan, Nepal). The roll-out of both the risk knowledge platform (Sub-Activity 1.2.6) and tracking system (Sub-Activity 1.2.7) will be supported by socialisation and outreach (e.g., youth 'code-a-thon') and demonstrations at regional and global events (e.g., UNFCCC COPs, Global Platform for Disaster Risk Reduction).

The new tracking system will be scalable: (i) horizontally, across sectors; (ii) vertically, to the lowest administrative units; and (iii) thematically, across climate, humanitarian, and disaster risk reduction domains. The system will ensure flexibility for customisation, suited to the country context and maturity, and will be interoperable with relevant databases and reporting systems. Furthermore, key ambitions of the tracking system are to maximise a) open access; b) open and non-proprietary data formats for all content; c) interoperability and data exchange functionality, global and national taxonomies, and other standards; and d) historical data migration from DesInventar complemented by ongoing and real-time data collection.

Output 2 – Strengthened observations, monitoring, modelling and impact-based forecasting

Activity 2.1 – Enhance equipment and technical capacity for observations and monitoring

Sub-Activity 2.1.1 – Strengthen the hydrometeorological observation network

The project will support MMS to enhance the hydrometeorological observation network in Maldives to ensure the availability of high-quality, high-resolution data to feed into weather and climate modelling and impact-based forecasting (Activity 2.2). This will include the upgrade of sensors for the manned station in Kaadedhdhoo, procurement and installation of visibility meters for five stations, and procurement of spare parts, which are essential to avoid delays in data acquisition in the case of sensor or station failure. This sub-activity will also support the acquisition of two national calibration kits and provide technical support to enable MMS to conduct regular field verification of the automatic weather station (AWS) network.

The installation of new equipment will be supported by comprehensive training for MMS staff on WMO Integrated Global Observing System (WIGOS) implementation and equipment operations, maintenance

[479] UNDRR, 2024. Disaster losses and damage tracking. Available at: https://www.undrr.org/disaster-losses-and-damages-tracking-system (Last accessed: 9 January 2024)

and calibration. In addition, the project will support the development of a 5-year Strategic Plan for MMS, which will incorporate the following: National Strategic Plan for Observations, National WIGOS Implementation Plan, and an Operation and Maintenance (O&M) plan covering existing and new infrastructure. These measures should help to ensure the longevity of infrastructure, skills and knowledge introduced through the project.

MMS will be responsible to ensure the operation and maintenance of the equipment purchased under this sub-activity following project implementation and up to a period of 20 years.

This sub-activity will complement the technical and financial assistance received by MMS through the Systematic Observations Financing Facility (SOFF). The SOFF Investment Phase[480] deliverables (e.g., Organisational Strategy and Gender Policy) will be incorporated within the 5-year Strategic Plan for MMS, where applicable. As the SOFF Implementing Entity for Maldives, UNEP will ensure coherence and alignment between GCF and SOFF investments. Additionally, this sub-activity will complement the observational infrastructure enhancements supported by the UNDP-led GCF project “Support of Vulnerable Countries in Maldives to Manage Climate Change-Induced Water Shortages” (FP007), which has installed six AWS in Maldives.

<u>Sub-Activity 2.1.2 – Enhance the ocean observation and monitoring system</u>

The project will expand and upgrade ocean observations and monitoring in Maldives for *in-situ* measurement of a range of physical oceanic variables (e.g., sea surface temperature, water level, current, wind speed and direction, and wave and swell height, direction and period) to generate localised data for improved ocean state forecasting. This will include the deployment of ocean buoys, tide gauges and a depth sonar, as well as the installation of ocean monitoring sensors on existing fisheries buoys. To complement the equipment deployments and promote sustainability, the following trainings and skills development will be provided to MMS and marine stakeholders: deployment, data retrieval and use, equipment maintenance, and marine observations and forecasting.

MMS will be responsible to ensure the operation and maintenance of the equipment purchased under this sub-activity following project implementation and up to a period of 20 years.

This sub-activity will complement the deployment of three metocean buoys in selected sites (Hanimaadhoo, Male’ and Gan), which is being supported under the JICA-led GCF project “Building Climate Resilient Safer Islands in the Maldives” (FP165).[481]

<u>Sub-Activity 2.1.3 – Establish a Training Institute to build and sustain meteorological capabilities</u>

This sub-activity will support capacity building and long-term sustainability of meteorological capabilities in Maldives through the establishment of a Training Institute at MMS. The project will fund the initial set-up costs (textbooks and IT infrastructure) as well as the cost of registration and accreditation. The main structured training to be delivered will be a Basic Meteorological Observation course for newly recruited staff. This course will cover weather observation – including general tropical weather systems, synoptic (SYNOP) and aviation (METAR, SPECI) weather reporting, basic climate data handling, familiarisation on multi-hazard early warning and alerting – and other hands-on practical training.

MMS will be responsible to ensure the operation and maintenance of the equipment purchased under this sub-activity following project implementation and up to a period of 20 years.

<u>Sub-Activity 2.1.4 – Build capacity for Internet of Things (IoT) and wireless technologies</u>

This sub-activity focuses on expanding the weather and climate monitoring network in the Maldives by deploying innovative, low-cost sensors that leverage Internet of Things (IoT) and wireless technologies. These sensors are designed to address the critical need for high-resolution weather data in data-sparse areas, offering a cost-effective and energy-efficient solution to complement the existing network of traditional weather stations, which are fewer in number and more expensive to deploy and maintain. By integrating these low-cost, low-power IoT sensors into the broader monitoring framework, the project aims to demonstrate their potential to enhance spatial coverage and data accuracy, enabling

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480 Further information on the SOFF Investment Phase is available here: https://mptf.undp.org/project/00140656 (Accessed: 10 December 2024)

481 The GCF-funded JICA project “Building Climate Resilient Safer Islands in the Maldives” (FP165) will establish and implement integrated coastal zone management (ICZM) and coastal conservation measures, with concurrent delivery of disaster warnings/information. Project documents: https://www.greenclimate.fund/project/fp165

more locally-relevant and informed decision-making in climate-sensitive sectors and at the community level.

Preliminary testing conducted in collaboration with the Maldives Meteorological Service (MMS) has demonstrated that IoT-based weather stations produce high-quality data comparable to traditional systems. These sensors are capable of capturing essential weather parameters such as temperature, humidity, rainfall, and wind speed with precision, making them a reliable addition to the monitoring network. The deployment of this proven technology ensures that the expanded network will generate accurate and actionable data, providing a robust foundation for improved forecasting, climate modelling, and disaster preparedness efforts in the Maldives.

To ensure the sustainability of the intervention, this sub-activity will include a strong capacity-building component. Workshops and hands-on training sessions will be conducted for MMS staff, equipping them with the knowledge and skills required to operate, maintain, and scale the IoT-based monitoring system independently after the project concludes. This approach not only strengthens the operational capacity of MMS but also ensures the long-term impact and scalability of the technology, aligning with national priorities for climate resilience and sustainable development.

Under this sub-activity, the project will support the renovation/replacement of 34 stations with low-cost, IoT-enabled sensors, as well as the deployment of 10 new stations.

Table 25. Locations of existing stations proposed for sensor replacement/renovation (Source: MMS, 2024)

Existing stations proposed for sensor replacement/renovation			
#	Island	Latitude	Longitude
1	AA. Thoddoo	4° 26' 18.00"	72° 57' 34.00"
2	AA. Himandhoo	3° 55' 14.00"	72° 44' 40.00"
3	ADh. Mahibadhoo	3° 45' 33.00"	72° 58' 12.00"
4	B. Thulhaadhoo	5° 01' 21.00"	72° 50' 19.00"
5	Baa. Goidhoo	4° 52' 24.00"	72° 59' 52.00"
6	Dh. Kudahuvadhoo	2°40' 02.5	72°53'15.7
7	F. Bilehdhoo [S8381]	3° 07' 04.00"	72° 59' 04.00"
8	F. Nilandhoo	3° 04' 32.00"	72° 58' 12.00"
9	Ga. Gemanafushi	0° 26' 34.00"	73° 34' 08.00"
10	Ga. Kolamaafushi	0° 50' 13.00"	73° 11' 09.00"
11	Gdh. Faresmaathodaa	0° 12' 07.00"	73° 11' 08.00"
12	Gdh. Thinadhoo	0° 31' 52.00"	72° 59' 52.00"
13	Ha. Hoarafushi	6° 58' 60.00"	72° 55' 52.00"
14	Ha.Kelaa	6° 57' 36.00"	73° 12' 46.00"
15	HDh. Kulhudhuffushi	6° 37' 34.00"	73° 04' 02.00"
16	HDh. Makunudhoo	6° 24' 36.00"	72° 42' 10.00"
17	K. Dhiffushi	4° 26' 31.00"	73° 42' 55.00"
18	K. Gaafaru	4° 44' 09.00"	73° 29' 59.00"
19	K. Guraidhoo	3° 54' 04.00"	73° 28' 04.00"
20	K. Kaashidhoo	4° 57' 36.00"	73° 27' 40.00"
21	L. Maavah	1° 53' 08.00"	73° 14' 36.00"
22	Lh. Olhuvelifushi	5° 16' 42.00"	73° 36' 26.00"
23	M. Muli	2° 55' 14.00"	73° 34' 49.00"
24	N. Maafaru	5° 49' 29.00"	73° 28' 34.00"
25	R. Alifushi[S8766]	5° 58' 11.00"	72° 56' 60.00"
26	R. Maduvvari	5° 29' 10.00"	72° 53' 49.00"

27	R. Dhuvaafaru [S8765]	5° 37' 41.00"	73° 02' 17.00"
28	S. Hithadhoo [S7723]	-0° 76'-60.00"	73° 05' 41.00"
29	S. Hulhumeedhoo	-0° 75' 65.00"	73° 13' 18.00"
30	Sh. Funadhoo	6° 08' 54.00"	73° 17' 21.00"
31	Sh. Kanditheemu	6° 26' 25.00"	72° 55' 05.00"
32	Sh. Komandoo	6° 03' 17.00"	73° 03' 07.00"
33	Th. Buruni	2° 32' 32.00"	73° 06' 31.00"
34	V. Rakeedhoo	3° 18' 54.00"	73° 28' 12.00"

Table 26. Proposed locations of new low-cost IoT-enabled weather stations

Proposed locations of new low-cost IoT-nebaled weather stations			
#	**Island**	**Latitude**	**Longitude**
1	N. Manadhoo	5° 45' 59.92"	73° 24' 42.82"
2	Villimale	4° 10' 19.95"	73° 28' 59.55"
3	Cinamale Bridge	4° 10' 18.98"	73° 31' 20.56"
4	Hulhumale Phase 2	4° 13' 49.92"	73° 32' 36.82"
5	Gulheefalhu (Male')	4° 10' 45.93"	73° 27' 19.14"
6	Funadhoo (Business Hub)	4° 11' 1.40"	73° 31' 4.57"
7	GDh. Maavarulu (Airport)	0° 20' 11.97"	73° 30' 35.44"
8	Fuvahmulah City (School)	-0° 17' 28.31"	73° 24' 56.08"
9	S. Maradhoo (School)	-0° 39' 57.30"	73° 7' 17.92"
10	S. Meedhoo (School)	-0° 35' 18.27"	73° 13' 39.09"

MMS will be responsible to ensure the operation and maintenance of the equipment purchased under this sub-activity following project implementation and up to a period of 20 years.

Activity 2.2 – Strengthen weather, climate and ocean modelling and impact-based forecasting

Sub-Activity 2.2.1 – Establish e-infrastructure for integrated observing and high-resolution forecasting

The project will configure and set up a server, hardware and equipment in the MMS data centre to consolidate, store, and process observation and forecast data for numerical weather prediction (NWP), limited-area modelling (LAM), and data assimilation. This sub-activity will complement the Systematic Observations Financing Facility (SOFF) Investment Phase project in Maldives, which is upgrading the data management system in MMS to ensure compliance with WIS 2.0. Training for MMS staff to use the upgraded data management system will be provided as part of the proposed GCF project.

MMS will be responsible to ensure the operation and maintenance of the equipment purchased under this sub-activity following project implementation and up to a period of 20 years.

Sub-Activity 2.2.2 – Undertake climate data rescue and digitisation

This sub-activity will support the recovery, preservation and digitisation of weather and climate records – including provision of guidance and techniques on data rescue and climate data management systems; quality control of data; digitisation of 30-year time series of key parameters for various stations across the country; and cataloguing, which can be applied for the analysis of historical time series as well as climate trends and extremes. This is essential to preserve all data at risk of being lost, due to deterioration, destruction, or obsolescence of the storage media, and ensure the accessibility of data for climate analysis and subsequent applications.

Sub-Activity 2.2.3 – Enhance downscaled weather, climate and ocean modelling and high-resolution forecasting

This sub-activity will support the co-development and/or customisation of forecasting systems for meteorology (forecaster workstation), aerometeorology, climatology, and ocean/marine services using an agile and user-driven approach. The GIS-based systems will integrate all available data and models from MMS, as well as global and regional sources, where applicable. System transfer to MMS will be implemented with the support of hands-on trainings and the development of standard operating procedures (SOPs).

<u>Sub-Activity 2.2.4 – Develop and sustain core competencies for user-centred climate services</u>

This sub-activity will involve the provision of targeted training to MMS and key stakeholders to enable technical staff to acquire the qualifications and competencies (knowledge, skills, and behaviour) to provide and/or use best available climate information for well-informed climate action. In line with the WMO Competency Framework for Climate Services and Training Areas,[482] the project will support the development and delivery of a tailored, competency-based training package focused on the following areas:

1. *Generation and interpretation of climate indices and model outputs:* This training area will focus on the generation of climate data and information using WMO-supported resources such as Climpact – a software package for the calculation of sector-specific climate indices – and the Climate Information Portal (CIP) – which provides access to projections of 28 pre-calculated climate and water indicators at a regional model scale, derived from fully coupled global and regional climate models. Specific topics could include climate extremes relevant to Maldives and projected changes in these extremes.

2. *Co-production of Climate Services – Focus on engaging with different climate science information producers and users:* This training area will focus on how to design and implement co-production, including the required criteria, principles, good practices, and approaches; how to establish effective communication channels and partnerships between producers and users of climate services; and how to comply with the interfacing requirements of the Global Framework for Climate Services (GFCS).

3. *Quality Management System (QMS) for Climate Services:* This training area will focus on improving MMS' climate services and products through the implementation of a QMS roadmap. The development and implementation of a QMS within an International Organization for Standardization (ISO) 9001 quality management framework will enhance the capacity of MMS to better integrate weather and climate services for forecasting; generate standardised climate information; establish strong user engagement; and be capable of effectively using global and regional inputs in a national context. This achievement will further facilitate the establishment of a National Framework for Climate Services (Sub-Activity 1.1.1) and enhance the provision of information through tools such as Climpact to serve decision-makers across a wide range of climate-sensitive sectors.

4. *QMS for Aviation Services:* The International Civil Aviation Organization (ICAO) Annex 3 provisions[483] require States to ensure that their designated meteorological authorities establish and implement a properly organised QMS, comprising procedures, processes, and necessary resources for the quality management of meteorological information provided to aviation users. The established QMS should be in conformity with the ISO 9000 series of quality assurance standards and should be certified by an approved organisation. The key objectives of this training area would be to update participants on the ICAO and WMO drivers for adopting a quality management approach for the provision of aviation weather services, to detail the step-by-step approach in line with WMO guidelines[484] for the implementation of the QMS in compliance with ISO 9001:2015, and to explain the process of QMS certification in line with ISO standards.

5. *National Meteorological and Hydrological Service (NMHS) Leadership and Management:* This training area will focus on enhancing leadership and management skills among MMS staff members to deliver critical weather and climate services, as well as modules on how to access

[482] WMO, 2022. Guidelines for the Assessment of Competencies for Provision of Climate Services. WMO-No. 1285
[483] ICAO, 2010. International Standards and Recommended Practices. Annex 3 to the Convention on International Civil Aviation. Meteorological Service for International Air Navigation
[484] WMO, 2017. Guide to the Implementation of Quality Management Systems for National Meteorological and Hydrological Services and Other Relevant Service Providers. WMO-No. 1100

climate finance. Broadly, WMO's Leadership and Management Programme focuses on several key areas, such as strategic planning, project and change management, effective communication, team leadership and motivation, key tools for scenario planning, coaching and mentoring, and conflict management. The overall learning objectives aim to enhance leadership and decision-making capabilities, focusing on practical skills and strategic insights necessary for effective management in complex organisational settings.

6. *Calibration and maintenance of instruments:* The aim of this training area is to introduce the fundamental principles of meteorology to enable relevant MMS technical personnel to possess the required qualifications to perform calibration operations, as required for certification under the ISO 17025 standard. The training will focus on familiarising participants with international meteorology vocabulary, different types of standards, the general principles for the computation of uncertainties, and the distinctions and complementarities between maintenance and calibration activities. Specific advanced trainings could also include calibration and maintenance of station hardware, such as rain gauges, thermometers, barometers, and other specialised hardware such as ocean buoys.
7. *Operational seasonal and sub-seasonal forecasting:* The main objective of this training area is to develop capacities of MMS staff to enable them to provide tailored, long-range forecast products to users. This training will focus on the full range of seasonal and sub-seasonal forecasting methodologies – including improving understanding of the main drivers and sources of predictability, accessing relevant data portals (e.g., WMO LC LRFMME, IRI Data Library), evaluation of forecasts from Global Producing Centres for Long-Range and for Sub-Seasonal Forecasts, applying a multi-model technique, verification of forecasts and hindcasts, statistical downscaling for regional and local scale forecasts, bias correction, and development of seasonal and sub-seasonal outlooks. A hands-on training will be provided in relevant software tools, such as CPT/PyCPT.
8. *Earth Observation (EO): Synthesis and interpretation of climate information for various climate applications.* This training area will build skills to interpret, formulate, and effectively articulate climate science analyses for various climate applications. To address climate risk and adaptation, defining climate hazard, exposure, and vulnerability will involve gathering and synthesising a diverse range of information, which will be unique for each climate action intervention. This training area will provide an overview of tools and techniques for synthesising past trends, variability, extremes, and future changes in climatic factors, and classification of different types of information sources with a specific focus on EO. Additionally, it will provide a synthesis of existing approaches and data that can be converted into an easily interpretable and usable form.

Sub-Activity 2.2.5 – Co-produce sector-specific impact-based forecasts and decision support for public and private sectors

The project will support Maldives to institute an impact-based forecasting approach to climate analytics and early warnings – transforming forecasts and warnings from information on "what the weather will be" to assessments of "what the weather will do" – enabling government agencies, sectors, and individuals to anticipate and take action to mitigate the impacts of hazardous weather and climate events.

This sub-activity will support the development of sector-specific decision support systems (DSSs) for five key sectors: agriculture and food security, disaster risk reduction, health, marine and fisheries, and tourism. The DSSs will integrate data and forecasts from MMS with sectoral exposure and vulnerability information to identify a range of location- and sector-specific risks and potential impacts. The DSSs will be co-designed through a series of workshops involving MMS and sectoral users. These stakeholders will also be engaged in the co-development of models and analytics relevant for generating risk and impact information, and in the co-development of sector-specific impact-based forecasts. Whenever feasible, the project will scale up the functionalities of existing sectoral applications toward impact-based forecasting and decision making. Specific considerations will be made to ensure that the DSSs incorporate inclusive features for different target users, including persons with disabilities (PWDs), such as the viewing of HTML text and text-to-speech functionalities, amongst others.

The assigned sectoral agencies who will manage the DSSs will be provided with equipment and hardware[485] for the DSS visualisation and to ensure that the DSSs are regularly operated, and data are constantly updated. Following deployment of the DSSs, the identified sectoral DSS administrators will be provided with training on the use and management of the systems. MMS staff will also be present during the trainings to ensure well-defined technical support in sharing and integrating their data and forecasts into the DSSs.

<u>Sub-Activity 2.2.6 – Develop sector-specific advisories for climate- and risk-informed decision making</u>

This sub-activity will co-develop gender-sensitive and sector-specific advisories to be disseminated through the sectoral DSSs established under Sub-Activity 2.2.5, for three priority sectors. Sectoral workshops will be facilitated to identify and define impact thresholds, which will subsequently be translated into warnings and advisories. The project will also develop mobile applications (Android and IOS versions) for three sectoral DSSs, to facilitate the effective transmission and receipt of advisories by the target end-users. This will also contribute to broadening access to the DSSs through smartphones. Prior to the system/application launch and deployment, sectoral workshops will be conducted to test and finalise the DSSs and mobile apps. This will also serve as a capacity building exercise to the target sectoral users of the DSSs.

<u>Sub-Activity 2.2.7 – Introduce climate analytics to support the development of Green Finance products</u>

This sub-activity will facilitate engagement between MMS and the SME Development Finance Corporation (SDFC) in Maldives to co-develop models and analytics relevant for generating tailored, gender-sensitive climate products, analyses and interpretation aimed at improving understanding and management of climate-related financial risks. In addition, the project will build capacity of SDFC to incorporate climate analytics in the design and delivery of green finance products for Small and Medium Enterprises (SMEs) – particularly in the tourism and fisheries sectors – which SDFC has identified as a priority to develop as part of its efforts towards achieving accreditation as a GCF Direct Access Entity. The project will support the co-design and customisation of a web-based portal integrating MMS data and climate predictions with SDFC products and information. This will be supported by training on operation and maintenance.

<u>Sub-Activity 2.2.8 – Enhance knowledge retention through hands-on learning and refresher training</u>

This sub-activity aims to reinforce, strengthen, and support new knowledge and skills developed under Output 2 to facilitate long-term sustainability, as well as improved efficiency and productivity within MMS. The project will deliver technical trainings for MMS on i) data transmission, storage, management, and processing; and ii) forecasting systems for meteorology, aerometeorology, climatology, and oceanography – as well as trainings for MMS and sectoral agencies on all sectoral decision support systems (DSSs) to be developed under Sub-Activity 2.2.5. Online (self-paced) trainings for database management, forecasting systems, and the sectoral DSSs will also be developed, which will enable staff to undertake refresher training (or initial training – in the case of new staff) as needed. In-person, hands-on refresher trainings will also be organised for MMS staff (meteorological technicians and forecasters) at a more advanced national hydrometeorological service in the region to further reinforce capacity development and knowledge retention.

Output 3 – Improved dissemination and communication of risk information and early warnings to the last mile

Activity 3.1 – Establish a people-centred, impact-based multi-hazard early warning system

<u>Sub-Activity 3.1.1 – Develop and implement Standard Operating Procedures (SOPs) for multi-hazard early warning advisories</u>

The project will support the development of SOPs for the timely and effective dissemination of disaster risk information and warnings for climate-related hazards. A key consideration will be to ensure that the SOPs address the complexities of the geographical setup of Maldives (i.e., widely dispersed island populations) to ensure that no one is left behind.

[485] Equipment and hardware will be set up within the premises of sectoral agencies or in the identified data centre

The SOPs will outline the roles and responsibilities for warning dissemination at the national, subnational (atoll) and local (island) level, ensuring a gender-sensitive approach. In developing the SOPs, the project will identify opportunities for local councils and volunteer networks to receive and disseminate warnings to help with last-mile dissemination. In addition, communication focal points will be appointed for each island. The SOPs will be developed through a multi-stakeholder consultative process in Year 1. Further consultations will be conducted in Year 5 to review the effectiveness of the SOPs and inform updates, as required.

Moreover, the project will conduct training on Common Alerting Protocol (CAP) usage for a range of stakeholders[486] to ensure consistent warning dissemination and communication practices across the country. This will include training of trainers for National Centre for Information Technology (NCIT) staff so that NCIT can continue to deliver trainings and promote CAP usage beyond the project implementation period.

<u>Sub-Activity 3.1.2 – Co-develop a socially inclusive and gender-responsive risk communication strategy</u>

The project will facilitate multi-stakeholder dialogue to analyse the effectiveness of existing warning dissemination and communication processes and identify the ways in which gender and other intersectional vulnerabilities impact on the accessibility, reach and understanding of climate and disaster risk information. As part of this sub-activity, a series of consultations will be conducted with local councils, civil society organisations, and community members – with a proactive focus on meaningful engagement with traditionally marginalised and vulnerable groups, including women, youth, older persons, and people with disabilities.

Informed by the multi-stakeholder consultations, the project will co-develop a socially inclusive and gender responsive communication strategy for disaster risk information and warnings. A key focus of the strategy will be to ensure that communications are contextually appropriate, and that specialist and scientific information is delivered in straightforward, non-technical language, without loss of accuracy or explicitness. The strategy will also address the need to use multiple communication channels to ensure redundancy, translation of information into local or migrant languages – as well as those of migrant communities – and tailoring of communications for people with low literacy levels. The multi-stakeholder co-development process will be key in this regard to ensure that local expertise and perspectives are incorporated.

<u>Sub-Activity 3.1.3 – Establish a national Multi-Hazard Alert System</u>

The project will support the establishment of a national Multi-Hazard Alert System for Maldives. The integrated system will transform disaster risk management (DRM) capabilities in Maldives, by enabling the translation of generic forecast information into actionable, impact-based early warnings and advisories for preparedness, emergency management, and long-term disaster risk reduction planning. The system will be co-developed under the leadership of MMS, in partnership with other key stakeholders such as NDMA.

The Alert System will integrate the outputs of several sub-activities in the proposed project, including: i) risk and vulnerability assessments (Sub-activities 1.2.3 and 1.2.5); ii) historical loss and damage data (Sub-Activities 1.2.6 and 1.2.7); and iii) models, thresholds and impact-based forecasts for the DRM sector (Sub-Activity 2.2.5). Warning messaging will follow the CAP technical data specification for simultaneous dissemination through various channels. In addition, the system will be linked with the Moosun app[487] and the project will support enhancement of the existing app functions, user interface, and adoption (i.e., download, access, and use).

<u>Sub-Activity 3.1.4 – Deploy innovative technologies to enhance warning communication</u>

The project will develop and implement a strategy to enhance EWS communications in Maldives through the deployment of innovative technologies, such as Terrestrial Trunked Radio (TETRA) linked to sirens and mobile messaging. The Communication Authority of Maldives (CAM) recommended that this sub-activity support the establishment of a new control centre within MMS and the deployment of new siren systems.

[486] Key stakeholders include the Local Government Authority (LGA), Ministry of Social and Family Development (MSFD), MMS, NCIT, NDMA, health and education sectors, and faith-based organisations.
[487] Moosun is the official mobile application of Maldives Meteorological Service

As recognised by the International Telecommunication Union (ITU), mobile networks are an extremely powerful communication channel to alert populations about an impending hazard[488] and are the most inclusive way to reach people in seconds.[489]

Sub-Activity 3.1.5 – Strengthen two-way feedback and evaluation mechanisms

The project will strengthen and expand current two-way communication mechanisms between disseminators and receivers of warning messages in Maldives and support national actors to implement a system that is suited to the challenging geography of the country and its dispersed population groups. The mechanisms will help to verify that warnings have been received and to correct potential failures in dissemination and communication.

Beyond verifying the delivery of warnings, this sub-activity will support the establishment of robust evaluation processes to provide detailed insights on the timeliness and accuracy of impact-based forecasts and improve understanding of how well warnings are received, perceived, and acted upon, ensuring due consideration to women and other vulnerable groups. Such information is critical to support continuous improvement of the MHEWS, in a gender-responsive and socially inclusive manner, as well as help to demonstrate the value of impact-based forecasts. As part of this endeavour, the project will build local capacities in adopting behavioural science approaches around processing and using information from end-users, which will further contribute to strengthening future impact-based forecasts and warnings. Ensuring that feedback is provided to end-users on alteration of future messages based on insights received will also be key.

Moreover, an inter-agency task team will be established to receive, review, and recommend actions based on feedback from end-users on the utility of impact-based forecasts and warnings, as well as on the ability to access and use the feedback mechanism itself.

Sub-Activity 3.1.6 – Strengthen communication systems to reach the last mile

This sub-activity will enhance inclusiveness and accessibility of MHEWS in Maldives by scaling up the use of multiple communication channels to disseminate information. Such channels could include hand-cranked radios, battery-operated sirens, satellite communication devices, loudspeakers (e.g., in mosques), and audio-enabled digital noticeboards. This will be informed by the findings of the Gender Assessment (Annex 4) and the multi-stakeholder consultations held under Sub-Activity 3.1.2. The use of multiple channels of communication will increase the likelihood of warning messages reaching the most vulnerable population groups, including women, children, elderly persons, and people with disabilities.

Sub-Activity 3.1.7 – Develop a multilingual glossary on climate change, early warning systems, and disaster risk reduction

This sub-activity will support the preparation of a glossary of climate change, early warning systems, and disaster risk reduction (DRR) terms. The glossary will provide translations between English and Dhivehi, as well as other local and migrant languages (e.g., Bangla, Hindi, Sinhala, and Tamil). Translation into languages commonly used by tourists will also be considered. The development of the glossary will build on existing efforts of MMS[490] and NDMA[491], and will incorporate the experiences of MRC in contextualising information to local capabilities and layperson terms. The glossary will be promulgated through outreach activities, including with schools, NGOs, and community organisations.

Sub-Activity 3.1.8 – Establish partnerships with the private sector to expand information dissemination and feedback mechanisms

The project will promote the establishment of public-private partnerships to strengthen integration, interoperability, and availability of climate-related information. Specifically, this sub-activity will support the development of information sharing protocols to ensure that climate-related information is interchanged and used effectively between public and private agencies[492] to speed up warning

[488] ITU, 2023. Early warning systems: Saving lives through mobile connection. Available at: https://www.itu.int/hub/2023/01/early-warning-systems-mobile-connectivity/
[489] Everbridge, 2022. Public Early Warning Systems for All. How mobile networks and services can help save lives
[490] MMS has a draft glossary on impact-based forecasting in English and Dhivehi, but this is incomplete and needs updating.
[491] NDMA has a (limited) glossary on disaster risk reduction.
[492] Private agencies would include SMEs, Maldives Association of Tourism Industry (MATI), and fisheries organisations.

dissemination. In addition, the project will support sensitisation of Media Personnel around the Early Warnings for All initiative to provide context and information about the efforts made, as well as available resources. Media personnel have the largest reach within the country in terms of news and access. A targeted sensitisation and capacity development workshop will focus on strengthening the capacity of media personnel to report and disseminate information around early warning mechanisms established.

Output 4 – Enhanced climate risk management capacity using climate information and early warnings

Activity 4.1 – Enhance awareness and capacity to prepare for and respond to climate-related hazards and risks

Sub-Activity 4.1.1 – Increase public awareness and education on climate-related hazards, vulnerabilities, exposure, and risks

The project will conduct a gender-sensitive nationwide awareness-raising and education campaign to improve climate literacy and enhance understanding on the Early Warnings for All (EW4All) initiative. The campaign will employ various mediums for communication, including a digital platform, radio, and printed materials, for wider dissemination. The nationwide campaign will be complemented by the delivery of targeted education and awareness materials related to climate risks, early warnings, and anticipatory actions at the community level.

As part of the campaign, this sub-activity will support the co-development and production of climate change and EW4All knowledge products and resources tailored to the needs of different communities and vulnerable population groups. An online information hub (web portal and app) will be developed for the delivery of knowledge products and educational materials, which will be co-produced by MRC in partnership with the Ministry of Education. Use of the information hub will bolster island-level awareness-raising efforts, as well as support targeted learning programs in the education sector. Specific subject areas to be covered will be ascertained in Years 1-2 of the project, based on identification of knowledge gaps and community demand. The project will also facilitate involvement of NDMA and MMS in the development of knowledge products and materials to ensure a streamlined approach to hazard communications amongst relevant national actors. In addition, this sub-activity will support the development of a radio programme to communicate climate change and EW4All resources and information to hard-to-reach community members, such as those with limited internet access and elderly persons.

Sub-Activity 4.1.2 – Mainstream Protection, Gender and Inclusion (PGI) into disaster preparedness

Mainstreaming Protection, Gender and Inclusion (PGI) and promoting gender equality and empowerment of women and girls is a key priority of the project – recognising that the effects of climate change are not felt equally, and that gender inequality can exacerbate disaster risks and impacts for women and girls.

This sub-activity will focus on the integration of PGI to facilitate that all awareness-raising and educational materials and resources developed, including the online resource platform/information hub (Sub-Activity 4.1.1), are accessible to all, including traditionally vulnerable and/or marginalised groups such as elderly persons, people with disabilities (PWDs), and migrants (documented and undocumented). As such, prior to the development of knowledge products and resources, MRC will host a national-level stakeholder consultation workshop with key government agencies, civil society organisations (CSOs), and international NGOs, as well as representatives of PWDs and migrants, including those within island communities. The consultation outcomes will form the basis of all materials produced, as well as inform overall mainstreaming of PGI. Pilot-testing of the knowledge products, including focus group discussions, will also be conducted.

The project will also engage a dedicated Social and Gender Safeguards (SGS) Specialist, who will be responsible for ensuring the integration of PGI elements across all project interventions to ensure the mainstreaming of inclusivity and accessibility to the whole of society. As part of Sub-Activity 4.1.2, the SGS Specialist will develop a standardised checklist of indicators to measure the integration and engagement of vulnerable groups and accessibility for all target islands under the MRC-led community-level interventions. The SGS Specialist will use the checklist during regular monitoring visits to the target islands to obtain feedback and evaluate performance in inclusivity and accessibility mainstreaming.

Sub-Activity 4.1.3 – Scale up the Y-Adapt youth engagement curriculum

The project will also support the roll-out of Y-Adapt: Climate Change Adaptation youth engagement curriculum to educate, engage and inspire youth to act in their communities to adapt to climate change and associated climate extremes and disaster risks. Y-Adapt is an innovative program that addresses a wide range of climate-related challenges, including rapid-onset events such extreme rainfall leading to flooding and slower-onset issues such as extreme heat causing drought. The program encourages youth to not only understand the complexities of climate change but also to develop and implement their own climate change adaptation and advocacy plans within their local communities. The roll-out of Y-Adapt will facilitate targeting of the youth demographic under the proposed project, creating a pool of youth volunteers who are climate literate and understand climate-related risks and hazards, and empower youth-led climate action.

Sub-Activity 4.1.4 – Strengthen national, sub-national and local capacity to use climate and disaster risk information and impact-based early warnings

Under this sub-activity, MRC will conduct atoll/community-level workshops focused on building capacities to access and use climate and disaster risk information and early warnings for enhanced preparedness to climate change-induced hazards. The workshops will convene atoll and island-level governance and response agencies.

Sub-Activity 4.1.5 – Enhance capacity of the private sector to manage climate-related risks

Under this sub-activity, the project will deliver a targeted awareness and education programme for state-owned enterprises (SOEs) that support development of the MSME sector in Maldives (e.g., Business Center Corporation and SME Development Finance Corporation). The programme will focus on improving climate risk awareness and understanding amongst SOE staff in relation to future climate projections and potential impacts. In addition, the programme will raise awareness on the value of impact-based forecasts and decision support systems (developed under Output 2) for disaster preparedness and climate risk management. The programme will be delivered through a series of webinars (Years 1-2) and workshops (Years 3-5). Staff in regional Business Centers will be supported to participate to facilitate knowledge transfer across the archipelago. In addition, the project will organise an international study tour for SOE staff to promote knowledge exchange and innovations in creating more resilient economies, based on success stories and lessons learned in other countries.

The project will also support direct engagement of MSMEs in building climate risk management capacities through annual MSME Pop-Up Events, which will be organised by Maldives Business Center Corporation (BCC). The events will provide an informal means for BCC to engage with MSMEs on the benefits of investing in climate resilience and environmental sustainability, whilst simultaneously providing an opportunity for MSMEs to sell their products. Each MSME Pop-Up Event will have a different theme, enabling five major issues to be addressed from a climate risk management perspective over the course of the project. The events will each be preceded by an online countrywide session for MSMEs, which will set the theme for the event and promote broader awareness raising.

To complement the work of BCC, MRC will conduct dedicated awareness-raising and education for the private sector to improve climate change literacy (i.e., understanding the scientific basis of climate variability and change affecting Maldives), as well as facilitate sensitisation on Early Warnings for All and associated knowledge products and resources available for the private sector. The primary target groups from the private sector will be MSMEs (particularly in the agriculture, fisheries and tourism sectors) and medium-large corporations such as tourism establishments operating in Maldives. In addition, MRC will organise workshops focused on helping MSMEs to develop disaster contingency and preparedness plans for business/service continuity in the event of weather and climate extremes. This intervention will build on existing efforts of MRC in piloting a capacity building component of business continuity targeted towards MSMEs.

Sub-Activity 4.1.6 – Scale up Community-Based Disaster Risk Management (CBDRM)

Under this sub-activity, MRC will carry out targeted and gender-responsive trainings for Community Emergency Response Teams (CERTs) to build resilience and disaster management capacities of local actors in island communities. Following the trainings, all target communities will be provided with the necessary equipment and resources to effectively manage disaster risks in the event of an emergency. This sub-activity will be implemented in coordination with NDMA.

Sub-Activity 4.1.7 – Develop Standard Operating Procedures (SOPs) for integrating Protection, Gender and Inclusion (PGI) into disaster response

Under this sub-activity, the project will work with NDMA, the Ministry of Social and Family Development (MSFD), and other key stakeholders to develop SOPs for the integration of PGI into disaster response. The SOPs will set out concrete actions to ensure dignity, access, participation and safety for all people in climate-related disaster situations, based on consideration of the distinct needs and safety risks associated with gender, age, disability, and other diversity factors.

An important focus of the SOPs will be to provide instructions for the prevention and management of gender-based violence (GBV) in disaster situations. As recommended by the Gender Equality Guideline for NDMA,[493] the SOPs will outline a holistic approach that covers reporting procedures, protecting victims' identities, and access to support services, such as emergency health and psychosocial counselling. Development of the SOPs will be informed by key informant interviews and focus group discussions, including in outer islands.

Activity 4.2 – Establish capacity for Forecast-based Action (FbA) and Anticipatory Action (AA)

Sub-Activity 4.2.1 – Develop a Roadmap for FbA/AA

The project will introduce Forecast-based Action (FbA) – also known as Anticipatory Action (AA) – in Maldives, an innovative mechanism whereby early actions are pre-planned based on in-depth forecast information and risk analysis and are funded and implemented when a specific threshold and trigger are reached.

Under this sub-activity, the Red Cross and Red Crescent Climate Centre (RCCC) together with MRC will facilitate the process of developing a national roadmap for FbA/AA in Maldives. The roadmap will include measurable objectives and activities with proposed roles and responsibilities across five major areas:

i) Risk analysis, forecasting, early warning systems and triggers
ii) Identifying, planning, operations and delivery of early actions
iii) Country-driven, scalable financial mechanism to provide a sustainable source of funding for FbA/AA
iv) Evidence generation, advocacy and learning
v) Policy, institutionalisation and coordination.

The first phase in the process of roadmap development will comprise a scoping study that will identify all relevant stakeholders for FbA, forecasting capabilities, and the institutional landscape and state of play of early warning/early action in Maldives. Following the scoping phase, the second phase of roadmap development will consist of co-development workshops with institutional stakeholders and local communities to delineate three key elements that would enable the country-led design of an FbA mechanism: i) menu of available early warning and risk information and proposed triggers based on improved forecasts and impact-based forecasting approach/models; ii) feasible early actions and their implementation/delivery mechanism; and iii) a potential framework for country-level ownership. Finally, a financial mechanism will be identified based on assessment of existing financial mechanisms currently operational in Maldives and potential to develop new financing tools and flexible mechanisms for early/ anticipatory action. In developing the roadmap, the role of gender in FbA/AA and specific entry points and approaches for gender mainstreaming and gender responsiveness will also be considered.

Sub-Activity 4.2.2 – Build capacity for FbA/AA

The project will ensure that MRC, NDMA and other key national stakeholders have the requisite knowledge and skills to understand the concept of FbA/AA and develop and implement associated Early Action Protocols (EAPs) for priority hazards, and ultimately foster ownership to establish a sustainable FbA/AA mechanism in Maldives.

This sub-activity will include a series of gender-sensitive capacity building trainings on FbA/AA at both the national and atoll level, and continuous technical support to connect with existing national and sub-national strategies, mechanisms and/or priorities to improve coordination and enhance countrywide

[493] The internal Gender Equality Guideline for NDMA was developed in 2022 but has not been officially launched or operationalised. Sub-Activity 1.1.7 of the TRACT project will support finalisation and publication of the internal guidelines, as well as develop broader national guidelines for gender-responsive disaster risk reduction.

understanding and buy-in for FbA/AA. Building on the multi-stakeholder feedback and evaluation mechanisms (Sub-Activity 3.1.5), this sub-activity will support the verification of forecasts and evaluation of early warnings specifically in relation to the skills (false alarms and hit rate) for weather extremes, which is required for setting up a trigger mechanism for AA.

Sub-Activity 4.2.3 – Co-develop impact-based forecast triggers for FbA/AA

Building on the impact-based forecasting (IBF) capabilities developed under Activity 2.2, this sub-activity will support the co-production of IBF products for the humanitarian sector that can serve as trigger models for FbA. With technical support from RCCC, the project will convene stakeholder dialogues to co-develop tailored IBF products and services for FbA/AA. Associated capacity building on IBF for FbA/AA will also be delivered to wider stakeholders. The co-developed IBF products for AA in disaster management will be integrated and visualised within the NDMA-administered disaster information system (see Sub-Activity 1.2.6), using open-source tools and platforms for wider access and system interoperability.

Sub-Activity 4.2.4 – Initiate Early Action Protocol (EAP) development

The project will facilitate the process of developing gender-sensitive Early Action Protocols (EAPs), as tools to guide the timely and effective implementation of early actions based on impact-based early warnings and forecast information. An EAP contains information on triggers, early actions, and funding allocation, and outlines the process for implementation of early actions once a trigger is reached. This sub-activity will initiate the process of EAP development at national scale for key priority and feasible hazards through an inclusive and participatory stakeholder engagement process to advance the risk assessment and set the trigger (building on Sub-Activity 4.2.1), and accordingly identify and select the most appropriate forecast-based early actions. The draft EAP will be presented to the identified key stakeholders for validation and refinement. In this regard, following national-level co-development workshops, the project will organise atoll/island level workshops covering north, south and central atolls. The atoll/island-level workshops will bring in key regional stakeholders and community groups from the most exposed and/or vulnerable islands to review and provide feedback on the draft EAP. Involvement of local communities in the development and implementation of EAPs will support enhanced acceptance and local ownership. Based on the atoll/island level consultations and feedback, the draft EAP will be reviewed and finalised by the national AA working group and put forward for inclusion in the national/atoll/island-specific disaster management operational plans.

Drawing on the expertise of RCCC, MRC will also develop its own institutional EAP (aligned with or contributing to the national EAP), which will enable it to access the Disaster Relief and Emergency Fund (DREF) following the confirmation of a trigger for an extreme weather event. Development of the institutional EAP will serve as a pilot for the national EAP, which will be broader in scope and coverage, and require engagement of a wider range of stakeholders. The national EAP will also be mainstreamed in the national disaster management frameworks and operations. Following the development of the national EAP, MRC's institutional EAP will be further revised and updated as required to ensure strong alignment and contribution to the government-led and owned national EAP(s).

11 IMPLEMENTATION ARRANGEMENTS

Accredited Entity

UNEP will be the Accredited Entity (AE) for the project and will be responsible for overseeing the implementation, financial management, evaluation, reporting, and closure of the activities under the project. UNEP will monitor and supervise the execution of the project and ensure the proper management and application of GCF Grant Proceeds by the Executing Entities. UNEP will ensure that the Grant Proceeds are utilised in accordance with the terms of the Funded Activity Agreement, to be entered into between the GCF and UNEP, and the Accreditation Master Agreement. UNEP will also assume a limited role as Executing Entity, as described in the sub-section below.

UNEP brings more than 25 years of experience working on climate change issues and is an established GCF AE. It has a strong track record in implementing adaptation and mitigation projects and programmes, bringing a comprehensive approach that it grounded in both natural science and economics and is tied to the environmental and development concerns of countries. UNEP's comparative advantage as a GCF AE lies in its scientific and technical expertise. UNEP is a science-based organisation that is supported by a wide network of world-class scientific institutions and collaborating centres, such as the World Conservation Monitoring Centre (WCMC), DHI, Technical University of Denmark (DTU), and the Frankfurt School. As the UN agency with a broad mandate on environmental issues, UNEP has a convening power and proven ability of working on issues through multi-stakeholder and multi-disciplinary approaches, providing the GCF with unique comparative advantages and partnership opportunities.

Through its Early Warning and Assessment Division, UNEP has longstanding expertise in environmental and climate change information management and early warning systems. For example, with GEF and EC funding it is currently supporting over 50 countries in establishing or strengthening their environmental information management systems and using them for reporting progress on SDGs and MEAs. Its Early Warning and Assessment Division manages the CLIMWARN and Country Level Impacts of Climate Change (CLICC) projects, the Global Environment Monitoring System for Air (GEMS Air), and UNEP also convenes and facilitates regional environmental information networks and the World Adaptation Science Programme (WASP – former PROVIA). Through its work on climate information, early warning and foresight, UNEP enables stakeholders to respond to the latest emerging issues related to environment and climate change. Concrete examples are the approved GCF-funded programme "Enhancing Climate Information and Knowledge Services for resilience in 5 island countries of the Pacific Ocean" (FP147)[494] and the GCF-funded project "Enhancing Early Warning Systems to build greater resilience to hydro-meteorological hazards in Timor-Leste" (FP171).[495] These initiatives have demonstrated UNEP's competence in strengthening capacities of SIDS in relation to meteorological observations, data analysis, and establishment of multi-hazard early warning systems.

UNEP is also a key player in the "One Health" approach – a cross-cutting and systematic approach to health that recognises the interdependence of human, animal and environmental health as critical for addressing the three planetary crises: the climate crisis, the nature and biodiversity crisis, and the pollution and waste crisis. As a member of the One Health High-Level Expert Council, UNEP is supporting the collection, distribution and publicising of reliable scientific information on the links between human, animal and environmental health, which in turn aims to assist public officials to make appropriate decisions to address future crises and to inform citizens.

Executing Entities

The Ministry of Tourism and Environment of Maldives (MTE) will serve as the national Executing Entity (EE). MTE will be accountable to UNEP as AE for project execution at the national level and for the efficient and effective use of resources. UNEP will enter into a Project Cooperation Agreement (PCA) with MTE for the execution of the project. The PCA will include specific obligations for the national EE on project execution, financial management, personnel administration and reporting, as well as arbitration and liability terms.

The national EE will be responsible for establishing project implementation arrangements in a relevant part of the government administration to provide implementation guidance and support to national service

[494] https://www.greenclimate.fund/project/fp147
[495] https://www.greenclimate.fund/project/fp171

providers and Technical Partners (see below section). The national EE will thus facilitate cooperation and coordination among the national service providers.

Limited EE functions will be undertaken by UNEP. Through its Global Support Services Agreement with UNOPS and similar agreements with other UN agencies, UNEP is able to operate at the country level without necessarily having a national office. Amongst others, the agreements cover the provision of HR and procurement services. UNEP will execute the project in line with its programme manual and standard business procedures and will contract international consultants and Technical Partners to undertake relevant activities as appropriate.

Project Management Unit

MTE will establish a Project Management Unit (PMU) in Male', Maldives. The PMU will be hosted by Maldives Meteorological Service (MMS), with support from MTE where required. The PMU will be responsible for the day-to-day management of the project and will be accountable to the national EE. In addition, the PMU will assume liaison functions with national government entities and stakeholders and will coordinate with UNEP and Technical Partners throughout the project implementation and reporting, in line with their obligations under the respective legal instruments and will coordinate to ensure that reports are received.

The PMU will consolidate all progress reports and financial management reports, including co-financing reports and annual audit reports, from the national EE and Technical Partners and submit these to the AE. The PMU will provide guidance and source expertise as needed on project management, financial management, procurement, and technical issues. It will establish contact with development partners working in Maldives to ensure that activities in related fields are complementary and to seek opportunities for collaboration. The PMU will also provide secretariat services to the Project Steering Committee (PSC).

Technical Partners

The project will benefit from the expertise of a coalition of Technical Partners who have long-standing experience and expertise on the ground, thereby ensuring coherence and complementarity. Technical Partners will be sub-contracted by UNEP in its capacity as EE, in line with UNEP's policies and procedures. Technical Partners will include the Abdus Salam International Centre for Theoretical Physics (ICTP), Red Cross and Red Crescent Climate Centre (RCCC), Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES), UN Office for Disaster Risk Reduction (UNDRR), and the World Meteorological Organization (WMO). In line with the priorities of Maldives, the Technical Partners will lead or provide support for the implementation of specific interventions that require highly technical or scientific expertise and are in line with the mandates and comparative advantages. Technical Partners will have no discretion in implementing activities, and any discretion, decision-making, and responsibility for delegated activities will be retained by UNEP as EE.

UNEP in its EE capacity will enter into cooperation agreements – Project Cooperation Agreement (PCA) or UN-to-UN Transfer Agreement, as relevant – with each Technical Partner. The Agreements will establish clear roles and responsibilities for the delivery of specific project activities and will include specific obligations on project delivery, financial management, personnel administration, and reporting, as well as arbitration and liability terms.

Project Steering Committee

A Project Steering Committee (PSC) will be established to provide high-level oversight and guidance towards achieving project objectives. The PSC is a consensus-based decision-making body within the project governance and will provide, review, and monitor strategic direction and policy guidance to the project team. The functions of the PSC will include:

- Providing overall guidance for project execution to the PMU, especially on cross-cutting issues that require consensus from the various stakeholders involved in the project
- Ensuring full cooperation of various regional and national stakeholders under their jurisdictions to provide access and support to the project team in carrying out their tasks
- Reviewing and monitoring progress in project execution, including in relation to environmental and social performance and ensuring the gender responsiveness of project implementation and achievement of targets in the Gender Action Plan

- Reviewing and approving the annual workplan and budget, and approving the project's annual report
- Ensuring that complementarity with other GCF-funded projects (in particular, the UNDP-led FP007 and JICA-led FP165) and UN Country Team (UNCT) initiatives is effectively operationalised.

The PSC will meet at least once per year, with additional *ad hoc* meetings held as and when deemed necessary. The PSC will be co-chaired by the National Designated Authority (MTE) and UNEP as AE. Participants will include:

- Project Manager;
- Representatives of the Early Warnings for All (EW4All) national pillar leads: Maldives Meteorological Service (MMS), National Disaster Management Authority (NDMA), Maldivian Red Crescent (MRC), Communications Authority of Maldives (CAM), National Centre for Information Technology (NCIT);
- Representatives of Technical Partner agencies: International Centre for Theoretical Physics (ICTP), Red Cross and Red Crescent Climate Centre (RCCC), Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES), United Nations Office for Disaster Risk Reduction (UNDRR), World Meteorological Organization (WMO);
- Representatives from additional national partners involved in project implementation: Ministry of Social and Family Development, Local Government Authority, SME Development Finance Corporation (SDFC), Maldives Business Center Corporation (BCC) and others as relevant;
- Representatives of civil society and women's organisations; and
- Representatives of the private sector.

Secretariat services to the PSC will be provided by the PMU. The minutes of the meetings will be provided to the AE by the Project Manager. Sex-disaggregated data will be collected for all PSC meetings.

National Service Providers

National Service Providers will be engaged through relevant agreement modalities by the national EE. These will include *inter alia* MMS, NDMA, MRC, and BCC.

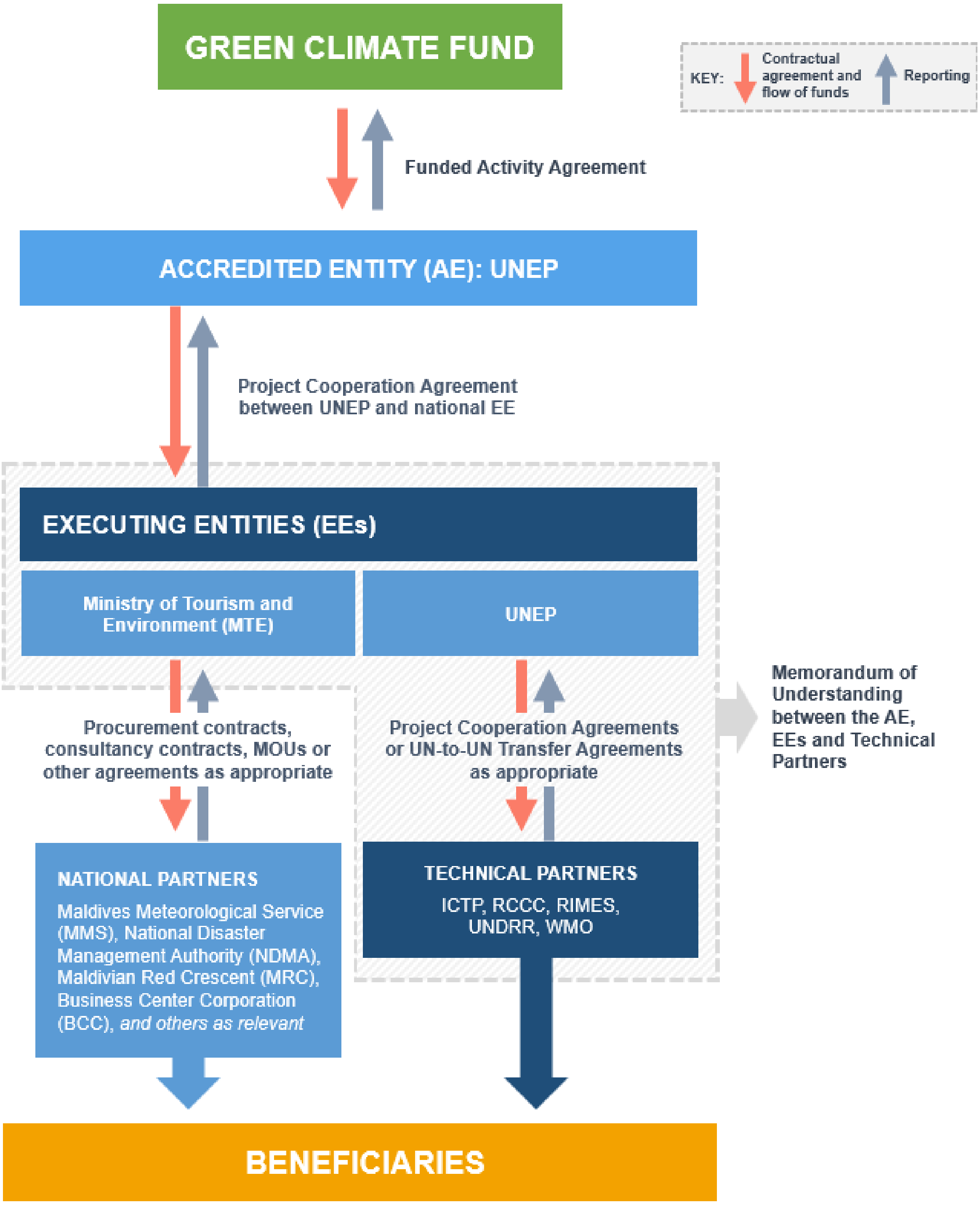


Figure 61. Flow of funds for project implementation.
The red arrows indicate the flow of funds while the blue arrows show the contractual arrangements, including the types of contracts between the relevant parties.

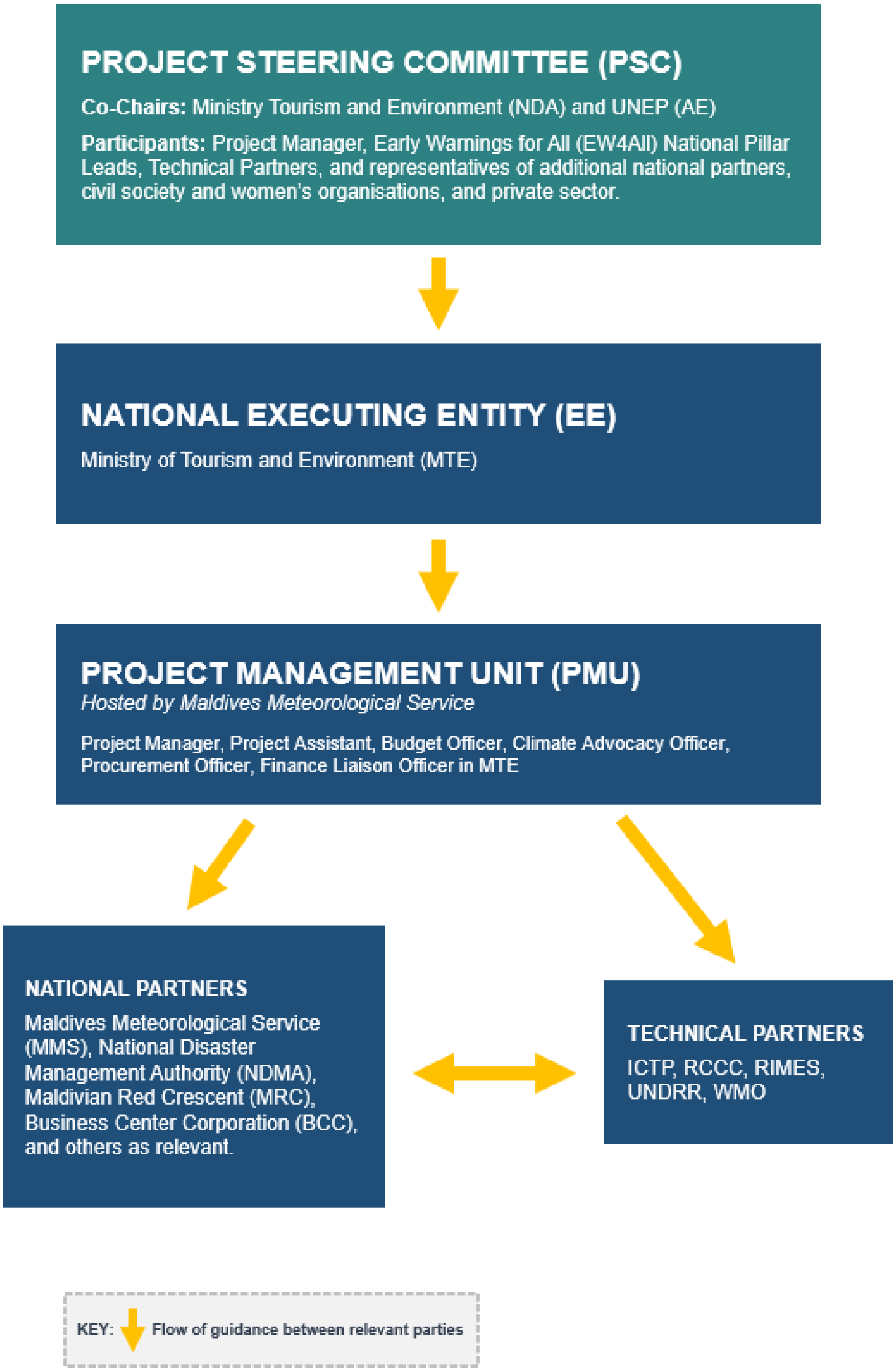


Figure 62. Project governance arrangements.
Yellow arrows indicate flow of guidance between relevant parties.

Overview of Roles and Responsibilities

The roles and responsibilities of the EEs and national/international partners for each project sub-activity are outlined in the table below.

Table 27. Roles and responsibilities for project sub-activities.
N.B. For the purpose of this table, the term "Implementing Partner" refers to national and international entities to be contractually engaged by the corresponding Executing Entity.

Activity	Sub-Activity	Executing Entity	Implementing Partner	Role of Partner
1.1 – Establish an institutional framework, legislation and delivery model for climate services and disaster risk management	*1.1.1 – Develop a National Framework for Climate Services (NFCS)*	MTE	MMS	Organise stakeholder consultation and validation workshops and high-level launch event for NFCS
		UNEP	WMO	Provide technical support and advisory to develop and establish the NFCS
	1.1.2 – Enhance inter-ministerial and multi-stakeholder coordination for climate services and disaster risk management	MTE	-	Contract Liaison Officers/Technical Coordinators for MMS and NDMA
			NDMA	Organise and facilitate National Platforms for Disaster Risk Reduction (DRR)
		UNEP	-	Contract a Technical Advisor to provide technical and coordination support
			UNDRR	Provide technical support and training to establish and/or strengthen the coordination mechanism for climate services and disaster risk management
	1.1.3 – Enhance the National Climate Outlook / Monsoon Forum	MTE	MMS	Organise biannual National Climate Outlook / Monsoon Forums
		UNEP	RIMES	Provide technical support to enhance the delivery of National Climate Outlook / Monsoon Forums
	1.1.4 – Strengthen strategic partnerships and knowledge brokering through regional and international fora	MTE	MMS	Organise national workshops and/or trainings
		UNEP	RIMES	Provide technical support and training to strengthen the engagement of MMS and key climate services users/sectors in regional and international fora
	1.1.5 – Establish a legal framework for enabling private sector investment in weather and climate services	MTE	MMS	Contract a legal firm to support update and finalisation of the draft Meteorological Act; Organise a validation workshop
	1.1.6 – Develop a financial framework and business delivery model for weather and climate services	MTE	MMS	Engage a local consultant and provide staff support to develop the financial framework and business delivery model; Participate in an international study tour; Engage a local consultant to undertake a socio-economic analysis of the benefits of strengthening weather and climate services and multi-hazard early warning systems (MHEWS); Organise a launch/sensitisation event for the socio-economic analysis
	1.1.7 – Establish National Guidelines for Integrating Protection, Gender and Inclusion (PGI) into Disaster Management	MTE	NDMA	Engage a local consultant and graphic designer to support preparation of the National Guidelines; Organise inception workshop, focus group discussions, stakeholder consultations, and a validation workshop
1.2 – Strengthen climate and disaster risk data	*1.2.1 – Develop and implement a National Climate and Disaster Risk Information Strategy*	UNEP	UNDRR	Provide technical support and training to develop and implement the National Climate and Disaster Risk Information Strategy

management, analysis and hazard mapping	*1.2.2 – Establish institutional arrangements for data governance and sharing*	MTE	NCIT/MMS	Organise stakeholder consultation workshops
		UNEP	RIMES	Provide technical support for the establishment of institutional arrangements for data governance and sharing
	1.2.3 – Establish standardised multi-hazard risk assessments and mapping	MTE	MMS	Organise stakeholder consultation workshops
		UNEP	RIMES	Provide technical support for the establishment of a standardised multi-hazard risk assessment and mapping approach, methodology and process
	1.2.4 – Strengthen local capacities to undertake climate-related risk assessments	MTE	MMS	Organise training workshops
		UNEP	RIMES	Conduct training to build/strengthen national capacity to undertake multi-hazard risk assessments and mapping (Sub-Activity 1.2.3)
		UNEP	UNDRR	Provide technical support and capacity building for climate-related risk assessments
	1.2.5 – Conduct Enhanced Vulnerability and Capacity Assessments (EVCAs)	MTE	MRC	Build capacity for EVCAs and implement the EVCA process in target communities
	1.2.6 – Establish a national disaster risk knowledge platform	MTE	MMS	Organise co-development workshops
		UNEP	RIMES	Provide technical support to co-develop and establish a national disaster risk knowledge platform
	1.2.7 – Establish a tracking system for hazardous events and losses and damages	UNEP	UNDRR	Provide technical support to establish and implement a new tracking system for hazardous events and losses and damages
2.1 – Enhance equipment and technical capacity for observations and monitoring	*2.1.1 – Strengthen the hydrometeorological observation network*	MTE	MMS	Procurement of new hydrometeorological equipment, including spare parts; Refurbishment of the calibration space within MMS
		UNEP	WMO	Provide technical support and training for equipment calibration and WIGOS implementation; Procure calibration kits; Provide technical support for the development of a 5-Year Strategic Plan for MMS
	2.1.2 – Enhance the ocean observation and monitoring system	UNEP	RIMES	Procure ocean observation equipment; Provide technical support for equipment deployment and operation
			WMO	Provide training to enhance skills and competencies related to marine observations and forecasting
	2.1.3 – Establish a Training Institute to build and sustain meteorological capabilities	MTE	MMS	Undertake registration and accreditation for the training institute; Procure textbooks and IT infrastructure
	2.1.4 – Build capacity for Internet of Things (IoT) and wireless technologies	UNEP	ICTP	Provide technical support to deploy IoT-enabled weather stations; Provide training for local staff on IoT networks for weather and climate monitoring

2.2 – Strengthen weather, climate and ocean modelling and impact-based forecasting	*2.2.1 – Establish e-infrastructure for integrated observing and high-resolution forecasting*	UNEP	-	Engage an international consultant/ expert to deliver trainings to MMS staff to maximise the use of the COROBOR data management system
			RIMES	Provide technical support to set up a server, hardware and equipment in the MMS data centre to consolidate, store and process observation and forecast data
	2.2.2 – Undertake climate data rescue and digitisation	MTE	MMS	Procure equipment for climate data rescue and digitisation; Travel to UK Met Office to check for Maldives' data and undertake data rescue as relevant
		UNEP	WMO	Provide technical support and training for the recovery, preservation and digitisation of weather and climate records; Procure equipment for climate data rescue and digitisation
	2.2.3 – Enhance downscaled weather, climate and ocean modelling and high-resolution forecasting	UNEP	RIMES	Provide technical support and training for the co-development and/or customisation of forecasting systems for meteorology, aerometeorology, climatology, and ocean/marine services
	2.2.4 – Develop and sustain core competencies for user-centred climate services	UNEP	WMO	Provide technical support and training to MMS and key stakeholders to strengthen capacity for user-driven climate services
	2.2.5 – Co-produce sector-specific impact-based forecasts and decision support for public and private sectors	MTE	MMS	Organise co-development workshops
		UNEP	RIMES	Provide technical support and training for the development of sector-specific decision support systems (DSSs) for key climate-sensitive sectors
	2.2.6 – Develop sector-specific advisories for climate- and risk-informed decision making	MTE	MMS	Organise co-development workshops
		UNEP	RIMES	Provide technical support and training for the development of sector-specific advisories for key sectors
	2.2.7 – Introduce climate analytics to support the development of Green Finance products	UNEP	RIMES	Provide technical support and training to support development and integration of climate analytics into the design and delivery of green finance products for small and medium enterprises (SMEs)
	2.2.8 – Enhance knowledge retention through hands-on learning and refresher training	UNEP	RIMES	Deliver technical training to MMS on data management and forecasting systems; Deliver technical training to MMS and key sectoral agencies on sectoral DSSs
3.1 – Establish a people-centred, impact-based multi-hazard early warning system	*3.1.1 – Develop and implement Standard Operating Procedures (SOPs) for multi-hazard early warning advisories*	MTE	NDMA	Engage a local consultant and graphic designer to support the development of SOPs; Organise inception, validation and evaluation workshops and stakeholder consultations to inform the development and refinement of SOPs
		UNEP	-	Engage an international consultant/ expert to deliver training on Common Alerting Protocol (CAP) usage
	3.1.2 – Co-develop a socially inclusive and	MTE	-	Engage a local consultant to develop a socially inclusive and gender-responsive

	gender-responsive risk communication strategy			risk communication strategy; Organise stakeholder consultations and a validation workshop
	3.1.3 – Establish a national Multi-Hazard Alert System	MTE	MMS	Organise a training workshop; Procure expertise to upgrade the CAP software in MMS
		UNEP	RIMES	Provide technical support and training to establish a national Multi-Hazard Alert System
	3.1.4 – Deploy innovative technologies to enhance warning communication	MTE	-	Procure services to develop a strategy for the deployment of innovative technologies to enhance warning dissemination; Procure and deploy communication technology equipment
	3.1.5 – Strengthen two-way feedback and evaluation mechanisms	UNEP	UNDRR	Provide technical support and training for the development and implementation of a two-way feedback mechanism; Engage a local consultant to conduct consultations to inform the mechanism development
	3.1.6 – Strengthen communication systems to reach the last mile	MTE	-	Procure services to strengthen early warning communication systems to reach 'last mile' population groups
	3.1.7 – Develop a multilingual glossary on climate change, early warning systems, and disaster risk reduction	MTE	-	Engage a local consultant to develop a multilingual glossary; Procure translation services to develop the glossary; Organise a validation workshop
	3.1.8 – Establish partnerships with the private sector to expand information dissemination and feedback mechanisms	MTE	MRC	Organise sensitisation workshops for media personnel and private sector actors
4.1 – Enhance awareness and capacity to prepare for and respond to climate-related hazards and risks	*4.1.1 – Increase public awareness and education on climate-related hazards, vulnerabilities, exposure, and risks*	MTE	MRC	Conduct a nationwide awareness-raising and education campaign on climate change and early warning systems; Develop an online information hub for the delivery of knowledge products and information materials
	4.1.2 – Mainstream Protection, Gender and Inclusion (PGI) into disaster preparedness	MTE	MRC	Organise a national stakeholder consultation workshop to inform PGI mainstreaming; Procure services to develop a radio programme for dissemination of early warning resources; Pilot test knowledge products in target communities; Organise PGI monitoring visits by the Social and Gender Safeguard Officer to target islands
	4.1.3 – Scale up the Y-Adapt youth engagement curriculum	MTE	MRC	Engage local facilitators to conduct Y-Adapt trainings; Conduct training for Y-Adapt facilitators; Organise Y-Adapt trainings in target communities
	4.1.4 – Strengthen national, sub-national and local capacity to use climate and disaster risk information and	MTE	MRC	Deliver capacity building workshops on climate-related disaster risks and early warning systems at atoll and island level

	impact-based early warnings			
	4.1.5 – Enhance capacity of the private sector to manage climate-related risks	MTE	MRC	Conduct awareness-raising and education for private sector actors to improve climate change literacy and understanding of early warning systems and associated resources; Conduct workshops for MSMEs to develop disaster contingency and preparedness plans
			BCCC	Conduct nationwide awareness-raising sessions on climate risk management for MSMEs; Organise annual Pop-Up Events to engage with MSMEs on building climate resilience
		UNEP	-	Engage an international consultant / expert to deliver a targeted awareness and education programme for state-owned enterprises that support development of the MSME sector
			RCCC	Provide technical support to MRC on SME capacity building
	4.1.6 – Scale up Community-Based Disaster Risk Management (CBDRM)	MTE	MRC	Engage local consultants to deliver specialised trainings for Community Emergency Response Teams (CERTs); Organise specialised trainings for CERT teams; Procure equipment for CERTs
	4.1.7 – Develop Standard Operating Procedures (SOPs) for integrating Protection, Gender and Inclusion (PGI) into disaster response	MTE	NDMA	Engage a local consultant and graphic designer to support the development of SOPs for integrating PGI into disaster response; Organise stakeholder consultations and a validation workshop
4.2 – Establish capacity for Forecast-based Action (FbA) and Anticipatory Action (AA)	*4.2.1 – Develop a Roadmap for FbA/AA*	UNEP	RCCC	Provide technical support to undertake sensitisation on FbA/AA and develop a national roadmap
	4.2.2 – Build capacity for FbA/AA	UNEP	RCCC	Provide technical support to build capacity of national stakeholders to implement FbA/AA
	4.2.3 – Co-develop impact-based forecast triggers for FbA/AA	UNEP	RCCC	Provide technical support for the co-development of impact-based forecast triggers for FbA/AA
	4.2.4 – Initiate Early Action Protocol (EAP) development	MTE	MRC	Organise EAP development workshops for MRC staff
		UNEP	RCCC	Provide technical support for the development of national and institutional (MRC) level EAPs

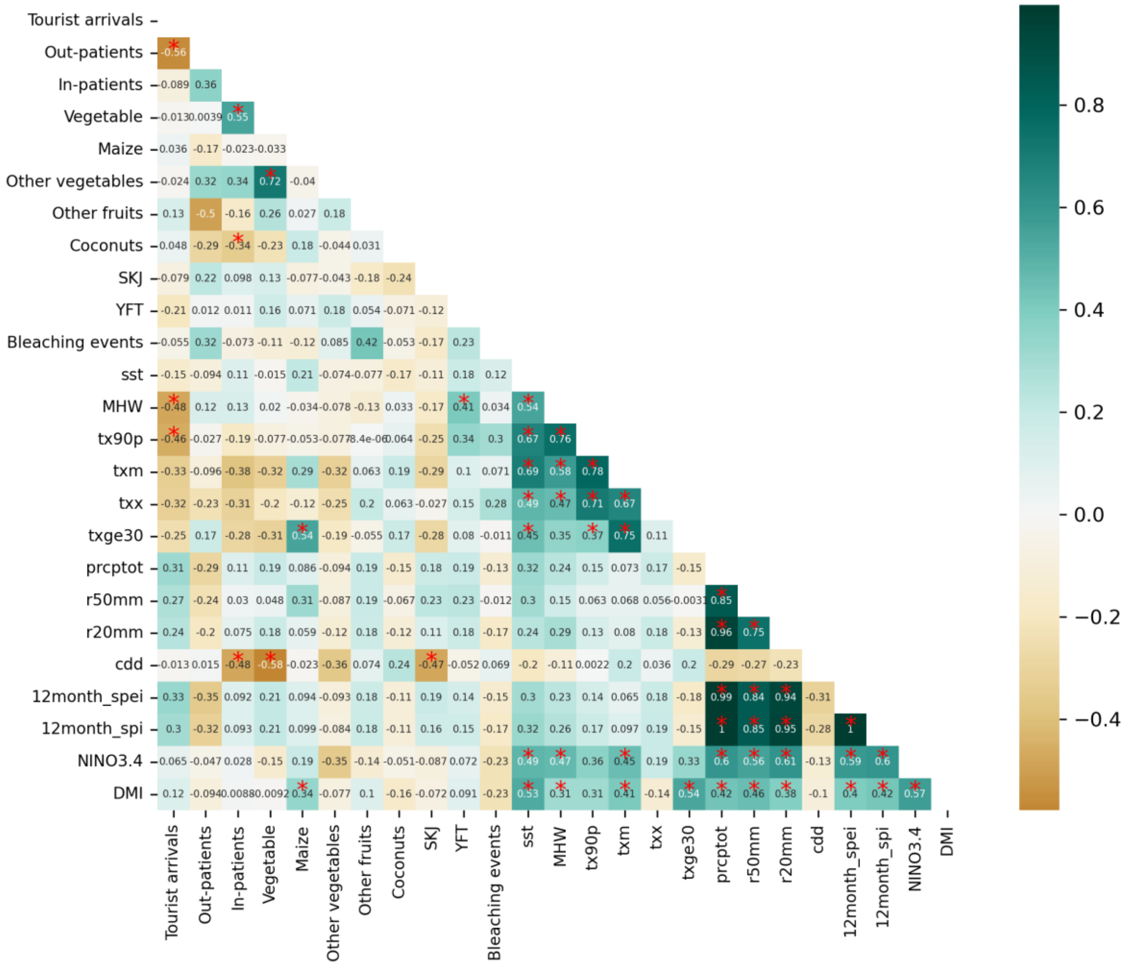
12 CONCLUSION

Greater urgency, speed and transformative action is critical to helping highly vulnerable SIDS, such as Maldives, to enhance their resilience to intensifying climate change threats and to enable a shift towards climate-resilient sustainable development pathways. The relative cost of responding to and recovering from extreme climate events is much greater in SIDS due to their high import dependence and the logistical challenge of reaching highly dispersed and isolated populations. In the event of a disaster, SIDS often need to divert their scarce resources towards immediate, short-term re-building needs, which compromises investment in long-term sustainable development and climate resilience. The result is a vicious cycle of increasing vulnerability to future climate change impacts.

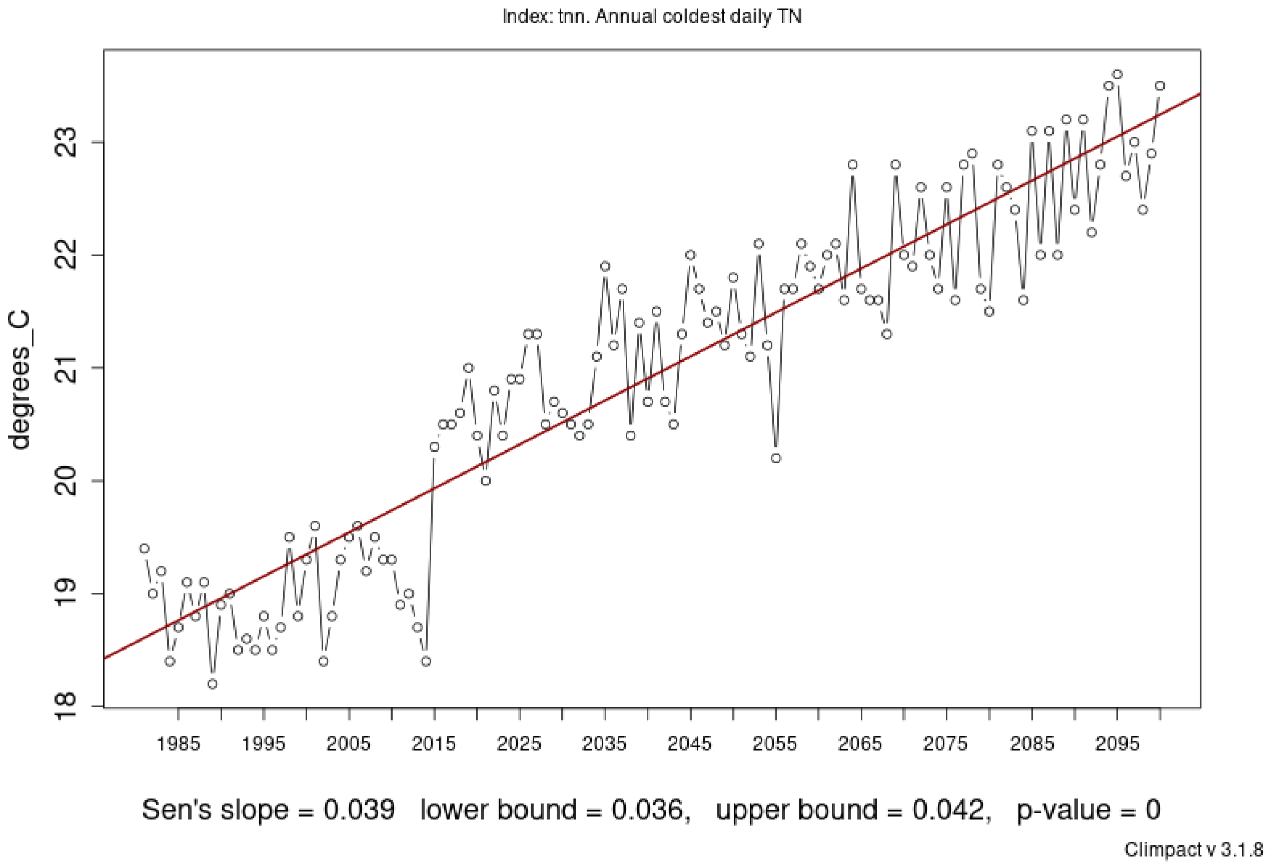
Overall, this project has strong potential to inform and drive climate resiliency in the Republic of Maldives by developing technical capacity and systems to provide accurate, timely and actionable climate information that can be leveraged by decision makers in policy, planning and response actions, and can empower sectors and communities in Maldives to adapt to increasing climate variability and change.

The proposed project will enable sustained generation, access to and use of localised climate information in Maldives, which is essential to institute science-based, risk-informed planning for climate change adaptation and sustainable development. This is a cost-effective alternative to reactive approaches to climate-related hazards that focus on ad-hoc recovery and investment in hard infrastructure, and risk expensive maladaptation. The project will significantly enhance the risk knowledge and preparedness capabilities of sectors and communities.

APPENDIX 1: SUPPLEMENTARY FIGURES TO THE CLIMATE ANALYSIS

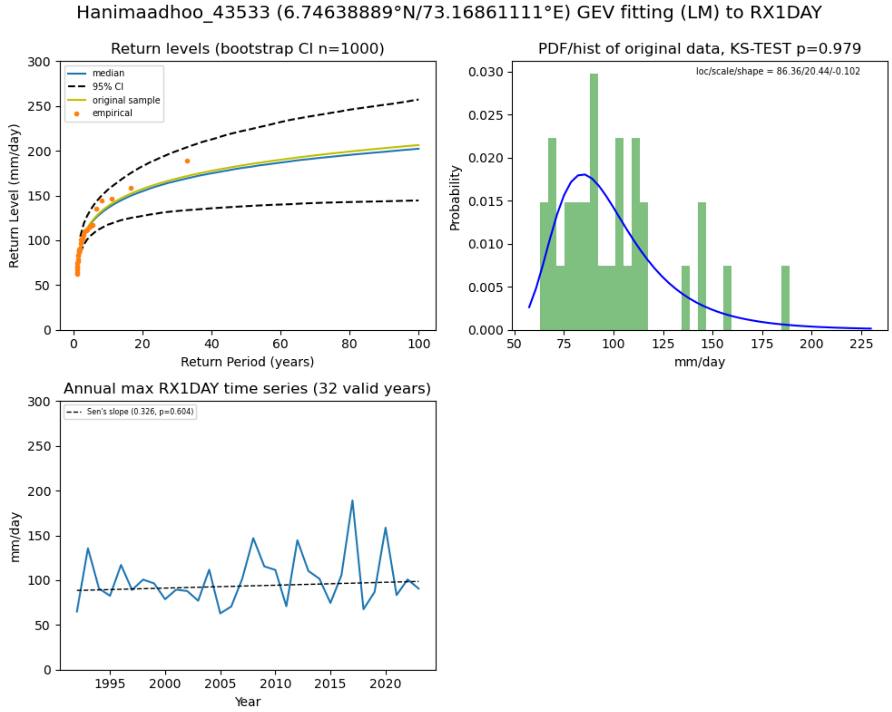


Supplementary Figure 1. Correlation matrix of climate and sector data.
This shows the relationship in interannual changes between sector and climate data where positive numbers indicate a positive relationship and negative numbers a negative relationship. Numbers close to zero indicate no or weak relationships. It should be noted that only a detrending and normalization process has been undertaken on the sector data and significant issues were found therein. Further effort could be allocated to curating some of these records – particularly the agricultural data from the FAO. Red asterisks indicate statistical significance at p=0.05. DMI = Dipole Mode Index (an index for the Indian Ocean Dipole), cdd = consecutive dry days, MHW = marine heatwave, YFT = yellowfin tuna catch, SKJ = skipjack tuna catch.

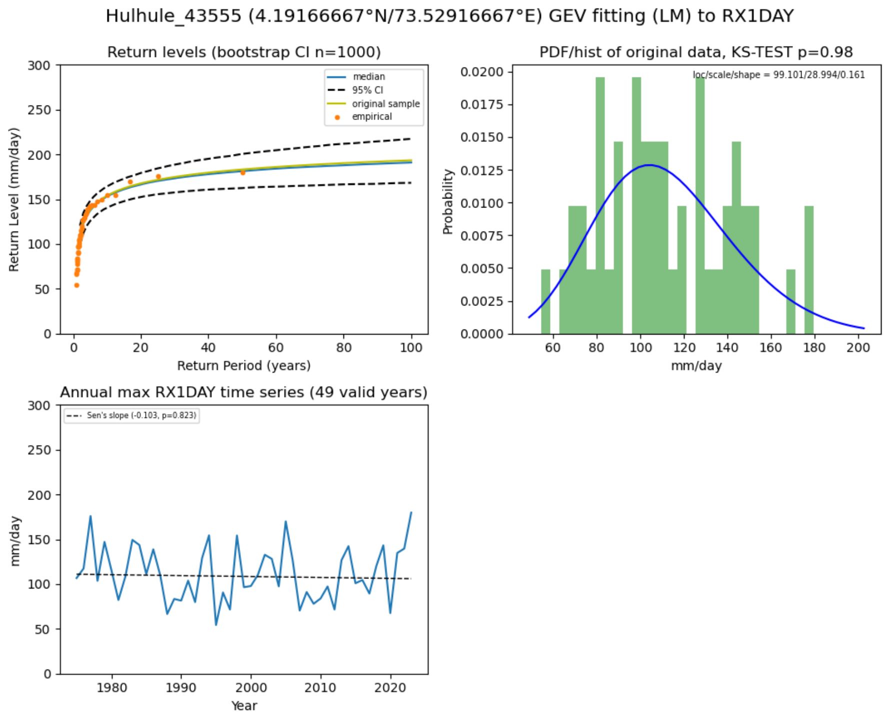


Supplementary Figure 2. An example of the artificial step changes observed in the downscaled CMIP6 dataset by Thrasher et al.[496] and the reason this dataset was eventually not used.
Plot shows coldest night-time temperatures from the downscaled MRI-ESM2 CMIP6 model.

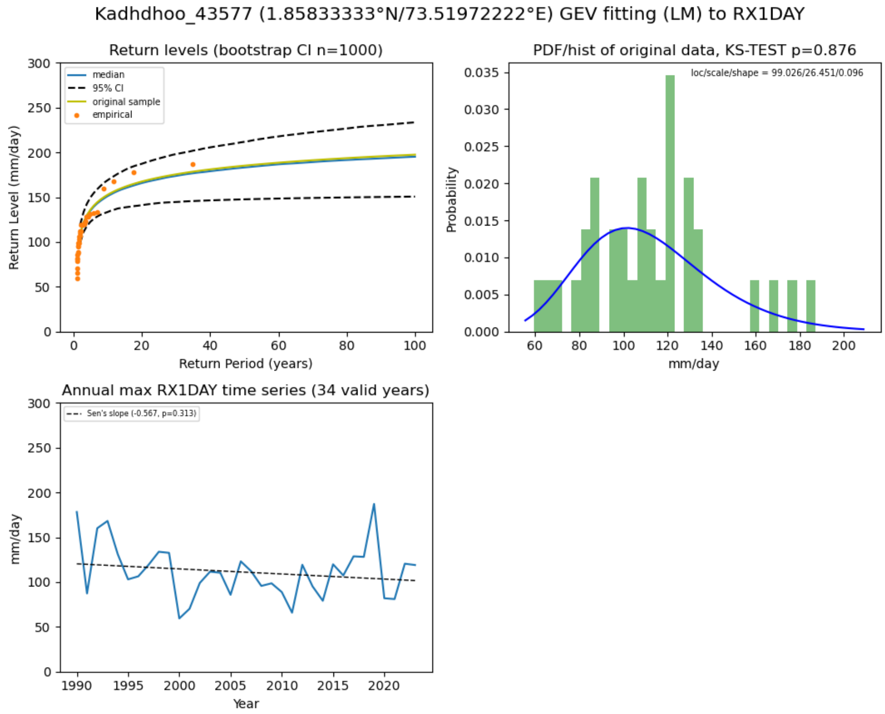
[496] Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T. and Nemani, R., 2022. NASA global daily downscaled projections, CMIP6. Scientific data, 9(1), p.262.



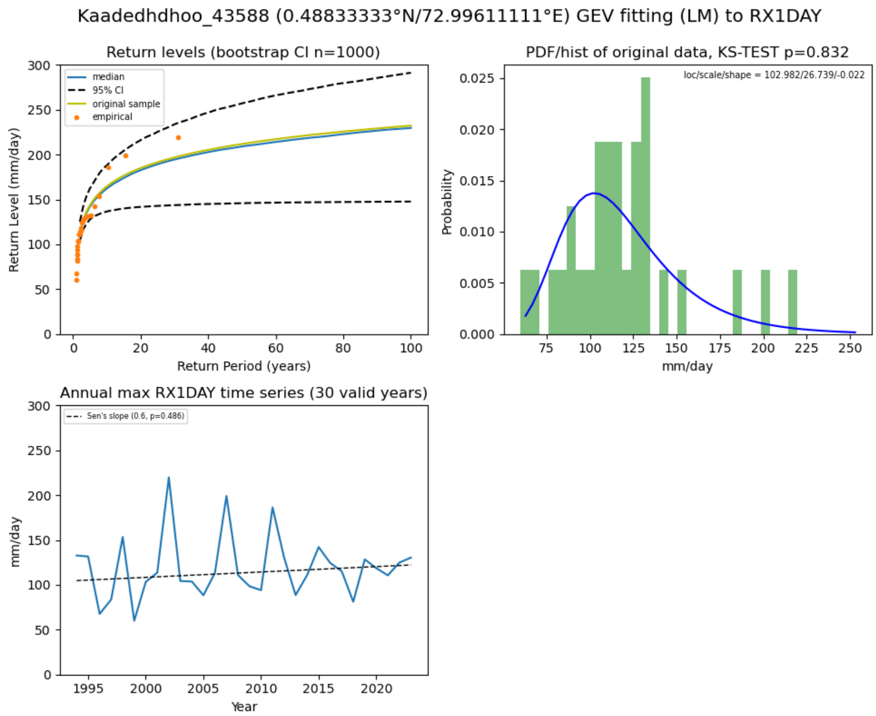
Supplementary Figure 3. Extreme value analysis for annual maximum daily rainfall at Hanimaadhoo. Top left: return levels and return periods based on the GEV. Orange dots represent observations. Dashed black lines represent 95% uncertainty. Top right: Histogram of annual maximum daily rainfall and the fitted GEV (blue). Bottom: time series and linear trend of maximum daily rainfall.



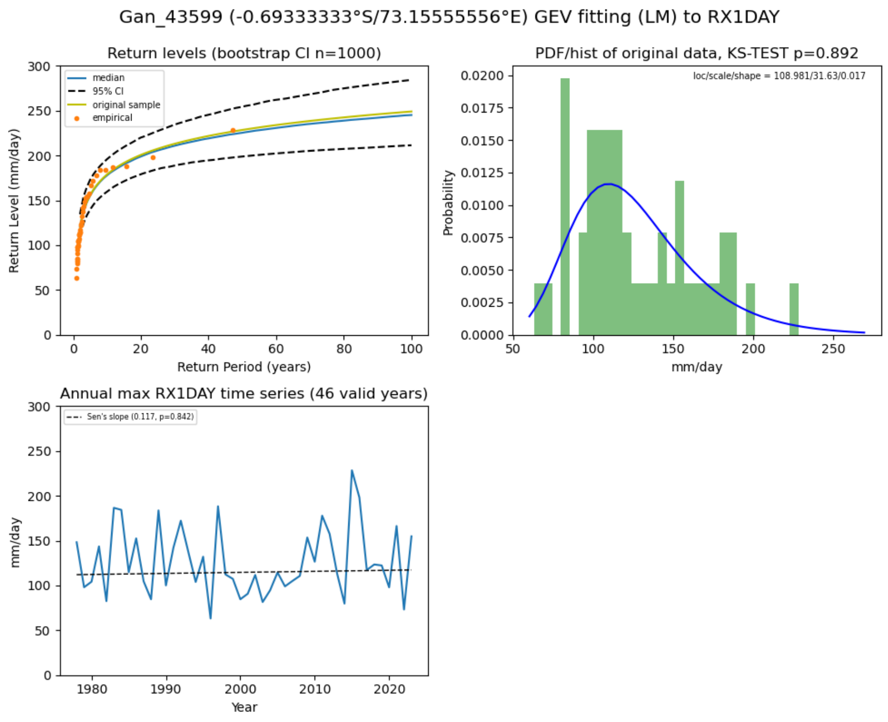
Supplementary Figure 4. Same as Supplementary Figure 3 except for Hulhule.



Supplementary Figure 5. Same as Supplementary Figure 3 except for Kadhdhoo.



Supplementary Figure 6. Same as Supplementary Figure 3 except for Kaadedhdhoo.



Supplementary Figure 7. Same as Supplementary Figure 3 except for Gan.