CLIMATE RISK COUNTRY PROFILE

TONGA

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This profile is part of a series of Climate Risk Country Profiles that are jointly developed by the World Bank Group (WBG) and the Asian Development Bank (ADB). These profiles synthesize the most relevant data and information on climate change, disaster risk reduction, and adaptation actions and policies at the country level. The profile is designed as a quick reference source for development practitioners to better integrate climate resilience in development planning and policy making. This effort is co-led by Veronique Morin (Senior Climate Change Specialist, WBG), Ana E. Bucher (Senior Climate Change Specialist, WBG) and Arghya Sinha Roy (Senior Climate Change Specialist, ADB).

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Climate and climate-related information is largely drawn from the Climate Change Knowledge Portal (CCKP), a WBG online platform with available global climate data and analysis based on the current Intergovernmental Panel on Climate Change (IPCC) reports and datasets. The team is grateful for all comments and suggestions received from the sector, regional, and country development specialists, as well as climate research scientists and institutions for their advice and guidance on use of climate related datasets.

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FOREWORD

Climate change is a major risk to good development outcomes, and the World Bank Group is committed to playing an important role in helping countries integrate climate action into their core development agendas. The World Bank Group (WBG) and the Asian Development Bank (ADB) are committed to supporting client countries to invest in and build a low-carbon, climate-resilient future, helping them to be better prepared to adapt to current and future climate impacts.

Both institutions are investing in incorporating and systematically managing climate risks in development operations through their individual corporate commitments.

For the World Bank Group: a key aspect of the World Bank Group's Action Plan on Adaptation and Resilience (2019) is to help countries shift from addressing adaptation as an incremental cost and isolated investment to systematically incorporating climate risks and opportunities at every phase of policy planning, investment design, implementation and evaluation of development outcomes. For all International Development Association and International Bank for Reconstruction and Development operations, climate and disaster risk screening is one of the mandatory corporate climate commitments. This is supported by the World Bank Group's Climate and Disaster Risk Screening Tool which enables all Bank staff to assess short- and long-term climate and disaster risks in operations and national or sectoral planning processes. This screening tool draws up-to-date and relevant information from the World Bank's Climate Change Knowledge Portal, a comprehensive online 'one-stop shop' for global, regional, and country data related to climate change and development.

For the Asian Development Bank (ADB): its Strategy 2030 identified "tackling climate change, building climate and disaster resilience, and enhancing environmental sustainability" as one of its seven operational priorities. Its Climate Change Operational Framework 2017–2030 identified mainstreaming climate considerations into corporate strategies and policies, sector and thematic operational plans, country programming, and project design, implementation, monitoring, and evaluation of climate change considerations as the foremost institutional measure to deliver its commitments under Strategy 2030. ADB's climate risk management framework requires all projects to undergo climate risk screening at the concept stage and full climate risk and adaptation assessments for projects with medium to high risk.

Recognizing the value of consistent, easy-to-use technical resources for our common client countries as well as to support respective internal climate risk assessment and adaptation planning processes, the World Bank Group's Climate Change Group and ADB's Sustainable Development and Climate Change Department have worked together to develop this content. Standardizing and pooling expertise facilitates each institution in conducting initial assessments of climate risks and opportunities across sectors within a country, within institutional portfolios across regions, and acts as a global resource for development practitioners.

For common client countries, these profiles are intended to serve as public goods to facilitate upstream country diagnostics, policy dialogue, and strategic planning by providing comprehensive overviews of trends and projected changes in key climate parameters, sector-specific implications, relevant policies and programs, adaptation priorities and opportunities for further actions.

We hope that this combined effort from our institutions will spur deepening of long-term risk management in our client countries and support further cooperation at the operational level.

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KEY MESSAGES

- Tonga's island groups have observed historical warming of around 0.6°C between 1979 and 2018.
- Future trends in warming are obscured by the inability of climate models to accurately simulate trends at sufficiently small spatial scales. Warming is likely to take place at a rate slightly lower than the global average. On the highest emissions pathway (RCP8.5) warming of around 2.6°C is projected by the end of the century.
- Tonga faces a diverse set of risks from climate change but data and reliable model projections are lacking, presenting challenges for decision makers.
- Potential threats to human well-being and natural ecosystems include increased prevalence of heatwave, intensified cyclones, saline intrusion, wave-driven flooding, and permanent inundation.
- Biodiversity and the natural environment of Tonga face extreme pressure, and loss of some species of fish, coral, bird, and terrestrial species is likely without very effective conservation measures.
- Tonga faces a potential long-term threat from permanent inundation and wave-driven flooding, and some studies have suggested that significant displacement of communities could take place.
- Research has suggested that the risk of large-scale flooding and inundation will depend on the success of coral conservation, and future geomorphological patterns which build and erode land.
- Tonga's population already lives in a dynamic ecosystem, to which it has adapted, but climate change is likely to increase variability, pose new threats, and place stress on livelihoods.
- Communities are likely to need support to adapt and manage disaster risks facing their wellbeing, livelihoods, and infrastructure. Geographic isolation and economic vulnerabilities, including dependence on remittance and foreign aid, will increase the challenges faced by communities and decision makers.

COUNTRY OVERVIEW

The Kingdom of Tonga is an archipelago consisting of four clusters of 172 coral and volcanic islands with a total area of 747 square kilometres (km^2), located in the Central South Pacific Ocean.[1] Tonga is situated at the subduction zone of the Indian-Australian and the Pacific tectonic plates and lies within the Ring of Fire where intense seismic activities occur. The islands are formed on the tops of two parallel submarine ridges stretching from Southwest to Northeast and enclosing a 50 km wide trough.[2] Most of the islands in Tonga originate from coral line, and some islands are of volcanic origin. The majority of these islands are comparatively flat except for those raised by tectonic action. Several volcanoes, some of which are still active, exist along the western ridge, while many coral islands have formed along the eastern ridge, amongst them are the Vava'u and Ha'apai island groups. Coral islands are in two categories, the low and raised coral islands.

1 WBG Climate Change Knowledge Portal (CCKP, 2020). Tonga. URL: https://climateknowledgeportal.worldbank.org/country/Tonga [accessed 10/08/2019]

2 Ministry of Environment and Climate Change (2021). Third National Communication to UNFCCC. URL: https://unfccc.int/sites/default/files/resource/Final%20TNC%20Report_December%202019.pdf [accessed 10/08/2019]

Tonga's climate is tropical and is defined by a wet season from November to April with moderate and variable rainfall, and a dry season from May to October.[1] The mean annual temperature in Tonga varies from 23°C to 26°C. Climate in Tonga and this portion of the Pacific in general is governed by a number of factors, which include the trade winds and the movement of the South Pacific Convergence Zone (SPCZ), a zone of high-pressure rainfall that migrates across the Pacific south of the equator. Year-to-year variability in climate is also strongly influenced by the El Niño Southern Oscillation (ENSO) in the south-east Pacific, which can bring prolonged drought conditions and contribute to a depletion of potable water, and tropical cyclones that occur during the wet season, causing extensive damage to local infrastructure, agriculture, and major food sources.

As of 2019, Tonga's population was estimated at nearly 104,500 people over 18,005 households – about 74% of the total population resides on the largest island of Tongatapu (at 260 km^2).[3] Tonga enjoys a relatively strong position as a lower middle-income country, in part due to its high migration and remittance culture. Tonga continues to rely on current transfers (workers' remittances and government transfers) to support household and government consumption.[4] It is estimated that about 50% of all Tongans live overseas and their remittances represent approximately 50–60%[2] of gross national domestic income.[1]

The economy of Tonga is highly dependent on climate sensitive sectors such agriculture, fisheries and tourism and a limited resource base that is sensitive to external shocks. According to Tonga's latest available statistics, in 2015–16 the service sector contribution to GDP (including tourism trade, and hospitality, and as measured in current prices) was 54.5%, while agriculture contributed 14.7% to GDP in current prices.[4] Increased local market production and export of fruit and vegetables including the main crop, squash, as well as kava, yams, and sweet potatoes, contributed to an increasing value of agriculture in the year of estimation. The agricultural sector supports the majority of the population for subsistence and for cash income, employing a third of the labour force and accounting for at least 50% of the export earnings.[2] The gross value-added of fishing activities increased from 7.4% of GDP in 2014–15 to 15.6% in 2015–16, largely as a result of increasing exports which includes prepared and preserved fish and seaweed.[4]

Green, Inclusive and Resilient Recovery

The coronavirus disease (COVID-19) pandemic has led to unprecedented adverse social and economic impacts. Further, the pandemic has demonstrated the compounding impacts of adding yet another shock on top of the multiple challenges that vulnerable populations already face in day-to-day life, with the potential to create devastating health, social, economic and environmental crises that can leave a deep, long-lasting mark. However, as governments take urgent action and lay the foundations for their financial, economic, and social recovery, they have a unique opportunity to create economies that are more sustainable, inclusive and resilient. Short and long-term recovery efforts should prioritize investments that boost jobs and economic activity; have positive impacts on human, social and natural capital; protect biodiversity and ecosystems services; boost resilience; and advance the decarbonization of economies.

[3] Tonga Department of Statistics (2019). Tonga Statistics at a Glance. URL: https://tonga.prism.spc.int/ [accessed 10/08/2019]
[4] Tonga Department of Statistics (2017). National Accounts Statistics 2015–16. URL: https://tonga.prism.spc.int/component/advlisting/?view=download&fileId=2240 [accessed 10/08/2019]

Tonga submitted its Third National Communication to the UNFCCC in 2020, its Initial Nationally Determined Contributions in 2016, its Second Nationally Determined Contributions in 2020 and ratified the Paris Agreement in 2016. This document aims to succinctly summarize the climate risks faced by the Kingdom of Tonga. This includes rapid onset and long- term changes in key climate parameters, as well as impacts of these changes on communities, livelihoods and economies, many of which are already underway. This is a high-level synthesis of existing research and analyses, focusing on the geographic domain of Tonga, therefore potentially excluding some international influences and localized impacts. The core climate projections presented are sourced from the Pacific-Australia Climate Change Science and Adaptation Planning Program,[5,6] as well as the World Bank Group's Climate Change Knowledge Portal (CCKP), incorporating climate projections from the Coupled Model Inter-comparison Project Phase 5 (CMIP5). This document is primarily meant for WBG and ADB staff to inform their climate actions. The document also aims and to direct the reader to many useful sources of secondary data and research.

TABLE 1. Key indicators

Indicator	Value	Source
Population Undernourished[7]	N/A	FAO, 2020
National Poverty Rate[8]	22.1% (2015)	ADB, 2020a
Share of Wealth Held by Bottom 20%[9]	6.8% (2015)	World Bank, 2019
Net Annual Migration Rate[10]	–0.8% (2015–20)	UNDESA, 2019
Infant Mortality Rate (Between Age 0 and 1)[11]	1.3% (2015–20)	UNDESA, 2019
Average Annual Change in Urban Population[12]	0.7% (2015–20)	UNDESA, 2019
Dependents per 100 Independent Adults[13]	69 (2020)	UNDESA, 2019
Urban Population as % of Total Population[14]	23.1% (2020)	CIA, 2020
External Debt Ratio to GNI[15]	41.3% (2018)	ADB, 2020b
Government Expenditure Ratio to GDP[16]	42.9% (2019)	ADB, 2020b

5 Australian Bureau of Meteorology and CSIRO (2014) Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports. Pacific-Australia Climate Change Science and Adaptation Planning Program Technical Report, Australian Bureau of Meteorology and CSIRO, Melbourne, Australia. URL: https://www.pacificclimatechangescience.org/wp-content/uploads/2014/07/PACCSAP_CountryReports2014_WEB_140710.pdf

6 The NextGen projections for the Pacific region under CMIP5 are expected to be available from July 2021. These will provide an update on the PACCSAP 2014 projections referenced in this profile. The process for providing the new NextGen CMIP6 projections for the Pacific is still in the planning phase.

7 FAO, IFAD, UNICEF, WFP, WHO (2020). The state of food security and nutrition in the world. Building Resilience for peace and food security. FAO. Rome. URL: http://www.fao.org/documents/card/en/c/ca9692en/

8 ADB (2020a). Basic Statistics 2020. URL: https://www.adb.org/publications/basic-statistics-2020

9 World Bank (2019). Income share held by lowest 20%. URL: https://data.worldbank.org/indicator/SI.DST.FRST.20 [accessed 15/02/2021]

10 UNDESA (2019). World Population Prospects 2019. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 15/02/2021]

11 UNDESA (2019). World Population Prospects 2019. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 15/02/2021]

12 UNDESA (2019). World Urbanization Prospects 2019. URL: https://population.un.org/wup/Download/ [accessed 15/02/2021]

13 UNDESA (2019). World Population Prospects 2019. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 15/02/2021]

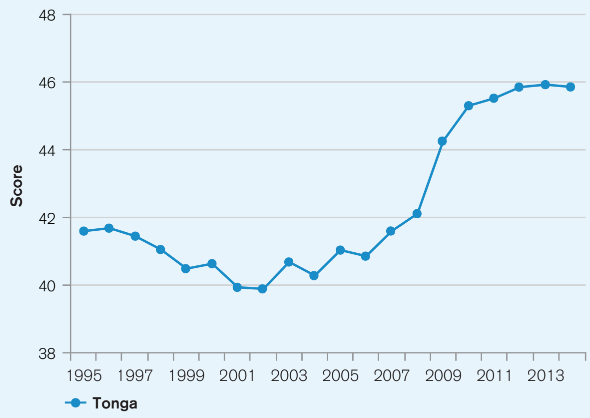
14 CIA (2020). *The World Factbook*. Central Intelligence Agency. Washington DC. URL: https://www.cia.gov/the-world-factbook/

15 ADB (2020b). Key Indicators for Asia and the Pacific 2020, 51st Edition. Asian Development Bank. Manila. URL: https://www.adb.org/sites/default/files/publication/632971/ki2020.pdf

16 ADB (2020b). Key Indicators for Asia and the Pacific 2020, 51st Edition. Asian Development Bank. Manila. URL: https://www.adb.org/sites/default/files/publication/632971/ki2020.pdf

Due to a combination of political, geographic, and social factors, Tonga is recognized as vulnerable to climate change impacts, ranked 121 out of 181 countries in the 2020 ND-GAIN Index.[17] The ND-GAIN Index ranks 181 countries using a score which calculates a country's vulnerability to climate change and other global challenges as well as their readiness to improve resilience. The more vulnerable a country is the lower their score, while the more ready a country is to improve its resilience the higher it will be. Norway has the highest score and is ranked 1st. **Figure 1** is a time-series plot of the ND-GAIN Index showing Tonga's progress.

FIGURE 1. The ND-GAIN Index score (out of 100) summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. It aims to help businesses and the public sector better prioritize investments for a more efficient response to the immediate global challenges ahead



CLIMATOLOGY

Climate Baseline

Overview

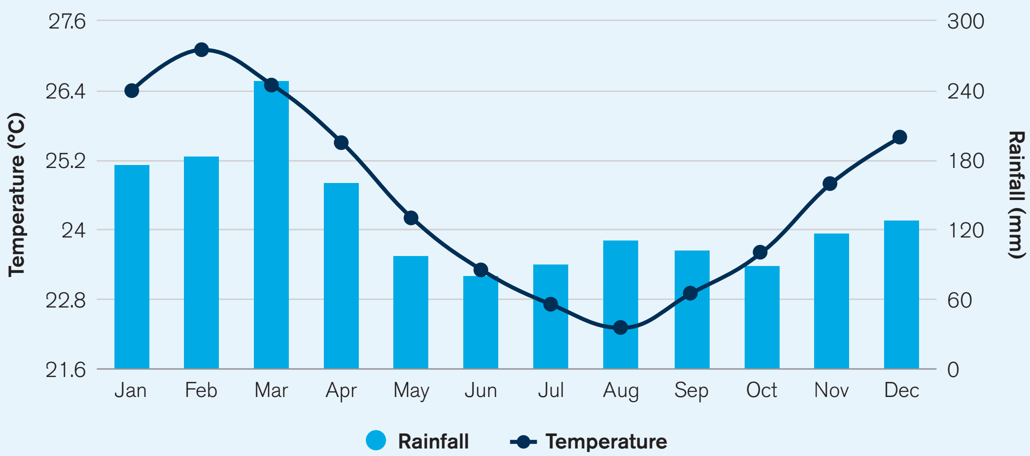
Tonga has a tropical climate throughout the year reflecting its position within the southeast trade wind zone of the South Pacific.[2] Mean annual precipitation has averaged 1,666 millimetres (mm) over the period 1901–2019, but there is a marked seasonality in the Tongan rainfall: a dry season from May to October and a wet season from November to April.[1] Most of Tonga's rainfall occurs from convective processes, from tropical cyclones and from rain associated with the cloud sheets of the subtropical jet.[2] While convective rainfall occurs all year round, it is most pronounced during the wet season. Meanwhile the organized large-scale precipitation (e.g. cold fronts) usually occurs during the cooler dry months. The spatial variation of monthly and annual rainfall over Tonga highlights that the northern-most islands receive the most rainfall due to the influences of the South Pacific Convergence Zone (SPCZ). Tonga's climate pattern is very much affected by the El Niño phenomenon.[2] As the warm sea surface temperatures move east during El Niño, moisture and water vapour required for cloud formation also migrate eastward, influencing drought conditions in Tonga. The last three major droughts that have occurred in Tonga in 1983, 1998 and 2006 have been directly linked to El Niño events around the same time.

[17] University of Notre Dame (2019). Notre Dame Global Adaptation Initiative. URL: https://gain.nd.edu/our-work/country-index/

The temperature in Tonga is generally tropical, with some limited seasonal and spatial variation.[2] Mean annual temperatures vary according to latitude from 27°C at Niuafo'ou and Keppel (in the north), to 24°C at Tongatapu (in the south). Diurnal and seasonal variations can reach as high as 6°C throughout the island group, while seasonal variation in temperature is more marked in the southern cooler islands. In general, across the island group, the mean annual temperature ranges from 23°C–26°C, averaging 24.5°C over the period 1901–2019. During the wet season, the average temperature ranges from 25°C–26°C, whereas during the dry season the average temperature ranges from 21°C–24°C , for the latest climatology, 1991–2020 (**Figure 2**).

Annual Cycle

FIGURE 2. Average monthly temperature and rainfall in Tonga, 1991–2020[1]



Key Trends

Temperature

Tonga's 2020 Third National Communication to the UNFCCC offers evidence of general warming trends across all of the five meteorological stations in Tonga.[2] While mean annual temperatures vary according to latitude, and are generally lower in the southern islands, climatologically, the largest average annual temperature change took place on Tongatapu (in the south), where an increase of 1.8°C was reported using data from 1949–2007.[2] This estimate is unusually high, and is different from rise estimated by the Berkeley Earth Dataset, which puts the rise in the region of 0.4°C–0.6°C over the same period.[18] Annual and November–April mean temperatures have increased at Nuku'alofa since 1949, with trends in Nuku'alofa annual maximum temperature and November–April maximum and minimum temperature also positive — this is consistent with global warming.[5] On average for the island groups, mean temperatures have increased by 0.4°C–0.8°C since 1970, with warming most rapid in the warmest season (November–April) and in the early 21st century.[1] As well, the frequency of hot days and hot nights has increased significantly across the Pacific.

[18] Carbon Brief (2018). Mapped: How every part of the world has warmed – and could continue to warm. [26 September 2018]. URL: https://www.carbonbrief.org/mapped-how-every-part-of-the-world-has-warmed-and-could-continue-to-warm [accessed 25/10/2019]

Precipitation

Due to the spatial distribution of the islands of Tonga, there is a disparity in the nature of rainfall in the country. Tonga's Third National Communication to the UNFCCC reports the annual mean rainfall at the five meteorological stations in Tonga between 1971–2007: Tongatapu reported an average of 1,721 mm, Vava'u an average of 2,150 mm, Ha'apai an average of 1,619 mm, Niua Fo'ou an average of 2,453 mm and Niua Toputapu an average of 2,374 mm.[2] All of the islands in the Tongan archipelago therefore receive very significant annual rainfall.

Tonga's Third National Communication to the UNFCCC highlights that the Ha'apai island group receives the lowest rainfall of all the island groups in Tonga and Niua Fo'ou the highest. Variation in annual rainfall averages relate particularly to each island's proximity to the South Pacific Convergence Zone (SPCZ) and the wet tropics. The Third National Communication reports changes over time in the annual rainfall seen at a number of Tongan islands, for example an increasing trend of 16 mm per year reported at Niuafo'ou and a decreasing trend of 6 mm per year at Ha'apai, but it is unclear the extent to which these trends represent a climate change influence or natural variation. Notable interannual variability associated with the ENSO is evident in Tonga, influencing the onset of drought conditions over the islands.[2]

Climate Future

Overview

The Representative Concentration Pathways (RCPs) represent four plausible futures, based on the rate of emissions reduction achieved at the global level. Four RCPs (i.e. RCP2.6, RCP4.5, RCP6.0, and RCP8.5) were selected and defined by their total radiative forcing (cumulative measure of GHG emissions from all sources) pathway and level by 2100. In this analysis, RCP2.6 and RCP8.5, the extremes of low and high emissions pathways, are the primary focus; RCP2.6 represents a very strong mitigation scenario, whereas RCP8.5 assumes business-as-usual scenario. For reference, **Table 2** provides information on all four RCPs over two-time horizons. In subsequent analysis RCPs 2.6 and 8.5, the extremes of low and high emissions pathways, are

A Precautionary Approach

Studies published since the last iteration of the IPCC's report (AR5), such as Gasser et al. (2018), have presented evidence which suggests a greater probability that earth will experience medium and high-end warming scenarios than previously estimated.[19] Climate change projections associated with the highest emissions pathway (RCP8.5) are presented here to facilitate decision making which is robust to these risks.

[19] Gasser, T., Kechiar, M., Ciais, P., Burke, E. J., Kleinen, T., Zhu, D., . . . Obersteiner, M. (2018). Path-dependent reductions in CO2 emission budgets caused by permafrost carbon release. Nature Geoscience, 11, 830–835. URL: https://www.nature.com/articles/s41561-018-0227-0?WT.feed_name=subjects_climate-sciences

the primary focus. RCP2.6 would require rapid and systemic global action, achieving emissions reduction throughout the 21st century enough to reach net zero global emissions by around 2080. RCP8.5 assumes annual global emissions will continue to increase throughout the 21st century. Climate changes under each emissions pathway are presented against a reference period of 1986–2005 for all indicators. For more information, please refer to the RCP Database.

TABLE 2. An overview of temperature change projections (°C) in Tonga under four emissions pathways. Projected changes over the 1986–2005 baseline are given for 20-year periods centred on 2050 and 2090 with the 5th and 95th percentiles provided in brackets.[5]

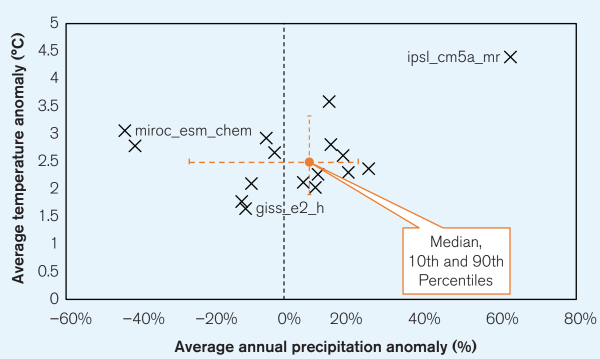
	Mean Surface Air Temp (Annual)		Max Temp (1-in-20 Year Event)		Min Temp (1-in-20 Year Event)	
Scenario	**2050**	**2090**	**2050**	**2090**	**2050**	**2090**
RCP2.6	0.6 (0.4, 1)	0.6 (0.2, 1.1)	0.7 (0.1, 1)	0.7 (–0.1, 1.1)	0.6 (0, 0.9)	0.6 (0.1, 0.9)
RCP4.5	0.9 (0.6, 1.4)	1.2 (0.8, 2.1)	0.9 (0.2, 1.2)	1.3 (0.6, 1.8)	0.9 (0.5, 1.3)	1.3 (0.7, 1.9)
RCP6.0	0.8 (0.6, 1.3)	1.6 (1.2, 2.4)	NA	NA	NA	NA
RCP8.5	1.2 (0.8, 2)	2.6 (1.8, 4.1)	1.4 (0.7, 2)	2.9 (1.7, 4.2)	1.3 (0.7, 1.9)	2.9 (2.1, 4.2)

Model Ensemble

Due to differences in the way global circulation models (GCMs) represent the key physical processes and interactions within the climate system, projections of future climate conditions can vary widely between different GCMs. This is particularly the case for rainfall related variables and at sub-national scales. Exploring the spread of climate model outputs can assist in understanding uncertainties associated with climate models. The range of projections from 16 GCMs on the indicators of average temperature anomaly and annual precipitation anomaly for the Cook Islands under RCP8.5 is shown in **Figure 3**.

The majority of the models from which outputs are presented in this report are from the CMIP5 round of standardization and quality assurance. Unfortunately, models of this generation operate at large spatial scales and are not well equipped to simulate the future climate of small islands. Typically, the changes projected will relate more to the expected changes over nearby ocean than the island itself. Caution should therefore be applied in interpreting results. This highlights a major area for future development, a research opportunity, and an urgent need from the perspective of policy makers planning for climate change.

FIGURE 3. 'Projected average temperature change' and 'projected annual rainfall change' in Tonga. Outputs of 16 models within the ensemble simulating RCP8.5 over the period 2080–2099. Models shown represent the subset of models within the ensemble which provide projections across all RCPs and therefore are most robust for comparison.[5] Three models are labelled.

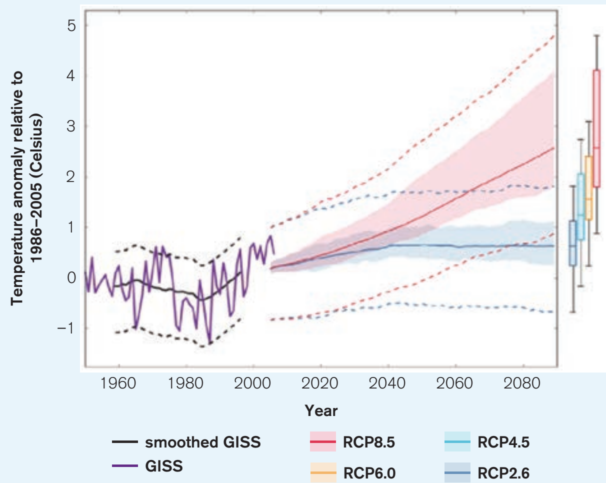


Temperature

Projections of future temperature change are presented in three primary formats. Shown in **Table 2** are the changes (anomalies) in maximum and minimum temperatures over the given time period, as well as changes in the average temperature. **Figures 3** and **4** display only the average temperature projections. While similar, these three indicators can provide slightly different information. Monthly and annual average temperatures are most commonly used for general estimation of climate change, but the daily maximum and minimum can explain more about how daily life might change in a region, affecting key variables such as the viability of ecosystems, health impacts, productivity of labour, and the yield of crops, which are often disproportionately influenced by temperature extremes.

Across the Pacific, temperatures are projected to increase between 1.4°C and 3.1°C.[1] As shown in **Figure 4**, localised temperature increases are expected across Tonga, with warming differences varying widely across RCPs, especially after 2030. For instance, as indicated in **Table 2**, relative to the 1986–2005 baseline, a warming of 0.2°C–1.1°C for RCP2.6, and 1.8°C–4.1°C for RCP8.5 is projected by the 2090s. While there is *very high confidence* that temperatures in the Tonga will rise, based on theory and observational evidence, there is *medium confidence* in the model average temperature changes.[5] As explained in Australian BOM & CSIRO (2014), this is possibly since models offer generally good simulations of past temperature changes.[5] It is also noted that because of natural climate variability there will still be relatively warm and cool years and decades, although likely projections indicate a warmer climate to influence more warm years and decades on average.[5]

FIGURE 4. Historical and simulated surface air temperature time series for the region surrounding Tonga. The graph shows the anomaly (from the base period 1986–2005) in surface air temperature from observations (the GISS dataset, in purple), and for the CMIP5 models under the very high (RCP8.5, in red) and very low (RCP2.6, in blue) emissions scenarios. The solid red and blue lines show the smoothed (20-year running average) multi-model mean anomaly in surface air temperature, while shading represents the spread of model values (5–95th percentile). The dashed lines show the 5–95th percentile of the observed interannual variability for the observed period (in black) and added to the projections as a visual guide (in red and blue). This indicates that future surface air temperature could be above or below the projected long-term averages due to interannual variability. The ranges of projections for a 20-year period centred on 2090 are shown by the bars on the right for RCP8.5, 6.0, 4.5 and 2.6.[5]



Future temperature rises in Tonga may likely be below the global average – the mean annual surface air temperature under the highest emissions pathway is projected to reach around 2.6°C by the 2090s, compared to around 3.7°C globally. This difference may reflect the moderating effect of large amounts of nearby ocean cover, but considering that ocean cover can also distort model simulations, and the current iteration of global models does not have the spatial accuracy to reliably capture climate processes over small island states, these projections should be approached with caution.

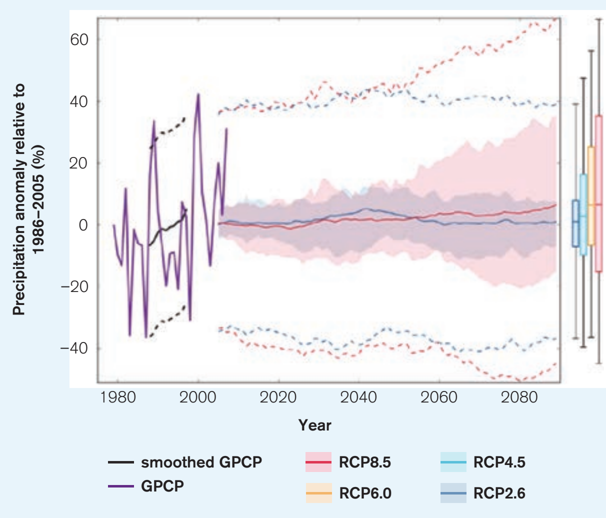
In addition, it is projected that the temperature on extremely hot days is likely to increase in tandem with average temperature increases – projected temperature increase of the 1-in-20-year hot day by the 2090s is 0.7°C for RCP2.6 and 3°C for RCP8.5. It is also expected that there will be an increase in the frequency and intensity of extremely hot days and a decrease in the frequency and intensity of cool days in Tonga, although the magnitude of the projected changes is less certain.[5]

Precipitation

As shown in **Figure 5**, while Tonga experienced an increase in mean precipitation over the 1979–2006 period, rainfall projection estimates vary from an increase to a decrease, with a slight increase expected on average. It is possible, then, that the historical increase could be due in part to natural variability, rather than purely driven by global warming.[5] Further, the range of the future projections vary by scenario, and the estimates under RCP8.5 show the largest range of uncertainty. Since there is no strong agreement as to the direction of change in the models, and it is uncertain how SPCZ will affect rainfall over Tonga, this lowers the confidence of the projected changes, and makes the likely direction of change difficult to determine. Confidence in the model average rainfall change is also challenged by the usual complexity of simulating precipitation as well as understanding the influence of the SPCZ and ENSO.[5]

In terms of extreme rainfall events, a warmer atmosphere is likely to lead to an increase in their frequency and intensity. However, the magnitude of such changes in extreme rainfall is not as certain due to possible underestimation and difficulty to capture certain process related to extreme rainfall events, the influence of the SPCZ over the islands, as well as the general coarse spatial resolution of GCMs.[5]

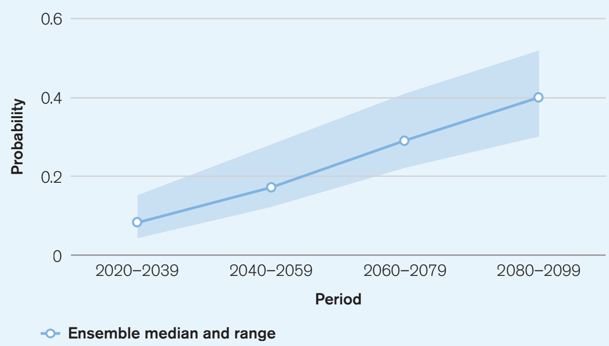
FIGURE 5. Historical and simulated annual average rainfall time series for the region surrounding Tonga. The graph shows the anomaly (from the base period 1986–2005) in rainfall from observations (the GPCP dataset, in purple), and for the CMIP5 models under the very high (RCP8.5, in red) and very low (RCP2.6, in blue) emissions scenarios. The solid red and blue lines show the smoothed (20-year running average) multi-model mean anomaly in rainfall, while shading represents the spread of model values (5–95th percentile). The dashed lines show the 5–95th percentile of the observed interannual variability for the observed period (in black) and added to the projections as a visual guide (in red and blue). This indicates that future rainfall could be above or below the projected long-term averages due to interannual variability. The ranges of projections for a 20-year period centred on 2090 are shown by the bars on the right for RCP8.5, 6.0, 4.5 and 2.6.[5]



Heatwaves

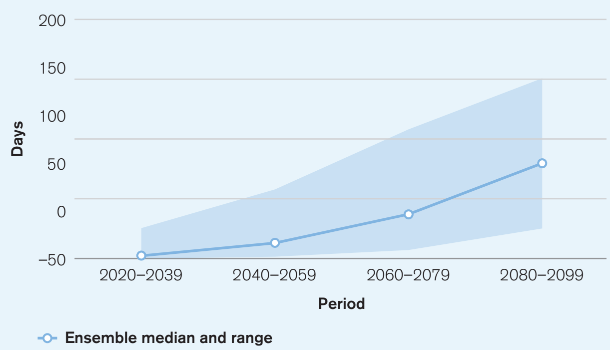
Heatwaves are defined as a period of 3 or more days when the daily temperature remains above the 95th percentile. **Figure 6** shows the projected change in heat wave probability under RCP8.5 (compared to 1986–2005), highlighting the daily probability of a sudden heat wave in subsequent time periods. For Tonga, this probability steadily increases in the long term. This is held within the global context in which the probability is expected to increase. It is noted that the tropics are particularly where systematic warming might lead to the largest increases in heat wave probability, simply because the historic (baseline) day-to-day and month-to-month variability is small.

FIGURE 6. Projected Change in probability of heat waves in Tonga under RCP8.5 (compared to 1986–2005)[1]



Generally, Tonga regularly experiences high temperatures, with a mean annual temperature of around 24.5°C and highest temperatures in January to March with a seasonal average of 26.38°C (see **Figure 2**). Ensemble-based mean annual temperatures anomalies in Tonga are projected to reach up to 2.6°C by 2100 (**Table 2**), with a projected ensemble mean change in the maxima of daily maximum temperature of 2.9°C, compared to the historical mean. When this rise is considered in combination with local humidity, as captured in the Heat Index measure, this highlights a significant increase in the number of days in which uncomfortable temperature conditions are reached. From a baseline situation in which the key threshold of Heat Index 35°C is rarely breached, Tonga can expect multiple breaches per year under all climate change scenarios (**Figure 7** shows RCP8.5). This signals the potential for conditions which are dangerous for human health, particularly in vulnerable populations. However, it is noted that further research is required to better understand the implications of climate change, and its interaction with the ENSO phenomenon, for Tonga's future regime and potential heatwaves.

FIGURE 7. Projected change in the count of days in which Heat Index exceeds 35°C (under RCP8.5)[1]



An additional factor for consideration is the potential for marine heatwaves. Research has shown that "from 1925 to 2016, global average marine heatwave frequency and duration increased by 34% and 17%, respectively, resulting in a 54% increase in annual marine heatwave days globally".[20] While such research has not specifically

[20] Oliver, E. C., Donat, M. G., Burrows, M. T., Moore, P. J., Smale, D. A., Alexander, L. V., . . . & Holbrook, N. J. (2018). Longer and more frequent marine heatwaves over the past century. Nature communications, 9(1), 1324. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5893591/

identified Tonga under threat, the consequences of these trend may be serious for marine ecosystems in the region, which are adapted to survive under very stable temperature regimes, as well as the livelihoods dependent on them.

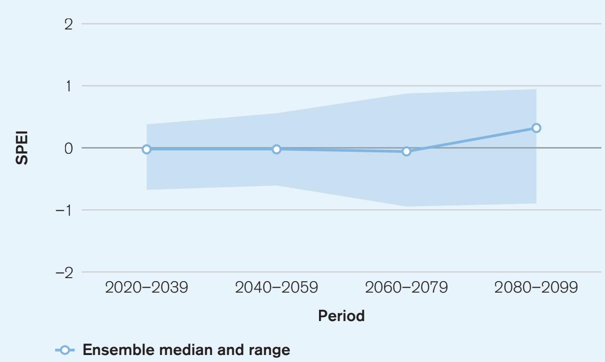
Drought

Drought can be expressed in many ways, from looking at simple precipitation deficits to complex estimates of remaining soil moisture. Research done for the report on "Climate Variability, Extremes and Change in the Western Tropical Pacific 2014", defines projected changes in the frequency and duration of mild, moderate, severe and extreme meteorological droughts using the Standardised Precipitation Index (SPI).[5] This index is based solely on rainfall (i.e. periods of low rainfall are classified as drought), and does not take into account factors such as evapotranspiration or soil moisture content. (It is noted that the SPI is commonly used in many regions including the Pacific due to the relative simplicity with which it is calculated, as well as its relevance across temporal and spatial scales.)[5] For Tonga, it is likely that the percent of time spent in drought may decrease, and this is generally shown across emissions scenarios.[5] However, it should be noted that complex processes relating to rainfall projections, including the limited consensus of future ENSO influence for the region, hinder the confidence of these projections of drought frequency and duration, as well as magnitude of change.[5]

Another lens through which to view drought risk is the standardised precipitation evapo-transpiration index (SPEI), which is computed over 12-month periods and captures the cumulative balance between gain and loss of water across the interannual time scale by incorporating both precipitation input variations as well as changes in the loss of water through evapotranspiration. It is widely used today as a global measure for drought monitoring over various cumulative time intervals.

Figure 8 looks the projected changes in the annual mean drought index for Tonga in subsequent time periods, under RCP 8.5, compared to 1986–2005. Since positive values indicate positive water balance (or wet) conditions and negative values indicate negative water balance (or dry) conditions, this signals that SPEI trends to 2100 in Tonga may vary widely. Overall confidence is very low and as such further research is required.

FIGURE 8. Projected change in Annual Mean Drought Index for Tonga under RCP8.5[1]



Flood, Cyclones, and Storm Surge

Analysis from the World Bank's Climate Change Knowledge Portal highlights that the most extreme rainfall episodes generally have the danger of leading to significant floods.[1] Individual daily rainfall is often linked to flash-floods of limited spatial extent, but multi-day rainfall generally has a broader spatial footprint and thus more extensive flooding can be explained. Rare precipitation events are often referred to as events of a certain return level, and the 5-day cumulative rainfall indicator focuses on the maximum rainfall amount over any 5-day period that can be expected once in an average 25-year period. Changes in this indicator may have potentially significant impacts on infrastructure and endanger life and property through direct physical effects and perhaps through water quality issues. As such, any significant changes in their magnitudes would need to be understood.

The boxplot in **Figure 9** shows recorded 5-Day Cumulative Rainfall for 1986–2005 and projected 5-Day Cumulative Rainfall 25-year Return Level by 2050 under all RCPs of CIMP5 ensemble modelling for Tonga. From this, it is noted that compared to the historical value, median ensemble projections seem to vary, and there is some difference in the range of change under the different scenarios. Looking at further future projections, **Figure 10** highlights the projected change in annual maximum 5-day rainfall of a 25-year return level (under RCP8.5), projected ensemble median changes seem to be close to 0 initially then increase closer to 2100, but the range of values is quite broad and needs to be further contextualised and understood.

FIGURE 9. 5-day precipitation – historical and projected scenarios of 25-year return level in Tonga for period 2040–2059[1]

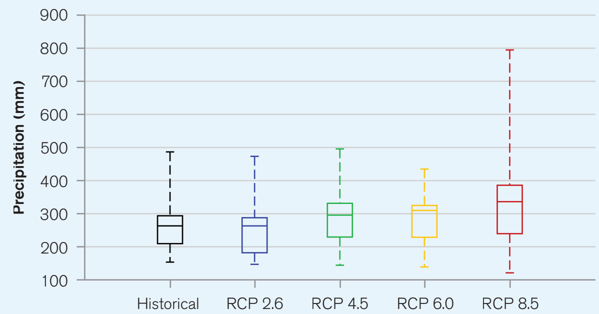
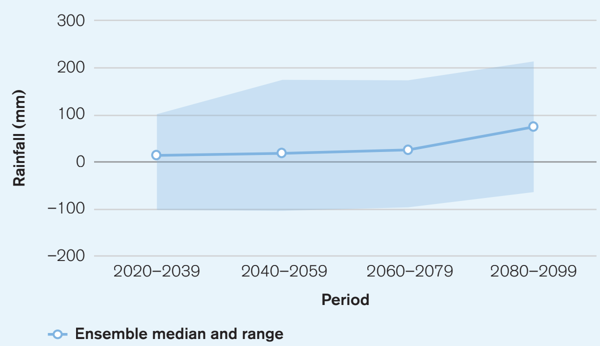


FIGURE 10. Projected change in annual maximum 5-day rainfall (25-year return level) under RCP8.5 for Tonga[1]



Tropical cyclones have historically affected Tonga, mainly between November and April. Historical data indicates that there have been at least 85 tropical cyclones developing within or crossing the Tonga EEZ between the 1969/70 and 2010/11 seasons, for an average of 20 cyclones per decade (albeit with high interannual variability).[5] Over the past 4 decades since 1981, there have been 55 tropical cyclones, of which 19 were considered severe events (i.e. Category 3 or higher). In Tonga, the projection is for a decrease in cyclone genesis (formation) frequency for the south-east basin, with *high confidence*, consistent with a general global projection for decreased cyclone frequency by 2100.[5] However, this should be understood in the context of ENSO, as there has been an increase in cyclone incidence during El Niño years,[2] but the certainty of future ENSO influence for the country is not well understood.

Nevertheless, according to available information compiled by the Global Facility for Disaster Reduction and Recovery (GFDRR) ThinkHazard! web-based tool, the risk of cyclone (hurricane/typhoon) hazard is classified as *high* in Tonga.[21] This means that there is more than a 20% chance of potentially-damaging wind speeds for the country in the next 10 years. While climate change is expected to interact with cyclone hazard in complex ways which are currently poorly understood, known risks include the action of sea-level rise to enhance the damage

[21] GFDRR (2016). ThinkHazard! Profile for Tonga. URL: http://thinkhazard.org/ [accessed 15/07/2019]

caused by cyclone-induced storm surges, and the possibility of increased wind speed and precipitation intensity. Modelling of climate change impacts on cyclone intensity and frequency conducted across the globe points to a general trend of reduced cyclone frequency but increased intensity and frequency of the most extreme events.[22] Further research is required to better understand potential changes in cyclone seasonality and routes, and the potential for cyclone hazards to be experienced in unprecedented locations.

As well, such risk potential is important to consider in the historical context of cyclone impacts for the country. The EM-DAT database highlights that there have been at least 16 tropical cyclones which have led to disasters within the Tongan island group since 1900. Tropical storms top the list of costly disaster events in Tonga, with events in 2001 and 2014 having an estimated economic damage tallies of US$51.3 and US$31 million respectively.[23] In addition, Tongans may perceive a high threat and impact of cyclones based on past events, offering an indication of vulnerability considerations and potential adaptation needs.[24]

CLIMATE CHANGE IMPACTS

Natural Resources

Water

Water resources in Tonga are mostly based on rainfall collection, and a few underground aquifers.[2] Surface water resources are not commonly present in Tonga, with the exception of the coral island of Eua and a number of volcanic islands including Niuafo'ou and Tofua (Ha'apai Island), and a large number of small islands in Ha'apai and Vava'u that rely entirely on rainwater tanks for their water.[1] As with most other Pacific island countries (PICs), Tonga's dependency on rainfall increases its vulnerability to future changes and distribution of rainfall. Low rainfall can lead to a reduction in the amount of water that can be physically harvested and a slower rate of recharge of the freshwater lens, which can result in prolonged droughts. Since most of the islands are dependent on surface water catchments for their water supply, it is likely that demand cannot be met during periods of low rainfall. This is particularly of concern given the uncertainty in rainfall projections for the country, and the slight tendency for possible precipitation declines. As well, the likelihood of increases in temperature and evaporation adds further concern.

[22] Walsh, K., McBride, J., Klotzbach, P., Balachandran, S., Camargo, S., Holland, G., Knutson, T., Kossin, J., Lee, T., Sobel, A., Sugi, M. (2015). Tropical cyclones and climate change. WIREs Climate Change: 7: 65–89. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/wcc.371

[23] EM-DAT (2019). Emergency Events Database. URL: https://www.emdat.be/ [accessed 22/08/2019]

[24] Beyerl, K., Mieg, H. A., & Weber, E. (2018). Comparing perceived effects of climate-related environmental change and adaptation strategies for the Pacific small island states of Tuvalu, Samoa, and Tonga. *Island Studies Journal, 13*(1). URL: https://islandstudies.ca/sites/default/files/ISJBeyerletalEffectsClimateTongSamoaTuvalu.pdf

The wet and dry cycles associated with El Nino Southern Oscillation episodes can also deliver serious impacts on water supply in Tonga as well as the other PICs, highlighting the vulnerability of water supplies to changes in the climate.[1] For instance, the strong El Niño of 1998–2000 was responsible for acute water shortages in many islands in the Pacific Ocean. Further vulnerabilities arise under future climate-induced droughts, as there is no centralized reticulated sewerage system in Tonga and poorly constructed or inappropriate sanitation systems are common, resulting in the potential for pathogens and nutrients being introduced into the surrounding environment, including ingress to groundwater.[1]

As for other small island states, rising sea levels are also a threat to water resources. Tonga's small size, minimal amount of storage, and limited fresh water render it highly susceptible to threats to fresh water availability and groundwater supplies are threatened by salt-water intrusion as a result of increasing sea levels.[1] Associated damage to water supplies, water treatment and hydrological research infrastructure may also prove to be significant and costly.

The Coastal Zone

Sea-level rise threatens significant physical changes to coastal zones around the world. Global mean sea-level rise was estimated in the range of 0.44 meters (m)–0.74m by the end of the 21st century by the IPCC's Fifth Assessment Report,[25] but some studies published more recently have highlighted the potential for greater rises (**Table 3**).

TABLE 3. Estimates of global mean sea-level rise by rate and total rise compared to 1986–2005 including likely range shown in brackets, data from Chapter 13 of the IPCC's Fifth Assessment Report with upper-end estimates based on higher levels of Antarctic ice-sheet loss from Le Bars et al. (2017).[26]

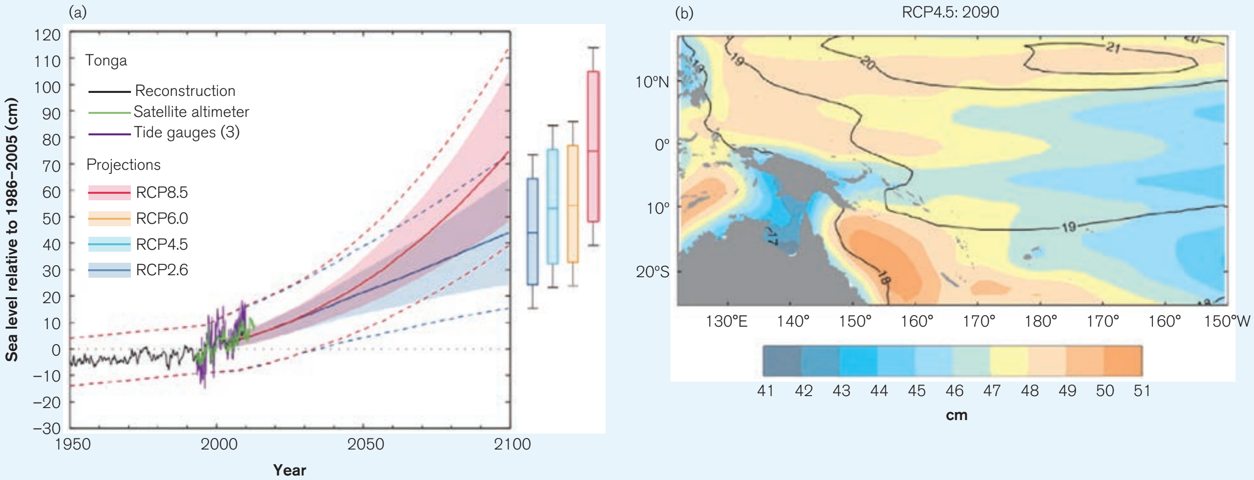
Scenario	Rate of Global Mean Sea-Level Rise in 2100	Global Mean Sea-Level Rise in 2100 Compared to 1986–2005
RCP2.6	4.4 mm/yr (2.0–6.8)	0.44 m (0.28–0.61)
RCP4.5	6.1 mm/yr (3.5–8.8)	0.53 m (0.36–0.71)
RCP6.0	7.4 mm/yr (4.7–10.3)	0.55 m (0.38–0.73)
RCP8.5	11.2 mm/yr (7.5–15.7)	0.74 m (0.52–0.98)
Estimate inclusive of high-end Antarctic ice-sheet loss		1.84 m (0.98–2.47)

According to its Third National Communication to the UNFCCC, Tonga already has witnessed general sea level rise of 6.4 mm per annum, using historical records from 1993–2007.[2] It is very likely that these increasing trends may increase through 2100, with estimations of 7 centimetres (cm)–17 cm by 2030 across various RCPs (see **Figure 11**).[5] By the 2090s, sea level rise is estimated at around 59.5 cm increase using historical records only,[2] or within the range of 40 cm–87 cm under RCP8.5.[5] Uncertainty in the projections of changes in the Antarctic ice sheet limit the certainty of knowledge of the range of this mean sea level change.

[25] Church, J. a., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., . . . Unnikrishnan, A. S. (2013). Sea level change. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1137–1216). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. URL: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf

[26] Le Bars, D., Drijhout, S., de Vries, H. (2017). A high-end sea level rise probabilistic projection including rapid Antarctic ice sheet mass loss. Environmental Research Letters: 12:4. URL: https://iopscience.iop.org/article/10.1088/1748-9326/aa6512

FIGURE 11. (a) The observed tide-gauge records of relative sea-level (since the late 1970s) are indicated in purple, and the satellite record (since 1993) in green. The gridded (reconstructed) sea level data at Tonga (since 1950) is shown in black. Multi-model mean projections from 1995–2100 are given for the RCP8.5 (red solid line) and RCP2.6 emissions scenarios (blue solid line), with the 5–95% uncertainty range shown by the red and blue shaded regions. The ranges of projections for four emission scenarios (RCPs 2.6, 4.5, 6.0, 8.5) by 2100 are also shown by the bars on the right. The dashed lines are an estimate of interannual variability in sea level (5–95% uncertainty range about the projections) and indicate that individual monthly averages of sea level can be above or below longer-term averages. (b) The regional distribution of projected sea level rise under the RCP4.5 emissions scenario for 2081–2100 relative to 1986–2005. Mean projected changes are indicated by the shading, and the estimated uncertainty in the projections is indicated by the contours (in cm).[5]



The Tongan Third National Communication highlights the potential threat of sea level rise to the Tongan land and people. Noting that the land is particularly low near the capital, at Nuku'alofa, sea level rise increases of 0.3 m and 1 m could cause potential land losses of 3.1 km and 10.3 km, respectively, or 1.1% and 3.9% of the total area of Tongatapu Island.[2] Such land losses has the potential to affect some 2700 and 9000 people, under each scenario, or the equivalent of 4.3% and 14.2% of the total population of Tongatapu.[2] However, the scientific field lacks consensus on the gravity of the land loss threat on raised atoll islands such as Tonga. Some studies have shown that atoll islands have potential to sustain and even grow despite sea-level rise thanks to geomorphological processes which build land.[27] The future picture is likely one of a dynamic ecosystem which will demand adaptive lifestyles and livelihoods from inhabitants.

[27] Kench, P. S., Ford, M. R., & Owen, S. D. (2018). Patterns of island change and persistence offer alternate adaptation pathways for atoll nations. Nature Communications, 9(1), 605. URL: https://www.nature.com/articles/s41467-018-02954-1

In addition to sea level rise-based flooding, rapid onset sea-level rise events represent a major threat. There has also been a historical interannual variability of sea levels of about 20 cm (5%–95% range, after removal of the seasonal signal), which is expected to be quite similar through 2100.[5] When natural variability peaks coincide with wave activity, cyclone-induced storm surge, or tsunamis, significant damage could occur.

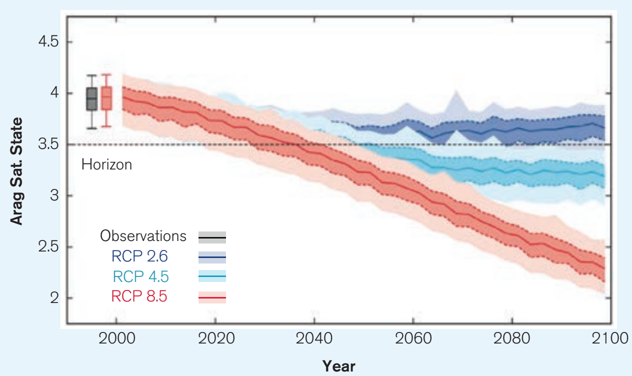
Concerning wave activity, there is currently generally a low confidence in potential changes over the year, likely due to the complexity and uncertainty of ENSO influence, as well as challenges reconciling simulated and hindcast estimates.[5] Studies have shown that the extent of wave-driven flooding is impacted by coral reef height and health, highlighting the importance of coral conservation as an adaptation.[28] Tonga's location near the Pacific 'Ring of Fire' increases its risk of tsunamis. A resulting tsunami from the September 29 2009 earthquake killed 9 persons, further affected 507 persons and caused an estimated US$9.5 million in damages.[21] GFDRR's ThinkHazard! tool highlights a *high* risk of tsunamis, indicating a 20% or more chance of the occurrence of a potentially-damaging tsunami in the next 50 years, and highlighting the critical need for adaptation action.[19] The National Communication highlights that "if a storm surge of the same degree occurs in conjunction with a 0.3 m sea level rise, 27.9 km (11% of the Tongatapu Island) and 23,470 people (37% of the Tongatapu population) would be at risk. These increase to 37.3 km (14%) and 29,560 people (46%) for a 1 m sea level rise." Cyclone Isaac, in 1982, influenced a storm surge of 2.8 m, which would likely currently affect up to 20,000 people living in low-lying areas in Tonga.

Furthermore, sea level rise also plays a role on freshwater lens recharge, to the extent that "if rising sea level causes land to be inundated at a much larger scale, then there will be a consequent loss in potential area for fresh groundwater occurrence."[2] This subsequently affects the quality and quantity of drinking water, as well as availability of water for agriculture and industry.

Coral Reefs and Fisheries

Calcium carbonite is used for the external skeletons of multiple marine organisms – for instance, plankton, coral reefs, and shell-fish. Increases in atmospheric carbon dioxide are understood to lead to reduced levels of calcium carbonite saturation on the ocean's service via an increase in ocean acidification and by decreasing carbonite ion concentrations. As a result, there are serious concerns that if carbonite minerals, such as aragonite, become under saturated, it could undermine current ocean ecosystems.[29] **Figure 12** shows the projected aragonite saturation state under three emission scenarios

FIGURE 12. Projected changes in aragonite saturation state in Tonga from CMIP5 models under RCP2.6, 4.5 and 8.5. Shown are the median values (solid lines), the interquartile range (dashed lines), and 5% and 95% percentiles (light shading). The horizontal line represents the threshold at which transition to marginal conditions for coral reef health typically occurs.[5]



[28] Beetham, E., Kench, P. S., & Popinet, S. (2017). Future Reef Growth Can Mitigate Physical Impacts of Sea-Level Rise on Atoll Islands. Earth's Future, 5(10), 1002–1014. URL: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2017EF000589

[29] Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., . . . & Key, R. M. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature, 437(7059), 681. URL: https://pubmed.ncbi.nlm.nih.gov/16193043/

for Tonga. Worryingly, under RCP4.5 and 8.5 the saturation state is expected to decrease below the threshold needed to sustain healthy coral reefs.

There is a high degree of confidence of the increased risk of coral bleaching due to a warmer ocean. However, specific change projections for Tonga are difficult due to limited confidence in the sea surface temperature change projections as well as complexities of understanding reef-scale changes.[5] As well, such potential changes may not include other reef stressors, such as local environmental concerns and human impacts, and impacts of ocean acidification are also likely to affect the entire marine ecosystem impacting the key ecosystem services provided by reefs.

The fisheries sector in Tonga has been identified as a sector with economic potential to contribute to the local economy,[2] and has been developing within recent years.[3] However, while limited data regarding on inshore fisheries catches and landings make it difficult to fully analyse and explain the influence of climate change, among other factors, on the local fisheries product, it is likely that warmer global temperatures, coral bleaching, as well as ocean acidification may play a central role. Studies on a regional level typically suggest a negative outlook in terms of total fish biomass and maximum catch potential.[30] This outlook is often regarded to be worse for near-shore fisheries than deep sea.[31]

Island Ecology

Sea-level rise not only threatens humans residing on Pacific islands, but also their unique ecosystem functions and ecology. Indeed, island biodiversity faces a variety of human pressures.[32] Research has shown that inundation of low-lying islands has the potential to remove important refuges for migrating sea birds.[33] As climate changes so the suitable range for species to inhabit shifts, typically either upslope or away from the equator. In the Island environment the capacity for species to shift is extremely limited and as such loss and extinction are becoming increasingly likely. Major concerns have been raised for the terrestrial ecology of low-lying Pacific islands, for example endemic lizards, which may become trapped in a shrinking habitat.[34] Research has also highlighted the risks to biodiversity in the Pacific through study of tree richness in New Caledonia, where the range sizes of 87%–96% of species was projected to decline, typically by 52%–84%.[35]

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30 Bell, J. D., Ganachaud, A., Gehrke, P. C., Griffiths, S. P., Hobday, A. J., Hoegh-Guldberg, O., . . . Waycott, M. (2013). Mixed responses of tropical Pacific fisheries and aquaculture to climate change. Nature Climate Change, 3, 591. URL: https://hal.archives-ouvertes.fr/hal-00996319

31 Mellin, C., Mouillot, D., Kulbicki, M., McClanahan, T. R., Vigliola, L., Bradshaw, C. J. A., . . . Caley, M. J. (2016). Humans and seasonal climate variability threaten large-bodied coral reef fish with small ranges. Nature Communications, 7(1), 10491. URL: https://www.nature.com/articles/ncomms10491

32 Jupiter, S., Mangubhai, S., & Kingsford, R. T. (2014). Conservation of Biodiversity in the Pacific Islands of Oceania: Challenges and Opportunities. Pacific Conservation Biology, 20(2), 206–220. URL: https://www.publish.csiro.au/pc/pc140206

33 Reynolds, M. H., Courtot, K. N., Berkowitz, P., Storlazzi, C. D., Moore, J., & Flint, E. (2015). Will the Effects of Sea-Level Rise Create Ecological Traps for Pacific Island Seabirds? PLOS ONE, 10(9), 1–23. DOI: https://doi.org/10.1371/journal.pone.0136773

34 Taylor, S., & Kumar, L. (2016). Global Climate Change Impacts on Pacific Islands Terrestrial Biodiversity: A Review. Tropical Conservation Science, 9(1), 203–223. URL: https://journals.sagepub.com/doi/full/10.1177/194008291600900111

35 Pouteau, R., & Birnbaum, P. (2016). Island biodiversity hotspots are getting hotter: vulnerability of tree species to climate change in New Caledonia. Biological Conservation, 201, 111–119. URL: https://agris.fao.org/agris-search/search.do?recordID=FR2017101025

Economic Sectors

Agriculture and Food

According to the latest available statistics in 2015–16, agriculture contributed 14.7% to GDP in current prices.[4] Increased local market production and export of fruit and vegetables including the main crop squash, as well as kava, yams, and sweet potatoes, contributed to an increasing value of agriculture in the year of estimation. It is noted that the agricultural sector supports the majority of the population for subsistence and for cash incomes, employing a third of the labour force and accounting for at least 50% of the export earnings.[2]

As indicated in Tonga's Third National Communication, since agriculture in Tonga is a "shifting cultivation" within which there are "various modified forms of crop rotation evolving on different islands, and with different combinations of crops and fallow species", this offers some protection to the agricultural base. In the event of a storm, for example, tree crops including coconut, breadfruit and banana may be damaged, but root crops, such as yam, taro, sweet potatoes, cassava, may be relatively less affected. As well, in times of drought, root crops may feel the effect in the short term while tree crops may have more of a delay in impact.

While such an agricultural base is intended to provide some sort of balance on average, it is noted that severe events could likely affect both type of crops, making the economy and livelihoods quite vulnerable. For instance, it is mentioned by the report that in 2010, Tropical Cyclone Renee severely affected Tongatapu, Vava'u and Ha'apai groups of islands, damaging agricultural rootcrops, fruit trees and vegetables. Impacts to the agricultural sector as a result of the storm was estimated at US$8.4 million (in current conversion), and the effects likely lead to further declines in local agricultural production and economic contribution.[2] It is noted that this disaster is not included within the EM-DAT database, perhaps because a criteria for definition was not met, but this also highlights the poor documentation and data collection on disaster-level events in remote communities.[21] As well, severe droughts in 1983, 1998, 2006 and 2015 stunted growth in both sweet potatoes and coconuts.

While all the household requirements from agriculture were traditionally provided by very complex, robust, and productive multi-storied rotational fallow farming systems, and historically they proved to be very sustainable, recent changes have affected this balance.[1] Increasing population and land pressures for urban development, the fallow periods have shortened and fertility has declined, further highlighting future vulnerability to agriculture production under increased drought periods and more El-Niño like weather. As well, the predicted climate change phenomenon will create a new pest and disease regime, and therefore the need to develop improved pest and disease management program. A changing climate seems likely to further affect both the economy and people (through effects on livelihoods, food security and customary obligations) of Tonga.

Tourism

Tourism is a key productive sector in the Tongan economy. Latest available statistics show that in 2015–16, the service sector contribution to GDP (including tourism trade, hotel and restaurant activity, and as measured in current prices) was 54.5%.[4] Tourism also contributes to the economy via foreign exchange earnings, and it is estimated that over the period 2003–2008 this was valued at T$30.3 million-T$42.8million (or US$13.6 million-US$18.1 million, in current conversion).[2] While these numbers are significant, tourism in Tonga is considered as limited in scale and pace when compared to neighbouring Pacific islands. A 2013 report on the "Tonga Tourism

Sector Roadmap 2014–2018" highlights that Tonga is "ranked ninth out of the fifteen South Pacific countries in terms of visitor arrivals, well behind neighboring countries such as Fiji, Samoa, Vanuatu and the Cook Islands".[36] Expansion of the tourism economy in Tonga, it is mentioned, offers great potential for economic growth and development, foreign sector earnings, increased employment (especially for relatively unskilled jobs), and cash income for rural communities.[34,2]

As with other small islands, tourism sector development should be reconciled with concerns for environmental sustainability, especially in the face of climate change impacts. The dual threats of rising sea levels and coastal erosion could reduce the quantity and quality of available beach space and, without significant adaptation measures, could therefore reduce the attractiveness of the country as a tourist destination. As well, potential losses to land area due to sea level rise would need to be considered for the building of desirable beachfront properly locations as well as berths for cruise ships, which is noted has been an increasing source of tourism.[37] Challenges to already-limited freshwater could become a problem in times of drought conditions, and storm threats could hinder the sun, sea, sand experience and require sufficient disaster preparedness actions. Studies have suggested adaptation techniques, including product diversification, education, and strengthening institutional capacity, which could help protect the Tongan tourism sector from the significant climate change threat.[38]

Communities

Poverty, Inequality and Vulnerability to Climate-Related Disaster

The current rate of poverty in Tonga is estimated at 22.1% in 2015,[39] up from 16.2% in 2001 and similar to the 2009 rate of 22.5%.[40] The Borgen Project (2017)[41] highlights that these poverty rates could be likely as a result of a high dependency on limited resources (specifically, only 24% of the land is arable, and there has been much outward migration), decreased tourism (due to decreasing travel in source markets such as New Zealand and Australia, and perhaps due to political instability), and climate change. Climate change effects such as increasing temperatures, sea levels, and extreme weather events, alongside changing precipitation, have the potential to further affect agricultural practices, affecting subsistence incomes, food security and cultural traditions, as well as the tourism product which currently seems to be driving the local economy. The outcomes experienced as a result of climate change-linked hazards will be a function of social vulnerability and adaptive capacity. In Tonga both of these issues are tightly linked to the remittance economy, and as such close monitoring of its health and functioning in terms of its distribution and inequality will be required.[42]

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[36] Trip Consultants (2013). Tonga Tourism Sector Roadmap 2014 – 2018. URL: http://macbio-pacific.info/wp-content/uploads/2017/08/Tonga-Tourism-Roadmap-2014-2018.pdf [accessed 28/10/2019].

[37] Tonga Bureau of Statistics (2019). Mode of Conveyance 2005–2010. URL: https://tonga.prism.spc.int/10-tourism/tourism [accessed 28/10/2019].

[38] van der Veeken, S., Calgaro, E., Munk Klint, L., Law, A., Jiang, M., de Lacy, T., & Dominey-Howes, D. (2015). Tourism destinations' vulnerability to climate change: Nature-based tourism in Vava'u, the Kingdom of Tonga. Tourism and Hospitality Research, 16(1), 50–71. URL: https://journals.sagepub.com/doi/abs/10.1177/1467358415611068

[39] ADB (2019). Poverty in Tonga. URL: https://www.adb.org/countries/tonga/poverty [accessed 28/10/2019].

[40] World Bank (2019). Development Indicators for Tonga. URL: https://data.worldbank.org/country/Tonga [accessed 28/10/2019].

[41] Borgen Project (2017). Why is Tonga Poor? URL: https://borgenproject.org/why-is-tonga-poor/ [accessed 28/10/2019].

[42] Brown, R. P. C., Connell, J., & Jimenez-Soto, E. V. (2014). Migrants' Remittances, Poverty and Social Protection in the South Pacific: Fiji and Tonga. Population, Space and Place, 20(5), 434–454. DOI: https://doi.org/10.1002/psp.1765

Many of the climate changes projected are likely to disproportionately affect the poorest groups in society. For instance, heavy manual labour jobs are commonly among the lowest paid whilst also being most at risk of productivity losses due to heat stress.[43] Poorer businesses are the least able to afford air conditioning, an increasing need given the projected increase in the need for air conditioning with temperature increases. Poorer farmers and communities are least able to afford local water storage, irrigation infrastructure, and technologies for adaptation. Women and dependents can lack the capital and mobility to adapt their livelihoods. Indeed, fostering participation from women in climate change adaptation and disaster risk reduction initiatives has been identified as a priority in the Pacific region.[44] Finally, while climate change represents a major physical threat to small Pacific islands such as Tonga, some scholars continue to argue that fundamental issues of marginalisation, poverty and inequality remain the key drivers of most negative outcomes experienced, rather than the climate drivers themselves.[45]

Gender

An increasing body of research has shown that climate-related disasters have impacted human populations in many areas including agricultural production, food security, water management and public health. The level of impacts and coping strategies of populations depends heavily on their socio-economic status, socio-cultural norms, access to resources, poverty as well as gender. Research has also provided more evidence that the effects are not gender neutral, as women and children are among the highest risk groups. Key factors that account for the differences between women's and men's vulnerability to climate change risks include: gender-based differences in time use; access to assets and credit, treatment by formal institutions, which can constrain women's opportunities, limited access to policy discussions and decision making, and a lack of sex-disaggregated data for policy change.[46]

Human Health

Heat-Related Mortality

Research has placed a threshold of 35°C (wet bulb ambient air temperature) on the human body's ability to regulate temperature, beyond which even a very short period of exposure can present risk of serious ill-health and death.[47] Temperatures significantly lower than the 35°C threshold of 'survivability' can still represent a major threat to human health. Climate change will push global temperatures closer to this temperature 'danger zone' both through slow-onset warming via an increase mean annual temperature and the intensity and frequency of heat waves. Although there are challenges of limited downscaled climate information to specify projections, it is likely that climate change will result in an increased number of people at risk of heat-related medical conditions, perhaps specifically related to the elderly, children, the chronically ill, the socially isolated and at-risk occupational groups.[48] It should be noted

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[43] Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O. (2016). Heat, human performance, and occupational health: A key issue for the assessment of global climate change impacts. Annual Review of Public Health: 37: 97–112. URL: https://www.annualreviews.org/doi/abs/10.1146/annurev-publhealth-032315-021740

[44] Aipira, C., Kidd, A., & Morioka, K. (2017). Climate Change Adaptation in Pacific Countries: Fostering Resilience Through Gender Equality BT - Climate Change Adaptation in Pacific Countries: Fostering Resilience and Improving the Quality of Life. In W. Leal Filho (Ed.) (pp. 225–239). Cham: Springer International Publishing. URL: https://www.springer.com/gp/book/9783319500935

[45] Kelman, I. (2014). No change from climate change: vulnerability and small island developing states. The Geographical Journal, 180(2), 120–129. URL: https://rgs-ibg.onlinelibrary.wiley.com/doi/abs/10.1111/geoj.12019

[46] World Bank Group (2016). Gender Equality, Poverty Reduction, and Inclusive Growth. URL: http://documents1.worldbank.org/curated/en/820851467992505410/pdf/102114-REVISED-PUBLIC-WBG-Gender-Strategy.pdf

[47] Im, E. S., Pal, J. S., & Eltahir, E. A. B. (2017). Deadly heat waves projected in the densely populated agricultural regions of South Asia. Science Advances, 3(8), 1–8. URL: https://advances.sciencemag.org/content/3/8/e1603322

[48] World Health Organisation (2015). Climate and Health Country Profile – 2015 Maldives. URL: http://www.searo.who.int/entity/water_sanitation/mav_c_h_profile.pdf?ua=1. [accessed 30/06/2019].

that the potential reduction in heat-related deaths achievable by pursuing lower emissions pathways is significant, as demonstrated by Mitchell et al. (2018).[49]

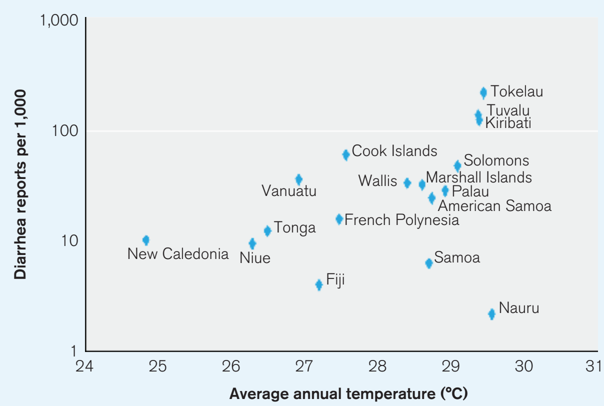
Disease and General Health

According to the WHO "some of the world's most virulent infections are also highly sensitive to climate: temperature, precipitation and humidity have a strong influence on the life-cycles of the vectors and the infectious agents they carry and influence the transmission of water and foodborne diseases".[45] Climate change threatens to slow progress in tackling the spread of disease.

Specifically, for Tonga, dengue has been identified has "one of the potential damaging health effects", with dengue fever outbreaks occurring in 1998, 2003, 2004, 2007 and 2009.[2] Tonga's Third National Communication indicates that there have been several deaths as a result of the disease – as many as 6 people died during the 2003 outbreak. While the impacts have been felt across Tongatapu, Ha'apai, and Vava'u as well as in 'Eua Island groups, the report highlights that most of the patients are in the main island of Tongatapu, and especially in the Western District in which the capital city of Nuku'alofa is located. Efforts to encourage prevention focused on minimising mosquito breeding grounds in brackish water areas, were sea water mixes with inland water. Sea level rise and accompanying salt water intrusion could further contribute to prime breeding grounds for mosquitos, as well as rising global temperatures which expand the range of the mosquito and disease.

As in other countries, loss of a clean water supply can result in water contamination, which will have significant medical concerns. Generally, an increase in atmosphere and sea temperatures could also intensify risks in water and vector-borne diseases, such as diarrhea, disaster-related fatalities, injuries and illnesses, heat stress, and conjunctivitis (pinkeye). It is noted that while the interaction between temperature and diarrheal disease is still unclear, one explanation of the association is that rotavirus and other bacteria that cause diarrhea are able to proliferate in warm marine water. Another possible explanation is that higher temperatures can cause food to spoil more rapidly, and thus cause food poisoning.[50] **Figure 13** shows research by Singh et al. (2001), which demonstrated the link between annual average temperature and average reporting rates of diarrheal disease specifically amongst Pacific island states.[51]

FIGURE 13. Annual average temperature and average reporting rates for diarrheal disease, Pacific islands (1986–1994). $r^2 = 0.49$; $p < 0.05$[48]



[49] Mitchell, D., Heaviside, C., Schaller, N., Allen, M., Ebi, K. L., Fischer, E. M., . . . Vardoulakis, S. (2018). Extreme heat-related mortality avoided under Paris Agreement goals. Nature Climate Change, 8(7), 551–553. DOI: 10.1038/s41558-018-0210-1

[50] Bentham, G., & Langford, I. H. (2001). Environmental temperatures and the incidence of food poisoning in England and Wales. *International journal of biometeorology, 45*(1), 22–26. URL: https://pubmed.ncbi.nlm.nih.gov/11411411/

[51] Singh, R. B., Hales, S., De Wet, N., Raj, R., Hearnden, M., & Weinstein, P. (2001). The influence of climate variation and change on diarrheal disease in the Pacific Islands. Environmental health perspectives, 109(2), 155–159. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240636/

POLICIES AND PROGRAMS

National Adaptation Policies and Strategies

TABLE 4. Key national adaptation policies, plans and agreements

Policy/Strategy/Plan	Status	Document Access
Intended Nationally Determined Contribution (INDC) to Paris Climate Agreement	Submitted	Sept. 2016
National Communications to the UNFCCC	Two submitted	Latest: Mar. 2012
Tonga: Climate Change Policy – A Resilient Tonga by 2035	Enacted	Feb. 2016

Climate Change Priorities of ADB and the WBG

ADB — Country Partnership Strategy

Tonga's Country Partnership Strategy falls under ADB's Pacific Approach 2016–2020.[52] This approach includes three strategic priorities, the third of which – managing risks – is heavily focused on climate change. Key components of this strategic priority include:

- Building capacity, knowledge, skills, and practices, in sector agencies working in climate change and disaster risk management areas in order to improve practice in risk appreciation, planning, and implementation of adaptation and risk management interventions.
- Ensuring climate and disaster risks are assessed and accounted for in infrastructure investments
- Developing and implementing climate and disaster risk financing mechanisms and arrangements
- Ensuring climate proofing of health projects
- Safeguarding the environment in environmental policy development and regulatory frameworks
- Assisting with the roll-out of well-designed social protection policies, including coverage of issues related to climate hazards and emigration.

WBG — Regional Partnership Framework

The World Bank Group has agreed its Regional Partnership Framework: Kiribati, Republic of Nauru, Republic of The Marshall Islands, Federated States of Micronesia, Republic of Palau, Independent State of Samoa, Kingdom of Tonga, Tuvalu, and Vanuatu which covers the period 2017–2021. Climate change is one of four key focus areas of the agreement, which states: "Protecting incomes and livelihoods. A key focus will be on strengthened preparedness and resilience to natural disasters and climate change. Interventions will also help countries strengthen health systems and address NCDs."

[52] ADB's Pacific Approach 2021–2025 is currently under development.

Under the heading of strengthening resilience to natural disasters and climate change, the RPF aims to continue to support regional and single-country activities that help the PIC9 strengthen their resilience against natural disasters and climate change. PICs combine high exposure to frequent and damaging natural hazards with low capacity to manage the resulting risks. Vulnerability is exacerbated by poor planning, which has increased losses and exposure to natural disasters, and by climate change, which is predicted to amplify the magnitude of cyclones, droughts, and flooding. Sea level rise will worsen coastal erosion and salinization of freshwater resources and increase the severity of storm surges, which will be particularly damaging in atoll islands and low-lying areas. All these impacts adversely affect agriculture, fisheries, coastal zones, water resources, health and ecosystems and the communities that rely upon them. The cost of inaction is substantial. Investments in disaster proofing and climate resilience cost substantially less than rebuilding after a disaster. The WBG will ensure that at least 35% of the total portfolio will directly or indirectly support climate-related co-benefits. The RPF further identifies a range of regional and country-specific interventions including vulnerability assessment and disaster risk planning, financing and insurance initiatives for climate risks and natural hazards, as well as support to resilience building interventions in areas such as transport, agriculture and water supply.

CLIMATE RISK COUNTRY PROFILE

TONGA

WORLD BANK GROUP

ADB ASIAN DEVELOPMENT BANK