CLIMATE RISK COUNTRY PROFILE

SAMOA

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ACKNOWLEDGEMENTS

This profile is part of a series of Climate Risk Country Profiles that are developed by the World Bank Group (WBG). 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) and Ana E. Bucher (Senior Climate Change Specialist, WBG).

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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 is 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.

The World Bank Group is investing in incorporating and systematically managing climate risks in development operations through its individual corporate commitments.

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 IDA and IBRD 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 Group's Climate Change Knowledge Portal, a comprehensive online 'one-stop shop' for global, regional, and country data related to climate change and development.

Recognizing the value of consistent, easy-to-use technical resources for client countries as well as to support respective internal climate risk assessment and adaptation planning processes, the World Bank Group's Climate Change Group has developed this content. Standardizing and pooling expertise facilitates the World Bank Group 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 developing countries, the climate risk 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.

It is my hope that these efforts will spur deepening of long-term risk management in developing countries and our engagement in supporting climate change adaptation planning at operational levels.

Bernice Van Bronkhorst
Global Director
Climate Change Group (CCG)
The World Bank Group (WBG)

KEY MESSAGES

- Samoa has experienced warming trends of approximately 0.6°C between 1980 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 in Samoa is projected to reach 2.7°C by the end of the century.
- Samoa 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 natural hazards such as extreme heat, intensified cyclones and extreme rainfall.
- In particular, subsidence driven by tectonic activity is accelerating the relative rate of sea-level rise, this is increasing the risks associated with saline intrusion, wave-driven flooding, and coastal erosion.
- Biodiversity and the natural environment of Samoa face extreme pressure, and loss of some species of fish, coral, bird, and terrestrial species is likely without very effective conservation measures.
- Samoa's population already lives in a volatile environment, to which it has adapted, but climate change is likely to increase its 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 will increase the challenges faced by communities and decision makers.

COUNTRY OVERVIEW

Located about halfway between Hawai'i and New Zealand, the Independent State of Samoa is a small island country in the southwest Pacific. Samoa is of volcanic origin with a total land area of about 2,900 square kilometres (km^2) across 4 main inhabited islands and six uninhabited islands.[1] The main islands are characterised by a rugged and mountainous topography, with some peaks rising more than 1,000 metres (m) above sea level – its highest peak is Mt Silisili, at 1,858 metres, on the island of Savai'i. Although there has been much forest depletion on some of the islands, more than 1,700 km^2 are categorised as forest areas; around 46% of Upolu and 69% of Savai'i's total land area is covered by lush vegetation and rainforest.[1] Samoa's climate is characterised by high rainfall and humidity, near-uniform temperatures throughout the year with slight seasonal variation, winds dominated by the south-easterly trade winds, and the occurrence of tropical cyclones during the southern-hemisphere summer.[1] Samoa has two seasons, marked by significant differences in rainfall. The annual rainfall is about 3,000 millimetres (mm) (varying from 2,500 mm in the northwest parts of the main islands to over 6,000 mm in the highlands of Savai'i), and about 75% of the precipitation occurs between November and February.[1] There are commonly tropical cyclones during Samoa's wet season, particularly between December and February. Samoa is also vulnerable to anomalously long dry spells that coincide with the El Niño Southern Oscillation (ENSO).

[1] UNDP & GEF (2010). Samoa's Second National Communication to the United Nations Framework Convention on Climate Change. URL: https://unfccc.int/sites/default/files/resource/SNC_Samoa_2010_final.pdf [accessed 24/07/2019]

As of 2020, Samoa had a population of nearly 198,410 people,[2] with an average population growth rate of 0.8% per year over the period 2006–2016.[3] The population growth rate is affected by significant levels of emigration (see **Table 1**), which has been evident since Samoa's independence in 1962 (in 1961, the growth rate was as high as 2.8% per annum),[4] and is partly attributed to the New Zealand quota scheme of 1,100 people, and annual seasonal employment opportunities.[4] Samoa has a small and developing economy, with a Gross Domestic Product (GDP) per capita of around US$4,068 in 2020. Like many other less-developed countries, the Samoan economy depends heavily on natural resources, both for the sustenance of its people and future economic expansion. While the services sector (including hospitality, transport, communication, finance, and business services) is the main contributor to GDP, Samoa's national income depends heavily on international trade, as well as overseas aid and remittances. The subsistence economy remains the backbone of local food production, consumption and income earning for rural areas, as about 15% of all persons over the age of 10 years are engaged in subsistence employment (all work related to agriculture, fishing and handicraft at home, either for sale or for consumption purposes); just around 25% of this population is engaged in some cash-based form of employment.[4]

Samoa is located within a region in the Pacific that is known for the frequent occurrence of tropical cyclones, which bring damaging winds, rains and storm surge especially during the period October to May,[6] and GDP growth rates in Samoa have been notably affected by external shocks over the past few years. Primary industries such as agriculture and fisheries underperformed in 2018 likely due to changing weather conditions and the cyclone which struck the country in February 2018, causing extensive damage to crops and prevented some of the large fishing vessels from going out to sea. Storm events have historically affected the islands, with 1990 and 1991's Cyclones Ofa and Val, and 2012's Evan, collectively contributing an estimated US$611 million in economic damages.[5] Samoa was ranked 51st of 179 countries in the Global Climate Risk Index 2012 report on nations suffering most from extreme weather events, and is expected to incur, on average over the long term, US$10 million per year in losses due to earthquakes and tropical cyclones.[6] Also, with approximately 70% of Samoa's population and infrastructure located in low-lying coastal areas, projected sea level rise could exacerbate coastal erosion, loss of land and property, and dislocation.[7]

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.

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2 World Bank (2021). World Development Indicators. DataBank. [accessed 20 October, 2021]. URL: https://databank.worldbank.org/source/world-development-indicators

3 Samoa Bureau of Statistics (2016). Samoa Socio-Economic Atlas 2016. URL: http://www.sbs.gov.ws/digi/7-SAMOA%20SOCIO-ECONOMIC%20ATLAS%202016.pdf [accessed 28/07/2019]

4 Samoa Bureau of Statistics (2017). 2016 Census Brief No.1 – October 2017. URL: http://www.sbs.gov.ws/digi/2-2016%20Census%20Brief%20No.1%20.pdf [accessed 28/07/2019]

5 EMDAT (2019). Emergency Events Database. URL: https://www.emdat.be/ [accessed 28/07/2019]

6 World Bank (2015). Country Note – Samoa. Disaster Risk Financing and Insurance | Pacific Catastrophe Risk Assessment and Financing Initiative. Available at http://pcrafi.spc.int/documents/172 [accessed 20/07/2019]

7 WBG Climate Change Knowledge Portal (CCKP 2021). Samoa. URL: https://climateknowledgeportal.worldbank.org/country/samoa

This document aims to succinctly summarize the climate risks faced by Samoa. 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 Samoa, 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,[8,9] as well as the World Bank Group's Climate Change Knowledge Portal (CCKP),[7] incorporating climate projections from the Coupled Model Inter-comparison Project Phase 5 (CMIP5). This document is primarily meant for WBG staff to inform their climate actions. The document also aims to direct the reader to many useful sources of secondary data and research.

TABLE 1. Key indicators

Indicator	Value	Source
Population Undernourished[10]	<2.5% (2017–19)	FAO, 2020
National Poverty Rate[11]	18.8% (2013)	ADB, 2020a
Share of Wealth Held by Bottom 20%[12]	6.8% (2013)	World Bank, 2021
Net Annual Migration Rate[13]	–1.4% (2015–20)	UNDESA, 2019
Infant Mortality Rate (Between Age 0 and 1)[14]	1.3% (2015–20)	UNDESA, 2019
Average Annual Change in Urban Population[15]	–0.5% (2015–20)	UNDESA, 2019
Dependents per 100 Independent Adults[16]	73 (2020)	UNDESA, 2019
Urban Population as % of Total Population[17]	17.9% (2020)	CIA, 2020
External Debt Ratio to GNI[18]	51.3% (2018)	ADB, 2020b
Government Expenditure Ratio to GDP[19]	34.7% (2018)	ADB, 2020b

[8] 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

[9] The NextGen projections for the Pacific region under CMIP5 are expected to be available from late 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.

[10] 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/

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

[12] World Bank (2021). Income share held by lowest 20%. URL: https://data.worldbank.org/indicator/SI.DST.FRST.20 [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] UNDESA (2019). World Population Prospects 2019. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 15/02/2021]

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

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

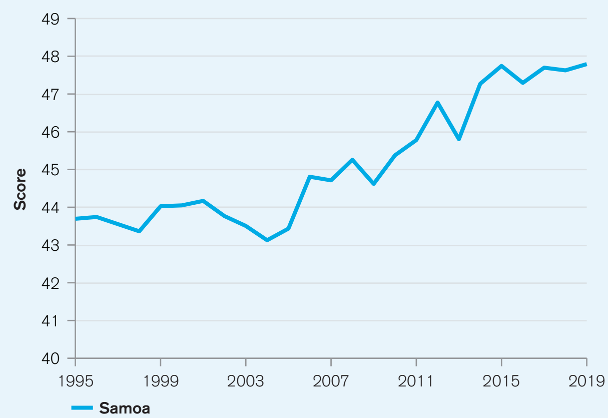
[17] CIA (2020). *The World Factbook*. Central Intelligence Agency. Washington DC. URL: https://www.cia.gov/the-world-factbook/

[18] 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

[19] 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, Samoa is recognized as vulnerable to climate change impacts, ranked 97th out of 182 countries in the 2020 ND-GAIN Index.[20] The ND-GAIN Index ranks 182 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 Samoa'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

Samoa's climate is typical of that associated with small tropical islands, and is characterised by high rainfall and humidity, near-uniform temperatures throughout the year, winds dominated by the south-easterly trade winds (which are directly associated with the South Pacific Convergence Zone),[21] and the occurrence of tropical cyclones during the southern-hemisphere summer.[1]

[20] University of Notre Dame (2021). Notre Dame Global Adaptation Initiative. URL: https://gain.nd.edu/our-work/country-index/

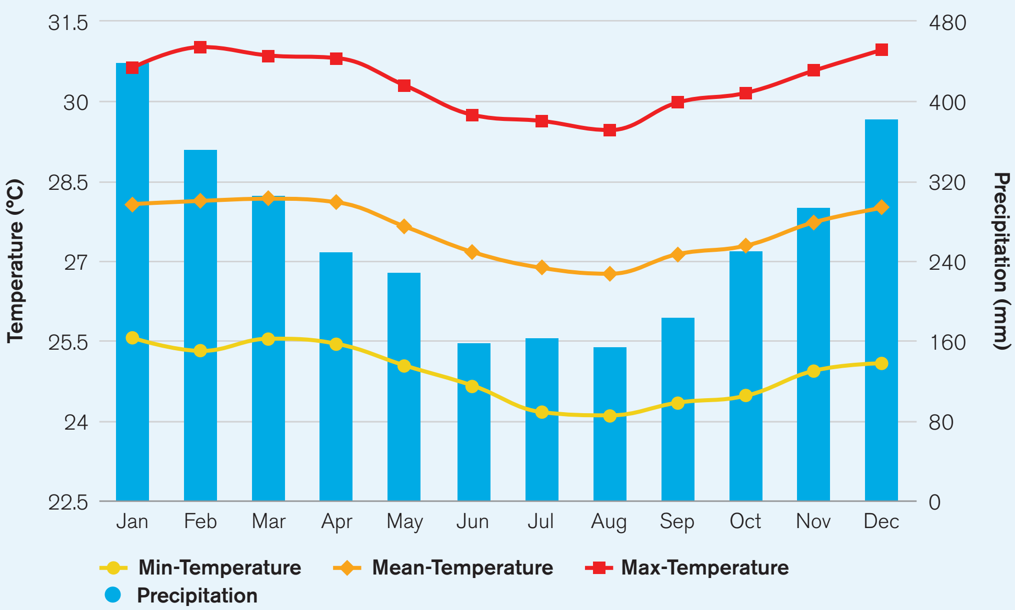
[21] The South Pacific Convergence Zone (SPCZ) is a zone of low-pressure rainfall that migrates across the Pacific south of the equator, which is also the largest and most persistent spur of the Inter-tropical Convergence Zone (ITCZ). The close proximity of the SPCZ to the Samoan islands during summer results in the winds being generally stronger than in winter. These periods are characterised by heavy rainfall throughout the country and strong winds (UNDP & GEF, 2015).

There are two seasons, marked by significant differences in rainfall: Samoa's wet season lasts from November to April and its dry season starts in May and ends in October. The annual rainfall total is about 3,000 mm (varying from 2,500 mm in the northwest parts of the main islands to over 6000 mm in the highlands of Savai'i), and about 75% of the precipitation occurs between November and February.[1] Samoa's topography has a significant effect on rainfall distribution – because of a predominant easterly wind, the mountain ranges determine the distribution of rainfall. Wet areas are generally those located in the southeast and the relatively drier areas are located in the northwest. Samoa is also vulnerable to anomalously long dry spells that coincide with the El Niño Southern Oscillation (ENSO).[1]

The temperature in Samoa is typically tropical (ranging from 24°C–32°C daily) and generally constant during the entire year with little seasonal variation due to Samoa's near-equatorial location (see **Figure 2**). Observations from the Meteorological Office at Mulinu'u have revealed that the highest mean temperature of 27.1°C occurs between December and March, while the lowest mean temperature of 26.0°C occurs between July and September.[7]

Annual Cycle

FIGURE 2. Average monthly mean, max, min temperature and rainfall in Samoa, 1991–2020[7]



Key Trends

Temperature

Samoa's 2010 Second National Communication to the UNFCCC offers evidence of warming trends across the islands. There has been increased inter-annual variability and significant upward trend in maximum temperatures over the last thirty years.[1] Meteorological data of Samoa collected over 101 years indicate mean, maximum, and minimum temperature increases.[7] The mean annual temperature has increased by 0.59°C, with the minimum and maximum temperature increasing by 0.67°C and 0.18°C, respectively, and across the Pacific, the numbers of hot days and hot nights have increased significantly. While mean air temperature trends show little change at Apia, the country's capital, since 1957, the annual number of Cool Days has decreased significantly, and inter-annual variability is evident in maximum air temperatures for the city.[1] The Berkeley Earth Dataset on historical warming shows a significant increase in the rate of warming post-1980, suggesting that the over the subsequent 40 year period the climate in the vicinity of Samoa warmed by approximately 0.6°C.[22]

Precipitation

Based on Samoa's Second National Communication to the UNFCCC, there is evidence of a greater frequency in extreme daily rainfall events,[1] although there has been little change in extreme daily rainfall amounts since 1961 and November–April rainfall since 1890.[8] Analysis of maximum daily rainfall recorded in Apia over the last forty-eight years and show a large range of inter-annual variability, which has become more pronounced in the last twenty years such that daily rainfall of at least 200 mm is more common.[1] While meteorological data[7] of Samoa collected over 101 years indicate a decreasing trend in precipitation by 49.28 mm, annual and May–October rainfall has increased at Apia since 1890 (and is statistically significant at the 5% level).[8] This is most likely due to a shift in the mean location of the South Pacific Convergence Zone (SPCZ) towards Samoa and/or there being a change in the intensity of rainfall associated with the SPCZ over the 122 year period.[8] Notable interannual variability associated with the ENSO is evident in the observed rainfall record for Apia.[8]

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 low and high emissions pathways, are the primary focus; RCP2.6 represents a very strong mitigation scenario, whereas RCP8.5 assumes a high-emissions 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 low and high emissions pathways, are the primary focus. RCP2.6 would

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.[23] Climate change projections associated with the highest emissions pathway (RCP8.5) are presented here to facilitate decision making which is robust to these risks.

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[22] 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]

[23] 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

require rapid and systemic global action, achieving significant emissions reduction throughout the 21st century. 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 Samoa 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.[8]

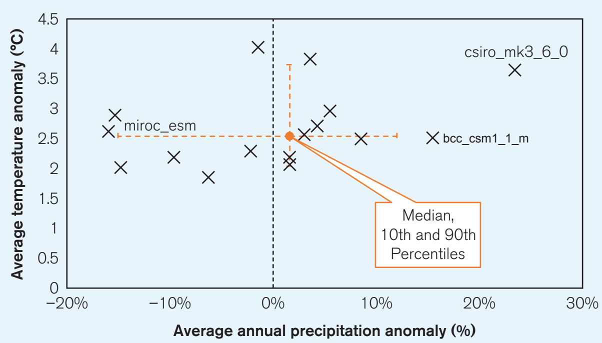
	Mean Surface Air Temp (Annual)		Max Temp (1-in-20 Year Event)		Min Temp (1-in-20 Year Event)	
Scenario	**2050**	**2090**	**2050**	**2090**	**2050**	**2090**
RCP2.6	0.7 (0.5, 1.1)	0.7 (0.3, 1.2)	0.6 (0, 0.9)	0.8 (0.3, 1.1)	0.6 (0, 0.9)	0.7 (0.3, 0.9)
RCP4.5	1 (0.7, 1.4)	1.3 (0.9, 2.1)	0.9 (0.3, 1.3)	1.3 (0.6, 2)	0.9 (0.5, 1.3)	1.2 (0.7, 2)
RCP6.0	0.9 (0.6, 1.4)	1.6 (1.1, 2.5)	NA	NA	NA	NA
RCP8.5	1.3 (1, 1.9)	2.7 (2, 4)	1.4 (0.9, 2.1)	2.9 (1.5, 4.1)	1.4 (0.8, 2.1)	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 Samoa 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 Samoa. 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.[7] Three models are labelled.

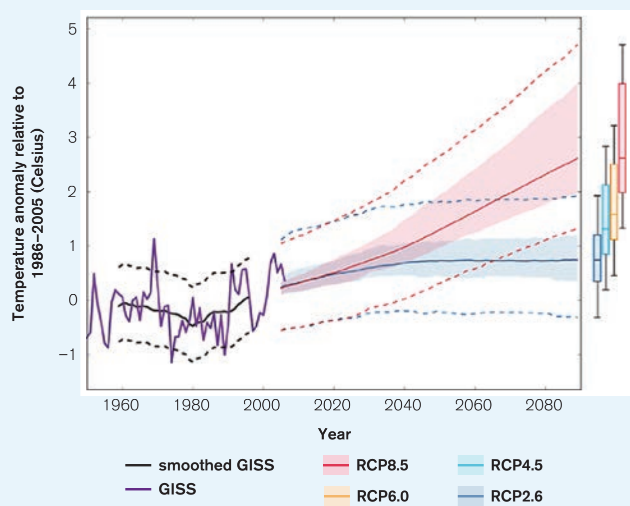


Temperature

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 labor, 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.[7] As shown in **Figure 4**, localised temperature increases are expected across Samoa, 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 0.5°C–1.1°C for RCP2.6, and 2.0°C–4.0°C for RCP8.5 is projected by the 2090s. While there is *very high confidence* that temperatures in the Samoa will rise, based on theory and observational evidence, there is *medium confidence* in the model average temperature changes.[8] As explained in Australian BOM & CSIRO (2014), this is possibly due to differences in model estimations of temperature changes in the recent past in Samoa as well as in other places, and/or a possible bias in the simulation of sea-surface temperatures and the SPCZ for this region. It is noted that this could likely affect projection uncertainty in both rainfall and temperature. 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.[8]

FIGURE 4. Historical and simulated surface air temperature time series for the region surrounding Samoa. 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. (Australian BoM and CSIRO, 2014)[8]



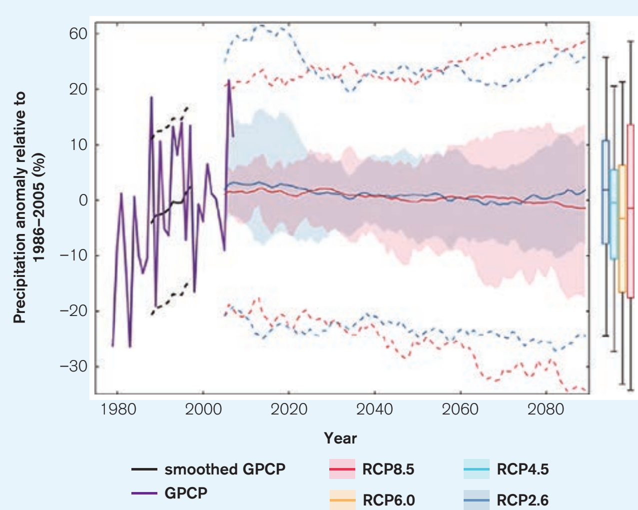
Future temperature rises in Samoa are likely to be below the global average – the mean annual surface air temperature under the highest emissions pathway is projected to reach around 2.7°C by the 2090s, compared to around 3.7°C globally. This difference may reflect the moderating effect of large amounts of nearby ocean cover. However, considering that ocean cover can also distort model simulations, and that 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.

Precipitation

As shown in **Figure 5**, while there has been an increase in mean rainfall prior to 2006, future precipitation changes in Samoa is uncertain. There is limited agreement in precipitation models and thus a range of projected changes in precipitation expected for Samoa.[8] As well, there is a low confidence that rainfall in Samoa will stay the same, since model output range from decrease to increase, and also some models predict little change, as well as due to challenges in understanding how the SPCZ and ENSO will change and/or affect localised rainfall.[8] It is noted that previous precipitation increases could have been as a result of natural variability, rather than global warming, and model simulations of future climate based on localised precipitation changes in Samoa may not fully capture key processes affecting these recent increases.

In terms of extreme rainfall events, more frequent and intense events are expected since our understanding is that a warmer atmosphere can hold more moisture, and localised changes in Samoa are consistent with projected changes in the Pacific and the SPCZ region.[8] As indicated in Australian BoM and CSIRO (2014), most precipitation models indicate that the current 1-in-20-year daily rainfall event will become, on average, a 1-in-9-year event for RCP2.6 and a 1-in-6-year event for RCP8.5 by 2090.[8] However, challenges of model underestimation exist, especially in this area due to the 'cold tongue bias', and as well, global models may not sufficiently capture localised processes related to extreme rainfall events.

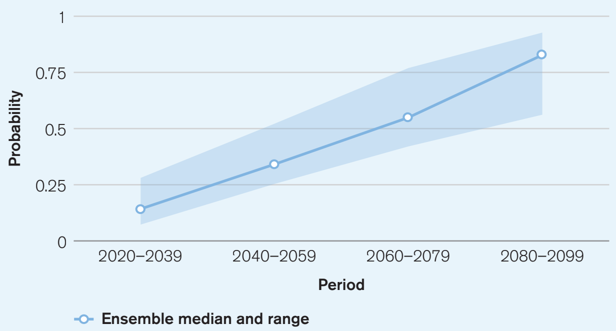
FIGURE 5. Historical and simulated annual average rainfall time series for the region surrounding Samoa. The graph shows the anomaly (from the base period 1986–2005) in rainfall from observations (the GPCP dataset, in purple), and for the CMIP5 models under the very high (RCP8.5, in red) and very low (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.[8]



Heat Waves

Heat waves are defined as a period of 3 or more days when the daily temperature remains above the 95th percentile.[7] **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 Samoa, this probability steadily increases in the long term. It is noted that the tropics are expected to see a particularly extreme rise in the probability of heat wave, when heat wave is measured against a historic temperature baseline. The stability of past temperatures means even a small temperature rise can result in temperatures which would be considered a heat wave according to the above definition.

FIGURE 6. Projected Change in probability of heat waves in Samoa under RCP8.5 (compared to 1986–2005)[7]



Generally, Samoa regularly experiences relatively high temperatures, with a mean annual temperature of around 26.8°C and highest temperatures in February and March at an average of 27.38°C (see **Figure 1**). With a projected ensemble mean change in the maxima of daily maximum temperature of 2.9°C (under RCP8.5), compared to the historical mean (**Figure 7a**), temperatures may climb towards levels which are uncomfortable for the human body.

Comfort levels can be assessed by also considering the impact of humidity through 'heat index'. By 2100, the projected change in the Heat Index 35 for Samoa is 274 (**Figure 7b**) – this Index represents a change in the total count of days where the daily mean heat index rose above 35°C relative to the reference period (1986–2005), under RCP8.5. While noted instances of Heat Index 35 may be primarily found in monsoon regions as well as some subtropical locations with high humidity,[24] in general the values vary between 0 and +150. The projected change for Samoa likely signals the potential for extremely uncomfortable conditions, with local impacts and repercussions. 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 its future regime and potential heat waves.

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

FIGURE 7A. Projected change in maxima of daily max temperature under RCP8.5[7]

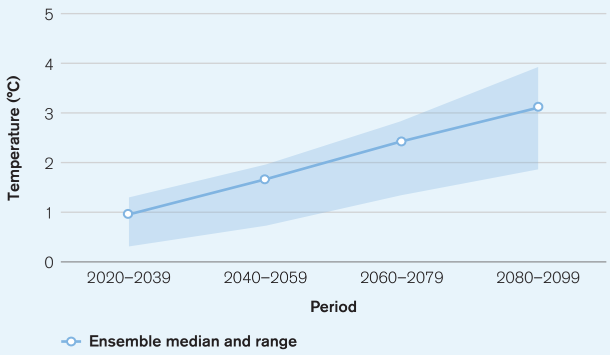
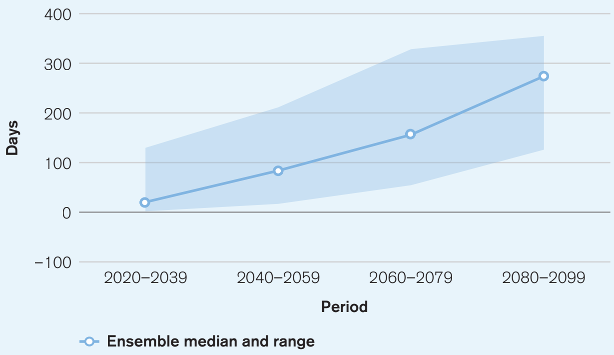


FIGURE 7B. Projected change in Heat Index 35 under RCP8.5[7]



An additional factor for consideration is the potential for marine heat waves. Research has shown that "from 1925 to 2016, global average marine heat wave frequency and duration increased by 34% and 17%, respectively, resulting in a 54% increase in annual marine heat wave days globally".[25] While such research has not specifically identified Samoa as 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",[8] defines projected changes in the frequency and duration of mild, moderate, severe and extreme meteorological droughts using the Standardised Precipitation Index (SPI). 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).[8] SPI drought projections for Samoa show that the overall percent of time that will be spent in drought conditions may slightly decrease under RCP2.6 but stay generally the same across other RCP scenarios.[8] Under RCP8.5, the highest emissions scenario, the frequency of mild, moderate and severe drought events is projected to decrease slightly, but the frequency of extreme drought as well as the duration of drought events in all categories is expected to remain stable.[8] The direction of these changes is considered with low confidence due to similar confidence levels in understanding rainfall changes, and as well that drought projections are only based on a subset of models, in addition to uncertainty in ENSO changes.

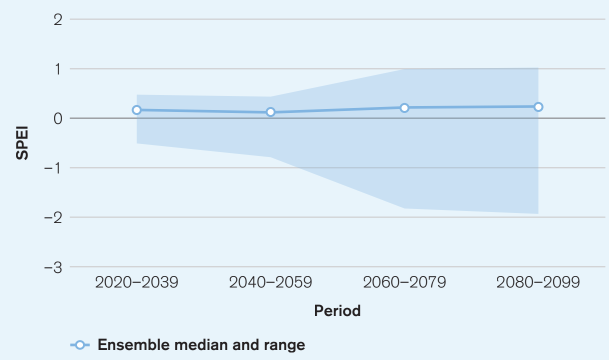
It is understood that drought projections may be somewhat controversial because a large part of the outcome hinges on the evapotranspiration (ET) feedback. One estimate to better understand drought in this context is the standardised precipitation evapotranspiration index (SPEI), which is computed over 12-month periods and captures the cumulative balance between gain and loss of water across the interannual time scale by

[25] 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/

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 Samoa in subsequent time periods, 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 Samoa may vary widely, and as such would require further research.

FIGURE 8. Projected change in Annual Mean Drought Index for Samoa[7]



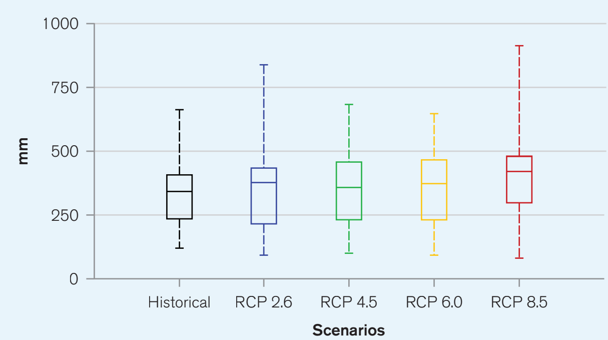
Flood, Cyclones, and Storm Surge

Despite experiencing less frequent disasters compared to other Pacific island countries (PICs), Samoa experiences a high degree of economic and social shock during disaster years: over 40% of the population of Samoa is affected and Samoa's economic losses have reached 46 percent of their GDP during major events. In the capital city of Apia, a cyclone with a 100-year return period, or with a 50% chance of occurring within the current generation, could likely inflict damage equivalent to 60% of GDP. Samoa is at risk to tropical cyclones, tsunamis, droughts, and floods.[7]

Analysis from the World Bank Group's Climate Change Knowledge Portal highlights that the most extreme rainfall episodes generally have the danger of leading to significant floods.[7] 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-yr Return Level by 2050 under all RCPs of CIMP5 ensemble modelling for Samoa. 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

FIGURE 9. 5-day precipitation — historical and projected scenarios of 25-year return level in Samoa for period 2040–2059[7]



of change under the different scenarios. Looking at further projections, **Figure 10** highlights the projected change in annual maximum 5-day rainfall of a 25-year return level, 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.

As well, it is noted that a rainfall event of 300 mm, which used to be extremely rare, is projected to occur on average every 7 years by 2050.[1] This is consistent with trends over the past 20 years, which have seen a significant intensification of rainfall in Samoa. Such extreme rainfall can potentially cause dangerous flooding, as has been observed already in parts of Samoa.[1]

Tropical cyclones have historically affected Samoa. Samoa was affected by devastating cyclones multiple times in the last few decades, with tropical cyclones Ofa and Val, in 1990 and 1991, causing fatalities and widespread destruction with total economic losses valued between US$300-500 million. **Figure 11** shows the level of wind speed due to tropical cyclones that have about a 40% chance to be exceeded at least once in the next 50 years (100 year mean return period). These wind speeds, if they were to occur, are capable of generating severe damage to buildings, infrastructure and crops with consequent large economic losses.[26]

It is noted that when tropical cyclones affect Samoa they tend to do so between November and April, and between 1969/70 and 2009/10 only Cyclone Keli occurred outside these months in June 1997.[8] The tropical cyclone archive for the Southern Hemisphere indicates that between the 1969/70 and 2010/11 seasons, 26 tropical cyclones developed within or crossed the Samoa EEZ, representing an average of 6 cyclones per decade.[8] The differences between tropical cyclone average occurrence in El Niño, La Niña and neutral years are not statistically significant. Looking forward, there is a projected decrease in cyclone genesis (formation) frequency for the south-east basin, with *high confidence*.[8]

FIGURE 10. Projected change in annual maximum 5-day rainfall (25-year return level) for Samoa[7]

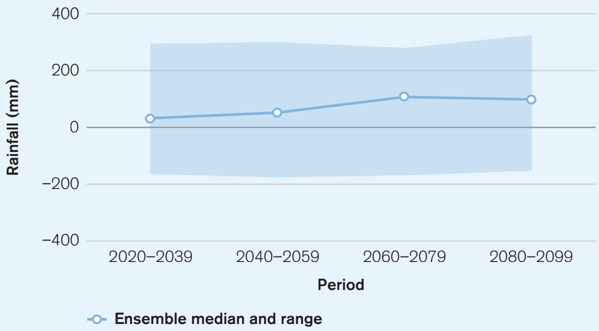
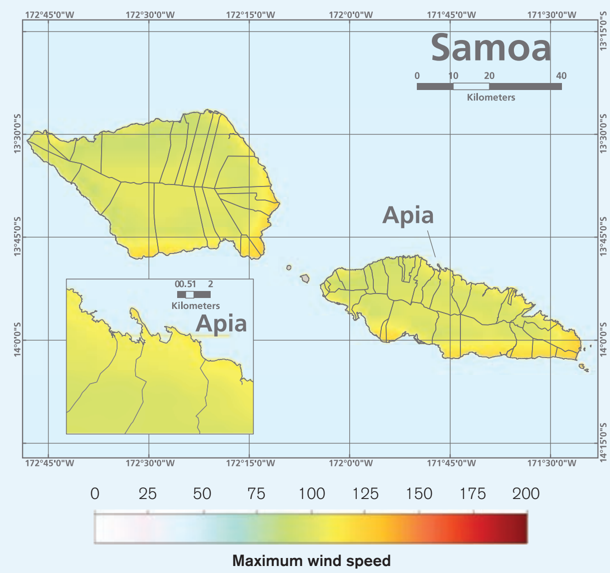


FIGURE 11. Maximum 1-minute sustained windspeed (in miles per hour) with a 40% chance to be exceeded at least once in the next 50 years[26]



[26] PCRAFI (2011). Country Risk Profile: Samoa. Pacific Catastrophe Risk Assessment and Financing Initiative. URL: http://pcrafi.spc.int/documents/241 [accessed 22/07/2019]

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 Samoa.[27] This means that there is more than a 20% chance of potentially-damaging wind speeds for the country in the next 10 years. However, 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 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.[28] In Samoa, research by the Australian Bureau of Meteorology suggests that the most likely scenario is of a reduction in the frequency of cyclone genesis in the vicinity.[8] However, this projection is associated with low confidence. 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.

Concerning wave activity, in general it is understood that while there may be a projected decrease in wave period under certain RCPs for particular times of the year, statistically significant change in wave height and wave direction is not apparent. However, projected wave activity changes are associated with low confidence due to associated low confidence in changes in ENSO, and differences between hindcast and simulated wave data are larger than future projections.

CLIMATE CHANGE IMPACTS

Natural Resources

Water

As with many other island nations, Samoa has uniquely fragile water resources. Samoa's water system services roughly 95% of the population, with the remainder receiving its supply exclusively from wells, springs and small rainwater reservoirs. Although water is widely available, only a small proportion of the population receives safe, treated water. In part, this is because some villages rely upon private water supplies that are frequently neither treated nor appropriately maintained.[1]

Samoa's Second National Communication describes that the country's water resources are particularly vulnerable to the effects of climate change.[1] Significant problems associated with climate change include periods of low rainfall, resulting in water shortages; heavy rains that cause flooding and subsequent damage to water infrastructure, quality and supply; enforced water rationing to compensate for inconsistent rainfall; rapid water evaporation, caused by higher temperatures; and salt water despoiling ground water and coastal springs as sea levels rise.[1]

[27] GFDRR (2016). ThinkHazard! Profile for Samoa. URL: http://thinkhazard.org/ [accessed 15/07/2019]
[28] 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

Specifically, in 1997, 1998 and 2001, periodic droughts associated with ENSO events meant that Samoa's water supply was rationed and water reservoirs were depleted. In October 2006, low flows resulting from a 57% below average rainfall (associated with a weak-moderate El Niño) resulted in water shortages despite rains for August and September being 32% and 41% above average respectively. Flooding, which is associated with cyclones and periods of heavy rainfall, has adversely affected water quality and quantity, due in part to erosion and sedimentation associated with flash flooding. The effect of flooding upon water quality and quantity in the urban areas is exacerbated by extensive forest clearance within the uplands of the watersheds to the south of Apia.[1]

Noting the wide range of precipitation projections (**Figure 5**), the direction of change will be significant in determining stream flows and groundwater recharge. An increase in annual precipitation will mean that the surface and groundwater resources will continue to be recharged and that water will be available for supply, development and the environment. While the agriculture sector may benefit from high rainfall through irrigation and the energy sector is expected to benefit through increased hydropower generation, higher rainfall can potentially cause floods that further mobilise sediments, increasing pressure on water treatment, flood control and watershed management. Water reticulation, treatment and infrastructure will also become more vulnerable to floods.[1] Extreme reduction in annual rainfall, however, coupled with projected higher annual maximum temperatures, would enhance evapotranspiration from the ground and plants, making surface and underground water increasingly scarce.[1]

The risk of saltwater inundating groundwater is expected to increase as sea levels rise. The recharging of groundwater is expected to lessen as annual rainfall lessens. Rising sea levels will also affect coastal springs as current boundaries become flooded. Damage to water supplies, water treatment and hydrological research infrastructure is expected to be significant and costly.[1]

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)–0.74 m by the end of the 21st century by the IPCC's Fifth Assessment Report,[29] 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).[30]

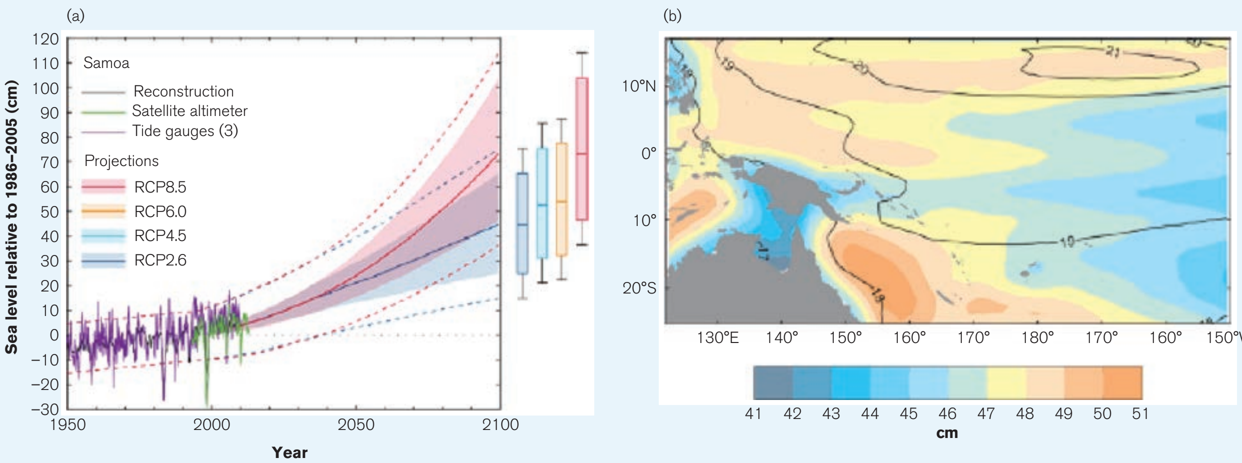
Scenario	Rate of Global Mean Sea-Level Rise in 2100	Global Mean Sea-Level Rise in 2100 Compared to 1986–2005
RCP2.6	4.4 mm/yr (2.0–6.8)	0.44 m (0.28–0.61)
RCP4.5	6.1 mm/yr (3.5–8.8)	0.53 m (0.36–0.71)
RCP6.0	7.4 mm/yr (4.7–10.3)	0.55 m (0.38–0.73)
RCP8.5	11.2 mm/yr (7.5–15.7)	0.74 m (0.52–0.98)
Estimate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

[29] 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

[30] 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

According to its Second National Communication to the UNFCCC, Samoa already has witnessed sea level rise of 5.2 mm per annum and maximum hourly sea level increasing at a rate of 8.2 mm per annum.[1] Mean sea level for Samoa is projected to continue to rise over the course of the 21st century, with *very high confidence* in the direction of change.[8] Projected changes across the different RCPs indicate an increase of 7–17 centimetre (cm) by 2030, with increases of 40–87 cm by 2090 under the RCP8.5 (**Figure 12**). It should be noted that these values should be considered alongside uncertainty regarding the contribution of the Antarctic ice sheet, as well as natural interannual sea level variability (which has been, and is likely to continue to be, about 20 cm within the 5–95% range, after removal of the seasonal signal).[8]

FIGURE 12. (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 Samoa (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).[8]



It is also noted that Samoa's southwestern location bordering the Pacific 'Ring of Fire' increases its risk to tsunamis. This area of high tectonic activity had 115 tsunamis since 1900, 22 of which led to significant damage.[7] The 2009 tsunami reportedly led to a tidal wave around 14 meters high.[31] Not only does sea-level rise threaten to increase the height and potential risk from such events, but the associated earthquakes have been shown to exacerbate

[31] NIWA (2009). NZ scientists learn lessons from Samoa tsunami. National Institute of Water and Atmospheric Research – News & Publications. [4 December, 2009]. URL: https://niwa.co.nz/news/nz-scientists-learn-lessons-samoa-tsunami

rates of relative sea-level rise. Subsidence induced by the 2009 earthquake is believed to be accelerating relative sea-level rise in Samoa by 8–16 mm/year.[32]

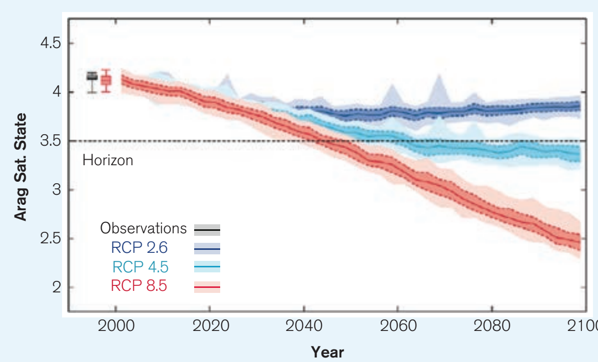
Sea level rise is expected to affect several sectors in Samoa. Firstly, Samoa's coastline is highly susceptible to erosion and flooding. It is noted that more than 75% of the Samoan population resides along the coastal planes, highlighting the strong reliance upon marine resources for subsistence and commerce. Infrastructure and utility services are also located in these coastal zones and are thus extremely vulnerable to extreme climate events. An extreme sea level rise of 1.8 metres with a return period of four years is likely to increase the risk of coastal flooding and coastal erosion, particularly where infrastructure protection is minimal or altogether absent. Furthermore, the effect on infrastructure and the agricultural sector will have a detrimental effect on the health of many, particularly those living in coastal areas.[1]

Although the current rate of sea level rise has a slight effect on watershed and aquifers thus far[1], the Second National Communication highlighted that several coastal springs are becoming inundated by what communities view as rising sea levels. Coastal springs used by some villages for bathing and as alternative water sources have become overwhelmed by seawater, even during low tides, and cement and rock walls built to protect some of these springs have been destroyed by storm surges and strong waves.[1]

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.[33] **Figure 13** shows the projected aragonite saturation state under three emission scenarios for Samoa. Worryingly, under RCP4.5 and RCP8.5 the saturation state is expected to decrease below the threshold needed to sustain healthy coral reefs.

FIGURE 13. Projected changes in aragonite saturation state in Samoa 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.[8]



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32 Han, S.-C., Sauber, J., Pollitz, F., & Ray, R. (2019). Sea Level Rise in the Samoan Islands Escalated by Viscoelastic Relaxation After the 2009 Samoa-Tonga Earthquake. Journal of Geophysical Research: Solid Earth, 124(4), 4142–4156. DOI: https://doi.org/10.1029/2018JB017110

33 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. DOI: 10.1038/nature04095

As well, as the ocean warms, the risk of coral bleaching increases, with *very high confidence*.[8] However, there is *medium confidence* in the projected rate of change for Samoa because there is medium confidence in the rate of change of sea-surface temperature (SST), and the changes at the reef scale (which can play a role in modulating large-scale changes) are not adequately resolved. The impacts of ocean acidification are also likely to affect the entire marine ecosystem impacting the key ecosystem services provided by reefs.

One of the main economic sectors in Samoa is fisheries and, according to the 2009 Second National Communication, the sector was critical both for commercial purposes and the sustenance of the population. According to the 2005 agricultural survey, a total of 5,060 households harvest fish: 77% of households consume all that they catch, 23% sell their surplus at market.[1] Data collected by the Samoan fisheries department shows a strong correlation between sea-surface temperatures and stocks for pelagic species, and warmer sea-surface temperatures have been linked to lower catches per-unit effort. The Second National Communication mentions that higher sea-surface temperatures have already damaged marine ecosystems, thus affecting near-shore fishing stocks. Coral bleaching has been of particular concern, and increasingly heavy rainfall has boosted sedimentation levels in coastal waters, again affecting fishing stocks. Each of these climate-related risks is expected to worsen because of climate change.[1]

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.[34] Research has shown that inundation of low-lying islands has the potential to remove important refuges for migrating sea birds.[35] 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 Pacific islands, for example endemic lizards, which may become trapped in a shrinking habitat.[36] 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%.[37]

Economic Sectors

Agriculture and Food

Agriculture plays an important role in Samoa's society and economy and is considered a key focal area in the Strategy for the Development of Samoa (SDS). While the agricultural sector accounted for just around 8% of Samoa's GDP in December 2018 (down from nearly 12% in 1998),[1] the vast majority of households produce

[34] 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

[35] 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

[36] Taylor, S., & Kumar, L. (2016). Global Climate Change Impacts on Pacific Islands Terrestrial Biodiversity: A Review. Tropical Conservation Science, 9(1), 203–223. DOI: https://doi.org/10.1177/194008291600900111

[37] 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

agricultural goods both for subsistence and commercial purposes. The Report on the Samoa Agricultural Survey 2015[38] highlighted that agriculture is important to households in Samoa to provide food for the family or as a source of income, and of the 28,119 households in Samoa in 2015, some 97% were agricultural households in that they grew some crops or raised some livestock. While many households in Samoa engaged in agriculture as only a secondary activity, most (about 55%) were major crop households (i.e. an agricultural household with more than 625 square yards of land under garden crops, or more than 20 coconut trees, or more than 20 banana plants; or more than 20 other tree crops) which were engaged in mainly subsistence agriculture. Samoan farming is still based on the traditional practice of mixed cropping where root crops are the most important staple food.[38]

Increasingly, agricultural production competes with other growing sectors such as tourism and manufacturing. Remittances and more attractive salary opportunities in Apia and overseas have likewise caused a shift away from agricultural production. Notwithstanding these socioeconomic changes, Samoa's Ministry of Agriculture and Fisheries has claimed that one of the factors contributing to the diminution of agricultural production in Samoa is climate change.[1] The current and anticipated occurrence of extreme weather events in the Pacific island countries and thus Samoa will cause irreparable damage to food crops and other livelihood material on which the island population depend.

Already, the numerous effects of climate change and variability, including cyclones, flash floods, high rainfall, high temperature and long dry periods, have already made agricultural production increasingly challenging.[1] Climatic changes have meant greater incidence of pests and pestilence, which meant a loss of quality and quantity in production, and unstable and inconsistent food production caused by climate change has affected farmers' capacity for self-sufficiency, and their ability to generate income from their crops.[1] The projected impacts of climate change for agriculture in Samoa include extended periods of drought and loss of soil fertility, which will seriously affect agriculture and food security, and tropical cyclones bringing flooding and winds that will damage crops. Much of the prime agricultural land is located on the coastal plains that are threatened by sea level rise. Further climate-induced changes in temperature, rainfall patterns, sea level, and the intensity of extreme weather events such as cyclones are projected to possibly affect the type of crops that can be grown and reduce agricultural yields due to greater heat stress, more frequent and intense drought conditions or water logging, increased flooding of river catchments, and more soil erosion. As well, such changes could favor the establishment and spread of new pests and disease vectors, further threatening the production of crops and livestock, and increase saltwater intrusion in atolls, further limiting what can be grown in these environments and exacerbating existing threats to food security.[38] Further, like most small island countries, Samoan exports are confined largely to agricultural produce and marine resources, and Samoa continues to face major barriers in terms of realizing its export potential in this sector.[1] The susceptibility of the agriculture sector to climate variability and change is further exacerbated by limited arable land and vast distances from the main world markets.

[38] Samoa Bureau of Statistics (2016). Report on Samoa Agricultural Survey 2015. URL: http://www.sbs.gov.ws/digi/2015%20Samoa%20Agricultural%20Survey.pdf [accessed 29/07/2019]

A further, and perhaps lesser appreciated, influence of climate change on agricultural production is through its impact on the health and productivity of the labor force. Dunne et al. (2013) suggest that global labor productivity during peak months has already dropped by 10% as a result of warming, and that a decline of up to 20% might be expected by the 2050s under the highest emissions pathway (RCP8.5).[39] Like many other small islands, the Marshall Islands likely operates an agricultural system highly dependent on physical labor inputs and hence is potentially vulnerable to higher temperatures without adaptation. In combination, it is highly likely that the above processes will have a considerable impact on national food consumption patterns both through direct impacts on internal agricultural operations, and through impacts on the global supply chain.

Tourism

The role of tourism in the Samoan economy has been growing in recent years. Samoa's 2009 Second National Communication to the UNFCCC highlighted that since 1994, tourism earnings have been the largest source of foreign exchange.[1] It documented that the number of tourists visiting Samoa increased from 39,414 to 87,688 between 1990 and 2000, with visitor numbers growing at an annual rate of 5.1%. Data from the Samoa Bureau of Statistics shows that this has grown significantly with visitor arrivals in 2018 totalling 172,496, with the majority (167,651) arriving by air.[40] Tourism earnings usually mirrors the trend in overall arrival numbers, and this has grown as well over the past few years, from US$40.6 million in 1999 to US$107.3 million in 2007.[1]

As with other small island states, the tourism sector is certainly vulnerable to related impacts of climate change and variability. In the long-term, the dual threats of rising sea levels and coastal erosion could reduce the quantity and quality of available beach space without significant adaptation measures and could therefore reduce the attractiveness of the country as a tourist destination. Another area of vulnerability is the burgeoning recreational diving sector, which could be threatened by environmental degradation, loss of reefs, and coastal erosion.

In addition to direct physical impacts, climate change may affect the tourism sector in Samoa through global efforts to mitigate climate change. While most tourists to Samoa are from relatively nearby (the Oceanic Region had the highest share of total visitors with 77.5%, and visitors from Asia amounted to 8.9% in June 2019, reflecting usual proportions), visitors from America and Europe are also keen to visit, totalling 10.4% and 2.5%, respectively.[40] As such, changes to the cost of international flights can certainly potentially affect visitor arrivals. One study estimated that while the cost of achieving an emissions-target compatible tourism sector may be proportionately low (3.6%), the necessary increase in trip costs (estimated at $11 when averaging across every global trip but potentially higher on a long-haul destination) may further reduce a country's attractiveness as a tourist destination.[41] Further research is required to better constrain the suite of potential climate change impacts on the sector.

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[39] Dunne, J. P., Stouffer, R. J., & John, J. G. (2013). Reductions in labour capacity from heat stress under climate warming. Nature Climate Change, 3(6), 563–566. URL: http://www.precaution.org/lib/noaa_reductions_in_labour_capacity_2013.pdf

[40] Samoa Bureau of Statistics (2019). International Arrival Statistics June 2019. URL: http://www.sbs.gov.ws/social-and-environment-statistics [accessed 28/07/2019]

[41] Scott, D., Gössling, S., Hall, C. M., & Peeters, P. (2016). Can tourism be part of the decarbonized global economy? The costs and risks of alternate carbon reduction policy pathways. Journal of Sustainable Tourism, 24(1), 52–72. DOI: https://doi.org/10.1080/09669582.2015.1107080

Communities

Poverty, Inequality and Vulnerability to Climate-Related Disaster

Samoa is considered a developing country, graduating in 2014 from its previous status as a Least Developed Country, and has been ardent in its approach to embrace the Sustainable Development Goals (SDGs), as the successor to the Millennium Development Goals (MDGs), and find solutions to ongoing hardship within the country.[42] Analysis of the 2013/2014 Household Income and Expenditure Survey (HIES) data in order to determine the progress of Samoa's population living under the Basic Needs Poverty Line (BNPL) highlights a reduction of the incidence of basic needs poverty in the population in Samoa from 26.9% in 2008 to 18.8% in 2013/2014 (see also **Table 1**).[42] The Samoan government maintains that this reduction demonstrates the benefits of inclusive government policies and a clear strategy for targeting the poor in planning processes, and as well notes various policy efforts targeting small business development after the destructive tsunami in 2009 and cyclone Evan in 2012.

While efforts are being made to continue this trend, the impacts of climate change and variability is certain to widely affect the economy and local livelihoods. As adverse impacts are expected on local fisheries stocks and climate-related stresses cause farmers significant financial hardship and disrupt food supply for local and export markets[1], and sea level rise and changes in precipitation threaten both locational and food security, the "islander lives" of the Samoans, and other Pacific Islanders, have been slowly changing.

As for many countries, most of the climate changes projected are likely to disproportionately affect the poorest groups in society. For instance, heavy manual labor 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.

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.[44]

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[42] Samoa Bureau of Statistics (2016). Samoa Hardship and Poverty Report – Analysis of the 2013/14 Household Income and Expenditure Survey. URL: http://www.sbs.gov.ws/economics [accessed 29/07/2019]

[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] 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

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.[45] 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.

Climate change is expected to result in a greater number of people at risk of heat-related medical conditions – the elderly, children, the chronically ill, the socially isolated and at-risk occupational groups are particularly vulnerable to heat-related conditions. Due to the methodological specification, the projected number of heat-related deaths for grids in which sea area is dominant becomes zero. Samoa, which has very small land areas surrounded by sea, constitutes some of these grids. Based on the climate projections, however, it is safe to say that the number of heat-related deaths is likely to increase in Samoa. It should be noted that the potential reduction in heat-related deaths achievable by pursuing lower emissions pathways is significant, as demonstrated by Mitchell et al. (2018).[46]

Disease and General Health

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. Socioeconomic development and health interventions are driving down burdens of several infectious diseases, and these projections assume that this will continue. However, climate conditions are projected to become significantly more favourable for transmission, slowing progress in reducing burdens, and increasing the populations at risk if control measures are not maintained or strengthened. According to Samoa's 2009 Second National Communication, there are a number of ways in which the Samoan health sector may be sensitive to climate stresses. The effect of climate change and variability can be noted both directly to weather and climatic events, for example potential fatalities in times of flooding or cyclonic activity, and also indirectly, for example considering water and vector-borne diseases in the wake of flood or cyclonic activity.

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[45] 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

[46] 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. URL: 10.1038/s41558-018-0210-1

As shown In **Table 4**, multiple sources of climate stresses ranging from high temperatures, to sea level rise and extreme weather events, is likely to have be highly impactful on vector-borne, food-borne, water-borne, and air-borne diseases. Water and food-borne diseases such as typhoid, diarrhoea and gastroenteritis remain highly prevalent, and vector-borne diseases including dengue and filariasis continue to receive highest priority in terms of control and prevention programmes. The report notes that the first major outbreak of typhoid in Samoa was recorded in 1994, following the two major cyclones Ofa and Val.[1] In Samoa, as it is for other small countries, local research into the links between climate-related extreme events and water- and vector-borne diseases has been minimal, and current monitoring and surveillance systems cannot provide precise data on disease incidences. As such, it is almost impossible to gather and analyse long-term data on how climate change affects human health in Samoa. However, there is general anecdotal evidence to suggest that public-health objectives are closely intertwined with climate-related risks.[1] In Samoa, public-health professionals consulted as part of the report's vulnerability and adaptation assessment confirmed that outbreaks of diseases such as typhoid and dengue fever correlate closely with changes in Samoa's climate.[1]

TABLE 4. Sensitivity of the Samoan health sector to climate stresses.[1]

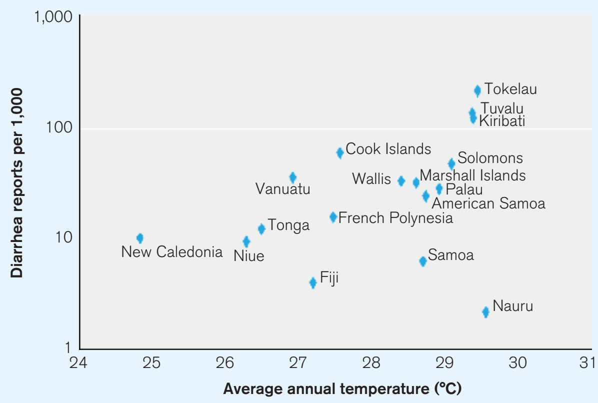
Climate Stress Sector Component	Extreme High Temperatures	Sea Level Rise	Extreme Winds	Drought	Flooding
Vector-Borne Diseases	High	High	Low	Medium	High
Food-Borne Diseases	High	High	High	High	High
Water-Borne Diseases	High	High	High	High	High
Direct Injuries – Including Skin Diseases	High	Medium	High	Medium	High
Mental Illness	Medium	High	High	High	High
Airborne Diseases	High	Medium	Low	High	High
Infrastructure	Low	High	High	Low	Medium

As well, psychological or emotional stress as well as mental illness, a usually overlooked area, is also cautioned as being a sensitive sector component to climate impacts, particularly in instances where there is bereavement and damage to property and livelihood. Those most directly affected by extreme weather events are the poor, who tend to reside in flood-prone areas.[1] People displaced because of climate-related land loss will have to face not only the economic hardship associated with relocation, in some instances significant, but also the psychological distress of dislocation. The loss of customary and private property will have a significant economic and cultural impact on Samoa.

The report also highlights that heavy rainfall and inadequate drainage mean that flooding is a frequent problem, compounded by land filling and the blocking of drains. Intense flooding causes foul water to be released to the surface, which poses a public health risk as septage and latrine runoff contaminate supplies. Increased settlements along coastal areas also put additional pressure on already diminishing agricultural and fishery resources in the urban areas. Those who live in coastal areas amongst tropical vegetation, tidal mudflats and mangroves are at increased risk from vector-borne diseases and complications from wounds and tropical ulcers. The resettlement of rural villagers in urban areas is also creating sub-standard conditions in some areas, with poor sanitation and overcrowded housing contributing to the spread of communicable diseases.

An increase in atmosphere and sea temperatures could also intensify risks in water and vector-borne diseases, such as diarrhoea, dengue fever, disaster-related fatalities, injuries and illnesses, heat stress and conjunctivitis (pink-eye). 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 diarrhoea 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.[47] **Figure 14** 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.[48]

FIGURE 14. Annual average temperature and average reporting rates for diarrheal disease, Pacific islands (1986–1994). $r^2 = 0.49$; $p < 0.05$[48]



POLICIES AND PROGRAMS

National Adaptation Policies and Strategies

- Second Nationally Determined Contribution (2021)
- Intended Nationally Determined Contribution (INDC) (2015)
- Second National Communication (2010)
- First National Communication (1999)

Climate Change Priorities of the WBG

WBG — Regional Partnership Framework

The World Bank Group has agreed a 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."

[47] 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. DOI: 10.1007/s004840000083

[48] 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/

Under the heading of strengthening resilience to natural disasters and climate change, the Regional Partnership Framework (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

SAMOA

WORLD BANK GROUP