CRPP Community Resilience Partnership Program

Annex 2.1

Design Study: Country Climate Risk Profiles

31 May 2023

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A. ABOUT THE ANNEX

This annex is part of annex 2 on the design study of the Community Resilience Partnership Program (CRPP).[1] This annex presents climate risk profiles of seven countries, namely Cambodia, Indonesia, Lao People's Democratic Republic (PDR), Pakistan, Papua New Guinea (PNG), Timor Leste, and Vanuatu. These profiles present a summary of the climate rationale for the inclusion of the countries in the Program and provide a background for the detailed discussion on the CRPP outputs presented in annex 2.2. While these profiles have guided the selection of seven countries proposed under the CRPP, individual sub-projects to be financed in these countries will be undertaking their project specific climate risk assessment in order to identify the current and future climate risk for project specific location/s (see annex 2.3 for further details).

The profiles in this document are largely based on country climate risk profiles jointly developed by the Asian Development Bank (ADB) and the World Bank and currently in final stages of publishing. The core climate projections presented in these profiles are derived from datasets made available on the World Bank's Climate Change Knowledge Portal (CCKP), unless otherwise stated. These are processed outputs of simulations performed by multiple General Circulation Models (GCM) developed by climate research centers around the world and evaluated by the IPCC for quality assurance in the CMIP5 iteration of models (for further information see Flato et al., (2013).[2,,3] Collectively, these different GCM simulations are referred to as the 'model ensemble'. Due to the differences in the way 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 national and local scales. Exploring the spread of climate model outputs can assist in understanding uncertainties associated with climate models. Modifications and other related data to create a better understanding of the country needs and its consequent climate risks on the poor and vulnerable populations were added and provided with a similar referencing style.

The Representative Concentration Pathways (RCPs) represent four plausible futures, based on the rate of emissions reduction achieved at the global level. RCP8.5 assumes annual global emissions will continue to increase throughout the 21st century. Studies published since the last iteration of the IPCC's report (AR5), such as Gasser et al. have presented evidence which suggests a greater probability that Earth will experience medium and high-end warming scenarios than previously estimated. Climate change projections associated with the highest emissions pathway (RCP8.5) are thus presented along with low and medium pathways to facilitate decision making which is robust to these risks.[4]

B. INTRODUCTION

The CRPP is a regional partnership program of the Asian Development Bank (ADB) which aims to help countries and communities in Asia and the Pacific region scale up investments in climate adaptation, especially investments at the community level, that explicitly target the nexus between climate change, poverty, and gender. The CRPP aims to contribute to

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[1] The other annexes under 2 includes (i) annex 2.2 design study, (ii) annex 2.3 description of project concepts, and (iii) annex 2.4 project selection approach and criteria.

[2] Flato, G., et.al. *Evaluation of Climate Models.* Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 741–866. 2013.

[3] Since the development of this annex, the World Bank Climate Portal has been updated to the CMIP6 GCM data, but the individual 2021 Climate Risk Country Profiles on the Portal are still based on CMIP5 (https://climateknowledgeportal.worldbank.org/country-profiles). While the CMIP6 data include new and better representations of physical, chemical and biological processes, as well as higher resolution, they do not significantly change the direction or magnitude of projected trends, nor do they reduce uncertainty. However, they do have higher average climate sensitivity than CMIP5 and this may increase risks slightly, including extreme and high-end risks. These issues will be considered in the updated analysis underpinning each technical feasibility study at the sub-project level.

[4] 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.

transformational change by; (i) mobilizing large-scale public investments that support community level adaptation of poor and vulnerable people; (ii) developing national and local policies, plans, and programs that promote financing for community-led adaptation; and (iii) increasing the meaningful participation of poor women and men in resilience related decision-making. In doing so, the CRPP will address the points of procedural and distributive justice so that the people most vulnerable to the impacts of climate change can engage in a fair process and receive a fair share of the benefits of adaptation efforts.

The CRPP will support countries to meet their commitments to the Paris Agreement, the Sendai Framework for Disaster Risk Reduction, and the Sustainable Development Goals. The program responds to the COP26 goal of scaling up adaptation to protect communities and natural habitats, and mobilizing finance for climate adaptation measures that meet the needs of the poor and vulnerable communities. It is also identified as flagship program under the locally led action track of the Global Commission on Adaptation, which aims to spur financing for adaptation measures at the local level, and to help create structures that support appropriate subsidiarity and give local actors greater influence for adaptation-related decision-making. The CRPP is directly aligned with the core recommendations of the recently released Intergovernmental Panel on Climate Change's (IPCC) Working Group 2 Report "Climate Change 2022: Impacts, Adaptation and Vulnerability", which highlights that for adaptation efforts to be effective, they must be concentrated on promoting climate justice and supporting the most economically and socially marginalized populations, and calls for integrated, multi-sectoral solutions that address social inequalities and cut across systems.

The CRPP is operationalized through the Community Resilience Financing Partnership Facility (CRFPF) which was established by ADB in August 2021 and comprises two separate but interlinked components; the **CRPP Trust Fund (TF)** focusing on upstream support to strengthen the enabling environment required for implementing local adaptation measures at scale; and the **CRPP Investment Fund (IF)** focusing on the efficient roll-out of local adaptation measures through downstream investments.

The TF will provide technical assistance and grant resources financed by development partners and administered by ADB, to selected developing member countries (DMC) of the ADB to implement the following three outputs: (1) Knowledge and action research on climate risk informed pro-poor community-level solutions strengthened; (2) Institutional and community capacity to develop and deliver climate adaptation investments at community-level strengthened; and (3) Inclusive and pro-poor adaptation investment projects identified and prepared. The TF will include a dedicated Gender Window with funds earmarked specifically for providing technical assistance and grants for identifying, developing, and implementing investments that explicitly strengthen the resilience of women, particularly poor women, and/or adaptation investments led by women that have a specific focus on supporting women to build their resilience. The TF will have a budget of US$75 million with roughly 15% earmarked for the Gender Window. To date, Government of United Kingdom, the Nordic Development Fund, and the French Development Agency has confirmed financial support for the TF, amounting to a total of ~ US$68 million. The TF will **not** be funded by GCF.

The IF will provide grant and loan financing to seven selected DMCs, namely, Cambodia, Indonesia, Lao PDR, Pakistan, PNG, Timor-Leste, and Vanuatu, to implement local adaptation measures as part of ADB financed sub-projects that are targeted at the poor and vulnerable population. The IF will deliver three climate related **outputs** that are the focus of this annex (**4**) **information and systems** for delivering applied climate-risk informed local investments at scale improved; (**5**) climate resilient pro-poor **livelihoods** investments implemented; and (**6**) pro-poor climate adaptation **infrastructure** investments implemented. All sub-projects financed by the IF will be implemented by the respective governments following ADB's procedures. The GCF is requested to provide US$100 million as grants and US$20 million as loan for the seven countries identified above (with each country receiving between USD 12 to

25 million) in support of the IF of this program, while the ADB will provide USD 555 million of grant and loan financing. The program will utilize GCF grant resources to co-finance at least 15 sub-projects implemented under the IF only, for outputs 4, 5 and 6. The IF will be part of an ADB administered trust fund set up for GCF financed projects under the umbrella of the CRFPF.

C. CAMBODIA CLIMATE RISK PROFILE

1. Summary of Climate Rationale

Cambodia is ranked 140th out of 181 countries in the ND-GAIN Index due to a combination of high vulnerability and low readiness. The country has a tropical monsoon climate with two distinct seasons, a rainy season from May to October and a dry season from November to April. Average temperatures are relatively uniform across the country and annual average rainfall is high (especially in the highlands and along the coast), most of which falls during the Monsoon. However, there is a high annual variability due to the influence of the monsoon and the El Niño Southern Oscillation (ENSO). The country has a varied topography, with mountainous and highland regions, the central plains, and a coastal zone, but it is dominated by the Mekong River, which flows directly from the north to Vietnam in the south. The Tonle Sap Lake, an outlet of the Mekong River, is located in the northwest region, and covers almost 10% of the country's surface area during the monsoon peak. The central alluvial plains of the Mekong and Tonle Sap represent approximately 80% of the country. These basins are characterized by a flood-pulse hydrology with fluctuations in water levels between seasons and are critical for agriculture and fisheries.

The combination of the monsoon, climate variability from the ENSO, and the geographical terrain makes Cambodia extremely vulnerable to weather-related extremes (e.g., floods, storms, and periodically droughts). These occur almost every year and lead to high losses, reported at US$1.4 billion over the last 20 years with annual damages of US$100 million to 250 million. Seasonal flooding is essential to agricultural and fisheries production, however, river and flash floods lead to major losses. Cambodia ranks as one of the world's most flood exposed countries in terms of the proportion of the population affected by floods (at 20-25%). There are also periodic droughts. During the 2015–2016 El Nino drought event, 2.5 million people were affected, and three-quarters of the wet season paddy rice production experienced a loss of more than 25% in yield. Tropical storms are rare, though in 2009 Typhoon Ketsana had a large impact with estimated damage of $132 million in Cambodia. These weather-related impacts particularly affect rural people because of the reliance on rain-fed agriculture, and the disproportionate impact on the poor. Many households in Cambodia have a high probability of falling into extreme poverty even when exposed to relatively low intensity flood and drought events.

Observations show that the climate of Cambodia is changing. There is a clear warming trend, with 0.18°C per decade reported increase since the 1960s, and slightly above this in the dry season, and an increase in the number of 'hot days'. The patterns of annual rainfall trends are more uncertain, with some areas experiencing increases and others decreases, although there are indications of increasing variability and increasing extreme rainfall.

The projected temperature increases for Cambodia indicates a further rise of 1°C to 2°C by mid-century. It is difficult to model rainfall changes due to the influence of Monsoon dynamics, but most climate models (and also the downscaled analysis) project increases in annual rainfall by the mid-century (2050s). There is more confidence from the climate models that heavy precipitation events will increase, which would increase the flood risks across the country. Modelling analysis for the Mekong River indicates higher discharge leading to increased floods with greater areas of land and more people at risk of flooding. Modeling of the potential climate change impacts on Tonle Sap Lake and floodplain indicates large possible impacts on the fisheries sectors. For the agriculture sector, Cambodia could suffer the largest reductions in rice yield in Southeast Asia, and large yield reductions are also projected. These could be amplified by the possible increased annual likelihood of drought and by increases in heat and humidity which will reduce labour productivity. There are also projected increases in health impacts, driven by an increase in vector borne disease. Finally, there will be impacts from sea-level rise and storm surge along the 435 kilometers (km) long coastal belt. Economic modelling studies estimate that climate change will reduce Cambodia's total gross domestic product (GDP) by 1.5 to 2.5% by 2030 and 3.5% to 10% by 2050.

2. Country Overview

Cambodia is a country located in the Indochina bordering Thailand in the northwest, Lao PDR in the north and Vietnam in the southeast. It has a total land area of 181,035 square kilometer (km^2) and is the third smallest in the Association of Southeast Asian Nations countries after Singapore and Brunei. There are two large rivers running in Cambodia, the Tonlé Sap River and the Mekong river. The Tonlé Sap River has its headstream in Tonlé Sap Lake, the largest freshwater lake in the Indochina.[5] The Tonle Sap is a vital natural resource, covering almost 10% of the nation's surface area during the peak of the Southwest Monsoon season and constituting the nation's primary protein source. The general landscape character of Cambodia can be described as having low-lying central plains of the Mekong surrounded by mountainous and highland regions.

The population of Cambodia was 16.4 million in 2019. About 76% of its population currently lives in rural areas; nonetheless, the country is experiencing a rapid rate of urbanization. The urban concentration of this population is located in the most fertile river valleys and flood plains characterized by highly predictable consequence of the changes from an agrarian to an urban-industrial pattern of development. Cambodia's population relies heavily on agriculture and fisheries, providing 25% of GDP and employing 49% of the country's labor force. Industry and services form rapidly growing sectors of the economy.

Cambodia is blessed with a rich natural resource base, however, the rate of undernourishment in Cambodia remains high, at around 15%, as does the national poverty rate (**Table 1**). Natural resource dependence is also high. The changes in the dynamics of the Mekong river is expected due to the large scale damming which is ongoing in most of the Mekong countries, may have negative ramifications for livelihoods in Cambodia.

Table 1: Cambodia Key Indicators

Indicator	Value	Source
Population undernourished[6]	14.5% (2017-2019)	FAO, 2020
National poverty rate[7]	12.9% (2018)	ADB, 2020
Net annual migration rate[8]	-0.19% (2015-2020)	UNDESA, 2019
Infant mortality rate (between age 0 and 1)[9]	2.4% (2015-2020)	UNDESA, 2019
Average annual change in urban population[10]	3.25% (2015-2020)	UNDESA, 2018
Dependents per 100 independent adults[11]	55.7 (2020)	UNDESA, 2019
Urban population as % of total population[12]	24.2% (2020)	CIA, 2020
External debt ratio to GNI[13]	58.2% (2018)	ADB, 2020b

[5] Tep, M. 2016. *Cambodia Country Profile: An Overview of Spatial Policy in Asian and European Countries*. Ministry of Land, Infrastructure, Transport and Tourism, Japan.
[6] FAO, IFAD, UNICEF, WFP, WHO (2020). The state of food security and nutrition in the world. Transforming food systems for affordable healthy diets. FAO. Rome. URL: http://www.fao.org/documents/card/en/c/ca9692en/
[7] Asian Development Bank (ADB). 2020. Poverty data: Cambodia. Available at: https://www.adb.org/countries/cambodia/poverty [accessed 17/12/20]
[8] United Nations Department of Economic and Social Affairs (UNDESA). 2019. World Population Prospects 2019: MIGR/1. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 17/12/20]
[9] UNDESA 2019. World Population Prospects 2019: MORT/1-1. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 17/12/20]
[10] UNDESA. 2019. World Urbanization Prospects 2018: File 6. URL: https://population.un.org/wup/Download/ [accessed 17/12/20]
[11] UNDESA. 2019. World Population Prospects 2019: POP/11-A. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 17/12/20]
[12] Central Intelligence Agency (CIA). 2020. *The World Factbook.* Washington DC. URL: https://www.cia.gov/the-world-factbook/
[13] ADB. 2020. Key Indicators for Asia and the Pacific 2020. Asian Development Bank. URL: https://www.adb.org/sites/default/files/publication/443671/ki2018.pdf

Indicator	Value	Source
Government expenditure ratio to GDP[14]	21.5% (2019)	ADB, 2020b

Source: The Word Bank and ADB (forthcoming). Climate Risk Profile: Cambodia.

The Royal Government of Cambodia launched the first Climate Change Strategic Plan 2014-2023 (CCCSP) in 2013. The CCCSP captures the main strategic objectives and directions for climate-smart development in Cambodia over the next 10 years. Cambodia's Nationally Determined Contribution (2016) further established the country's commitment to its mitigation and adaptation efforts. These documents build synergies with existing government policies to ensure strategic cohesion to address a wide range of climate change issues linked to adaptation, greenhouse gas mitigation, and low-carbon development. Cambodia's Second National Communication to the UNFCCC (NC2) 2016 identifies the impacts of climate change in Cambodia upon human lives and the expected significant damage to economic development and natural resources.[15] These include intensified floods, droughts, saline intrusion, and extreme weather events. Cambodia remains highly vulnerable to the impacts of climate change due to its high dependency on climate-sensitive sectors such as agriculture, water resources, forestry, fisheries, tourism, etc., which form the critical foundation of its economic growth and support the livelihoods of a great majority of its population. Cambodia's NC2 outlines its measures to mitigate and adapt to climate change and related plans, programs, and projects in these areas; financial commitments, technology transfer and international cooperation; systematic research and observation; education, training, and public awareness; and constraints, gaps and related financial, technical and capacity needs.[16]

Figure 1: Map of Cambodia

Source: Royal Government of Cambodia. 2016. Cambodia's Second National Communication submitted under the UNFCCC.

[14] ADB. 2020. Key Indicators for Asia and the Pacific 2020. Asian Development Bank. URL: https://www.adb.org/sites/default/files/publication/443671/ki2018.pdf

[15] Royal Government of Cambodia. 2016. Cambodia's Second National Communication submitted under the UNFCCC. URL: https://unfccc.int/sites/default/files/resource/khmnc2.pdf

[16] Ibid

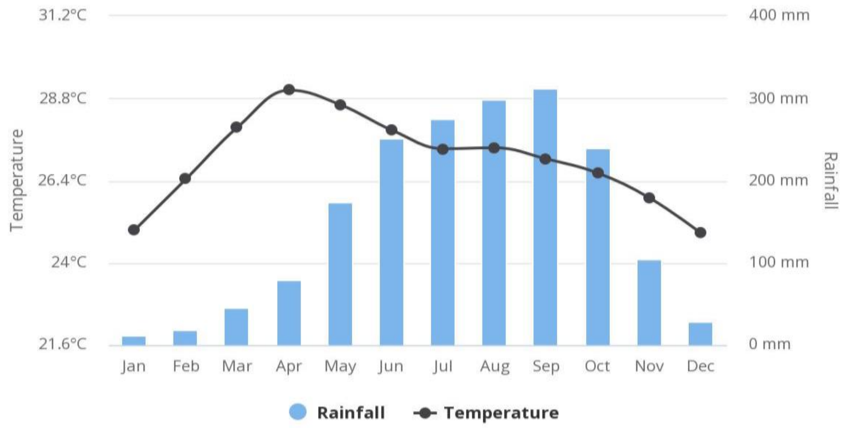
3. Climatology

Cambodia has a tropical monsoon driven climate, with high temperatures, and two distinct seasons: a monsoon-driven rainy season (May-October) with south-westerly winds ushering in clouds and moisture that accounts for between 80-90% of the country's annual precipitation, and a dry season (November-April), with cooler temperatures, particularly between November and January. Average temperatures are relatively uniform across the country, but are highest in the early summer months before the rainy season, when maximum temperatures often exceed 32°C. Temperatures are between 25-27°C throughout the rest of the year. The annual average rainfall is typically 1,400-2,000 millimeter (mm). Inter-annual variations in climate result from the El Niño Southern Oscillation, which influences the nature of the monsoons. El Nino events generally bring warmer and drier than average winter conditions across Southeast Asia, while La Niña episodes bring cooler than average conditions. Temperatures in Cambodia are generally consistent throughout the year **(Figure 2),** averaging between 25℃ and 27℃. Average maximum temperatures can reach 38℃ (April) and average minimum temperatures 17℃.

Rainfall in Cambodia varies widely across the country. Average annual rainfall can be as low as 1,400 mm in the central lowlands and as high as 4,000 near the Cardamom mountains and nearby coastal areas in the southwest **(**

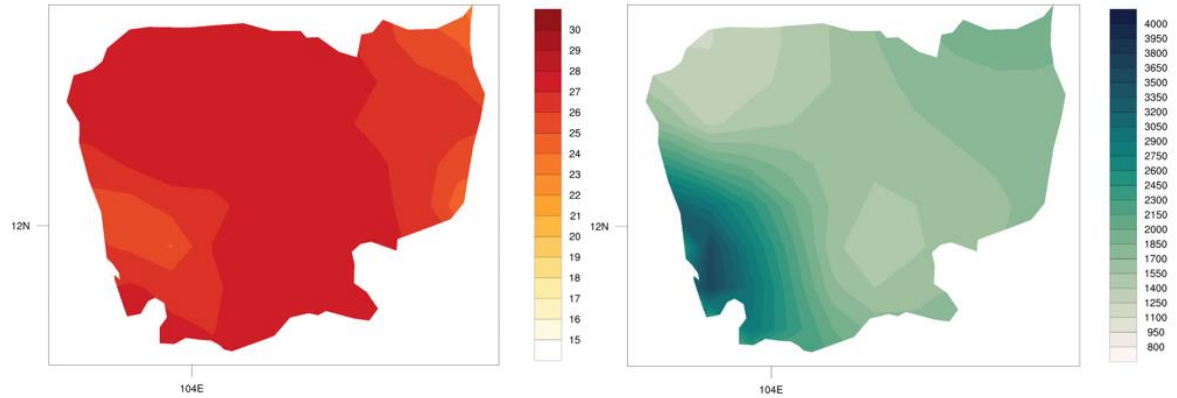
Figure 3). The monsoons deliver approximately three-fourths of the country's annual rainfall and are the primary contributor to the flood-pulse so essential to the region, especially along the central alluvial plains of the Mekong and Tonle Sap Rivers that comprise roughly 80% of the country's landmass. The country's eastern plains receive approximately 2,000 mm to 2,600 mm of rainfall annually and may exceed those amounts in the mountainous areas in the Northeast. Precipitation variability is linked to the El Niño Southern Oscillation phenomenon, with years of strong El Niño correlated with years of moderate and severe drought over the 20th century.

Figure 2: Average monthly temperature and rainfall in Cambodia, 1901–2016



Source: World Bank Group (WBG) Climate Change Knowledge Portal. 2020. Climate Data: Historical.

Figure 3: Annual Mean Temperature (left), and Annual Mean Rainfall (mm) (right) in Cambodia, 1901–2016



Source: WBG Climate Change Knowledge Portal. 2020. Climate Data: Historical.

Climate trends

Observations show that the climate of Cambodia is changing.[17] There is a clear warming trend, with 0.18°C per decade reported increase since the 1960s[18], and slightly above this level of warming in the dry season, at 0.20℃ to 0.23℃ per decade. The number of 'hot days' has increased over the last century, by as much as 46 days per year. The patterns of annual rainfall trends are more uncertain, with some areas experiencing increases and others decreases, although there are indications of increasing variability and increasing extreme rainfall.

Future climate change projections

Future climate change projects presented below are based on compiled climate model projections. A number of studies have been considered, but the data focuses on the information from World Bank climate portal data. This uses multi-model data from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) included in the IPCC's Fifth Assessment Report (AR5). The data is derived from 35 available global circulation models (GCMs) used by the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report. Data and downscaled through bi-linear interpolation.[19]

Table 2 and **Table 3)**. Projections for future temperature change are presented as the changes (or anomalies) in maximum and minimum temperatures, as well as changes in the average temperature. By mid-century (2050s) a further rise of broadly 1°C to 2°C (central estimate),

[17] National Council for Sustainable Development Kingdom of Cambodia. 2015. 2nd National Communication to the UNFCCCC.
[18] UNDP. 2012. UNDP Climate Change Country Profiles: Cambodia. United Nations Development Program. URL: https://www.geog.ox.ac.uk/research/climate/projects/undp-cp/UNDP_reports/Cambodia/Cambodia.hires.report.pdf
[19] World Bank. 2021. Metadata for the Climate Change Knowledge Portal. https://climateknowledgeportal.worldbank.org/themes/custom/wb_cckp/resources/data/CCKP_Metadata_Final_January2021.pdf

relative to a baseline 1986–2005 period is projected, depending on scenario and model. Temperature is projected to rise after this time under high emission scenarios (with no global mitigation), and could reach nearly 4°C (central estimate) by the end of the century. There are projected increases in hot and very hot days.

Table 2: An overview of temperature change (ºC) projected for Cambodia over different time horizons, emissions pathways, and measures of temperature, showing the median estimates of the full CCKP model ensemble and the 10th and 90th percentiles in brackets

Scenario	Average Daily Maximum Temperature		Average Daily Temperature		Average Daily Minimum Temperature	
	2040–2059	2080–2099	2040–2059	2080–2099	2040–2059	2080–2099
RCP2.6	0.8 (-0.5, 2.7)	1.1 (-0.5, 2.8)	0.9 (-0.1, 2.3)	1.0 (-0.2, 2.3)	1.0 (-0.1, 2.0)	1.0 (-0.2, 2.1)
RCP4.5	1.3 (-0.3, 3.1)	1.7 (0.2, 3.8)	1.3 (0.1, 2.6)	1.8 (0.6, 3.3)	1.4 (0.2, 2.4)	1.9 (0.7, 3.1)
RCP6.0	1.1 (-0.5, 2.8)	2.2 (0.5,4. 2)	1.1 (0.0, 2.4)	2.2 (0.8, 3.8)	1.2 (0.0, 2.2)	2.3 (0.8, 3.6)
RCP8.5	1.7 (0.0, 3.5)	3.6 (1.5, 6.0)	1.7 (0.5, 3.1)	3.7 (2.1, 5.5)	1.8 (0.6, 2.9)	3.8 (2.2, 5.4)

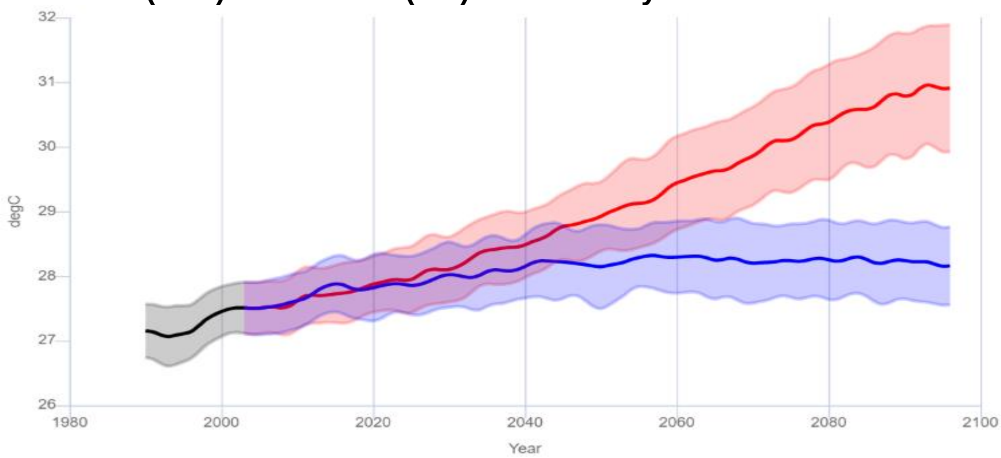
Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections*.

Table 3: Projections of average temperature change (ºC) in Cambodia for different seasons (3-monthly time slices) over different time horizons and emissions pathways, median estimates of full CCKP model ensemble and the 10th and 90th percentiles in brackets

Scenario	2040–2059		2080–2099	
	Jun-Aug	Dec-Feb	Jun-Aug	Dec-Feb
RCP2.6	0.8 (0.5, 1.3)	0.9 (0.4, 1.5)	0.8 (0.4, 1.5)	0.9 (0.3, 1.9)
RCP4.5	1.1 (0.9, 1.5)	1.2 (0.5, 2.2)	1.5 (1.2, 2.4)	1.7 (0.7, 3.1)
RCP6.0	1 (0.7, 1.4)	1 (0.6, 1.6)	1.9 (1.5, 2.7)	2 (1.1, 3.1)
RCP8.5	1.5 (1.2, 2)	1.6 (1, 2.5)	3 (2.7, 4.7)	3.1 (2.2, 5.2)

Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections*.

Figure 4: Historic and projected average annual mean temperature in Cambodia under RCP2.6 (blue) and RCP8.5 (red) estimated by the model ensemble

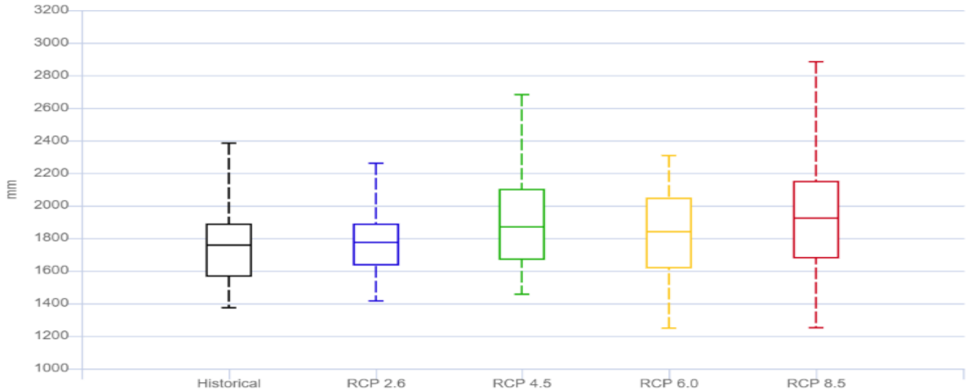


Note: Shading represents the standard deviation of the model ensemble.

Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections*.

Precipitation Changes. There is lower confidence in the changes in precipitation, because it is extremely difficult to model rainfall changes in Cambodia. The climate models generally project modest changes in rainfall by the mid-century (2050s), with an increase in annual precipitation rates, and larger changes under higher emissions pathways. However, uncertainty in precipitation trends remains high as reflected in the range of model estimates **(Figure 5).**

Figure 5: Projected average annual precipitation (mm) for Cambodia, 2080-2099



Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections*.

This uncertainty is also seen in the very limited number of studies applying downscaling techniques to assessing precipitation changes analysis in Cambodia (e.g. Thoeun, 2015[20]). The poor performance of global climate models in consistently projecting precipitation trends has been linked to their poor simulation of the El Niño phenomenon,24[21] an important area for future development.

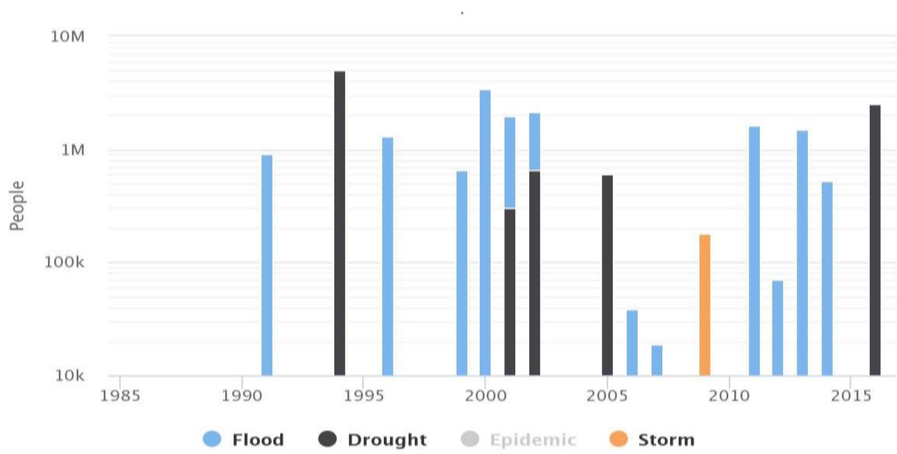
There is more robustness in projections of extreme rainfall events, which increase with temperature. The intensity of sub-daily extreme rainfall events appears to be increasing with temperature, a finding supported by evidence from different regions of Asia.[22]

4. Natural Hazard Risk

Cambodia faces high disaster risk levels from all hydrometeorological event from floods, storms, and droughts. These occur almost every year and frequently affect more than 1 million people.

Figure 6: Number of people affected by disasters, 1985–2018

[20] Heng Chan Thoeun.2015. Observed and projected changes in temperature and rainfall in Cambodia. Weather and Climate Extremes Volume 7, 2015, Pages 61-71, https://doi.org/10.1016/j.wace.2015.02.001.
[21] Yun, K.S., Yeh, S.W. and Ha, K.J. 2016. *Inter-El Niño variability in CMIP5 models: Model deficiencies and future changes.* Journal of Geophysical Research: Atmospheres, 121, 3894-3906.
[22] Westra, S. et.al. 2014. *Future changes to the intensity and frequency of short-duration extreme rainfall*. Reviews of Geophysics, 52, 522–555. 2014.

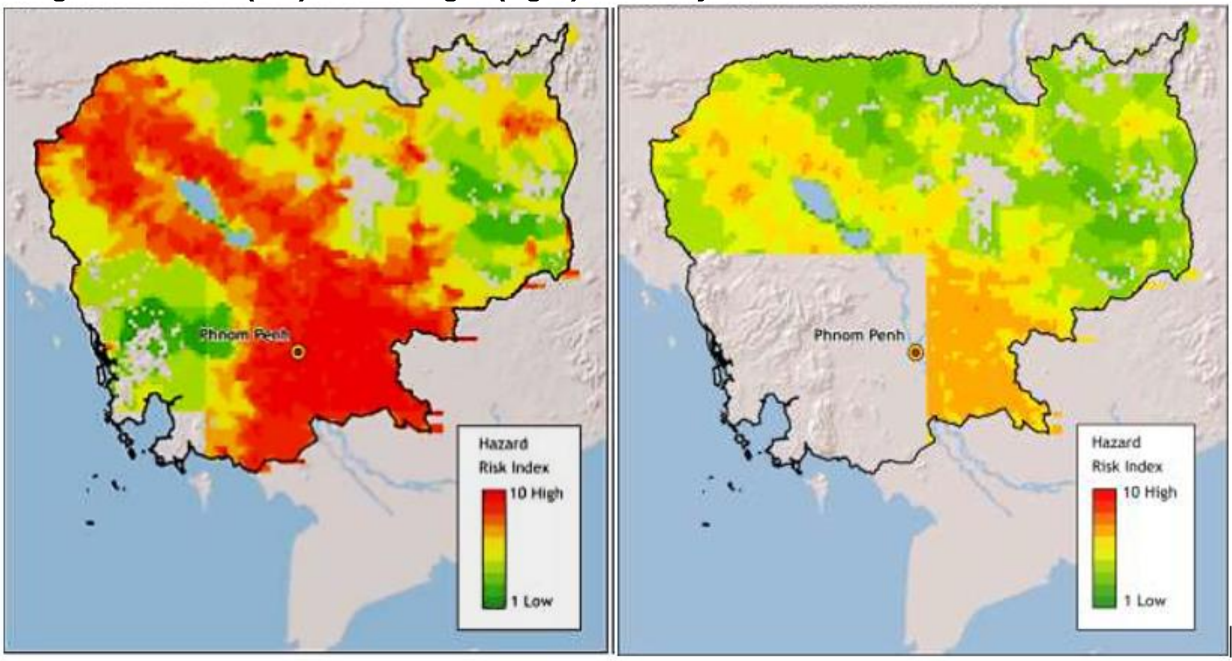


Source: WBG Climate Change Knowledge Portal.

These events lead to high losses, reported at US$1.4 billion over the last twenty years[23] with annual damages of US$100 million to 250 million[24].

Cambodia has extremely high exposure to flooding (and is ranked joint 4th globally by the INFORM 2019 Index[25]), including, riverine and flash flooding. There are also periodic droughts. During the 2015–2016 El Nino drought event, 2.5 million people were affected, and three-quarters of the wet season paddy rice production experienced a loss of more than 25% in yield.[26] Tropical storms are rare, though in 2009 Typhoon Ketsana had a large impact ($132 million in Cambodia, UNDRR, 2019).

Figure 7: Flood (left) and drought (right) mortality risk and distribution: 1981–2000



Note: Figures shown are from Columbia University Center for Hazards and Risk Research and Columbia University Center for International Earth Science Information Network.
Source: United States Agency for International Development (USAID). 2019. Cambodia Climate Risk Profile.

[23] DesInventar. 2021. Disaster loss data for Sustainable Development Goals and Sendai Framework Monitoring System. https://www.desinventar.net/; and EM-DAT (2021). The Emergency Events Database - Universite catholique de Louvain (UCL) - CRED, https://emdat.be/.
[24] UNDRR. 2019. Disaster Risk Reduction in Cambodia PDR. Status Report 2019.
[25] European Commission. 2019. *INFORM Index for Risk Management: Cambodia Country Profile*.URL: https://drmkc.jrc.ec.europa.eu/inform-index/Countries/Country-Profile-Map
[26] World Bank. 2017. Cambodia - Sustaining strong growth for the benefit of all. Washington, D.C. https://hubs.worldbank.org/docs/imagebank/pages/docprofile.aspx?nodeid=27520556

Flood. There is good agreement among models that there will be increasing intensity of extreme precipitation events, increasing the risk of surface (pluvial) flooding, associated impacts include infrastructural damage in urban environments, and landslide risk in rural areas. Paltan et al. (2018) demonstrate that even under lower emissions pathways, consistent with the Paris Climate Agreement, almost all Asian countries face an increase in the frequency of extreme river flows.[27] What would historically have been a 1 in 100-year flow, could become a 1 in 5- year or 1 in 25-year event in most of South, Southeast, and East Asia.

The World Resources Institute's AQUEDUCT Global Flood Analyzer can be used to establish a baseline level of flood exposure. As of 2010, assuming protection for up to a 1 in 25-year event, the population annually affected by flooding in Cambodia is estimated at 90,000 people and expected annual urban damage is estimated at $105 million. Economic development and climate change are both expected to increase these figures. The climate change component can be isolated and by 2030 is expected to increase the annually affected population by 70,000 people, and urban damage by $226 million under the RCP8.5 emissions pathway (AQUEDUCT Scenario B).

In terms of the proportion of the population affected Cambodia is one of the world's most flood exposed countries in the world.[28] Willner et al. (2018) suggest that around 4 million people, or 25% of the population, are affected when an extreme river flood strikes (**Table 4**).[29] Another study conducted by the World Bank put the increase in the population exposed to flood by 2050 at 19%.36[30] The UNISDR estimate that Cambodia experiences over $250 million in average annual losses (just over 1% of GDP). Vastila et al. (2010) show that increases in rainfall during the wet season (i.e. increasing extremes) resulting from climate change have strong potential to increase the peak discharge of the Mekong river and hence increase the population exposed to river flooding in the vicinity of its floodplains.[31] However, the impact of upstream hydropower development along the Mekong and its tributaries may act to offset the climate change signal, causing dry season flows to increase and wet season flows to reduce.[32]

Table 4: Estimated number of people in Cambodia affected by an extreme river flood in the historic period 1971-2004 and the future period 2035–2044

Estimate	Population exposed to extreme flood (1971–2004)	Population exposed to extreme flood (2035–2044)	Increase in affected population
16.7 Percentile	4,035,515	4,219,445	183,930
Median	4,239,603	4,413,765	174,162
83.3 Percentile	4,369,511	4,567,258	197,747

Note: Extreme river flood is defined as being in the 90th percentile in terms of numbers of people affected. Figures represent an average of all four RCPs and assume present day population distributions.

[27] Paltan, H., et.al. *Global implications of 1.5°C and 2°C warmer worlds on extreme river flows Global implications of 1.5°C and 2°C warmer worlds on extreme river flows.* Environmental Research Letters, 13. 2018. https://doi.org/10.1088/1748-9326/aad985. URL: https://www.researchgate.net/publication/326964132_Global_implications_of_15_C_and_2_C_warmer_worlds_on_extreme_river_flows

[28] Kundzewicz, Z. W. et.al. *Flood risk and climate change: global and regional perspectives.* Hydrological Sciences Journal,59(1),1–28. 2014. URL: https://www.tandfonline.com/doi/full/10.1080/02626667.2013.857411

[29] Willner, S., Levermann, A., Zhao, F., Frieler, K. *Adaptation required to preserve future high-end river flood risk at present levels*. Science Advances: 4:1. 2018. URL: https://advances.sciencemag.org/content/4/1/eaao1914

[30] Winsemius, H. C., et.al. 2015. *Disaster risk, climate change, and poverty: assessing the global exposure of poor people to floods and droughts* (English). Policy Research working paper; no. WPS 7480. Washington, D.C.: World Bank Group. URL: http://documents.worldbank.org/curated/en/965831468189531165/pdf/WPS7480.pdf

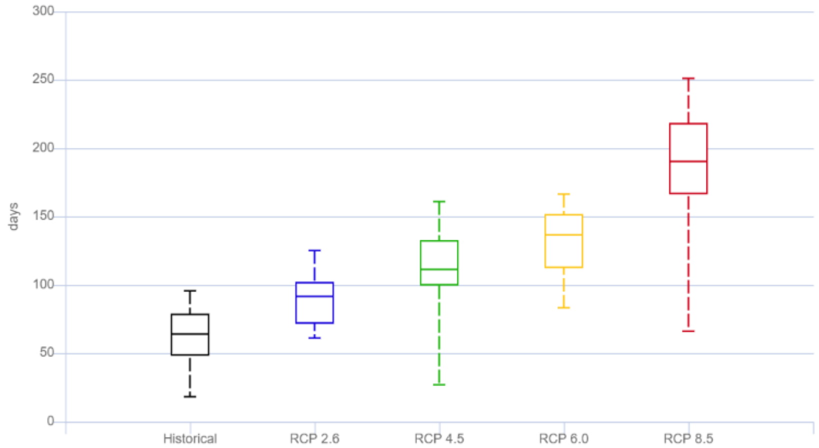
[31] Vastila, K., Kummu, M., Sangmanee, C., & Chinvanno, S. 2010. *Modelling climate change impacts on the flood pulse in the Lower Mekong floodplains.* Journal of Water and Climate Change, 1(1), 67–86. URL: https://iwaponline.com/jwcc/articleabstract/1/1/67/31006/Modelling- climate-change-impacts -on-the-flood?redirectedFrom=fulltext

[32] Lauri, H., et.al. 2012. *Future changes in Mekong River hydrology: impact of climate change and reservoir operation on discharge.* Hydrology and Earth System Sciences, 16(12), 4603–4619. URL: https://www.hydrol-earth-syst-sci.net/16/4603/2012/

Heat Waves. Cambodia already experiences very high temperatures by global levels, with an estimated national average of 64 days per year when the maximum temperature exceeds 35ºC. The current median probability of a heat wave (defined as a period of 3 or more days where the daily temperature is above the long-term 95th percentile of daily mean temperature) is around 3%.[17] An increase in the frequency and intensity of heatwaves has been observed across recent decades. Thirumalai et al. (2017) suggest climate change made a 29% contribution to the extreme temperatures experienced across Southeast Asia in April 2016, while ENSO contributed 49%.[33] There is sufficient existing data to infer that Cambodia also faces a transition to a state of permanent heat stress as a result of temperatures which regularly surpass levels safe for humans and biodiversity.

While heatwaves refer to the occurrence of exceptionally high heats (based on a static baseline), the incidence of permanent (chronic) heat stress is likely to increase significantly in Cambodia under all emissions pathways. At the national level the extent of this risk can be captured in the prevalence of days with Heat Index >35ºC, this represents the combination of temperature and humidity to produce dangerous conditions for human health. As shown in Figure 8, the average annual frequency of dangerous days is expected to increase under all emissions pathways by the 2090s, with a particularly large potential increase under the highest emissions pathway, RCP8.5.

Figure 8: Box plots showing historical (1986–2005) and projected (2080–2099) average annual frequency of days with Heat index >35ºC



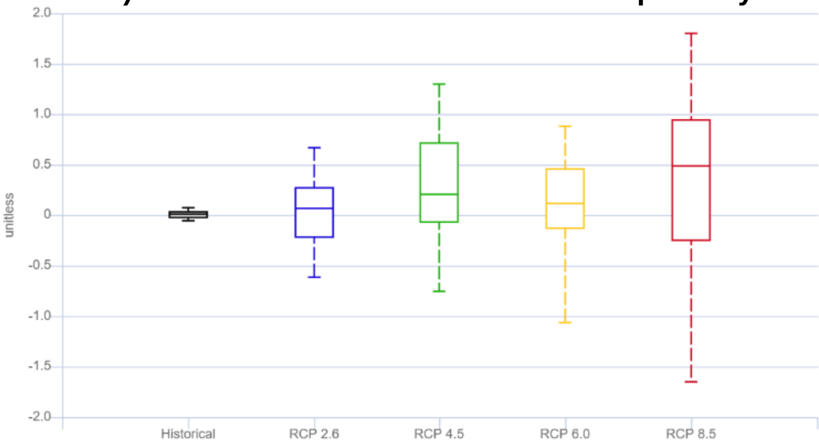
Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical*. https://climateportal.worldbank.org.

Drought. Two primary types of drought may affect Cambodia, meteorological (usually associated with a precipitation deficit) and hydrological (usually associated with a deficit in surface and subsurface water flow, potentially originating in the region's wider river basins). At present Cambodia faces an annual median probability of severe meteorological drought of around 4%,[34] as defined by a standardized precipitation evaporation index (SPEI) of less than -2. Naumann et al. (2018) provide a global overview of changes in drought conditions under different warming scenarios.[35] Projections for Southeast Asia suggest that the return periods of droughts will be reduced. This trend is less significant under lower levels of global warming, but once warming reaches 2-3ºC events that presently occur only once every hundred years may return at frequencies greater than once in every fifty years. **Figure 9** shows the model ensemble's projection of drought probability for the period 2080–2099 in Cambodia under

[33] Thirumalai, K., DiNezio, P. N., Okumura, Y., & Deser, C. 2017. *Extreme temperatures in Southeast Asia caused by El Niño and worsened by global warming*. Nature Communications: 8: 15531. URL: https://www.nature.com/articles/ncomms15531
[34] Ibid.
[35] Naumann, G., et.al. *Global Changes in Drought Conditions under Different Levels of Warming*. Geophysical Research Letters, 45(7), 3285–3296. 2018. URL: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017GL076521

different emissions pathways. Uncertainty remains high, but all emissions pathways indicate an increase in median annual probability from 4% to 5–9%.

Figure 9: Annual probability of experiencing a 'severe drought' in Cambodia (-2 SPEI index) in 2080–2099 under four emissions pathways



Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical*. https://climateportal.worldbank.org.

Cyclone and Storm Surge. 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. The 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.3[36] This is broadly supported by recent trends over Southeast Asia, which have seen cyclone activity moving eastward and away from the Mekong Basin. Consequences include a reduction in peak runoff volumes, and hence a reduction in sediment transport.40[37] 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. Cambodia's coastal zones are known to hold exposure to cyclone and tsunami-induced storm surge, albeit at lower levels than a number of other Southeast Asian nations.

5. Climate Change Impacts

Due to a combination of political, geographic, and social factors, Cambodia is vulnerable to climate change impacts, ranked 140th out of 181 countries in the 2018 ND-GAIN Index.[38] The nation scored low in the combined risk factor affecting the agricultural capacity and also low scores in social readiness, particularly in education and innovation indicators.

[36] Walsh, K. et al. 2015. *Tropical cyclones and climate change.* WIREs Climate Change: 7: 65-89. URL: https://onlinelibrary .wiley.com /doi/full/ 10.1002 /wcc.371

[37] Darby, S. E., et.al. 2016. *Fluvial sediment supply to a mega-delta reduced by shifting tropical-cyclone activity.* Nature, 539(7628), 276–279. https://www.ncbi.nlm.nih.gov/pubmed/27760114

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

Notre-Dame GAIN Index Ranking (2018)	
140th	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 (University of Notre-Dame, 2018).

Water. Water resources in Cambodia are in a state of flux as a result of major human development interventions impacting on the Mekong River and Tonle Sap Lake. Various have shown that a lack of modern irrigation infrastructure is holding back agricultural production in Cambodia, and potentially enhancing the nation's vulnerability to climatic extremes.[39] Cambodia is simultaneously highly dependent on the resources provided by the natural river flow regime and the flood regime. In a context of dramatic changes to future water flows, likely exacerbated by climate change, a key focus area discussed in Cambodia's NC2 is on maintaining the flow levels necessary to sustain ecosystem services. As discussed in the UNDP's overview of climate change impacts on the water sector a failure to maintain the necessary productivity of the ecosystem supporting Cambodia's inland fisheries would represent a major threat to the nation's primary source of protein.[40] Similarly, with a large proportion of the Cambodian population still dependent on natural water sources for domestic consumption, drought and other reductions to the natural water supply could have serious human consequences.

The Tonle Sap lake is a unique and vital natural resource in Cambodia. The lake's complex hydrological interactions with the Mekong river make it vulnerability to changes in the Mekong river basin, including development-focused interventions taking place in upstream nations as well as climate change. ENSO also has an inter-annual influence over the hydrological regime.[41] The ongoing damming of the Mekong is likely to very significantly alter the services provided by the lake.[42] Research shows that alterations to the tropical cyclone regime over the Mekong Basin, driven by climate change, may be having an impact on its hydrological flows.[43] Any climate changes which modify the flood pulse which feeds the Tonle Sap Lake during the peak monsoon season will have significant implications for its unique wetlands, forest and aquatic ecosystems.[44]

Sea Level Rise

Rising sea levels could pose a significant threat to coastal areas in Cambodia, which already suffer from storm surges, high tides, beach erosion, and seawater intrusion.

Sea-level rise threatens significant physical changes to coastal zones around the world. Global mean sea-level rise was estimated in the range of 0.44-0.74 m by the end of the 21st

[39] Chun, J. A., et.al. 2016. *Assessing rice productivity and adaptation strategies for Southeast Asia under climate change through multi-scale crop modelling*. Agricultural Systems, 143, 14–21.URL: https://koreauniv.pure.elsevier.com/en/publications/assessing-rice-productivity-and-adaptation-strategies-for-southeast

[40] United Nations Development Program (UNDP). 2011. *Climate change and water resources: Cambodia Human Development Report 2011*. URL: http://hdr.undp.org/sites/default/files/cambodia_2011_nhdr.pdf

[41] Frappart, F., et.al. 2018. *Influence of recent climatic events on the surface water storage of the Tonle Sap Lake*. Science of the Total Environment, 636, pp.1520-1533. URL: https://www.ncbi.nlm.nih.gov/pubmed/29913613

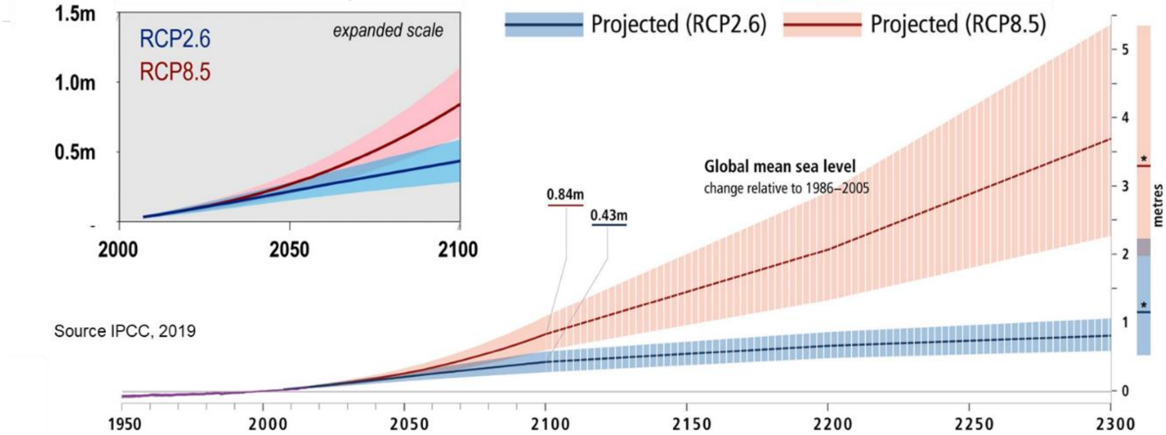
[42] Arias, M. E., et.al. 2014a. *Impacts of hydropower and climate change on drivers of ecological productivity of Southeast Asia's most important wetland.* Ecological Modelling, 272, 252–263. URL: https://research.aalto.fi/en/publications/impacts-of-hydropower-and-climate-change-on-driversof-ecological-productivity-of-southeast-asias-most-important-wetland(52afb37f-9eb0-4fa9-b635-b41ce1076124).html

[43] Darby, S. E., et.al. 2016. *Fluvial sediment supply to a mega-delta reduced by shifting tropical-cyclone activity.* Nature, 539, 276. URL: https://www.ncbi.nlm.nih.gov/pubmed/27760114

[44] Arias, M., Cochrane, T., and Elliot, V. 2014b. *Modelling future changes of habitat and fauna in the Tonle Sap wetland of the Mekong.* Environmental Conservation, 41(2), 165–175.URL: https://www.cambridge.org/core/journals/environmentalconservation/article/modelling-future-changes-of-habitat-and-fauna-in-the-tonle-sap-wetland-of-themekong/7D7092517BEB0FE4740AECB1C77C9984

century by the IPCC's Fifth Assessment Report.[45] More recently, the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate report has reassessed the likely levels of future sea-level rise (SLR).[46] This includes the addition of ice sheet contributions and projects much higher levels of SLR globally. It reports a much higher upper range, with 0.6 to 1.1 meters likely by 2100 under a high-emission scenario, due to the increased ice loss from the Greenland and Antarctic ice sheets. Even under low emission scenarios, it is likely that the coastal areas will experience at least 1-metre of sea level rise over the long-term. Recent expert elicitations[47] raises the possibility of even higher increases under high-emission scenarios, with conceivably 2 meters by 2100. Sea level will continue to rise for centuries, even if the Paris agreement is achieved, due to the thermal inertia of the oceans (the 'commitment to sea-level rise'

Figure 10: Projected global sea level rise



Source: IPCC SROCC (2019).

The impacts of sea-level rise in Cambodia are understudied. While the Cambodian section of the Mekong Delta and Cambodia's western coastline are high enough above sea-level to afford some protection, several studies have suggested that future impacts will be important. For example, the UK Met Office's estimate, puts the population flooded by sea-level rise at a maximum of 30,000 without adaptation by 2070-2100 under RCP8.5,[48] and the World Bank show that 1 meter of sea-level rise (slightly above the RCP8.5 estimate) could flood around 80,0000 people and cost 0.5–1% of GDP.[49] The 2nd National Communication (RGC, 2015) estimates that a total area of about 25,000 hectares will be permanently inundated by a sea level rise of 1 meter. Additional risks require further research, these include issues such as coastal erosion, saltwater intrusion and the impact of changes in the hydrology of the Mekong Delta on Cambodia. Most existing studies focus primarily on the Vietnamese portion of the Delta. These risks must also be viewed in the context of extensive ongoing and proposed damming of the Mekong River and its tributaries.

[45] Church, J. A., et.al. 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

[46] Oppenheimer, M. et al.2019. Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

[47] Bamber, J.L., Oppenheimer, M., Kopp, R.E., Aspinall, W.P. and Cooke, R.M. 2019. Ice sheet contributions to future sea-level rise from structured expert judgment. Proceedings of the National Academy of Sciences, 116(23), 11195, doi:10.1073/pnas.1817205116; and Garner, A.J., Weiss, J.L., Parris, A., Kopp, R.E., Horton, R.M., Overpeck, J.T. and Horton, B.P. 2018. Evolution of 21st Century Sea Level Rise Projections. Earth's Future, 6(11), 1603-1615, doi:10.1029/2018ef000991.

[48] UK Met Office. 2014. *Human dynamics of climate change: Technical Report*. Met Office. DOI: 10.13140/RG.2.1.4095.7525.

[49] Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D., Yan, J. 2007. *The impact of sea-level rise on developing countries: A comparative analysis.* World Bank Policy Research Working Paper 4136.

Table 5: The average number of people experiencing flooding per year in the coastal zone in the period 2070-2100 under different emissions pathways (assumed medium ice-melt scenario) and adaptation scenarios for Cambodia

Scenario	Without adaptation	With adaptation
RCP2.6	9,820	40
RCP8.5	30,660	80

Source: Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D., Yan, J. *The impact of sea-level rise on developing countries: A comparative analysis.* World Bank Policy Research Working Paper 4136. 2007.

Biodiversity, Forestry and Land-use. Cambodia has the highest proportion of forests but also the highest deforestation rate among all Mekong Basin countries.[50] Seasonally flooded forests in the Lower Mekong Basin (LMB) are caused by Cambodia's unique flood pulse and provide important habitat for fish (175), bird (225), reptile (42), and mammal (46) species.56[51] Such landscapes provide for the rich natural resources of Cambodia feeding both wildlife species and as sources of peoples' livelihoods and at the same time, supporting flooded forests, grasslands, and wetlands.

Tonle Sap Lake (TSL), which is one of the biggest inland fisheries in the world, supports the local peoples' agriculture and fisheries and the highly productive biodiversity.[52] Nonetheless, the area is undergoing immense change in its ecological productivity due to climate change, over-fishing, and stream flow alteration from hydropower dams.[53] Human induced impacts; aside from the threats of climate change makes the natural resources management in the country more complex yet less understood by the people taking up much of the resources for their survival needs. Threats imposed on this highly valuable ecosystem in Cambodia's landscape are related to the increment of river discharge expected during flood season and plausibility of severe droughts in the dry season.[54] Such an environment is critical for a large population depending on the resources and services of TSL basin, the national agriculture and food security, terrestrial and freshwater ecosystems, and human health.[55]

Agriculture. On an international level, these impacts are expected to damage key staple crop yields, even on lower emissions pathways. Shifts in the optimal and viable spatial ranges of certain crops are also inevitable, though the extent and speed of those shifts remains dependent on the emissions pathway.[56] In Cambodia's context, agricultural and fishery activities comprise about 27 and 12 percent of GDP respectively and are essential for food security and livelihoods. Agriculture is directly impacted by the conditions of the Tonle Sap Lake and Mekong river. The flows of water in these two systems largely supply the country's freshwater resources for agriculture. Thus, it further influences the Cambodians' survival activities like farming and fisheries for their livelihoods.[57]

[50] Milne, S. 2015. *Cambodia's unofficial regime of extraction: Illicit logging in the shadow of transnational governance and investment*. Crit. Asian Studies, 47, 200–228. 2015; and Potapov, P. et al. 2019. *Annual continuous fields of woody vegetation structure in the Lower Mekong region from 2000-2017 Landsat time-series*. Remote Sensing Environ, 232, 111278.

[51] Kummu, M. and J. Sarkkula. 2008. *Impact of the Mekong river flow alteration on the Tonle Sap flood pulse.* Ambio, 37, 185–192.

[52] Uk S. et al. 2018. *Tonle Sap Lake: current status and important research directions for environmental management.* Lakes Reserve Resource Management, 23(3):177–189. https://doi.org/10. 1111/lre.12222.

[53] Arias, M.E. et al. 2012. *Quantifying changes in flooding and habitats in the Tonle Sap Lake (Cambodia) caused by water infrastructure development and climate change in the Mekong Basin*. Journal of Environmental Management. 112, 53–66.

[54] Oeurng C, et.al. *2018. Assessing climate change impacts on river flows in the Tonle Sap Lake Basin, Cambodia.* Water 11(3):618.https://doi.org/10.3390/w11030618

[55] Institute for Global Environmental Strategies (IGES). 2020. *Environmental Changes in Tonle Sap Lake and its Floodplain: Status and Policy Recommendations*. ISBN: 978-4-88788-230-0

[56] Tebaldi, C., and Lobell, D. 2018. *Differences, or lack thereof, in wheat and maize yields under three low-warming scenarios.* Environmental Research Letters: 13: 065001. URL: https://iopscience.iop.org/article/10.1088/1748-9326/aaba48

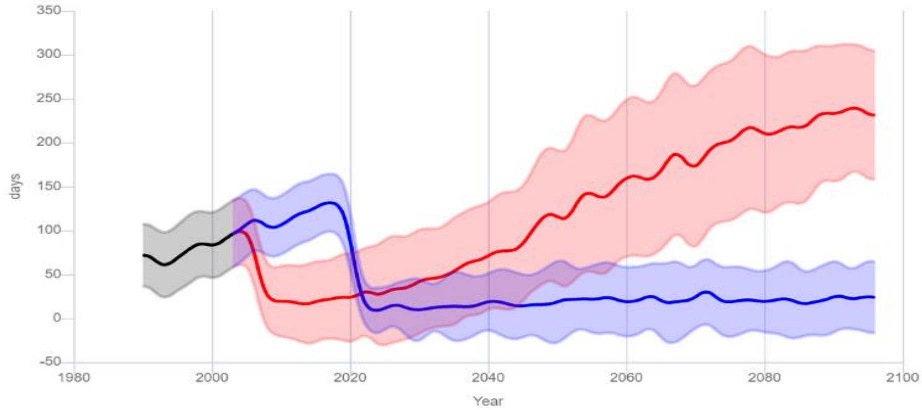
[57] Nguyen, T.T., et al. 2015. *Rural livelihoods and environmental resource dependence in Cambodia*. Ecological Economics. 120, 282–295.; and Sok, S. and Y. Yu. 2015. *Adaptation, resilience and sustainable livelihoods in the communities of the Lower Mekong Basin, Cambodia.* International Journal on Water Resources Development. 31, 575–588.

Rice is a staple crop in Cambodia, crucial to national food security and subsistence livelihoods. Li et al. (2017) suggest that Cambodia faces some of the highest net rice yield losses in Southeast Asia, as a result of climate change.[58] Without adaptation, but with the benefits of increased atmospheric concentrations of CO^2 included, the authors report expected yield losses of 10-15% by the 2040s under both RCPs 4.5 and 8.5. These losses link primarily to increases in the average temperature during the growing season. Li et al. (2017) do suggest, however, that it may be possible to mitigate most of the projected yield losses through adaptations such as changes to the planting date.65[59] A series of studies have looked at the effects of climate change on yields in Cambodia and present negative findings, for example, Kim et al. (2018)[60] projected climate change will reduce rice yields by 13% even by 2030. The vulnerability of Cambodia's rice agriculture is linked particularly to the very high prevalence of rain-fed (rather than irrigated) systems, which are susceptible to damage from both lack and excess of water, but also the temperature tolerance of the crop.

For many households, fishing is the only revenue stream to support essential household expenditures. Given this, fishing serves as the secondary source of income and acts as a vital source of regular revenue, as well as nutrition, for households.[61] The deterioration of fish habitat due to pollution, eutrophication, and forest degradation in seasonally inundated areas contributes to lower fish catches. Increasing pressure in fishing activities results to the changing water levels in the Tonle Sap Lake fishing grounds as observed water is reportedly shallower than the typical level (i.e., 9-10 meters) during the peak flooding season. As a result, the communities' high dependency on fish catch for the daily income further increases their vulnerability to the consequences of continuous disruption to the hydrological cycle.[62]

Figure 11) is likely to increase labour productivity as well as having impacts on water resource and yields.[63] There are, however, significant differences between emissions pathways, with higher emissions scenarios resulting in notably larger increases in daily maximum temperatures (**Figure 12**).

Figure 11: Increase in the annual average number of hot days (>35oC) in Cambodia under two emissions pathways RCP2.6 (blue) and RCP8.5 (red)



[58] Li, S., Q. Wang, & J.A. Chun. 2017. *Impact assessment of climate change on rice productivity in the Indochinese Peninsula using a regional-scale crop model.* International Journal of Climatology, 37(April), 1147–1160. URL: https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/joc.5072

[59] Nguyen, T.T. et al. 2015. *Rural livelihoods and environmental resource dependence in Cambodia*. Ecological Economics. 120, 282–295.

[60] Kim, Jeonghyun; Park, Hojeong; Chun, Jong A.; Li, Sanai. (2018). "Adaptation Strategies under Climate Change for Sustainable Agricultural Productivity in Cambodia" Sustainability 10, no. 12: 4537. https://doi.org/10.3390/su10124537

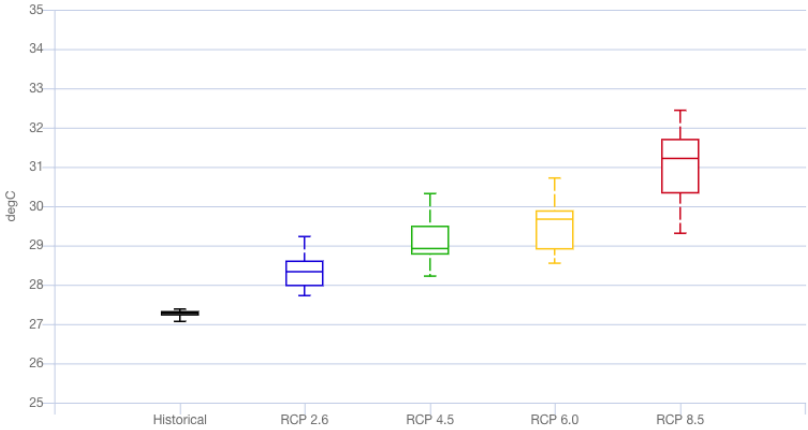
[61] Institute for Global Environmental Strategies (IGES). *Environmental Changes in Tonle Sap Lake and its Floodplain: Status and Policy Recommendations*. 2020. ISBN: 978-4-88788-230-0

[62] Ibid.

[63] Elliott, J. et al. *Constraints and potentials of future irrigation water availability on agricultural production under climate change.* Proceedings of the National Academy of Sciences: 111: 3239–3244. 2014.

Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical*. URL: https://climateportal.worldbank.org.

Figure 12: Average temperature in Cambodia under four emissions pathways over the period 2080-2099



Urban. Cambodia's urban fabric is generally concentrated in the fertile area inundated by waters from both Tonle Sap Lake and Mekong river interface. Cambodia's robust informal economy, which provides employment for nearly 60% of its population through garments production, is directly impacted by the changing climatic conditions. For example, in 2015, adverse climate impacts resulted in losses of approximately $1.5 billion, equivalent to 10% of annual GDP.

The effects of temperature rise and heat stress in urban areas are increasingly compounded by the phenomenon of Urban Heat Island (UHI). Particularly high urban heat island levels have been reported in Cambodia's capital Phnom Penh, with the temperature differential between rural and urban areas reaching as high as 4ºC during the daytime according to Furuuchi et al. (2006).[64] As well as impacting on human health, the temperature peaks that will result from combined UHI and climate change, as well as future urban expansion, are likely to damage the productivity of the service sector economy. These may occur both through direct impacts on labor productivity, but also through the additional costs of adaptation.

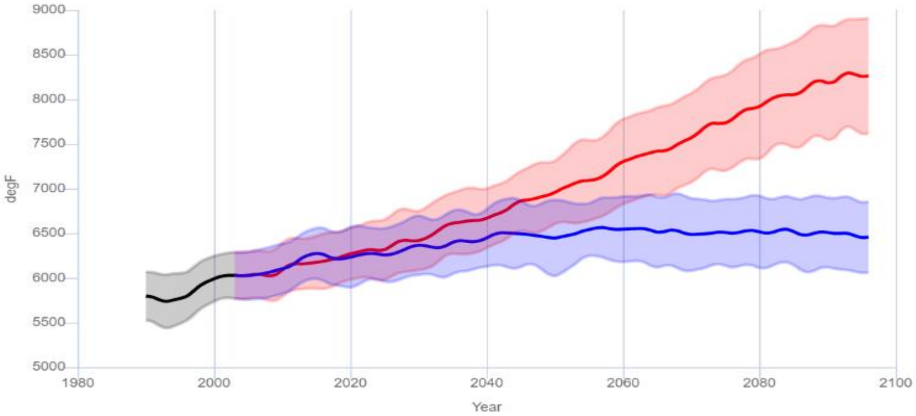
Research suggests that on average a one degree increase in ambient temperature can result in a 0.5-8.5% increase in electricity demand for cooling.[65] This increase in demand places strain on energy generation systems which is compounded by the heat stress on the energy generation system itself, commonly due to its own cooling requirements, which can reduce its efficiency.[66] **Figure 13** highlights the large projected increase in cooling demand in Cambodia, doubling under RCP8.5.

[64] Furuuchi, M., et.al. *Temperature Distribution and Air Pollution in Phnom Penh , Cambodia - Influence of Land Use and the Mekong and Tonle Sap.* Aerosol and Air Quality Research, 6(2), 134–149. 2006. URL: http://www.aaqr.org/article/detail/AAQR-06-06-OA-0003

[65] Santamouris, M., C. Cartalis, A. Synnefa, & D. Kolokotsa. *On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—A review*. Energy and Buildings, 98, 119–124. 2015. URL: https://pdfs.semanticscholar.org/17f8 /6e9c161542a7a5acd0ad500f5da9f45a2871.pdf

[66] Asian Development Bank (ADB). *Climate Change Profile of Pakistan.* Asian Development Bank Publication. 2017. URL: https://www.adb.org/sites/default/files/publication/357876/climate-change-profile-pakistan.pdf

Figure 13: Historic and projected annual cooling degree days in Cambodia (cumulative degrees above 65°F) under RCP2.6 (blue) and RCP8.5 (red)



Note: The values shown represent the median of 32 GCM model ensemble with the shaded areas showing the 10-90th percentiles.
Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical*. URL: https://climateportal.worldbank.org.

Human Health and Nutrition. As of 2014-2016 an estimated 15.3% of the Cambodian population was undernourished (**Table 1**). The World Food Program estimate that without adaptation the risk of hunger and child malnutrition on a global scale could increase by 20% respectively by 2050.[67] Work by Springmann et al. (2016) has assessed the potential for excess, climate-related deaths associated with malnutrition.[68] The authors' projections suggest there could be approximately 59.24 climate-related deaths per million population linked to lack of food availability in Cambodia by the year 2050 under RCP8.5.

Cambodia's direct food security linkage to agriculture and livelihood makes its population vulnerable to changes in these aspects of human health and nutrition. The basic protein source for most of the Cambodians comes from the huge inland fisheries of the Tonle Sap Lake and at the same time with rice production, as the country's staple crop, is largely dependent on the water resources from the seasonal inundation events in the Tonle Sap lake and Mekong river. Changing conditions of the Mekong river and Tonle Sap Lake's water resources have direct impacts on food production, making the nutrition and health risks, especially the poor and other vulnerable sectors of the population, an apparent reality.

Also, with the Cambodian's direct dependence and contact on the freshwater resources, activities such as washing raw food and fish, bathing, hand washing, and swimming are predisposed to the poor quality of water resources due to effluents from toilets in floating villages is discharged directly into the lake due to the lack of facilities for safe storage, treatment and disposal. Such deplorable conditions are further enhanced by the higher risks of infection from waterborne diseases, particularly during the dry season.[69]

For Cambodia, the World Health Organization (WHO,2015)[70] estimated that under a high emission scenario, heat-related deaths in the elderly (65+ years) are projected to increase to

[67] World Food Program. *Two minutes on climate change and hunger: A zero hunger world needs climate resilience.* The World Food Program. 2015. URL: https://docs.wfp.org/api/documents/WFP-0000009143/download/
[68] Springmann, M. et al. 2016. *Global and regional health effects of future food production under climate change: a modelling study.* The Lancet: 387: 1937–1946.URL: https://www.ncbi.nlm.nih.gov/pubmed/26947322.
[69] Ung, P. et al. 2019. D*ynamics of bacterial community in Tonle Sap Lake, a large tropical flood-pulse system in Southeast Asia.* Science of the Total Environment 664: 414-423. doi:https://doi.org/10.1016/j.scitotenv.2019.01.351.
[70] World Health Organisation (WHO). 2015. Climate and Health Country Profile: Cambodia.

about 56 deaths per 100,000 by 2080 compared to the estimated baseline of about 4 death per 100,000 annually between 1961 and 1990.

Climate change pressures, such as increased incidence of drought, extreme rainfall and flood, as well as higher temperatures, represent environmental drivers of vector and water-borne diseases. Higher average, maximum, and minimum temperatures all correlate with greater dengue incidence.[71] WHO (2015) report an increase in dengue transmissibility in Cambodia, as well as rising cases of malaria, with a total number of estimated cases of 22 million annually by 2070.

Cambodia also has exposure to water-related diseases, such as diarrheal diseases, typhoid fever, leptospirosis, melioidosis, viral hepatitis, and schistosomiasis.93[72] While human development in the Mekong Basin may act to regulate flows and floods in Cambodia the climate change driver is likely to increase the intensity of flooding through its impact on precipitation extremes. Disease transmission is known to worsen during and after flood events in Cambodia, demonstrated for example in the spread of diarrheal disease.[73]

Diarrheal disease is a significant health risk for children in Cambodia. UNICEF estimates that around 700 children under five years of age died as a result of diarrheal disease in 2016.[74] This represents around 6% of all under five deaths in Cambodia. While overall deaths are projected to decline significantly, modelling by WHO estimates the change in the number of diarrheal deaths in under fifteen-year-olds attributable to climate change under the A1B scenario in the Southeast Asia region. Climate change is projected to increase the number of deaths in 2030 by around 3–10% and by around 4–14% in 2050.[75] These relationships highlight the need for both further research and adaptation initiatives in public health and other interrelated sectors.

Poverty and Inequality. Many 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.[76] Poorer businesses are least able to afford air conditioning, an increasing need given the projected increase in cooling days. Poorer farmers and communities are least able to afford local water storage, irrigation infrastructure, and technologies for adaptation.

Poverty reduction in Cambodia has been rapid, yet climate change threatens to slow progress. Two key features of progress in Cambodia are highlighted by ADB (2016) first, the rate of poverty decline is broadly outpaced by the rate of GDP growth, indicating that growth is not inclusive and inequality may be growing (data is scarce); second, poverty declines are strongly centered in urban areas, with changes considerably slower in rural areas.[77] Rural areas face some of the most serious climate change threats, for instance a potential increase in ambient temperatures towards levels unsafe for outdoor laborers.

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[71] Choi, Y. et al. 2016. *Effects of weather factors on dengue fever incidence and implications for interventions in Cambodia.* BMC Public Health, 16(1), 1–7.URL: https://www.ncbi.nlm.nih.gov/pubmed/26955944.

[72] McIver, L. J. et al. 2016. *Review of Climate Change and Water-Related Diseases in Cambodia and Findings from Stakeholder Knowledge Assessments.* Asia Pacific Journal of Public Health, 28(2_suppl), 49S–58S.URL: https://journals.sagepub.com/doi/abs/10.1177/1010539514558059.

[73] Davies, G. I. et al. 2015. *Water-borne diseases and extreme weather events in Cambodia: Review of impacts and implications of climate change*. International Journal of Environmental Research and Public Health, 12(1), 191–213.URL: https://www.ncbi.nlm.nih.gov/pubmed/25546280.

[74] UNICEF. 2019. *Data: Diarrhoeal Disease*. https://data.unicef.org/topic/child-health/diarrhoeal-disease/ [accessed 29/01/2019]

[75] World Health Organization (WHO). 2014. *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s.* https://www.who.int/globalchange/publications/quantitative-risk-assessment/en/

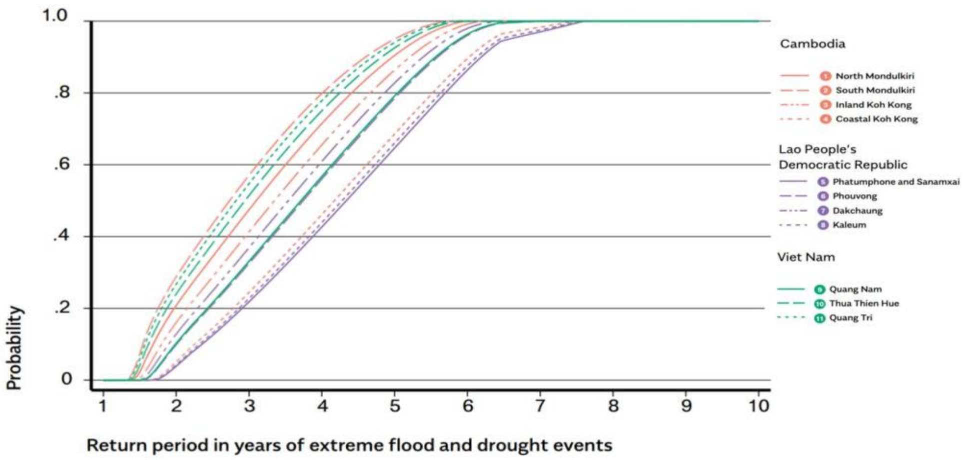
[76] Kjellstrom, T. et.al. 2016. *Heat, human performance, and occupational health: A key issue for the assessment of global climate change impacts.* Annual Review of Public Health: 37: 97-112. https://www.ncbi.nlm.nih.gov/pubmed/26989826

[77] ADB. 2016. *Measuring multidimensional poverty in three Southeast Asian countries using ordinal variables.* ADBI Working Paper Series No. 618. https://www.adb.org/sites/default/files/publication/214871/adbiwp618.pdf

As subsistence agriculture remains prevalent in Cambodia, and rates of undernourishment high, the threat of yield reductions in staple crops and the potentially high cost of adaptation also represent major risks. While climate change is only one of many pressures on livelihoods in the vicinity of the Tonle Sap Lake, the low adaptive capacity of rural communities in this area, particularly their limited ability to diversify income sources, demands attention.[78] Ultimately, research has shown that if increases in environmental stressors make traditional livelihoods less stable or tenable migration is likely to result.[79] Migration may take many forms: migration from rural to urban areas is already happening at a rapid pace, as is international migration. Without adequate planning such migration can often lead to the transfer or creation of new types of risk.

Work by ADB (2017) suggests that many households in Cambodia have a high probability of falling into extreme poverty even when exposed to relatively low intensity flood and drought events.[80] For example, an event at a frequency of once in every three years impacting in the four highly exposed communities analyzed by ADB (**Figure 14**) has approximately a 50% chance of pushing a household into extreme poverty. This highlights the precarious nature of life in Cambodia for many households even under current conditions. While many households will not have the same level of exposure, climate change threatens to enhance and expand exposure through its impacts on extreme events.

Figure 14: Probability of falling into extreme poverty by return period of combined flood and drought events



Source: ADB. 2017. Risk financing for rural climate resilience in the greater Mekong subregion. Greater Mekong Subregion Core Environment Program. P. 30,d.

Economic impact of climate change

Economic modelling studies have been undertaken to assess the impact of climate change in Cambodia. The UNDP analysis uses a Climate Economic Growth Impact Model (CEGIM) to scientifically compute the estimated of the impact of climate change on Cambodia's economic development in the medium and long terms. Without climate change, CEGIM projects that real GDP will grow at an average of 6.9% per year from 2017 to 2060. Its projects that climate

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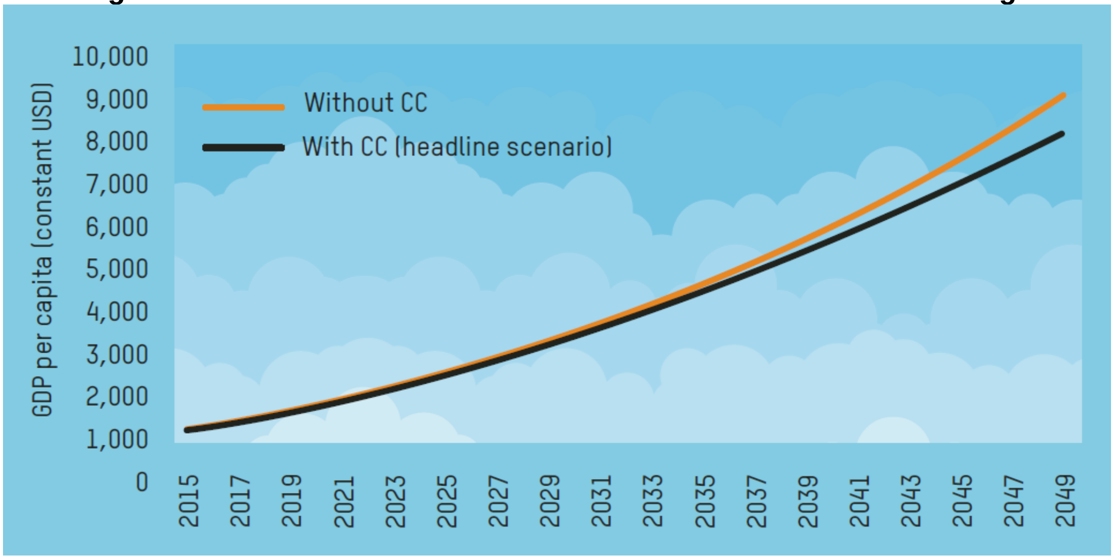
78 Nuorteva, P., M. Keskinen and O. Varis. 2010. *Water, livelihoods and climate change adaptation in the Tonle Sap Lake area, Cambodia: Learning from the past to understand the future.* Journal of Water and Climate Change, 1(1), 87–101. https://research.aalto.fi/en/publications/water-livelihoods-and-climate-change-adaptation-in-the-tonle-sap-lake-area-cambodialearning-from-the-past-to-understand-the-future(08b8d642-b3ea-41e4- 9a20-d4db9265e67d)/export.html

79 Bylander, M. 2015. *Depending on the Sky: Environmental Distress, Migration, and Coping in Rural Cambodia.* International Migration, 53(5), 135–147. https://onlinelibrary.wiley.com/doi/abs/10.1111/imig.12087

80 ADB. 2017. Risk financing for rural climate resilience in the greater Mekong subregion. Greater Mekong Subregion Core Environment Program. Asian Development Bank. P. 30. https://www.adb.org/sites/default/files/publication/306796/riskfinancing-rural-climate-resilience-gms.pdf

change reduces average GDP growth to 6.6% and reduces absolute GDP by 0.4% in 2020, 2.5% in 2030 and 9.8% in 2050, under a RCP4.5 Scenario.[81]

Figure 15: Gross Domestic Product with and without climate change



Source: UNDP (2018). Addressing Climate Change Impacts on Economic Growth in Cambodia

[81] Royal Government of Cambodia (RGC). 2015. "Climate Change Financing Framework."; and UNDP (2018). Modelling of Climate Change Impacts on Growth. https://www.kh.undp.org/content/cambodia/en/home/library/environment_energy/modelling-of-climate-change-impacts-on-growth.html

D. INDONESIA CLIMATE RISK PROFILE (80cm-2,90m)

1. Summary of Climate Rationale

Indonesia, the world's largest archipelagic nation, has high exposure to extreme climate events such as coastal and river flooding, tropical cyclones, and heatwaves. Between 2005 and 2015, Indonesia recorded more than 1,800 disaster events. Poor and vulnerable households in rural and urban areas are particularly exposed to these shocks as they often occupy and live off the marginal land, such as low-lying coastal zones and flood plains, and suffer from the lack of access to good quality infrastructure and services. Prior to coronavirus disease (COVID-19), an estimated 61.8 million people, or 21.5% of the population, were considered poor or have a high risk of falling into poverty, making them vulnerable to shocks. This figure is likely to be significantly higher post COVID-19 impacts. Roughly 7% of urban population live below the poverty line and almost equal percentage of population live just above the poverty line. The impact of extreme events and climate variability on livelihoods and food security is a particular concern. Nationally, roughly 40 percent of livelihoods are dependent on agriculture, however in some areas, such as East Nusa Tenggara, rural households' have a historically much higher dependence on agriculture, and here food security related concerns such as malnutrition is very high.

The geography of Indonesia means that changes in climate are highly variable across the country, and historic observations are generally only available from the larger islands such as Sumatra and Borneo. However, some general trends are present. The mean annual temperature of the country has increased by 0.3ºC since 1900 with an annual temperature rise of 0.04ºC per decade recorded during 1985-2015. Since 1960, hot days and nights have increased by 88 and 95 per annum, respectively. Projections for annual average temperature rise for Indonesia are 3ºC under the RCP8.5 emissions pathway by 2080-2099. Under the same pathway and time-period, the annual averages of monthly maximum and minimum temperatures are projected to increase greater than annual average temperatures, 3.8ºC and 3.5ºC, respectively. Warming projections suggest a rise of ambient temperatures from approximately 26.5ºC towards 29-30ºC, significantly increasing the frequency of days >30ºC. Considering the limitation of some current models, this can be considered a conservative estimate. Future rainfall projections are more uncertain than temperature, however they suggest increases in median annual rainfall under all emissions pathways – an increase of 7% under RCP6.0 pathway and 11% under RCP8.5 pathway, from the historical baseline median of 2884 mm. Considering global trends, the intensity of sub-daily extreme rainfall is likely to increase with temperature, although there will be considerable variability regarding spatial and temporal distribution. Conservative estimates assume a sea-level rise of 10 cm by 2030 and 21 cm by 2060.

Annual losses as a result of climate change in Indonesia are projected to be more than 6% of GDP by 2100, more than double the global average loss. The rural and urban poor will bear the brunt of the climate change burden as poorer households in Indonesia are much less likely to take adaptive measures and plan for longer-term horizons than wealthier households, making them more exposed to environmental shocks and disasters. Indonesia is particularly vulnerable to sea-level rise. With the country ranked the fifth highest in terms of population inhabiting the lower elevation coastal zone, large numbers of Indonesians face amplified coastal flood risk, particularly the urban poor living in low-lying cities. Coastal areas are already exposed to permanent inundation, high tides and land subsidence, affecting settlements, rice fields, ponds and harbours/airports. It is estimated that by 2030 around 5.5-8 million people could reside in a 100-year floodplain (an area exposed to 1-in-100-year coastal floods resulting from storm surges), growing to 9.5 – 14 million by 2060. The number of Indonesians exposed to river flood risk could also increase by up to 75% in four decades between 2015 and 2055. Indonesia is positioned as one of the most vulnerable countries to potentially extreme heatwaves according to climate model projections, risking increased loss of life and productivity losses due to heat stress of both manual labor and crop yields. The dependence on agriculture of the rural poor for their livelihoods is of particular concern for climate change impacts in rural areas, with the productivity of major staple crops being threatened by temperature increases and rainfall variability. Rice is particularly sensitive to temperature changes, with some estimates suggesting that an increase of 1ºC could reduce national production by 10–25%.

2. Country Overview

The Republic of Indonesia, the world's largest archipelagic nation, consists of more than 17,500 islands spread over a huge area between 7ºN and 11ºS and 94ºE and 141ºW situated along the Indian (south-west) and Pacific (east) oceans. Indonesia's island archipelagic geography is home to an extremely varied topography, and climate, ranging from montane forests and peat swamps to coastal and marine ecosystems.[82]

With over 81,000 km of coastline from a land area of 1,811,569 km^2 and a population estimate of 270 million as of 2020.[83] Most of Indonesia's landmass is covered by forests that harbor a wealth of biodiversity. Forests, coastal-marine ecosystems provide vital services to sustain millions of livelihoods and drive economic growth.

Indonesia has the largest economy in Southeast Asia. The industry sector is the economy's largest and accounts for 46.4% of GDP, this is followed by services (38.6%) and agriculture (14.4%). Although the contribution of agriculture sector to Indonesia's total GDP is less than 15 percent, roughly 40 percent of livelihoods are dependent on agriculture99[84]. With rapid economic growth, the poverty rates in the country in recent decades decreased from 24% in 1999 to 9.78% in 2020. Nonetheless, about 26.42 million Indonesians still live below the poverty line.[85]

Indonesia is one of the largest emitters of greenhouse gases in the world. In 2007, the national strategy on climate change was developed by its Ministry of Environment and in its recent Biennial Update Report, the country outlines a set of policies it believes will allow it to achieve its target of a 26% emission reduction compared to business-as-usual by 2020 using only national resources, and up to 41% if coupled with international support. Indonesia ratified the Paris Agreement on October 31, 2016.[86]
Table 6).

Table 6: Indonesia Key indicators

Indicator	Value	Source
Population undernourished	9% (2017-2019)	FAO, 2020
National poverty rate[87]	9.7% (2017)	World Bank, 2020
Share of wealth held by bottom 20%	7.2% (2013)	World Bank, 2018
Net annual migration rate	-0.07% (2010-2015)	UNDESA, 2017

[82] Naylor, R. et al. 2007. *Assessing Risks of Climate Variability and Climate Change for Indonesian Rice Agriculture.* Proceedings of the National Academy of Sciences of the United States of America. 104. 7752-7.
[83] World Bank. 2020. *The World Bank in Indonesia*. Jakarta, Indonesia. https://www.worldbank.org/en/country/indonesia/overview.
[84] Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES). 2013. *Country Report Climate Risk Management in Indonesia.* UNDP-BCPR-RDP, New York, NY 10017 USA.
[85] Ibid.
[86] Ministry of Environment and Forestry. 2015. *Indonesia First Biennial Update Report (BUR) Under the United Nations Framework Convention on Climate Change.*
[87] World Bank. 2020. *The World Bank in Indonesia*. Jakarta, Indonesia. Last updated: 1 October 2020. https://www.worldbank.org/en/country/indonesia/overview.

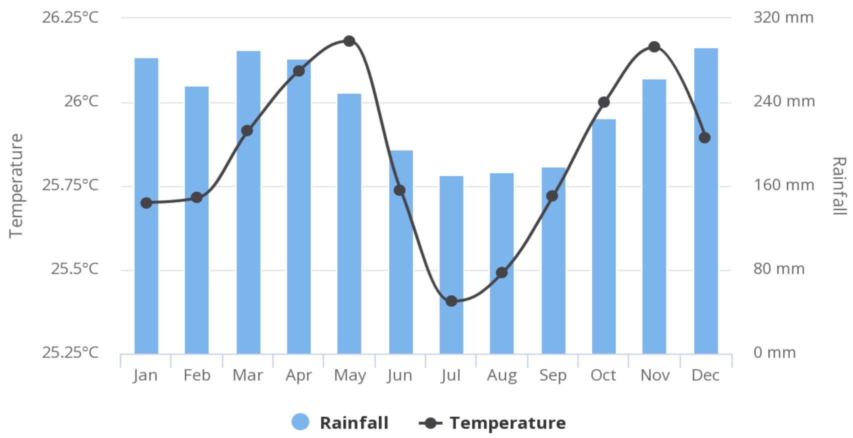
Infant mortality rate (between age 0 and 1)	2.5% (2010-2015)	UNDESA, 2017
Average annual change in urban population	1.32% (2010-2015)	UNDESA, 2018
Dependents per 100 independent adults	71.4 (2015)	UNDESA, 2017
Urban population as % of total population	55.3% (2018)	CIA, 2018
External debt ratio to GNI	35.1% (2016)	ADB, 2018b
Government expenditure ratio to GDP	15.7% (2017)	ADB, 2018b
Notre-Dame GAIN Index Ranking (2018)		
97th	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 (University of Notre-Dame, 2018).	

This document summarizes the climate risks faced by Indonesia. This includes short 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. Some of the core information is sourced from data behind the World Bank's Climate Change Knowledge Portal and other relevant publications.

3. Climatology

The tropical climate of Indonesia denotes the wet and dry seasons. The wet season occurs between November and April, leaving May through October typically dry. There is little seasonal variation in temperature and relatively little variation by elevation (averaging 23°C in the mountainous areas and 28°C in the coastal areas). Precipitation variability is a function of elevation wherein the average annual rainfall in the lowlands is around 1800-3200mm compared with the mountainous regions reaching up to 6,000 mm.[88] The climate of Indonesia is mainly influenced by the El Nino Southern Oscillation (ENSO), where drier conditions are experienced during El Niño events and wetter conditions during La Nina event.[89]

Figure 16: Average monthly temperature and rainfall in Indonesia, 1901–2016



Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical.* https://climateportal.worldbank.org

The mean monthly temperature in Indonesia is approximately 25–26°C. However, variability in the average monthly rainfall is expected in the months of June to September**Figure 16**). On average there is 300 mm of rainfall during the May and November months, which is approximately twice that of the driest months. This phenomenon is associated with monsoons occurring between October to May.

[88] USAID. 2015. *Climate Risk Profile: Indonesia Fact Sheet.* https://www.climatelinks.org/resources/climate-risk-profile-indonesia.
[89] Polade, S. 2014. *The key role of dry days in changing regional climate and precipitation regimes.* Scientific reports.

Based on the observed decadal data, the mean annual temperature of the country has increased by 0.3ºC since 1900[90], with an annual temperature rise of 0.04ºC per decade recorded during 1985-2015. Since 1960, hot days and nights have increased by 88 and 95 per annum, respectively, especially during the summer months of July–September.[6] Observational climate data generally relates to Sumatra and Borneo, with limited data availability for the country's archipelago.[91]

Precipitation trends vary across the country, some studies point to an overall decrease in average annual precipitation.[92] Areas such as Kalimantan, Java, Sumatra and Papua are experiencing increased rainfall between 1998 and 2010, whereas the western and southern coast of Sumatra, eastern Java, southern Sulawesi, Maluku Islands, western Papua and Bali Island saw a decrease in rainfall patterns11.[93] The United States Agency for International Development's (USAID) climate risk profile for Indonesia describes a decreased average annual precipitation of 3% during 1901–2013, but a 12% increase between 1985 and 2015. The greatest decreases in rainfall have occurred during the dry season, while the greatest increases have occurred in the north.[94]

Evidence suggests a greater probability that earth will experience medium and high-end warming scenarios than previously estimated,114[95] since the last iteration of the IPCC's report (AR5). The Representative Concentration Pathways (RCPs) represent four plausible futures, based on the rate of emissions reduction achieved at the global level. RCPs 2.6 and 8.5, for instance, show the extremes of low and high emissions pathways. RCP2.6 would require rapid and systemic global action, achieving emissions reduction throughout the 21st century sufficient 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 (**Table 7** and **Table 8**).

Table 7: An overview of Indonesia's temperature projections (anomaly °C) over different time horizons, emissions pathways, and measures of temperature, showing the median estimates of the full CCKP model ensemble and the 10th and 90th percentiles in brackets

Scenario	Annual average of monthly maximum		Annual average		Annual average of monthly minimum	
	2040–2059	2080–2099	2040–2059	2080–2099	2040–2059	2080–2099
RCP2.6	0.9 (0.6, 1.4)	0.9 (0.6, 1.5)	0.8 (0.6, 1.2)	0.8 (0.5, 1.4)	1 (0.6, 1.4)	0.9 (0.6, 1.3)
RCP4.5	1.3 (0.9, 1.8)	1.6 (1.3, 2.5)	1.1 (0.9, 1.6)	1.4 (1.2, 2.2)	1.2 (0.9, 1.6)	1.7 (1.3, 2.3)
RCP6.0	1.1 (0.8, 1.5)	2.1 (1.6, 2.9)	0.9 (0.8, 1.3)	1.7 (1.6, 2.5)	1.1 (0.8, 1.5)	2.1 (1.6, 3)
RCP8.5	1.7 (1.3, 2.3)	3.8 (2.8, 4.9)	1.4 (1.3, 2)	3 (2.5, 4.3)	1.6 (1.3, 2.2)	3.5 (2.8, 4.5)

Table 8: Projections of average temperature anomaly (ºC) in Indonesia for different seasons (3-monthly time slices) over different time horizons and emissions

[90] Case, M., F. Ardiansyah and E. Spector. 2007. *Climate Change in Indonesia Implications for Humans and Nature*. World Wide Fund For Nature. http://wwf.panda.org/?118240/.

[91] Office, M. et al. 2011. *Climate: observations, projections and impacts.*

[92] Aldrian, E. 2007. *Decreasing trends in annual rainfalls over Indonesia: A threat for the national water resource?*. Journal Meteorologi dan Geofi sika. 7. 40-49.

[93] As-syakur, Abd. R. et al. 2013. *Indonesian rainfall variability observation using TRMM multi-satellite data.* International Journal of Remote Sensing. 34. 7723-7738. DOI: 10.1080/01431161.2013.826837.

[94] USAID. 2015. *Climate Risk Profile: Indonesia Fact Sheet*. https://www.climatelinks.org/resources/climate-risk-profile-indonesia.

[95] Gasser, T. et al. 2018. *Path-dependent reductions in CO2 emission budgets caused by permafrost carbon release.* Nature Geoscience, 11, 830-835.

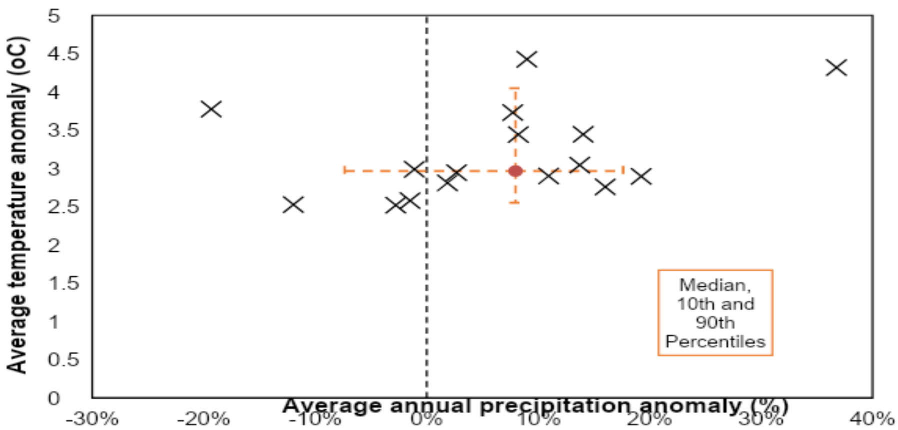
pathways, showing the median estimates of the full CCKP model ensemble and the 10th and 90th percentiles in brackets

Scenario	2040-2059		2080-2099	
	Jun–Aug	Dec–Feb	Jun–Aug	Dec–Feb
RCP2.6	0.8 (0.6, 1.3)	0.8 (0.6, 1.1)	0.7 (0.5, 1.3)	0.8 (0.5, 1.3)
RCP4.5	1.1 (0.9, 1.5)	1.1 (0.9, 1.5)	1.4 (1.2, 2.2)	1.4 (1.1, 2.2)
RCP6.0	0.9 (0.8, 1.3)	0.9 (0.8, 1.3)	1.7 (1.6, 2.5)	1.7 (1.5, 2.5)
RCP8.5	1.4 (1.3, 2)	1.4 (1.2, 2)	3 (2.6, 4.4)	2.9 (2.5, 4.2)

Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical.* https://climateportal.worldbank.org.

The following shows processed outputs of simulations performed by multiple General Circulation Models (GCM) developed by climate research centers around the world and evaluated by the IPCC in the CMIP5 iteration of models (for further information see Flato et al., 2013). Collectively, these different GCM simulations are referred to as the 'model ensemble'. Due to the differences in the way 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 national and local 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 Indonesia under RCP8.5 is shown in **Figure 17**.

Figure 17: 'Projected average temperature anomaly' and 'projected annual rainfall anomaly' in Indonesia



Note: 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 that provide projections across all RCPs and therefore are most robust for comparison.
Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical.* https://climateportal.worldbank.org.

Unless otherwise stated the global projections shown here represent changes against the 1986–2005 baseline. An additional 0.61ºC of global warming is estimated to have taken place between the periods 1850–1900 and 1986–2005. The global average temperature changes projected between 1986–2005 and 2081–2100 in the IPCC's Fifth Assessment Report are: RCP2.6: 1.0ºC; RCP4.5: 1.8ºC; RCP6.0: 2.2ºC; RCP8.5: 3.7ºC

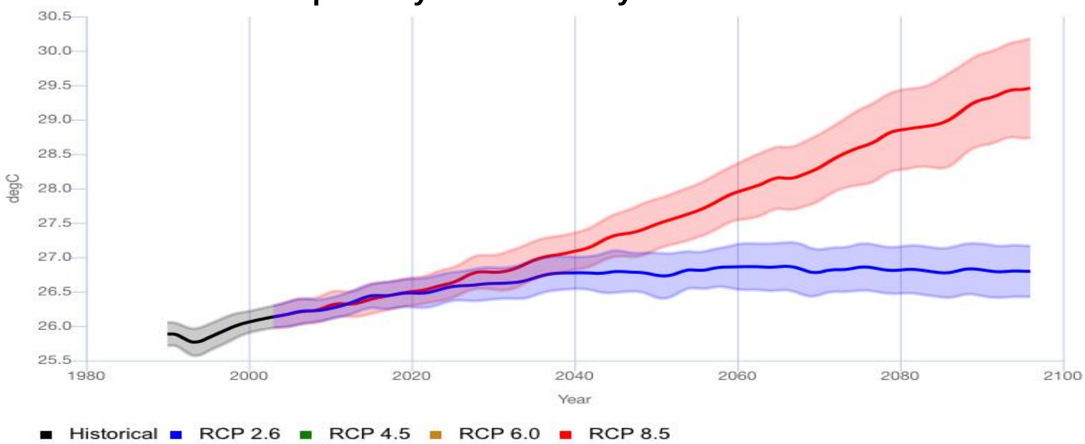
Temperature Changes. Future temperature change projections are presented in three primary formats (**Table 7**, **Figure 18**, and **Figure 19**). Although inferring similar trends in temperature projections, these three indicators can provide slightly different information. For

instance, monthly/annual average temperatures are most commonly used for general estimation of climate change (
Figure 17 and **Figure 19**), but the daily maximum and minimum can inform more about how daily life might change in a region (**Table 7**), affecting key factors such as viability of ecosystems, health impacts, productivity of labour, and the yield of crops, which are often disproportionately influenced by temperature extremes.

Projections for annual average temperature rise for Indonesia from the Climate Change Knowledge Portal (CCKP) model ensemble are less than the global average: 3ºC compared to 3.7ºC under the RCP8.5 emissions pathway by 2080–2099. Under the same pathway and time-period, the annual averages of monthly maximum and minimum temperatures are projected to increase greater than annual average temperatures, 3.8ºC and 3.5ºC, respectively. Warming projections suggest a rise of ambient temperatures from approximately 26.5ºC towards 29-30ºC, significantly increasing the frequency of days >30ºC. However, all these projections are distorted by the inability of current global climate models to distinguish between ocean and land cover over Indonesia's smaller islands. The KNMI Climate Explorer, which can interpolate to finer spatial scales, suggests that significantly higher rates of warming may be experienced in Indonesia's inland regions117.[96] For example, warming by the end of the century under RCP8.5 approaches 4ºC over central regions of Kalimantan and Sumatra. As such, adaptation planning should take account of potential temperatures rises higher than those shown in **Table 7** and **Table 8**.

As **Table 8** and **Figure 19** show, there is very little seasonal variation in temperature changes projected by the CMIP5 ensemble of models under any emissions pathway and over any time period.

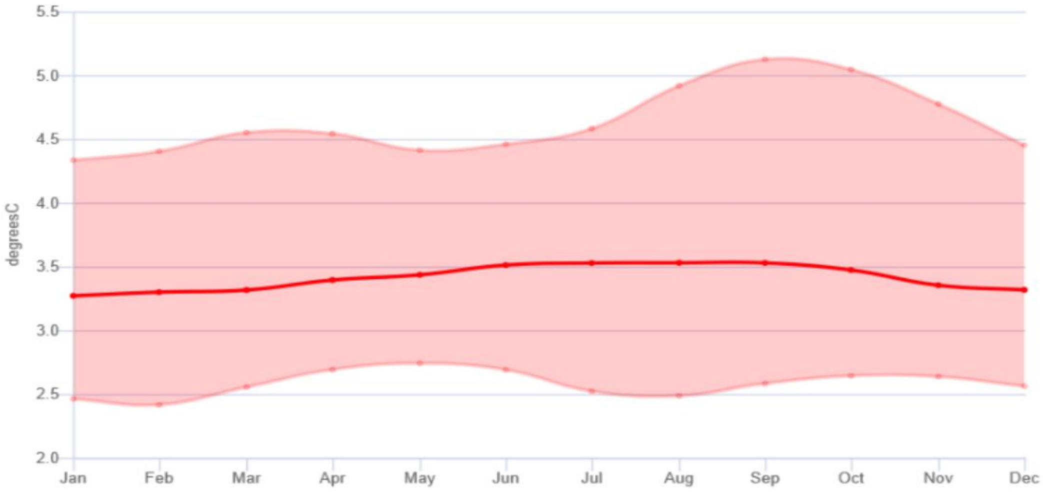
Figure 18: Historic and projected average annual temperature in Indonesia under four emissions pathways estimated by the model ensemble



Note: Shading represents the standard deviation of the model ensemble.
Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical.* https://climateportal.worldbank.org.

Figure 19: Projected change (anomaly) in monthly temperature, shown by month, for Indonesia for the period 2080-2099 under RCP8.5

[96] World Meteorological Organization. 2020. *European Climate Assessment & Dataset (KNMI Climate Explorer CMIP5 projections)*. https://climexp.knmi.nl/start.cgi



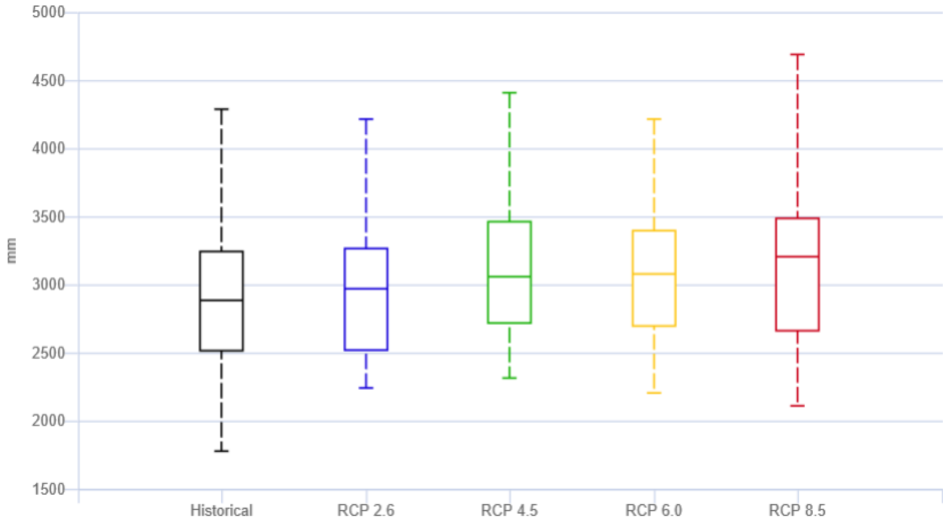
Note: The value shown represents the median of the model ensemble with the shaded areas showing the 10th–90th percentile.
Source: WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org.

Precipitation Changes. Climate model projections of future rainfall are more uncertain than temperature. The CCKP model ensemble suggests increases in median annual rainfall under all emissions pathways. However, there is large uncertainty in this estimate (as seen in the interquartile range shown in **Figure 20**). CCKP data, presented in **Figure 20**, shows a slight increase in precipitation levels under all emissions pathways by 2080-2099. For example, median annual precipitation is projected to increase by 7% under RCP6.0 pathway and 11% under RCP8.5 pathway, from the historical baseline median of 2,884 mm.

While considerable uncertainty clouds projections of local future precipitation changes, some global trends are evident. The intensity of sub-daily extreme rainfall events appears to be increasing with temperature, a finding supported by evidence from different regions of Asia.[97] However, as this phenomenon is highly dependent on local geographical contexts, research specifically focusing on Indonesia is required to understand impacts to the country. Downscaling studies for Indonesia suggest considerable variability and uncertainty regarding spatial and temporal distribution. For example, one points to western Indonesia experiencing a significantly increased number of dry days by 2060–2099 under RCP8.5 emissions pathway.[98] Another study finds rainfall trajectories in 2060 in Lombok and Sumbawa islands to be uncertain between December and February, decreasing up to 10% between March and May, and little change for other seasons.[99]

Figure 20: Boxplots showing the projected average annual precipitation for Indonesia, 2080–2099

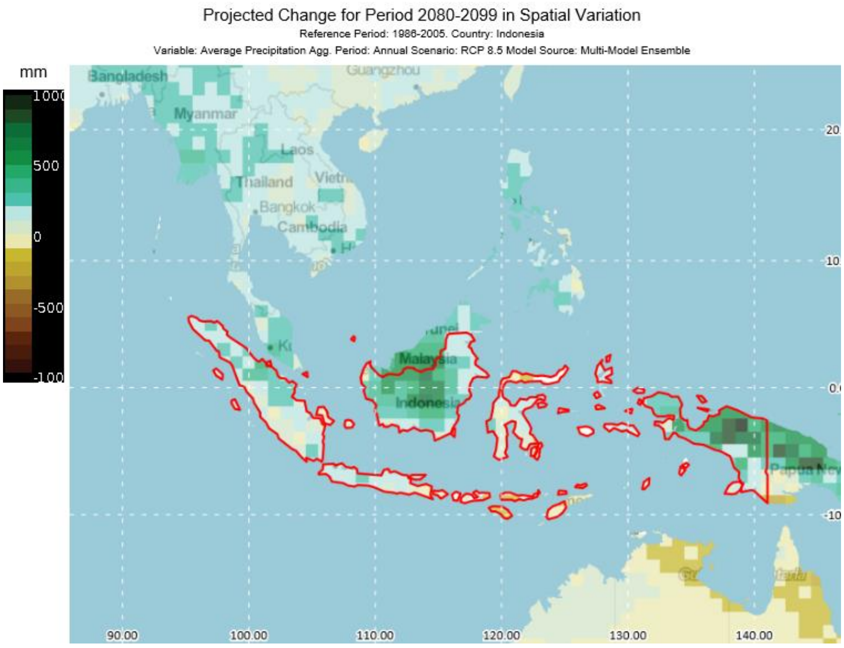
[97] Westra, S. et al. 2014. *Future changes to the intensity and frequency of short-duration extreme rainfall*. Reviews of Geophysics, 52, 522–555.
[98] Polade, S. et al. 2014. The *key role of dry days in changing regional climate and precipitation regimes*. Scientific reports.
[99] McGregor, J.L. et al. 2016. *High-resolution climate projections for the islands of Lombok and Sumbawa, Nusa Tenggara Barat Province, Indonesia: Challenges and implications.* Climate Risk Management, 12, 32-44.



Source: WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org.

Figure 21 presents CCKP multi-model ensemble data for the spatial variation of average annual precipitation change in Indonesia for 2080–2099 under the RCP8.5 emissions pathway. The central region of Kalimantan and eastern region of Papua (Irian Jaya) show the greatest increase in precipitation, with the western region of Sumatra showing the least.

Figure 21: Projected change in average annual precipitation for Indonesia in the period 2080–2099 under RCP8.5 pathway



Source: WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org.

4. Natural Hazard Risk

Indonesia is ranked in the top-third of countries in terms of natural hazard risk (59 out of 191) by the 2020 INFORM Risk Index (

Table 9). In particular, Indonesia has high exposure to flooding, tropical cyclones, tsunami and is ranked the 20th most hazard-risk country. Despite this high exposure to natural hazards, Indonesia ranks moderately in terms of its vulnerability and coping capacity, where it is ranked in the top half (102 and 88 respectively).

Table 9: Selected indicators from the INFORM 2020 Index for Risk Management for Indonesia

Flood (0-10)	Tropical Cyclone (0-10)	Drought (0-10)	Vulnerability (0-10)	Lack of Coping Capacity (0-10)	Overall Inform Risk Level (0-10)	Rank (1-191)
8.1 [4.5]	6.1 [1.7]	3.4 [3.2]	3.2 [3.2]	4.5 [4.5]	4.7 [3.9]	**59**

Note: For the sub-categories of risk (e.g., “Flood”) higher scores represent greater risks. Conversely the most at-risk country is ranked 1st. Regional average scores are shown in brackets.

Heat Waves. Indonesia regularly experiences high maximum temperatures, with an average monthly maximum of around 30.6^{o}C. Indonesia experiences a generally very stable temperature regime, with the hottest month, October, having a maximum of 31.1^{o}C. The current median probability of a heat wave (defined as a period of 3 or more days where the daily temperature is above the long-term 95th percentile of daily mean temperature) is around 2%.

Indonesia is positioned as one of the most vulnerable countries to potentially extreme heatwaves according to climate model projections.[100,101] Under all emissions pathways, the likelihood of experiencing conditions that would historically (1986–2005) class as a heatwave increases dramatically by 2080–2099: approximately 71% under the RCP6.0 pathway and 96% under the RCP8.5 pathway. In their study introducing a new Heat Wave Magnitude Index, Russo et al. (2014) suggest Indonesia might experience an extreme heatwave as often as once every two years by the end of the 21st century under the RCP 8.5 emissions pathways.[102] However, as these indices are in part a reflection of Indonesia’s historically stable baseline climate, and the continual rise in temperatures away from these conditions, extreme heat should also be explored through other indicators. Heat Index is a measure of climate conditions which better captures the effective temperature experienced by the human body by factoring in relative humidity. A Heat Index of 35^{o}C is often highlighted as a threshold beyond which conditions become extremely dangerous for human health. Shown in **Figure 22** are projections of the number of days with Heat Index >35^{o}C. Under RCP8.5 Indonesia experiences extremely dangerous conditions almost every day of the year.

Figure 22: Boxplots showing historical (1986–2005) and projected (2080–2099) annual number of days with Heat Index > 35^{o}C under four emissions pathways

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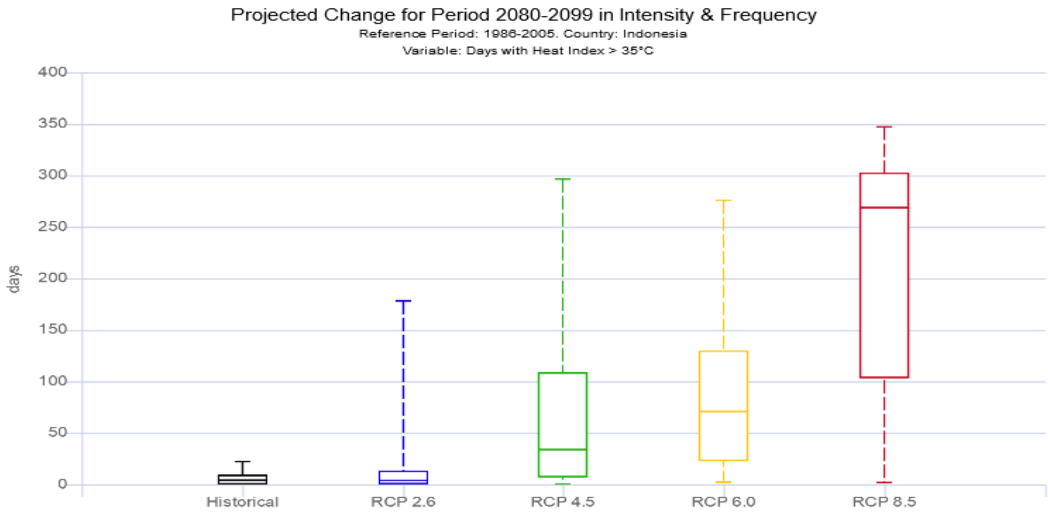
[100] Mora, C., et.al. 2017. *Global risk of deadly heat*. Nature Climate Change, 7, 501-507; and Matthews, T., R.L. Wilby and C. Murphy. 2017. *Communicating the deadly consequences of global warming for human heat stress. Proceedings of the National Academy of Sciences*, 114, 3861-3866.

[101] Matthews, T., R.L. Wilby and C. Murphy. 2017. *Communicating the deadly consequences of global warming for human heat stress. Proceedings of the National Academy of Sciences*, 114, 3861-3866.

[102] Russo, S., et.al. 2014. *Magnitude of extreme heat waves in present climate and their projection in a warming world.* Journal of Geophysical Research Atmospheres. 19. 12500–12512. DOI: 10.1002/2014JD022098.



Source: WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org.

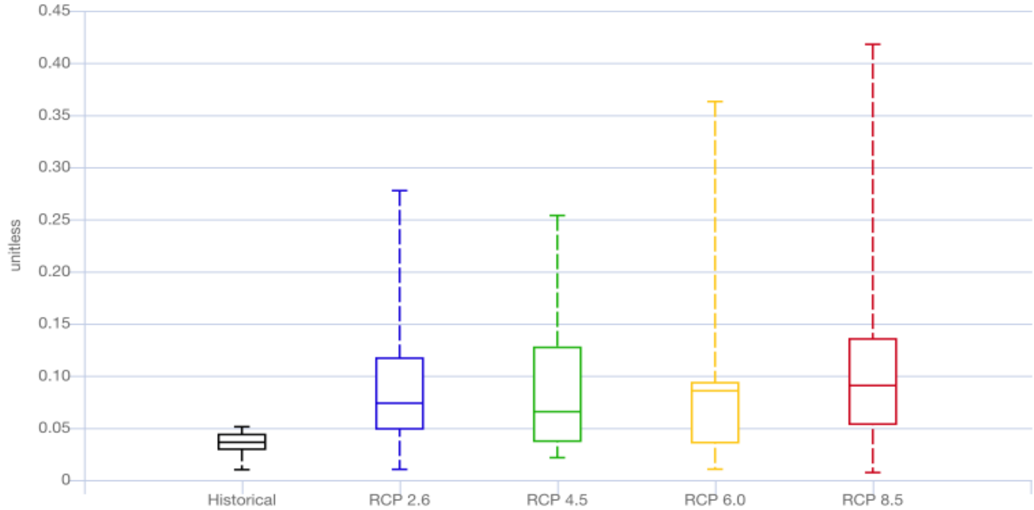
Drought and Fire. Two primary types of drought may affect Indonesia, meteorological (usually associated with a precipitation deficit) and hydrological (usually associated with a deficit in surface and subsurface water flow, potentially originating in the region's wider river basins). At present Indonesia faces an annual median probability of severe meteorological drought of around 4%, as defined by a standardized precipitation evaporation index (SPEI) of less than -2.

Naumann et al. (2018) provide a global overview of changes in drought conditions under different warming scenarios.[103] In comparison to West and Central Asia, Southeast Asia is less likely to experience extreme increases in drought intensity. As **Figure 23** shows that changes in the annual probability of experiencing a year with a severe drought by 2080-2099 roughly doubling from 4% to 9% under RCP 2.6 and RCP 8.5 emissions pathways. At a national scale, there exists few studies on climate change impacts on water stress and drought in Indonesia. However, droughts are expected to increase in frequency and intensity given the association of accentuated drought with El Niño events, which are expected to increase in frequency and intensity through warmer global temperatures.[104]

Figure 23: Annual probability of experiencing a 'severe drought' in Indonesia (-2 SPEI index) in 2080-2099 under four emissions pathways

[103] Naumann, G., et.al. 2018. *Global Changes in Drought Conditions Under Different Levels of Warming*. Geophysical Research Letters, 45(7), 3285–3296.

[104] Naylor, R. et al. 2007. *Assessing Risks of Climate Variability and Climate Change for Indonesian Rice Agriculture.* Proceedings of the National Academy of Sciences of the United States of America. 104. 7752-7. DOI:10.1073/pnas.0701825104; and King, A., G. van Oldenborgh and D. Karoly. 2016. *Climate Change and El Niño Increase Likelihood of Indonesian Heat and Drought.* Bulletin of the American Meteorological Society. 97. S113-S117.



Source: WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org.

Droughts contribute to intense fire events in Indonesia, such as those that took place in 1997 and 2015, and are strongly associated El Niño Southern Oscillation.[105] An increase in forest fires has been observed in the Sumatra region during October, following persistent droughts in the dry season from June to November. Climate change projections point to more frequent and severe droughts and subsequently more forest fires.[106] Furthermore, some studies show that increased fire risk is not only associated with drought years, but also temperature rise in non-drought years: during the summer months of July to October, anomalously warmer months increased the probability of fires considerably more than anomalously dry months during this period. [107]

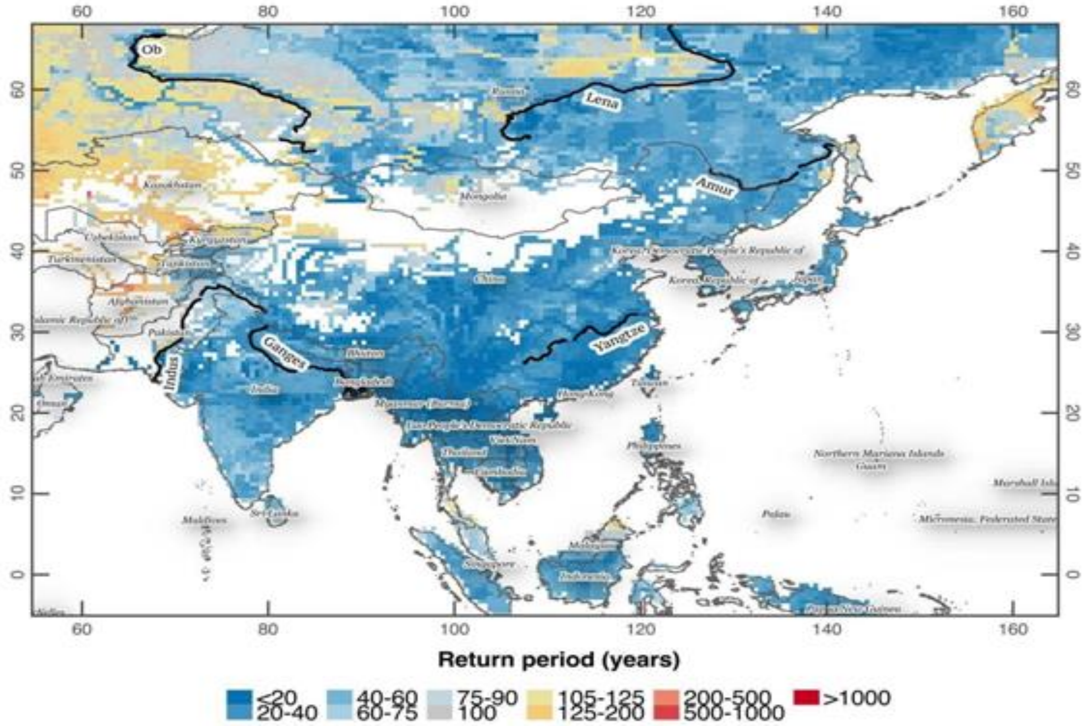
Flood. The World Resources Institute's AQUEDUCT Global Flood Analyzer can be used to establish a baseline level of flood exposure to large-scale river flooding. As of 2010, assuming protection for up to a 1-in-25-year event, the population annually affected by flooding in Indonesia is estimated at 1.5 million people and expected annual urban damage is estimated at $1.4 billion.[108] Development and climate change are both likely to increase these figures. The climate change component can be isolated and by 2030 is expected to increase the annually affected population by 400,000 people, and urban damage by $6.1 billion under the RCP8.5 emissions pathway (AQUEDUCT Scenario B).

Paltan et al. (2018) demonstrates that even under lower emissions pathways consistent with the Paris Climate Agreement, almost all Asian countries face an increase in the frequency of extreme river flows.[109] What would historically have been a 1-in-100 year flow, could become a 1-in-50 year or 1-in-25 year event in most of South, Southeast, and East Asia (**Figure 24**). There is good agreement among models about this trend. Wilner et al. (2018) suggest this increase in flows could lead to an increase in the population affected by an extreme flood by 817,000–2,537,000 people (**Table 10**).

[105] Field, R.D. et al. 2016. *Indonesian fire activity and smoke pollution in 2015 show persistent nonlinear sensitivity to El Niño-induced drought. Proceedings of the National Academy of Sciences*, *113*(33), pp.9204-9209.
[106] Lestari, R.K. et.al. 2014. *Increasing potential of biomass burning over Sumatra, Indonesia induced by anthropogenic tropical warming*. Environmental Research Letters, 9(10), p.104010.
[107] Fernandes, K. et.al. 2017. *Heightened fire probability in Indonesia in non-drought conditions: the effect of increasing temperatures*. Environmental Research Letters, *12*(5), p.054002.
[108] World Resources Institute (WRI). 2018. *AQUEDUCT Global Flood Analyzer.* https://floods.wri.org/#
[109] Paltan, H. et al. 2018. *Global implications of 1.5°C and 2°C warmer worlds on extreme river flows Global implications of 1.5°C and 2°C warmer worlds on extreme river flows*. Environmental Research Letters, 13. https://doi.org/10.1088/1748-9326/aad985

Muis et al. (2015) explored flood risk and adaptation strategies in Indonesia under increased climate change and urban expansion. They found high uncertainty around climate change impacts on increased river flood risk but estimated that climate change could amplify coastal flood risk 19-37% by 2030 (measured by Expected Annual Damage).[110]

Figure 24: Multi-model median return period (years) for future river flow corresponding to the historical 100-year flow under a 2ºC warming scenario



Note: Blue colors indicate a more frequent historical 100-year flow whereas red colors indicate a reduction in the frequency.
Source: Muis, S. et al. 2018. *Flood risk and adaptation strategies under climate change and urban expansion: A probabilistic analysis using global data.* Science of The Total Environment. Volume 538, 15 December 2015, Pages 445-457.

Table 10: Estimated number of people in Indonesia affected by an extreme river flood in the historic period 1971-2004 and the future period 2035–2044

Estimate	Population exposed to extreme flood (1971–2004)	Population exposed to extreme flood (2035–2044)	Increase in affected population
16.7 Percentile	12,622	829,739	817,117
Median	56,806	1,480,701	1,423,895
83.3 Percentile	378,358	2,916,021	2,537,663

Note: Extreme river flood is defined as being in the 90th percentile in terms of numbers of people affected.
Source: Willner, S., et.al. 2018. *Adaptation required to preserve future high-end river flood risk at present levels.* Science Advances: 4:1.

Cyclones and Storm Surge. Climate change is expected to interact with cyclone hazards in complex ways that 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. Alongside Bangladesh, India, Peoples Republic of China, and Viet Nam, Indonesia is estimated to have one of the largest coastal populations exposed to flooding from 1-in-100-year storm surges.[111] Modelling of climate change impacts on cyclone intensity and frequency conducted across the globe points to a

[110] Source: Muis, S. et al. 2018. *Flood risk and adaptation strategies under climate change and urban expansion: A probabilistic analysis using global data.* Science of The Total Environment. Volume 538, 15 December 2015, Pages 445-457.
[111] Neumann, B. et al. 2015. *Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment*. *PloS one*, *10*(3), p.e0118571.

general trend of reduced cyclone frequency and increased intensity and frequency of the most extreme events.[112] 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.

Indonesia is impacted from the movement of tropical cyclones in the south eastern Indian Ocean between January and April and the eastern Pacific between May and December, their impacts taking the form of strong winds and heavy rainfall (although due to Indonesia's equatorial location, the country is not directly in the path of cyclones). Increased sea-surface temperatures associated with climate change are projected to increase tropical cyclone intensity.[113]

5. Climate Change Impacts

Climate change trajectories are evident; however, its consequent impacts on various sectors in Indonesia, exacerbated by the increasing demands of the population and rapid urbanization, show very alarming scenarios making immediate adaptations necessary. Indonesia's rich natural resources are at risk due to the changing climate impacts significantly on their livelihoods.

Water. Despite having over 21% of the freshwater reserves of Asia, Indonesia has great difficulty in providing potable water as well as freshwater supplies to meet the demands of society, industry, and agriculture. In particular, areas such as Java, Bali and East Nusa Tenggara possess water deficits.[114] Indonesia's Second Nationally Determined Contribution outlines how total water demand to support irrigation, domestic, municipal and industrial uses are 1,074 m^3/sec, however a low flow through the climatic year are approximately 790 m^3/sec, 76% of the total demand.[115] Moreover, climate modelling points to increased water scarcity in Indonesia over the next decades. At present, 14% of Indonesia 453 districts are recorded as having no months of surplus water. By 2025, this is projected as approximately 20% and 31% by 2050.[116] Rural communities are more susceptible as modelling future seasonal rainfall variability in Nusa Tenggara Barat province found significant implications for the water sector due to direct reliance of its population on rainwater.[117] Crop water demand estimates suggest projected changes will impact the rice growing period between November and March and that there will likely be insufficient water for the second growing period, March to June, when chillies and tobacco are grown.[118]

Alongside water scarcity, saltwater intrusion is an issue facing Indonesia's water resources. It is currently experienced along Indonesia's coastline and is exacerbated by factors including land subsidence, sea level rise, groundwater exploitation and coastal flooding. Sea level rise driven by climate change will likely result in greater saltwater intrusion over the next.[119] In addition, increased rainfall during already wet times of the year may lead to high flood risks,[120]

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[112] Walsh, K. et al. 2015. *Tropical cyclones and climate change*. WIREs Climate Change: 7: 65-89.
[113] Retno G.D. et al. 2010. *Indonesia Second National Communication Under The United Nations Framework Convention on Climate Change (UNFCCC)*. http://unfccc.int/files/national_reports/non-annex_i_natcom/submitted_natcom /application/pdf/indonesia_snc.pdf
[114] United Nations-Economic and Social Affairs (UN-ESA). 2004. *Fresh Water Country Profile: Indonesia*. https://www.un.org/esa/agenda21/natlinfo/countr/indonesa/Fresh waterindonesia04f.pdf
[115] Retno G.D., et.al. *Indonesia Second National Communication Under The United Nations Framework Convention on Climate Change (UNFCCC)*. 2010. URL: http://unfccc.int/files/national_reports/non-annex_i_natcom/submitted_natcom /application/pdf/indonesia_snc.pdf
[116] Ibid
[117] Ibid
[118] Kirono, D.G., et.al. 2016. *Historical and future seasonal rainfall variability in Nusa Tenggara Barat Province, Indonesia: Implications for the agriculture and water sectors*. *Climate Risk Management*, *12*, pp.45-58.
[119] Rahmawati, N., J.F. Vuillaume and I.L.S. Purnama. 2013. *Salt intrusion in Coastal and Lowland areas of Semarang City*. *Journal of hydrology*, *494*, pp.146-159.
[120] World Health Organization (WHO). 2007. *Emergency and Humanitarian Action News Update*.

which also claims lives and properties as collateral damages.[121] Nonetheless, there are still not enough facilities and infrastructure available to abate these existing flooding conditions.[122]

Sea-level rise. Global mean sea-level rise was estimated in the range of 0.44-0.74 meter by the end of the 21st century by the IPCC's Fifth Assessment Report[123] but some studies published more recently have highlighted the potential for more significant rises (**Table 11**). Indonesia's Second National Communication describes how rising sea-levels and strong wave action contribute to significant coastal erosion—a situation exacerbated by climate change. Coastal areas are exposed to permanent inundation, high tides and land subsidence, affecting settlements, rice fields, ponds and harbours/airports.[124]

Indonesia is particularly exposed to sea-level rise, with the country ranked the fifth highest in terms of population inhabiting the lower elevation coastal zone.[125] The total population likely to be exposed to permanent flooding by 2070–2100 is high at 4,215,690 without adaptation (**Table 12**). It is estimated that by 2030 around 5.5-8 million people could reside in a 100-year floodplain (an area exposed to 1-in-100-year coastal floods resulting from storm surges), growing to 9.5–14 million by 2060. These estimates assume a modest sea-level rise of 10cm by 2030 and 21cm by 2060.

Table 11: 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)

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		**1.84m (0.98-2.47)**

Source: Le Bars, D., S. Drijhout, and H. de Vries. 2017. *A high-end sea level rise probabilistic projection including rapid Antarctic ice sheet mass loss*. Environmental Research Letters: 12:4.

Table 12: The average number of people in Indonesia experiencing flooding per year in the coastal zone in the period 2070-2100 under different emissions pathways (assumed medium ice-melt scenario) and adaptation scenarios for Indonesia

Scenario	Without adaptation	with adaptation
RCP2.6	1,377,530	2,850
RCP8.5	4,215,690	5,930

Source: UK Met Office. 2014. *Human dynamics of climate change: Technical Report*. Met Office, UK Government.

Biodiversity, Forestry and Land-use. As a known biodiversity hotspot, climate change is forecasted to have significant impacts on global biodiversity. Land-use in the Asia-Oceania region is the prominent factor rendering up to 77% of its tropical forest vulnerable to

[121] Diela, T. and S. Widianto. 2002. *After Indonesia's deadly floods, few hear climate 'wake up call'.* Reuters. https://www.reuters.com/article/us-indonesia-floods-climate-change-idUSKBN1Z305X

[122] Junaidi, A., N. Nurhamidah, and D. Daoed. 2018. *Future flood management strategies in Indonesia.* MATEC Web of Conferences 229.

[123] Church, J. A. et al. 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.

[124] Retno G.D., et.al. 2010. *Indonesia Second National Communication Under the United Nations Framework Convention on Climate Change (UNFCCC)*. http://unfccc.int/files/national_reports/non-annex_i_natcom/submitted_natcom/application/pdf/indonesia_snc.pdf

[125] Neumann, B. et al. 2015. *Future coastal population growth and exposure to sea-level rise and coastal flooding - A global assessment*. PLoS ONE, 10(3).

biodiversity changes. Indeed, deforestation in Indonesia has led to over half its original forest cover becoming lost[126] so, as the habitat for endemic species.

The reduction in emissions from forestry-sector sources comprises about 58% of Indonesia's total commitment. The forest and peat degradation comprised about half of Indonesia's greenhouse gas emissions in 2010.[127] Therefore, it plays a key role in the country's climate change mitigation efforts in the future.[128] Although there is a continued success in the social forestry program (including conditional cash transfers,[129] etc.) as an adaptation measure, still, about 10 million people in forest-frontier areas live under the poverty line[130] needing adequate attention related to forest livelihoods.

Impacts to other sectors are evident, directly and indirectly, as the jeopardy of the natural resources caused by climate change results in a spectrum of events for other equally important sectors.

Agriculture. Impacts of climate change projections in Indonesia's Agriculture sector can be direct and indirect. Direct effects include alterations to carbon dioxide availability, precipitation, and temperatures while those indirect effects include impacts on water resource availability and seasonality, soil organic matter transformation, soil erosion, changes in pest and disease profiles, the arrival of invasive species, and a decline in arable areas due to the submergence of coastal lands and desertification. Tebaldi and Lobell (2018), on the international level calculations, estimate 5% and 6% declines in global wheat and maize yields respectively even if the Paris Climate Agreement is met and warming is limited to 1.5^{o}C. Shifts in the optimal and viable spatial ranges of certain crops are also inevitable, though the extent and speed of those shifts remains dependent on the emissions pathway.

According to FAO, Indonesia is a leading producer of palm oil and a major global producer of rubber, copra, cocoa and coffee, and the world's second largest marine fisheries producer. Fifteen percent of agricultural land is made up of larger plantations cultivating export crops. Majority of farm households (70%) are more vulnerable to the impacts of climate change. In absolute terms, of the 25 million farm households, 17 million are rice farmers with an average land possession of 0.6 ha.[131]

Past trends indicate a low capacity for the agriculture sector to adapt to changes in climate. This is proven by harvest failures that reached 100,000 tons per district between 1981 and 1990 and even worsen to 300,000 tons per district in the period between 1991 and 2000; these losses are overwhelmingly agricultural and directly impact the small holder farming families.

Rice is a major staple in Indonesia, its production is vulnerable to changes in the onset and length of the wet season. El Nino events influence rice production, delaying rainfall and increasing the risk of annual rice deficits, with such events projected to increase from climate change. Naylor et al. (2007) project an increase in the probability of 30-day delay in the wet season from 9-18% today to 30-40% by 2050 (for the main rice-producing areas of Java and

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[126] Hughes, A.C. 2017. *Understanding the drivers of Southeast Asian biodiversity loss*. Ecosphere, *8*(1).
[127] Alisjahbana A.S. and J. M. Busch. 2017. *Forestry, Forest Fires, and Climate Change in Indonesia*. Bulletin of Indonesian Economic Studies, 53:2, 111-136.
[128] German Federal Ministry for Economic Cooperation and Development (BMZ). 2019. *Forests and climate change programme (FORCLIME)*.
[129] Jong, H.N. 2020. *Helping the poor can protect forests too, Indonesian welfare program shows*. Mongabay Series: Global Forests, Indonesian Forests. https://news.mongabay.com/2020/08/indonesia-welfare-program-poverty-alleviation-pkh-deforestation-study/
[130] Climate Land Ambition and Rights Alliance (CLARA). *Social Forestry Helps Adapt to Climate Change*. UNEP, UN Climate Action Summit. (n.d.)
[131] BPS-Statistics Indonesia. *The number of farm household, cultivation area, and average cultivation area for food crops (in Indonesian: Jumlah Rumah Tangga, Luas Tanam, dan Rata-rata Luas Tanam Usaha Tanaman Padi dan Palawija menurut Jenis Tanaman)*. URL: https://st2013.bps.go.id/dev2/index.php/site/tabel?tid=66&wid=0

Bali). Consequently, another study in South Kalimantan supports this as the future water requirement in rice production will increase by around 56% in dry season (July) and 25% during wet season in September and October.[132] Further, USAID assumes the burden to these rural households as total agricultural loss among the provinces of East, Central, and West Java provinces can account for 19 percent, 15 percent, and 9.5 percent, respectively.[133] Rice is particularly sensitive to temperature changes, with some estimates suggesting that an increase of 1°C could reduce national production by 10–25%.[6] Moreover, the value of Indonesia's agricultural sector could reduce by 10% by 2050.[4] Climate change is also projected to impact palm oil, a significant crop for Indonesia, with the climatic suitability of growing oil palm in the region gradually decreasing up to 2030 and becoming more pronounced up to 2100.

The impact of climate change on Indonesia's fisheries is uncertain. Some models suggest climate change could lead to a 15–30% decrease in total fisheries catch in Indonesian waters.[134] However, in some areas like the south coast of Java, that includes the Bali Strait, models suggest an increase in productivity. This increased productivity is the consequence of climate change intensifying wind stress on the ocean surface, contributing to coastal upwelling.[135]

Alongside gender roles in the agriculture sector, around 40 percent of family smallholder farmers are women, amounting to 7.4 million according to the latest available data.[136] Women contribute to all stages of production and also a significant player in the sector, however, their living conditions remain far beneath the standard, putting women more marginalized in the impacts imposed by climate change.

Poverty and Inequality. Megacities, such as Jakarta, are not safe either to frequent flooding (coastal and erratic rainfall) incidence.[137] Aside from flooding, urban poor is greatly affected as they bear the brunt of climate change given that they are the most vulnerable sector. Such burdens include the worsening living conditions in the urban areas attributed to the effects of temperature rise (anywhere in the range of 0.1–3°C)[138] and heat stress that is increasingly compounded by the phenomenon of Urban Heat Island (UHI). Numerous studies have shown how land-use changes associated with urbanization in Indonesia have resulted in the UHI effect, especially in the capital Jakarta.[139] Added to the fact that this same sector is economically and socially insecure.

Rural or urban, the poorest of the poor are likely to be disproportionately affected. 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.[140] Poorer farmers and communities are least able to afford local water storage, irrigation infrastructure, and technologies for adaptation further making them trapped vicious cycle of poverty.

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[132] Achyadi, M.A., K. Ohgushi and T. Morita. 2019. Impacts of Climate Change on Agriculture for Local Paddy Water Requirement Irrigation Barito Kuala, South Kalimantan, Indonesia.URL: http://ijwem.ulm.ac.id/index.php/ijwem

[133] USAID. 2016. *Indonesia: Costs of Climate Change 2050.* Washington, DC.

[134] ADB. 2016. *Indonesia Country Water Assessment*. Manila; and Lumban-Gaol, J. et al. 2012. *Climate change impact on Indonesian Fisheries. World Meteorological Organization*.

[135] Lumban-Gaol, J. et al. 2012. *Climate change impact on Indonesian Fisheries. World Meteorological Organization*.

[136] The ASEAN Post. 2019. *Indonesia's female farmers treated unfairly.* https://theaseanpost.com/article/indonesias-female-farmers-treated-unfairly

[137] Shatkin, G. 2019. *Futures of Crisis, Futures of Urban Political Theory: Flooding in Asian Coastal Megacities.* International Journal of Urban Regimes. Res., 43(2), 207–226.

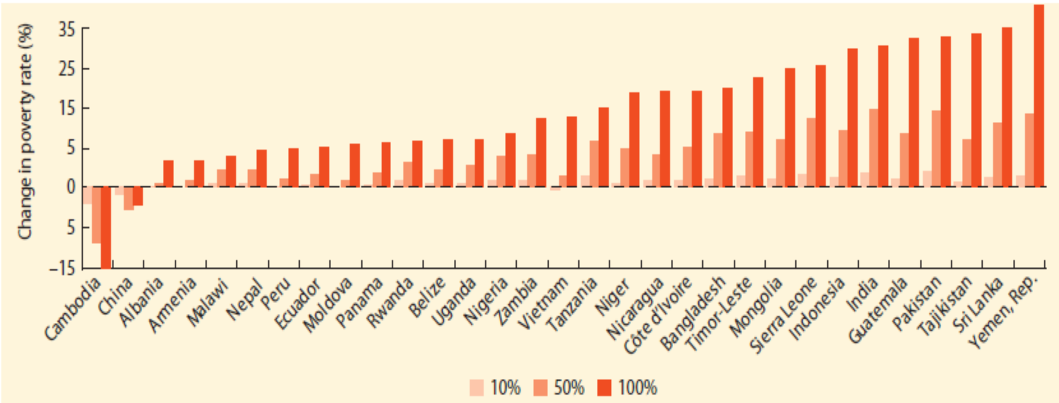
[138] Zhou, D. et al. 2014.*Surface urban heat island in China's 32 major cities: Spatial patterns and drivers*. Remote Sensing of Environment, 152, 51–61.

[139] Manik, TK and S. Syaukat. 2015. *The impact of urban heat islands: assessing vulnerability in Indonesia. IIED.* http://pubs.iied.org/10721IIED/; and Tursilowati, et.al. 2013. *Relationship between Urban Heat Island Phenomenon and Land Use/Land Cover Changes in Jakarta – Indonesia.* 3. 645-653.

[140] Kjellstrom, et.al. 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.

As mentioned above, the changes in agricultural production impact on food prices. The poor in Indonesia are particularly vulnerable to food price rises, where a 100% increase in food prices could increase the number of Indonesians in extreme poverty by just over 25% (**Figure 25**).

Figure 25: Modelled change in extreme poverty rate in different countries based on food price rises of 10%, 50%, and 100%



Source: Ivanic and Martin 2014.
Note: Based on microeconomic simulations specified with the Global Trade Analysis Project (GTAP) general equilibrium model. Simulations measure the short-term impacts on poverty (without any supply or wage adjustments) of a uniform change in all food prices for 10, 50, and 100 percent (without productivity effects). Poverty is defined by the percentage of households living on less than $1.25 per day.

Source: Hallegatte, S.B. et al. 2015. *Shock Waves: Managing the Impacts of Climate Change on Poverty.* Original source: Ivanic, M. and Martin, W. 2014. Short- and Long-Run Impacts of Food Price Changes on Poverty.

Poorer households, about 26.42 million Indonesians (living below the poverty line), are much less likely to take adaptive measures and plan for longer-term horizons than wealthier households, which make them more exposed to environmental shocks and disasters, including the COVID-19 shock.[141] Nonetheless, a meta-review found that 17 of 20 social protection programs and its consequent expansion, due to the pandemic,[142] resulted in improvements in several food security indicators–notably food intake, dietary diversity and food quality (Tirivayi et al. 2013).

Women are another subsector in the discussion of poverty and inequality in Indonesia. As their household and livelihood participation is seen as equally important, there is a clear lack in access to leadership and decision-making for women, especially relating to small holder farming activities. Indonesian women are poorer across the life cycle and face disadvantages at school and, especially, in employment[143] making them more vulnerable to the impacts of climate change.

Human Health and Nutrition. Given the huge population of Indonesia and the proportion of its urban poor,[144] and the extremely vulnerable indigenous populations living in remote or hard-to-reach locations,[145] it is an urgent call to make sure the poor will be more resilient to the

[141] Hallegatte, S.B. et al. 2014. *Shock Waves: Managing the Impacts of Climate Change on Poverty.* 2015. Original Source: Ivanic, M. and Martin, W. 2014. Short- and Long-Run Impacts of Food Price Changes on Poverty. http://documents.worldbank.org/curated/en/106581468325435880/pdf/WPS7011.pdf

[142] Kjellstrom T. et al. 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.

[143] Organization for Economic Co-operation and Development (OECD). 2019. *Social Protection System Review of Indonesia.* oecd.org/social/inclusivesocietiesanddevelopment/SPSR_Indonesia_ebook.pdf

[144] Kjellstrom, et al. 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.

[145] Spray, A. 2015. *Leveraging Social Protection Programs for Improved Nutrition: Report on the Proceedings of the Global Forum on Nutrition-Sensitive Social Protection Programs*. Global Forum Report, The World Bank Group, Secure Nutrition, Russian Federation.

climatic changes.[146] Without attention to these realities, the general developmental wellbeing of the population is also impacted. For instance, although Indonesia was able to reduce the stunting rate to 27.6% in 2017, adding the double burden of food insecurity and malnutrition, its next generation will only be 54% as productive as she or he could have been with full health and complete education.[147] Also, Dunne et al. (2013) suggests that global labor productivity during peak months has already dropped by 10% as a result of warming temperature, and that a decline of up to 20% might be expected by 2050 under the highest emissions pathway (RCP8.5).

Rural poor and coastal communities are affected with their staple food and survival livelihoods as climate-related impacts affect fisheries distribution, availability and safety.183F183F[148] This has also been the problem in East Nusa Tenggara where rural households' dependence on agriculture is more than 80 percent and food security related concerns such as malnutrition is very high.[149] Although social protection measures are seen as an adaptation support, a study show that it must be designed in a nutrition-sensitive way185[150] pointing clearly that adaptation measures exist. Without measures for adaptation, the World Food Program estimates that the risk of global hunger and child malnutrition could increase by 20% by 2050.[151] Further, the projections suggest there could be approximately 35.1 climate-related deaths per million population linked to lack of food availability in Indonesia by the year 2050 under RCP8.5.

A further, and perhaps less appreciated influence of climate change on agricultural production is through its impact on the health and productivity of the labor force. 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.

In terms of population mortality, climate change is expected to push global temperatures closer to this temperature 'danger zone' both through slow onset warming and intensified heat waves. This is supported by a research that has placed a threshold of 35^{o}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 the risk of serious ill-health and death.[152] Honda et al. (2014) utilized the A1B emissions scenario from CMIP3 (most comparable to RCP6.0) to estimate that without adaptation, annual heat-related deaths in the Southeast Asian region could increase 295% by 2030 and 691% by 2050.[153] Under the RCP8.5 emissions pathway, heat-related deaths for 65+ year-olds are projected to increase dramatically by 2080, from a baseline of <1 per 100,000 in 1961-1990 to 53 per 100,000.[154] The potential reduction in heat-related deaths achievable by pursuing lower emissions pathways is significant, as demonstrated by Mitchell et al. (2018). Lastly, the links between increased droughts, fires, and heat associated with climate change will have implications on regional air quality and subsequently public health in Indonesia.[155]

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[146] Dalimunthe, S.A. 2014. *Urban poor face climate change impacts.* The Jakarta Post. https://www.thejakartapost.com/news/2014/12/08/urban-poor-face-climate-change-impacts.html.

[147] World Bank. 2020. *The World Bank in Indonesia*. Jakarta, Indonesia. https://www.worldbank.org/en/country/indonesia/overview.

[148] Food and Agriculture Organization (FAO) of the United Nations. 2008a. *Food safety and climate change*. FAO high level conference on food security and the challenges of climate change and bioenergy. Rome.

[149] Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES). 2013. *Country Report Climate Risk Management in Indonesia*. UNDP-BCPR-RDP, New York, NY 10017 USA.

[150] Sabates-Wheeler, R. and S. Devereux. 2018. *Social Protection and the World Food Programme.* Institute of Development Studies, World Food Program Rome, Italy.

[151] World Food Program. 2018. *Two minutes on climate change and hunger: A zero hunger world needs climate resilience.*

[152] Im, E. S., J.S. Pal and E.A.B. Eltahir. 2017. *Deadly heat waves projected in the densely populated agricultural regions of South Asia*. Science Advances, 3(8), 1–8.

[153] Honda, Y., et.al. 2014. *Heat-related mortality risk model for climate change impact projection.* Environmental Health and Preventive Medicine 19: 56-63.

[154] World Health Organisation (WHO). 2015. *Climate And Health Country Profile- Indonesia*. https://www.who.int/globalchange/resources /country-profiles/PHE-country-profile-Indonesia.pdf

[155] Marlier, M. E. et al. 2015. *Regional air quality impacts of future fire emissions in Sumatra and Kalimantan.* Environmental Research Letters 10, no. 5.

The rise in infectious and vector-borne diseases under low or high RCP emissions pathways is also threatening the human population. Around 308 million people (out of a projected population of 340 million) in Indonesia could be at risk of malaria by 2070, from a baseline (1961–2000) of approximately 160 million people. Similarly, the vector capacity of dengue fever is expected to increase by 2070.[156] El Niño Southern Oscillation (ENSO) events, projected to increase from climate change, can contribute to favorable dengue fever outbreak conditions in Indonesia adding to fluvial conditions.[157]

[156] Im, E. S., J.S. Pal and E.A.B. Eltahir. 2017. *Deadly heat waves projected in the densely populated agricultural regions of South Asia*. Science Advances, 3(8), 1–8.

[157] Lee Corwin, et.al. 2001. *Epidemic dengue transmission in southern Sumatra, Indonesia*. Transactions of the Royal Society of Tropical Medicine and Hygiene. 95. 257-65. DOI: 10.1016/S0035-9203(01)90229-9.

E. LAO PEOPLE'S DEMOCRATIC REPUBLIC CLIMATE RISK PROFILE

1. Summary of Climate Rationale

The Lao People's Democratic Republic (PDR) is a landlocked country in Southeast Asia. A large part of the country is mountainous, but there is a large central area, as well as low-lying alluvial plains along the Mekong River. It is ranked 142nd out of 181 countries in the ND-GAIN Index, and as the 36th most vulnerable country globally. Rural areas in Lao PDR account for nearly 90% of the poor population, and rural poverty is almost three times higher than in urban areas. The poverty head count rate in the central provinces is some of the highest in the country and is showing the slowest rate of reduction. Lao PDR has a tropical monsoon climate. The climate is hot and tropical, with the rainy season between May and October, a cool dry season from November to February, and a short hot, dry season in March and April. The central region experiences high temperatures and high average annual rainfall (which is concentrated in monsoon months), however, there is high variability due to the influence of Monsoon dynamics and the El Niño Southern Oscillation (ENSO).

The combination of the monsoon climate, high variability, and the geographical terrain makes Lao extremely vulnerable to weather related extremes, notably from floods, storms, landslide and droughts. The whole country experiences regular flooding and there are also frequent storms: three of the five costliest events on record having taken place since 2009. Typhoon Ketsana in 2009 and Haima in 2011 caused damages of US$ 94 million and US$ 66 million respectively, and in 2018 a confluence of storm and flood disasters affected over 600,000 people and led to losses of US$ 371 million. There are also periodic droughts: in, 2015 a severe drought, driven by a strong El Niño event, damaged tens of thousands of hectares of rice, and fruit crops including in the central region. Historical damage data indicates that annual expected losses range between 3.3% and 4.1 percent of GDP. Disasters disproportionate impact on the poor, and the rural poor are particularly vulnerable to ENSO-related shocks. Rural areas experience widespread food insecurity due to the reliance on rain-fed agriculture, and these households have a high probability of falling into extreme poverty even when exposed to relatively low frequency flood and drought events.

Recent observations show that the climate of Lao PDR is changing. There is a clear warming trend, with 0.1 to 3°C per decade reported across the entire country. The patterns of annual rainfall trends are more uncertain, although there are trends of increasing variability and increasing extreme rainfall. Future climate change will exacerbate existing risks. The projected temperature increases for Lao PDR indicates a further rise of broadly 1°C to 2°C by mid-century (central multi-model ensemble values, for RCP2.6 and RCP8.5 respectively, relative to a baseline 1986-2005 period. It is difficult to model rainfall changes due to the influence of Monsoon dynamics, but most climate models project increases in annual rainfall by the mid-century (2050s) and there is more confidence that heavy precipitation events will increase. This will increase the flood risks across the country. Modelling for the country's rivers – from northern watershed, through the central region, and in the Mekong - indicate higher discharge leading to increased floods with greater areas of land and more people at risk of flooding, and higher value at risk. These effects will be exacerbated by climate change, notably increases in heat and humidity (including heatwaves) which will reduce labour productivity. There are also projected direct and indirect impacts of climate change on agriculture itself, with reductions in yields in Lao PDR, noting these could be amplified by the possible increased annual likelihood of drought.

2. Country Overview

Lao PDR is a landlocked country in Southeast Asia. The nation shares borders with five other countries (People's Republic of China to the north, Viet Nam to the east, Cambodia to the south, Thailand to the west, and Myanmar to the northwest), and lies in the lower Mekong Basin of the Indochina Peninsula. Lao PDR has a total land area of 236,800 km^2.193F193F[158]

The country is characterized by hilly to mountainous terrain over approximately 80% of its land area, with the remaining 20% comprising of low-lying plains along the Mekong River. The country's altitude ranges from 104 msl (Attapeu) to 2,820 msl at Phu bia Mountain. More than two-thirds of the population people live in the southern and central parts of the country.[159]

Lao PDR has a total population of 7.2 million people as of 2019[160] and is classified as a lower middle-income country with an approximate GDP of $17 billion. The three economic subsectors contributing to the country's GDP include the service (46.8%), industry (35.5%) and agriculture (17.7%).[161] The share of employment in the country shows a shift from agricultural towards the service and industry sectors, at around 3% in a span of 5 years. Nonetheless, agriculture remains the dominant employer, accounting for 65.2% of the labor force in 2015[162]. The urban population resides primarily in Vientiane, the capital, which sits along the riverbanks of Mekong.

Lao PDR is endowed with abundant natural resources, such as water, forests, minerals and biodiversity. These assets remain in a comparatively healthy state. However, since the turn of the 21st century, the development and exploitation of natural resources has accelerated, including the construction of a cascade of new hydropower dams on the Mekong River and its tributaries. Lao PDR's topographic, land-locked, location makes it heavily dependent on road transportation for trade and economic growth.

The table below shows the key indicators for the country.

Table 13: Lao PDR Key Indicators

Indicator	Value	Sources
Population undernourished[163]	18.5% (2014-2016)	GHI, 2015
National poverty rate	18.3% (2018-2019)	World Bank, 2020
Share of wealth held by bottom 20%[164]	7.6% (2012)	World Bank, 2018
Net annual migration[165]	-0.55% (2010-2015)	UNDESA, 2017
Infant mortality rate (between age 0 and 1)	4.73% (2010-2015)	UNDESA, 2017
Average annual change in urban population[166]	1.93% (2010-2015)	UNDESA, 2018
Dependents per 100 independent adults	93.5 (2015)	UNDESA, 2017
Urban population as % of total population[167]	35% (2018)	CIA, 2018
External debt ratio to GNI	93.1% (2016)	ADB, 2018b
Government expenditure ratio to GDP[168]	21.6% (2017)	ADB, 2018b

[158] Lao PDR. 2013. *Second National Communication to the UNFCCC.* https://unfccc.int/sites/default/files/resource/Laonc2.pdf
[159] Food and Agriculture Organization (FAO). 2011. *AQUASTAT Country Profile – Lao People's Democratic Republic*. Rome, Italy. http://www.fao.org/3/ca0397en/CA0397EN.pdf.
[160] World Bank. 2020. *Population Data.* World bank database. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=LA
[161] Laos Statistical Information Service. 2020. *GDP and economic subsectors*. Department of Economic Statistics, LSB, MPI, Vientiane, Laos.
[162]Ministry of Planning and Investment. 2016. *8th Five-Year National Socioeconomic Development Plan (2016–2020)*. VIIIth National Assembly's Inaugural Session, 20–23 April 2016, Vientiane. Laos. https://laopdr.un.org/sites/default/files/2019-08/2016_8th%20NSEDP_2016-2020_English.pdf
[163] International Food Policy Research Institute. 2015. *Global Hunger Index: Armed Conflict and the Challenge of Hunger.* https://reliefweb.int/sites/reliefweb.int/files/resources/global-hunger-index_2015_english.pdf.
[164] World Bank. 2018. *Income share held by lowest 20%.* 2018. https://data.worldbank.org/indicator/SI.DST.FRST.20.
[165] United Nations Department of Economic and Social Affairs (UNDESA). *World Population Prospects 2017.* 2017. URL: https://population.un.org/wpp/Download/Standard/Population/.
[166] United Nations Department of Economic and Social Affairs (UNDESA). *World Urbanization Prospects 2018*. 2018. URL: https://population.un.org/wup/Download/
[167] Central Intelligence Agency (CIA). 2018. *The World Factbook*. Washington DC.https://www.cia.gov/library/publications/the-world-factbook/geos/ch.html
[168] ADB. 2018b. *Key Indicators for Asia and the Pacific 2018,* 49th Edition. Asian Development Bank. https://www.adb.org/sites/default/files/publication/443671/ki2018.pdf

In 2016, Lao PDR ratified its Nationally Determined Contribution (NDC) to the Paris Climate Agreement and launched its climate change action plan. Lao PDR's Second National Communication to the UNFCCC (NC2) (2013) identifies the impacts of climate change to be particularly important to the country's water and forestry resources, agriculture, energy, and health sectors,[169] respectively.

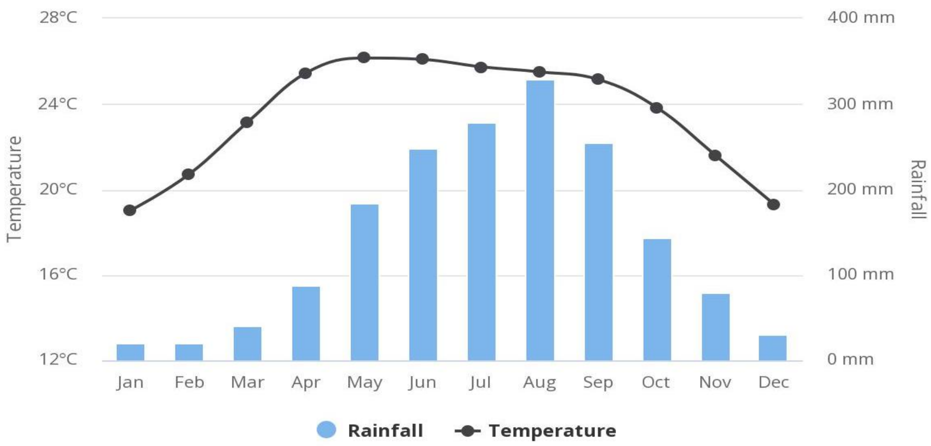
This document summarizes the climate risks faced by Lao PDR. This includes historic data, current climate variability and short and long-term changes in key climate parameters, as well as impacts of these changes on communities, livelihoods, and economies. It is a synthesis of existing research and analyses. The data is derived from a review of various data sources, reports and academic publications. In particular, this references Lao PDR's second national communication (2013),[170] World Bank Climate Risk Profiles (GFDRR, 2011[171], WB, 2020[172]) and the World Bank Climate Portal.[173]

3. Current and Future Climatology

Lao PDR has a tropical climate influenced by the southeast monsoon, which brings 70% or more of annual rainfall. There are two distinct seasons evident: the rainy season, or monsoon, from May to mid-October, which is followed by a dry season from mid-October to April (Figure 26). Mean annual temperatures of 20°C are observed in the northern and eastern mountainous areas and the plateaus, whereas 25-27°C temperatures are recorded in the plains. The average rainfall can be as high as 3,000 mm per year.

Temperature and precipitation rates are affected by El Niño Southern Oscillation (ENSO), but to a lesser extent than some other Southeast Asian nations.[174]

Figure 26: Average monthly temperature and rainfall in Lao PDR, 1901-2016



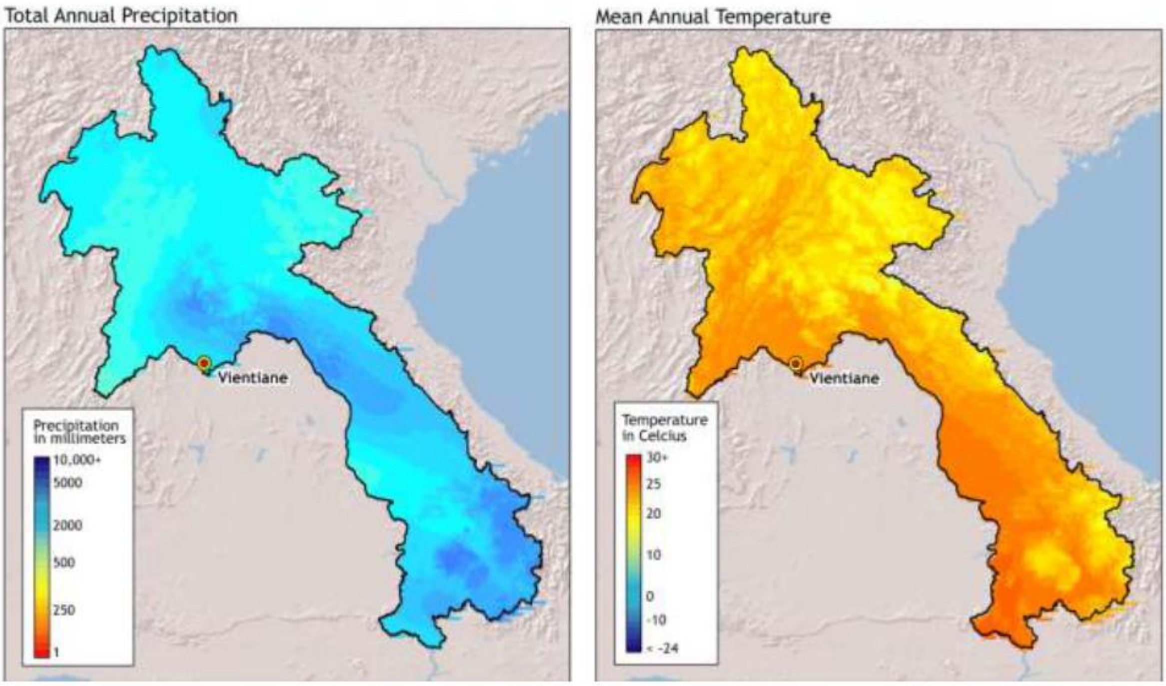
Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical*. https://climateportal.worldbank.org

Given the varying altitudes, Lao PDR has three different climatic zones: The northern mountainous areas above 1,000 msl have a montane temperate and hilly sub-tropical climate with temperature ranges lower than the rest of the country; The central mountainous areas –

[169] Lao PDR. 2013. *Second National Communication to the UNFCCC*. https://unfccc.int/sites/default/files/resource/ Laonc2.pdf
[170] Lao PDR. 2013. Second national communication to the UNFCCC. 2013. https://unfccc.int/non-annex-I-NCs
[171] Global Facility for Disaster Reduction and Recovery (GFDRR). 2011. Vulnerability, Risk Reduction, and Adaptation to Climate Change. Climate Risk and Adaptation Country Profile for Lao PDR.
[172] World Bank and ADB. 2020. Climate Risk Country Profile Lao PDR.
[173] https://climateknowledgeportal.worldbank.org/
[174] Villafuerte, M. Q. and J. Matsumoto. 2015. *Significant influences of global mean temperature and ENSO on extreme rainfall in Southeast Asia*. Journal of Climate, 28(5), 1905–1919. https://journals.ametsoc.org/doi/pdf/10.1175/JCLI-D-14-00531.1; and Thirumalai, K. et al. 2017. *Extreme temperatures in Southeast Asia caused by El Niño and worsened by global warming*. Nature Communications, 8, 15531. https://www.nature.com/articles/ncomms15531.pdf.

the focus of the project - vary in altitude between 500 to 1,000 msl having a tropical monsoonal climate with high temperatures and average rainfall total; and the tropical lowland plain and floodplains along the Mekong River and its main tributaries[175].

Figure 27: Average annual precipitation (left) and annual temperature (right) of Lao PDR



Source: GFDRR (2011).

Climate Trends

Recent observations show that the climate of Lao PDR is changing. There is a clear warming trend, with 0.1 to 3°C per decade reported across the entire country.[176] The Berkeley Earth Dataset – for the vicinity of Vientiane where the project is centered - shows similar trends and suggests warming has accelerated rapidly since the turn of the 21st century.

The patterns of annual rainfall trends are more uncertain (Lao PDR 2NC, World Bank, 2020, Westra et al., 2014[177]), with different patterns reported across the country, although Lao PDR's NC2 reports a transition in the country's precipitation regime over the 20th century towards more intense precipitation periods, with the frequency of months of experiencing more than 600 mm rainfall increasing. Patterns of precipitation remain influenced by the complex relationship between climate and ENSO.

Climate Change Projections

This annex has compiled climate model projections. A number of studies have been considered, but the data focuses on the information from World Bank climate portal data. This uses multi-model data from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) included in the IPCC's Fifth Assessment Report (AR5). The data is derived from 35 available

[175] ADB. 2018. *Basic Statistics 2018.* Manila. https://www.adb.org/publications/basic-statistics-2018.

[176] GFDRR. 2011. Climate Risk and Adaptation Country Profile: Lao PDR. Vulnerability, Risk Reduction, and Adaptation to Climate Change. GFDRR and World Bank; WBG Climate Change Knowledge Portal. 2019. Climate Data: Projections. https://climateknowledge portal worldbank.org/country/laos; ADB and World Bank. 2020. Climate Risk Country Profile: Lao PDR.

[177] Westra, S., et.al. 2014. *Future changes to the intensity and frequency of short-duration extreme rainfall. Reviews of Geophysics, 52, 522–555.* https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2014RG000464

global circulation models (GCMs) used by the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, data and downscaled through bi-linear interpolation (World Bank, 2021)[178]. The use of GCMs is necessary as there is very little regional or downscaled climate modelling runs for Lao PDR.

Temperature. The projected temperature increases for Lao PDR for the four Representative Concentration Pathways (RCPs) are shown in the table below. The data from the World Bank downscaled analysis is shown below. Climate change under each RCP is shown for Lao PDR presented against a reference period of 1986-2005 for all indicators (**Table 14** and **Table 15**). By mid-century (2050s) a further rise of broadly 1°C to 2°C (central estimate), relative to a baseline 1986-2005 period is projected, depending on scenario and model. Temperature is projected to rise after this time under high emission scenarios (with no global mitigation), and could reach nearly 4°C (central estimate) by the end of the century. There are also projected increases in hot and very hot days. Projections for future temperature change are presented as the changes (or anomalies) in maximum and minimum temperatures over the given time period, as well as changes in the average temperature.

Table 14: Overview of temperature change (ºC) projected for Lao PDR over different time horizons, emissions pathways, and measures of temperature, showing the median estimates of the full CCKP model ensemble and the 10th and 90th percentiles in brackets

Scenario	Annual average of monthly maximum		Annual average		Annual average of monthly minimum	
	2040–2059	2080–2099	2040–2059	2080–2099	2040–2059	2080–2099
RCP2.6	01.3 (0.4, 2.1)	1.3 (0.4, 2.2)	1.1 (0.4, 1.8)	1.1 (0.4, 2.1)	1.1 (0.4, 1.9)	1.1 (0.3, 2.2)
RCP4.5	1.7 (0.7, 2.7)	2.2 (1.1, 3.4)	1.4 (0.8, 2.3)	1.8 (1, 3.1)	1.5 (0.6, 2.4)	2 (1.1, 3.3)
RCP6.0	1.4 (0.3, 2.2)	2.5 (1.3, 4)	1.1 (0.5, 1.9)	2.1 (1.4, 3.4)	1.2 (0.4, 2)	2.4 (1.3, 3.7)
RCP8.5	2.1 (1.1, 3)	4.3 (2.6, 6)	1.7 (1.1, 2.7)	3.6 (2.6, 5.5)	1.8 (0.9, 2.9)	3.9 (2.7, 5.5)

Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections*.

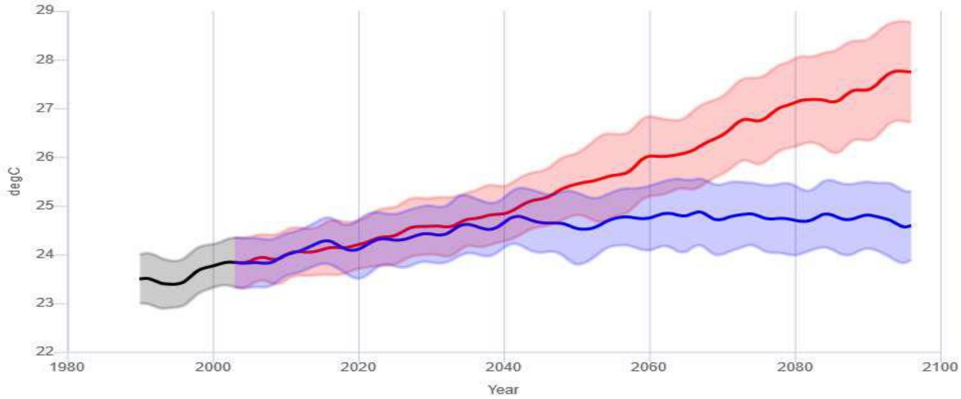
Table 15: Projections of average temperature change (ºC) in Lao PDR for different seasons (3-monthly time slices) over different time horizons and emissions pathways, showing the median estimates of the full CCKP model ensemble and the 10th and 90th percentiles in brackets

Scenario	2040–2059		2080–2099	
	Jun-Aug	Dec-Feb	Jun-Aug	Dec-Feb
RCP2.6	0.9 (0.5, 1.6)	1 (0.2, 1.9)	0.8 (0.5, 1.8)	1.1 (0.3, 2.3)
RCP4.5	1.3 (0.9, 1.8)	1.4 (0.5, 2.2)	1.4 (1.1, 2.8)	1.9 (0.8, 3.1)
RCP6.0	1 (0.7, 1.7)	1 (0.5, 1.7)	1.9 (1.4, 3.2)	2.2 (1.3, 3.2)
RCP8.5	1.6 (1.1, 2.4)	1.7 (0.8, 2.7)	3.4 (2.8, 5.1)	3.5 (2.4, 5.6)

Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections*.

[178] World Bank. 2021. Metadata for the Climate Change Knowledge Portal. https://climateknowledgeportal.worldbank.org/themes/custom/wb_cckp/resources/data/CCKP_Metadata_Final_January2021.pdf

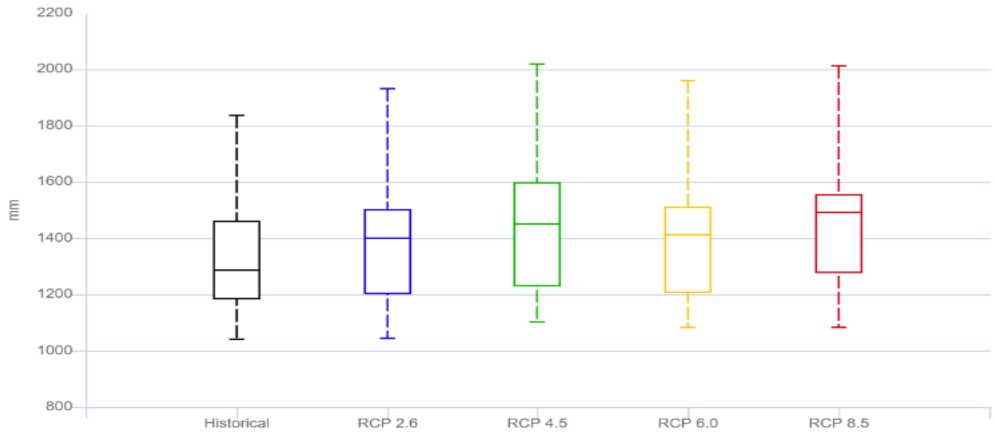
Figure 28: Historic and projected average annual mean temperature in Lao PDR under RCP2.6 (blue) and RCP8.5 (red) estimated by the model ensemble



Note: Shading represents the standard deviation of the model ensemble.
Source: WBG Climate Change Knowledge Portal. 2018. *Interactive Climate Indicator Dashboard.*

Precipitation Changes. There is lower confidence in the changes in precipitation, because it is extremely difficult to model rainfall changes in Lao PDR. The climate models generally project modest changes in rainfall by the mid-century (2050s), with an increase in annual precipitation rates, and larger changes under higher emissions pathways. However, uncertainty in precipitation trends remains high as reflected in the range of model estimates. There are some studies that apply downscaling techniques to the region, but these use older driving models[179] and still show high variation in rainfall. The World Bank Climate Change Knowledge Portal data is shown below for Lao PDR. This model ensemble projects that the average largest 5-day cumulative rainfall could increase from around 135 mm to over 150 mm under RCP6.0 and RCP8.5 emissions pathways (**Figure 29**), respectively.

Figure 29: Projected average annual precipitation (mm) for Lao PDR, 2080-2099



Source: WBG Climate Change Knowledge Portal. 2018. *Interactive Climate Indicator Dashboard.*

There is more robustness in projections of extreme rainfall events, which increase with temperature, a finding supported by evidence from different regions of Asia and documented in Lao PDR.[180]

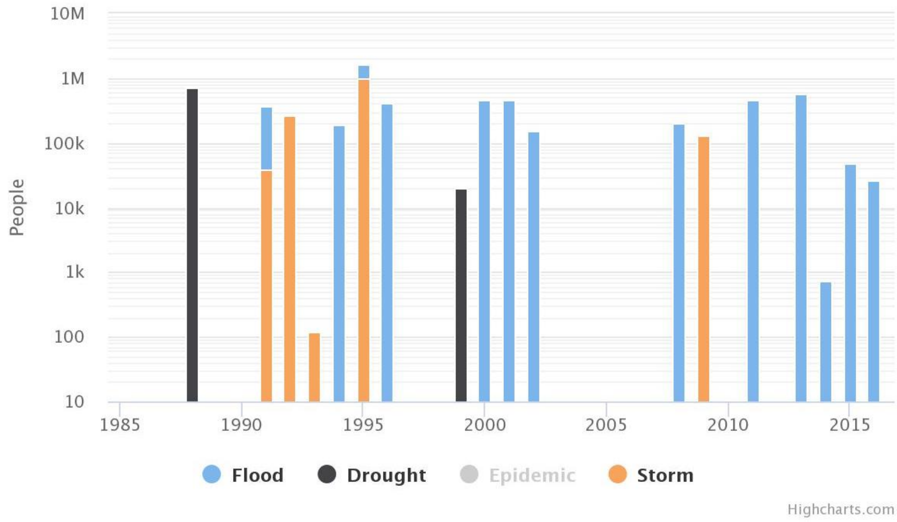
[179] Lacombe, G., C.T. Hoanh, and V. Smakhtin. 2012. Multi-year variability or unidirectional trends? *Mapping long-term precipitation and temperature changes in continental Southeast Asia using PRECIS regional climate model.* Climatic Change, 113(2), 285–299. https://link.springer.com/article/10.1007%2Fs10584-011-0359-3; and Shrestha, B., et al. 2013. *Impact of climate change on sediment yield in the Mekong River basin: a case study of the Nam Ou basin, Lao PDR*. Hydrology and Earth System Sciences, 17(1), pp.1-20. https://www.hydrol-earth-syst-sci.net/17/1/2013/hess-17-1-2013.pdf

[180] Westra, S. et al. 2014. *Future changes to the intensity and frequency of short-duration extreme rainfall. Reviews of Geophysics, 52, 522–555.* https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2014RG000464

4. Natural Hazard Risk

The combination of the monsoon climate, high variability, and the geographical terrain makes Lao extremely vulnerable to weather related extremes, notably from floods, storms, landslide and droughts.[181] The whole country experiences regular flooding and there are also frequent storms: three of the five costliest events on record having taken place since 2009.[182] Typhoon Ketsana in 2009 and Haima in 2011 caused damages of US$ 94 million and US$ 66 million, respectively, and in 2018 a confluence of storm and flood disasters affected over 600,000 people and led to losses of US$ 371 million.[183] Historical damage data indicates that annual expected losses range between 3.3% and 4.1 percent of GDP.[184] There are also periodic droughts: in, 2015 a severe drought, driven by a strong El Niño event, damaged tens of thousands of hectares of rice, and fruit crops[185] - droughts can occur anywhere in the country but are most common in the central region. Disasters disproportionate impact on the poor, and the rural poor are particularly vulnerable to ENSO-related shocks.[186] The repeated patterns of these events can be seen below.

Figure 30: Number of people affected 1985–2018



Source: World Bank Climate Portal.

The three central regions that are the focus of this study are some of most heavily affected by floods, as shown in the DESINVENTAR data.[187]

[181] UNDP. 2010. National Risk Profile of Lao PDR. National Disaster Management Committee Government of Lao PDR / United Nationals Development Programme (UNDP) Lao PDR. November 2010.

[182] EM-DAT. 2021. The Emergency Events Database - Universite catholique de Louvain (UCL) - CRED, https://emdat.be/; and DESINVENTAR. 2021. Disaster loss data for Sustainable Development Goals and Sendai Framework Monitoring System. https://www.desinventar.net/

[183] UNDRR. 2019. Disaster Risk Reduction in Lao PDR. Status Report 2019. https://www.undrr.org/publication/disaster-risk-reduction-lao-pdr

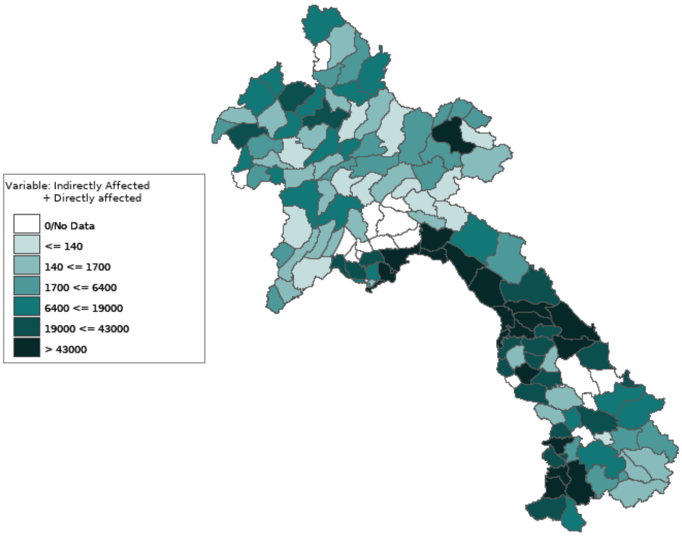
[184] World Bank. 2017. Lao PDR: Systematic Country Diagnostic. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/983001490107755004/lao-pdr-systematic-country-diagnostic-priorities-for-ending-poverty-and-boosting-shared-prosperity

[185] Sutton, W. et al. 2019. *Striking a balance: Managing El Niño and La Niña in Lao PDR's Agriculture*. World Bank Group. https://www.worldbank.org/en/country/lao/publication/striking-a-balance-managing-el-nino-and-la-nina-in-lao-pdrs-agriculture

[186] Sutton, W., et.al. 2019. Striking a balance: Managing El Niño and La Niña in Lao PDR's Agriculture. World Bank Group. https://www.worldbank.org/en/country/lao/publication/striking-a-balance-managing-el-nino-and-la-nina-in-lao-pdrs-agriculture

[187] DESINVENTAR. 2021. Disaster loss data for Sustainable Development Goals and Sendai Framework Monitoring System. https://www.desinventar.net/

Figure 31: Number of people affected by Flood (directly and indirectly)

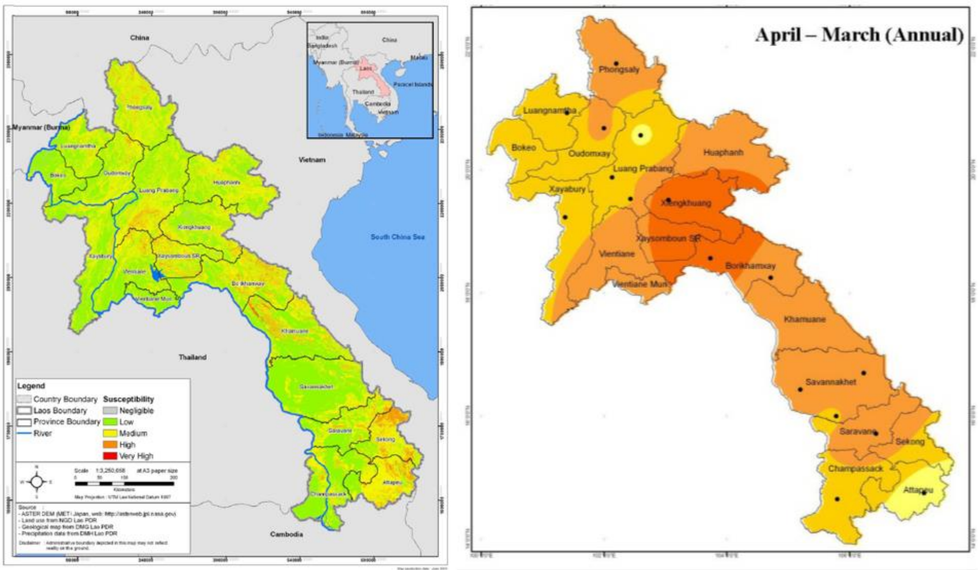


Source: DESINVENTAR. 2021. Disaster loss data for Sustainable Development Goals and Sendai Framework Monitoring System. https://www.desinventar.net/

A UNDP disaster risk hazard mapping exercise undertook flood hazard assessments for Lao PDR.[188] For floods, eight priority river basins were considered. The analysis found high flood related hazards for various flood return periods in the three central areas. It also identified landslide risk which includes high risk areas in these areas. Finally, the analysis looked at drought risk - while droughts can occur anywhere in the country, they are most common in the central region.

Lao PDR also regularly experiences high temperatures, with an average monthly maximum of around 28°C and an average maximum of 31°C for May (warmest month). The current median probability of a heat wave (defined as a period of three or more days where the daily temperature is above the long-term 95th percentile of daily mean temperature) is around 3%.[189]

Figure 32:Landslide hazard map (left) and annual moderate to extreme drought risks (right) for Lao PDR.



Source: UNDP (2010)

[188] UNDP. 2010. Developing a National Risk Profile of Lao PDR. Part 1: Hazard Assessment 2010 Disaster Management Committee Government of Lao PDR and United Nationals Development Programme Lao PDR

[189] WBG Climate Change Knowledge Portal. 2019. *Interactive Climate Indicator Dashboard.*

5. Climate Change Impacts

It is clear that climate change will have a major impact on Lao PDR. The ND-GAIN ranking highlights Lao is due to a combination of political, geographic, and social factors. Lao PDR is recognized as very vulnerable to climate change impacts, and is ranked 142th out of 181 countries in the ND-GAIN Index.[190] 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. Lao PDR is the 36th most vulnerable country and the 50th least ready country.

Notre-Dame GAIN Index Ranking (2018)	
142nd	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 (University of Notre-Dame, 2018).

The information on future impacts are set out below.

Floods. Using the World Resources Institute's AQUEDUCT Global Flood Analyzer to establish a baseline level of river flood exposure,[191] and assuming protection for up to a 1 in 25-year event (as of 2010), the population annually affected by flooding in Lao PDR is estimated at 48,000 people and the expected annual damages is $159 million. Climate change is expected to increase the affected population by 40,000 people and the damages by $295 million, under the RCP8.5 emissions pathway by the 2030s (AQUEDUCT Scenario B).

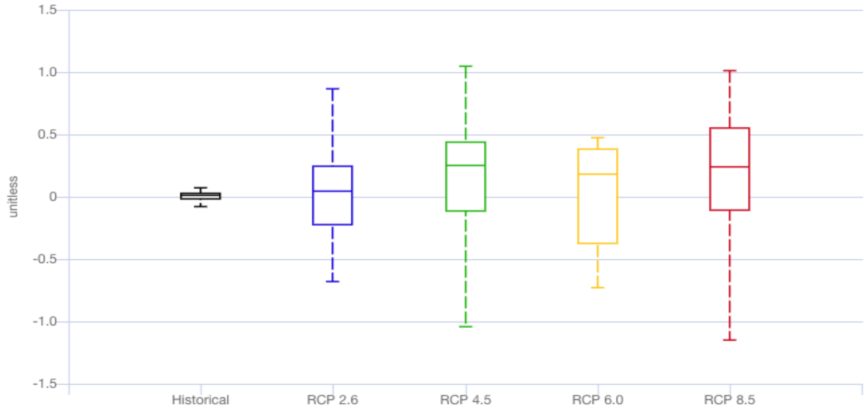
Even under lower emissions pathways coherent with the Paris Climate Agreement, almost all Asian countries face an increase in the frequency of extreme river flows.[192] What would historically have been a 1 in 100-year flow, could become a 1 in 50-year or 1 in 25-year event in most of South, Southeast, and East Asia. Further, the model ensemble project an increase of up to 23% under the highest emissions pathway in the amount of rainfall accumulated during extreme rainfall events. This phenomenon may increase the risk of flash or surface flooding, and associated issues such as landslides.

Drought. Two primary types of drought may affect Lao PDR, meteorological (usually associated with a precipitation deficit) and hydrological (usually associated with a deficit in surface and subsurface water flow, potentially originating in the region's wider river basins). At present, Lao PDR faces an annual median probability of severe meteorological drought of around 4%, as defined by a standardized precipitation evaporation index (SPEI) of less than -2.22.[193] Naumann et al. (2018) provide a global overview of changes in drought conditions under different warming scenarios.[194] Projections for Southeast Asia suggest that the return periods of 12-month droughts could be reduced. This trend is less significant under lower levels of global warming, but once warming reaches 2- 3°C, events that presently occur only once every hundred years may return at frequencies greater than once in every fifty years. The projections of the CCKP model ensemble on meteorological drought hold some uncertainty, but generally point towards an increased annual likelihood of drought (**Figure 33**). The rise in drought probability appears not to correlate with emissions in a linear fashion.

[190] University of Notre Dame. 2019. *Notre Dame Global Adaptation Initiative.* https://gain.nd.edu/our-work/country-index/
[191] World Resources Institute (WRI). 2018. *AQUEDUCT Gobal Flood Analyzer.* https://floods.wri.org/#
[192] Paltan, H. et al. 2018. *Global implications of 1.5°C and 2°C warmer worlds on extreme river flows Global implications of 1.5°C and 2°C warmer worlds on extreme river flows*. Environmental Research Letters, 13. https://doi.org/10.1088/1748-9326/aad985.
[193] WBG Climate Change Knowledge Portal. 2019. *Interactive Climate Indicator Dashboard.* https://climatedata.worldbank. org / CRMePortal/web/water/land-use-/-watershed-management?country=LAO&period=2080-2099.
[194] Naumann, G., et al. 2018. *Global Changes in Drought Conditions Under Different Levels of Warming*. Geophysical Research Letters, 45(7), 3285–3296. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2017GL076521

Overall, it is likely that future drought patterns will depend on the influence of climate change on monsoon and ENSO patterns,[195] though further research is required to constrain this impact.

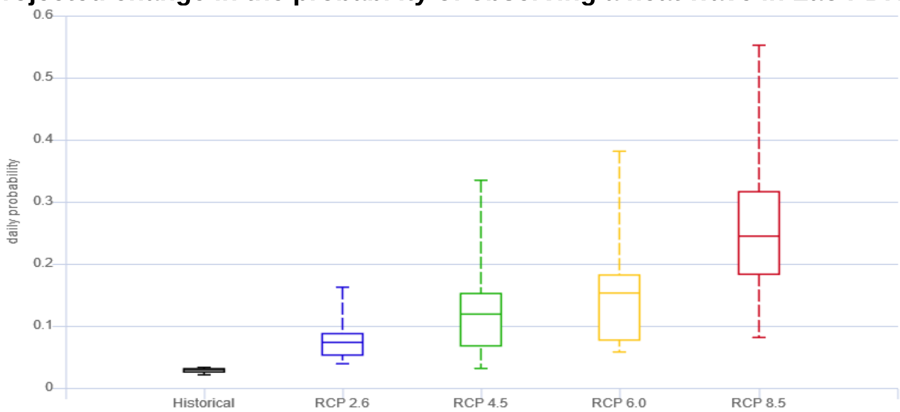
Figure 33: Annual probability of experiencing a 'severe drought' in Lao PDR (-2 SPEI index) in 2080-2099 under four emissions pathways



Source: WBG Climate Change Knowledge Portal. 2019. *Interactive Climate Indicator Dashboard.* https://climatedata.worldbank. org / CRMePortal/web/water/land-use-/-watershed-management?country=LAO&period=2080-2099.

Heat waves. As shown in the CCKP model ensemble, there are significant increases in the annual probability of a heat wave under the different emissions pathways (**Figure 34**). General warming and increased climate variability are both almost certain to increase the probability of heat waves compared with the historical baseline (1986-2005). The increase in the number of days in which temperatures exceed 35ºC is projected to increase from approximately 40 days to 50-110 days depending on emissions pathway and climate model.

Figure 34: Projected change in the probability of observing a heat wave in Lao PDR, 2080–2099



Agriculture. Climate change is projected to impact on food production via direct and indirect effects on crop growth processes. On an international level, these impacts are expected to damage key staple crop yields. The Lao PDR has a total irrigated area of over 515,000 ha, including approximately 100,000 ha planted with rice as well as those areas planted with other crops such as vegetables.[196] These areas are severely affected by flooding events and drought.

[195] Adamson, P. and J. Bird. 2010. *The Mekong: a drought-prone tropical environment?* International Journal of Water Resources Development, 26(4), pp.579-594. 2010. URL: https://www.tandfonline.com/doi/abs/10.1080/07900627.2010.519632

[196] Government of Lao PDR. 2004. *National Biodiversity Strategy to 2020 and Action Plan to 2010.* https://www.cbd .int/doc/world/la/la-nbsap-01-en.pdf

Specifically, shifts in the optimal and viable spatial ranges of certain crops are projected, though the extent and speed of those shifts remains dependent on the emissions pathway. Most of the agricultural areas in Lao PDR are dedicated to paddy rice production, but with a growing proportion for maize. Rice remains a staple of household food security in Lao PDR and a number of studies have suggested that there are some potential benefits of climate change in terms of net primary productivity of rice plants. However, the overall outlook for rice production is uncertain. Changes in the onset, duration and intensity of the rainy season, increased drought frequency, and increased incidence of heat wave, if coinciding with key phases towards the start and end of the cropping cycle, may have strong negative implications for total rice production, as well as its reliability as a source of income and calories.[197] Rice is particularly vulnerable to elevated night time minimum temperatures.[198] Minimum temperatures are expected to rise much faster than average temperatures in Lao PDR. One study has suggested that the influence of climate change on temperature and rainfall patterns could depress local rice yields by around 5–20% by the 2040s, with losses typically larger on higher emissions pathways.[199]

A further influence from climate change on agricultural production is through its impact on the health and productivity of the labor force. Dunne et al. (2013) report 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 mid-century under the highest emissions pathway (RCP8.5).[200] 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.

Biodiversity, Forestry and Land Use. The forestry sector contributes to both the national economy and livelihoods of the Laotians. Lao PDR's forests consist of a set of different forest types. There are subtropical montane forest areas in the north, lowland semi-evergreen Dipterocarp forest on the Mekong River Plain, and dry Dipterocarp forest in the southern area.[201] The ecosystem services provided by forests have been noted as particularly important to poorer smallholder farmers. In addition, forests provide resilience to the high inter-annual variability in success of rain-fed agriculture by diversifying incomes.[202]

Up to 80% of the Lao population depends on forests and forest products, and 73% of rural citizens rely on small-scale agriculture and forestry for their livelihoods. In some rural communities, more than 50 percent of a family's income is derived from non-timber forest products (Ketpanh et al. 2012). In congruence, national studies have found that sales of Non-Timber Forest Products (NTFPs) are worth an average of 11% of cash income, rising to 55% in forest rich areas, this is an excess positive income distributed to the rural families. For instance, in Houapanh Province, NTFPs contributed an average of 38% of village cash income, rising as high as 56% for households living within and adjacent to forests and on the Nakai Plateau amounting to over three quarters of family income. On average NTFPs are

[197] Laing, A. M. et al. *2018. Mechanized dry seeding is an adaptation strategy for managing climate risks and reducing labor costs in rainfed rice production in lowland Lao PDR.* Field Crops Research, 225(May), 32–46. URL:https://doi.org/10.1016/j.fcr.2018.05.020.

[198] Welch, J. R. et al. 2010. *Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures.* Proceedings of the National Academy of Sciences, 107(33), 14562–14567. https://www.pnas.org/content/pnas/107/33/14562.full.pdf

[199] Li, S., Q. Wang and J.A. Chun. 2017. *Impact assessment of climate change on rice productivity in the Indochinese Peninsula using a regional-scale crop model*. International Journal of Climatology, 37(April). https://rmets.onlinelibrary.wiley.com/doi/epdf/10.1002/joc.5072

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

[201] FAO. 2010. *Global Forest Resources Assessment.* Rome. http://www.fao.org/3/al547E/al547E.pdf.

[202] Russell, A., J. Foppes, D. Behr, S. Ketphanh, and S. Rafanoharana. 2015. *How Forests Enhance Resilience to Climate Change: The Case of Smallholder Agriculture in Lao PDR*. Washington DC: Program on Forests. https://www.profor.info/sites/profor.info/files/How%20Forests%20Enhance%20Resilence%20To%20Climate%20Change%20Case%20Studies%20from%20Burkina%20Faso%2C%20Honduras%20and%20Lao%20PDR_0.pdf

worth a total of almost $320 per year for rural households in the Lao PDR, contributing to about 44% of subsistence value, 55% of cash income, or 46% of the total household economy.[203] Loss or lack of access to these forest resources due to drought and other factors denote struggles among rural communities.

More severe droughts in combination with a rise in the frequency of lightning strikes under altered climatic conditions could together both stress forests and increase the extent and damage caused by natural forest fires.[204] Regional variations in rainfall patterns and increasing trends of droughts push the Lao PDR population, especially the rural dwellers, directly to poverty due to their direct dependence on forest resources.

Poverty and Inequality. Inequalities have been widening in Lao PDR since the turn of the 21st century.[205] An income gap between rural and urban areas of 18.6% had opened by 2013, and both real and absolute income growth has accrued proportionately more to the rich than to the poor.[206] The growth in inequality in Lao PDR is in affect slowing progress in tackling poverty, which remains high at 23% in 2012. Moreover, the poor intensely depend on biodiversity and natural resources for livelihoods, such as the provision of fish and aquatic resources that make up to 90% of local diets, and the reliance on non-timber forest products (NTFPs), which account for an estimated 30% of Lao PDR's GDP. Thus, climate change is likely to pose formidable threats to the economy and society at large.[207] With agriculture as main sector employing the Lao PDR population, direct impacts of climate change could put the livelihoods of the people in jeopardy, potentially increasing the proportion of the country's population back into poverty. In addition, the majority of rural citizens in Lao PDR have problems with land ownership and tenure is extremely insecure. This marginalizing access issue leaves millions of forest-dependent communities vulnerable to land expropriation.[208]

Many of the climate changes projected are likely to disproportionately affect the poorest groups in society. Flooding and extreme heat stand out as key threats, as heavy manual labor jobs are commonly among the lowest paid whilst also being most at risk of productivity losses due to heat stress.[209] Poorer businesses are least able to afford air conditioning, an increasing need given the projected increase in cooling days. Poorer farmers and communities are least able to afford disaster insurance, local water storage, irrigation infrastructure, and technologies for adaptation. Recent events elicit this low adaptive capacity as more than 200 families living in Laos' Bokeo province have suffered because of sudden increases in the height of the river, threatening their livelihoods.[210]

The ADB has highlighted that many households in Lao PDR have a high probability of falling into extreme poverty even when exposed to relatively high frequency flood and drought events.[211] For example, an event occurring once in every five years has approximately a 50%

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[203] Government of Lao PDR. 2004. *National Biodiversity Strategy to 2020 and Action Plan to 2010.* https://www.cbd.int/doc/world/la/la-nbsap-01-en.pdf

[204] Thomas, I. L. 2015. *Drivers of Forest Change in the Greater Mekong Subregion: Laos Country Report. USAID Lowering Emissions in Asia's Forests (USAID LEAF).* https://www.uncclearn.org/wp-content/uploads/library/fao13102015_4.pdf

[205] Tselios, V. and E.L.Tompkins. 2019. *What causes nations to recover from disasters? An inquiry into the role of wealth, income inequality, and social welfare provisioning.* International Journal of Disaster Risk Reduction, 33, 162–180. https://www.sciencedirect.com/science/article/pii/ S221242091830712X?via%3Dihub

[206] United Nations. 2019. *SDG 10: Inequalities. Lao PDR*. http://www.la.one.un.org/sdgs/sdg-10-inequalities.

[207] Government of Lao PDR. 2010. *Strategy on Climate Change of the Lao PDR*. https://mirror.unhabitat.org/downloads/docs/12679_1_595432 .pdf

[208] Saunders, J., A. Flanagan, and N. Basik. 2014. *Forest Conversion in Lao PDR: Implications and Impacts of Expanding Land Investments*. Forest Trends and Policy Briefs. Forest Governance, Markets and Climate Program, DFID.

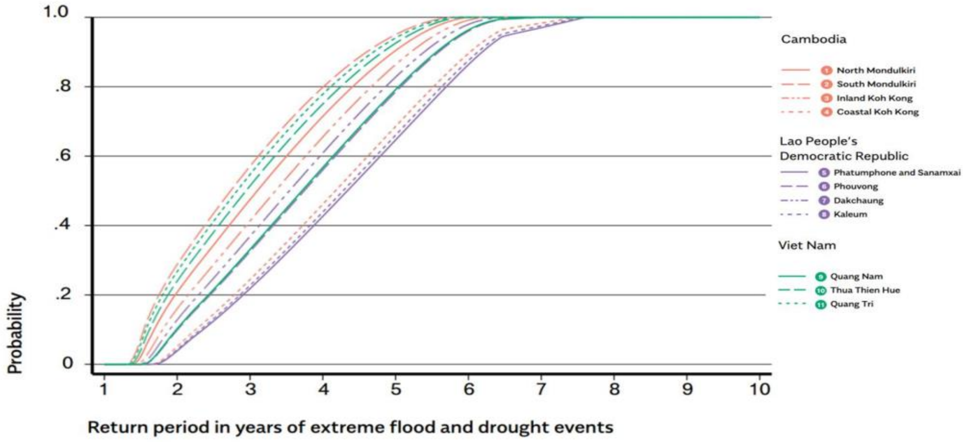
[209] Kjellstrom, T., et.al. *Heat, human performance, and occupational health: A key issue for the assessment of global climate change impacts.* Annual Review of Public Health: 37: 97-112. 2016. URL: https://www.annualreviews.org/doi/pdf/10.1146/annurev-publhealth-032315-021740

[210] Whong, E. 2019. *Livelihood of locals in Laos & Thailand are affected by the sudden water releases of Chinese dams.* Radio Free Asia.

[211] ADB. 2017. *Risk financing for rural climate resilience in the greater Mekong subregion*. Greater Mekong Subregion Core Environment Program, Asian Development Bank. https://www.adb.org/sites/default/files/publication/306796/riskfinancing-rural-climate-resilience-gms.pdf

chance of pushing a household into extreme poverty (**Figure 35**). This highlights the precarious nature of life in Lao PDR for many households under current conditions. While many households will not have the same level of exposure, climate change threatens to enhance and expand exposure through its impacts on extreme events, notably flooding and extreme temperatures. In addition, UNISDR estimates average annual losses from disaster at around 1-2% of GDP, most of which is due to flooding.[212] However, in a country where even modest hazards intensities can have significant wellbeing and living standards[213] impacts on local communities, it is very likely that this figure underestimates the true scale of climate-related hazards. Issues such as landslides and flash flooding in remote areas are likely to be under-reported. Notably, the transport network and hydropower dams in Lao PDR, and the communities' dependent on it, are known to be vulnerable to landslide damage induced by heavy rainfall.[214] Past work has also shown the high economic impact associated with landslide damage to transport and hydropower infrastructure.[215]

Figure 35: Probability of falling into extreme poverty by return period of combined flood and drought events



Source: ADB. 2017. *Risk financing for rural climate resilience in the greater Mekong subregion*. Greater Mekong Subregion Core Environment Program. P. 30,d.

Women participation in Lao PDR shows another dimension of the probably impacts of climate change. A gender report published in 2012, women's work is considered largely informal, 73% of women (compared to 78% for men) contribute to the country's labor force, 70% is engaged in agriculture related activities. Further, women and girls constitute over 70% of unpaid family workers, but only 32% are identified as 'own account workers'. This suggests that women are less likely engaged in productive work with income that they control. Clearly, gender wage gaps are present,[216] not only the undervalued significant work of women in the agriculture sector but also the fact that they work longer hours than men as they spend 7 hours per day on productive and reproductive tasks, compared to the 5.7 hours spent by men. Also, women

[212] UNISDR. 2014. *PreventionWeb: Basic country statistics and indicators*. 2014. URL: https://www.preventionweb.net/countries.

[213] Mani, M., et.al. 2018. *South Asia's Hotspots: The Impact of Temperature and Precipitation changes on living standards.* South Asian Development Matters. World Bank, Washington DC. http://documents.worldbank.org/curated/en/201031531468051189/pdf/128323-PUB-PUBLIC-DOC-DATE-7-9-18.pdf

[214] Mongabay. *Lao government says it will suspend new hydro projects after dam collapse kills 31*. August 13, 2018.

[215] Hearn, G.J. et al. 2008. *Landslide impacts on the road network of Lao PDR and the feasibility of implementing a slope management program*. In International Conference on Management of Landslide Hazard in the Asia-Pacific Region, Sendai, Japan. https://assets.publishing.service.gov.uk/media/57a08ba8ed915d622c000e03/Seacp21-02.pdf

[216] UN Women Regional Office for Asia and the Pacific. 2018. https://asiapacific.unwomen.org/-/media/field%20office%20eseasia/docs/ publications /2018/08/factsheetunwomeninlaopdrrevisedversion2f08compressed.pdf?la=en&vs=1124

increasingly run their own businesses, but these tend to be smaller than those owned by men, adding to the difficulty of finding access to finance and technical skills.[217]

Human Health. The WHO highlights that climate change threatens to stall progress in reducing disease risk in Lao PDR. Malaria is a particular threat for the country, and an increase in the population at risk of around 400,000 is projected when moving from RCP2.6 to RCP8.5 by the 2040s and 2070s, respectively.[218] Similarly, the vectoral capacity for dengue fever increases under both emissions pathways, but by slightly less under RCP2.6 as compared to RCP8.5. Projections suggest an increase in the population affected by flooding, which also raises the risk of the spread of waterborne diseases. *Leptospirosis* is among several diseases linked to flooding in Lao PDR.[219] Global research has also linked both drought and flood to increased incidence of diarrheal disease.[220] As of 2016, diarrheal disease was responsible for 11% of all under-5 deaths in Lao PDR.[221] Also, with altered groundwater levels, contamination is highly possible, thus drinking water in Lao PDR can be contaminated with harmful chemicals and human waste, causing a variety of health issues[222] further adding burden to the marginalized sector of the population.

[217] ADB and World Bank. 2012. *Country Gender Assessment for Lao PDR-Reducing Vulnerability and Increasing Opportunity: Lao PDR*. https://www.adb.org/sites/default/files/institutional-document/33755/files/cag-lao-pdr.pdf
[218] WHO. 2015. *Climate and Health Country Profile: Lao People's Democratic Republic.* World Health Organization, Geneva. https://apps.who.int/iris/bitstream/handle/10665/246139/WHO-FWC-PHE-EPE-15.39-eng.pdf?sequence=1&isAllowed=y.
[219] Lau, C. L., L.D. Smythe, S.B. Craig, and P. Weinstein. 2010. *Climate change, flooding, urbanization and leptospirosis: Fueling the fire?* Transactions of the Royal Society of Tropical Medicine and Hygiene, 104(10), 631–638. https://www.ncbi.nlm.nih.gov/pubmed/20813388
[220] Wu, X., et.al. 2016. *Impact of climate change on human infectious diseases: Empirical evidence and human adaptation.* Environment International, 86, 14–23. https://www.sciencedirect.com/science/article/pii/S0160412015300489?via%3Dihub
[221] WHO. 2018.*Maternal and Child Epidemiology Estimation Group (MCEE).* Data Estimates 2018. https://www.who.int/healthinfo/global_burden_disease/childcod_methods_2000_2016.pdf
[222] UNICEF-Laos. 2017. *Water, Sanitation & Hygiene and Climate Change Resilience: Safe water, sanitation and good hygiene practices*. https://www.unicef.org/laos/wash#:~:text=Drinking%20water%20in%20Lao%20PDR, clean%20water%20and%20sanitation%20facilities.

F. PAKISTAN CLIMATE RISK PROFILE

1. Summary of Climate Rationale

Pakistan is a very large and climatically diverse country with high altitude mountains in the north and west, arid deserts in the south, the hot and dry Indus River Valley in the centre and south, and a humid coastline. Most of the country receives very little rainfall, with the majority occurring in the summer monsoon. Pakistan faces some of the highest climate related disaster risk levels in the world, and has high exposure to flooding, including, riverine, flash, and coastal, as well as exposure to tropical cyclones, droughts and heatwaves. The coastal area is a particular hot spot for the risks of storm surges, erosion and cyclones. The Indus Delta, is low-lying and flat, with around 4,750 km^2 below 2m above sea-level. Around 5 million people in Pakistan live in this low-lying coastal area, but because of population growth, it is projected that the population could increase six-fold to reach 30 million people by 2060. Cyclones do arise the Arabian sea, and when they hit landfall in Pakistan in this area, they can cause major impacts.

Recent observations show that the climate of Pakistan is changing already. There is a clear warming trend, which has accelerated since the 1960s (with reported 0.5 to 1°C of warming), and higher numbers of heatwaves and hot days. The patterns of rainfall are more uncertain, and differ across the country and by season, but there are multiple sources that report that rainfall in the coastal area has declined by 10–15% since the 1960s. However, heavy rainfall events have increased, with the heaviest rain intensities recorded over the last decade. Coastal areas of Pakistan have experienced changes in mean sea level in the past, with observations at Karachi indicating an increase in the mean sea level of about 1 mm/yr during the 20th century. Recent analysis has found that climate change has had a major role in increasing cyclone activity in the Arabian sea.

The projected temperature increases for Pakistan indicate increases above the global average. By mid-century (2050s) a further rise of 1.5°C to 2.5°C (central estimate), relative to a baseline 1986-2005 period is projected. There are also projected increases in hot and very hot days. There is lower confidence in the changes in precipitation, because it is extremely difficult to model rainfall changes due to the influence of Monsoon dynamics and El Niño events. The climate models generally project modest changes in rainfall by the mid-century (2050s). There is more confidence that heavy precipitation events will increase, which could have implications for floods. The projections of sea level rise are a particular concern for the coastal area. Around one million people are projected to experience coastal flooding annually by the period 2070–2100. SLR will also lead to saline intrusion in these areas, degrading land quality and agricultural yields. These effects are projected to be exacerbated by increases in the average intensity, magnitude of storm surge and precipitation rates of tropical cyclones. Coastal areas will also be affected by other climate impacts, including on agriculture, water and ecosystems, and the effects of heat on labor productivity and health.

2. Country Overview

Pakistan is situated in South Asia, located between 23°35’ to 37°05’ North latitude and 60°50’ to 77° 50’ East longitude. The country touches the Hindukush Mountains in the north and extends from the Pamirs to the Arabian Sea. It has a total area of 796,095 km^2 and is characterized by diverse topography, ecosystems, and climate zones. Pakistan is rich in natural resources, including fertile agricultural lands, natural gas reserves, and mineral deposits.

A semi-industrialized country, Pakistan has grown from a primarily agriculture-based to a mostly service-based economy (with services constituting 56.3% of GDP in 2017). As of 2017 agriculture was still the largest employer, occupying 42.3% of the workforce. As of 2015 approximately 24.3% of the population still lived below the national poverty line and as of 2014–2106, 19.9% of the population remained undernourished (**Table 16**). The majority of Pakistan's 216 million people live along the Indus River, an area prone to severe flooding in July and August. Major earthquakes are also frequent in the mountainous northern and western regions.

The Government of Pakistan established the Ministry of Climate Change and issued its first National Policy of Climate Change in 2012. The National Climate Change Policy recognizes that while Pakistan is working on a strategy that seeks to conserve energy, improve energy efficiency and optimize fuel mix to support global efforts for reduction in greenhouse gas emissions, the more immediate and pressing task is to prepare itself for adaptation to climate change. Pakistan ratified the Paris Agreement on November 10, 2016.

This annex aims to succinctly summarize the climate risks faced by Pakistan, and demonstrate the climate rationale for CRPP sub-projects in Pakistan. This includes historic data, current climate variability and short 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 happening. It is a high-level synthesis of existing research and analyses, focusing on the geographic domain of Pakistan, therefore potentially overlooking some international flows and localized impacts. The data is derived from a review of various data sources, reports and academic publications. In particular, this references the Government of Pakistan's second national communication[223], the Climate Projections profiles[224], the ADB Climate profile[225], World Bank Climate Risk Profiles[226], World Bank Climate Portal[227], and the USAID climate profile[228].

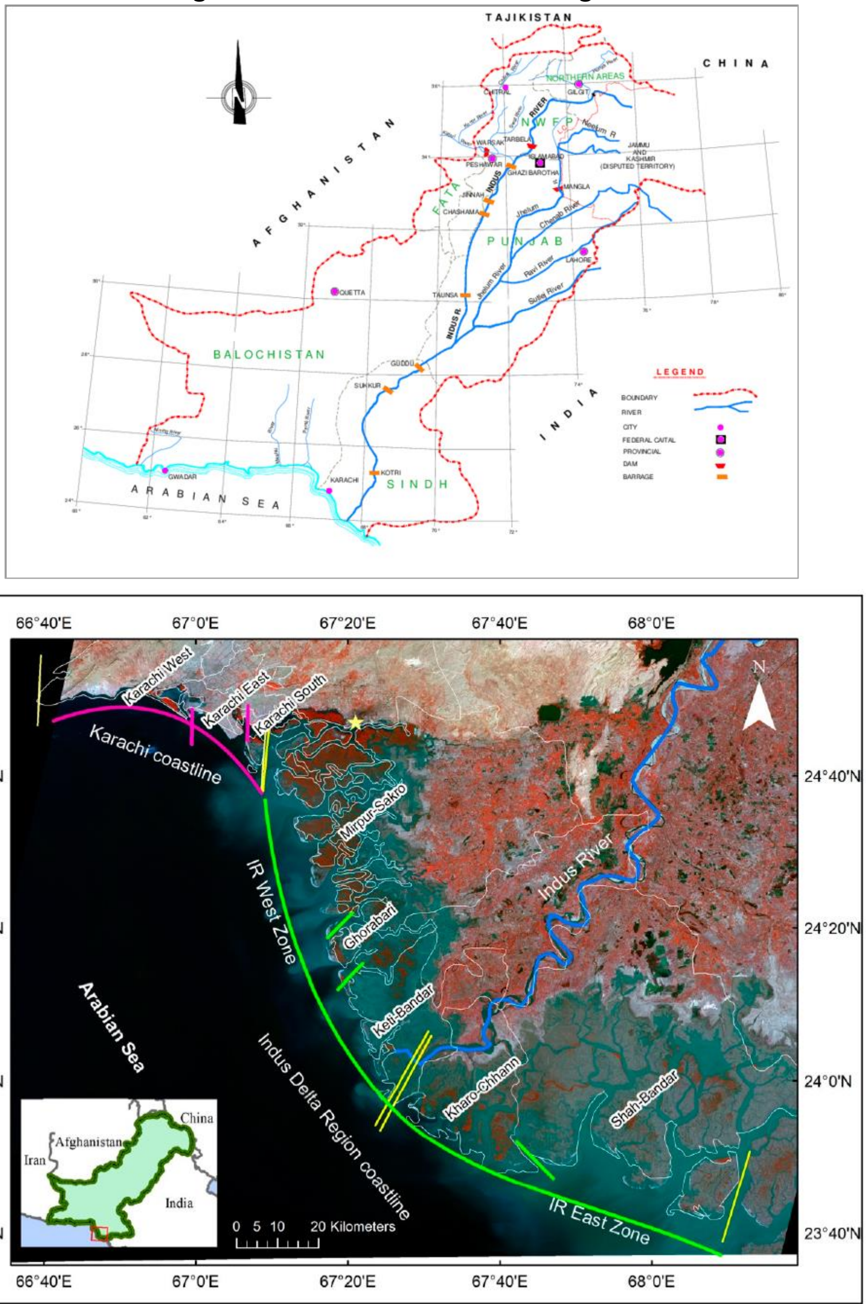
Table 16: Pakistan Key indicators

Indicator	Value	Source
Population undernourished	19.9% (2014–2016)	FAO, 2017
National poverty rate	24.3% (2015)	ADB, 2018
Share of wealth held by bottom 20%	9.2% (2013)	World Bank, 2018
Net annual migration rate	–0.13% (2010–2015)	UNDESA, 2017
Infant mortality rate (between age 0 and 1)	6.9% (2010–2015)	UNDESA, 2017
Average annual change in urban population	0.58% (2010–2015)	UNDESA, 2018
Dependents per 100 independent adults	98.9 (2015)	UNDESA, 2017
Urban population as % of total population	36.7% (2018)	CIA, 2018
External debt ratio to GNI	22.9% (2015)	ADB, 2017a
Government expenditure ratio to GDP	20.6% (2016)	ADB, 2017a

The coastal zone of the Indus River Delta has very high vulnerability,[229] as it is particularly low-lying. The Indus delta is the world's sixth largest deltaic region. It covers an area of about 60,000 hectares and is characterized by 17 major creeks and a much larger number of minor creeks, mud flats and fringing mangroves. The delta supports wetlands rich in nature and culture, and also nurtures a very large area of arid climate mangroves. The area is very low lying and flat, and very sensitive to storm surges, and it is also subject to high levels of erosion.[230]

[223] Ministry of Climate Change. 2018. Pakistan's Second National Communication on Climate Change to United Nations Framework on Climate Change. Government of Pakistan.
[224] GERICS. 2015. Climate-Fact-Sheet Pakistan. Climate Service Center Germany.
[225] ADB. 2017. Climate Change Profile of Pakistan.
[226] GFDRR. 2011. Vulnerability, Risk Reduction, and Adaptation to Climate Change. Climate Risk and Adaptation Country Profile for Pakistan; and ADB and World Bank. 2020. Climate Risk Country Profile Pakistan.
[227] WBG Climate Change Knowledge Portal https://climateknowledgeportal.worldbank.org/.
[228] USAID. 2018. Pakistan Climate Risk Profile.
[229] Salik, K.M., S. Jahangir, W. ul Zafar Zahdi, and S. ul Hasson. 2015. Climate change vulnerability and adaptation options for the coastal communities of Pakistan, Ocean & Coastal Management, Volume 112, 2015, Pages 61-73, ISSN 0964-5691, https://doi.org/10.1016/j.ocecoaman.2015.05.006.
[230] Kanwal, S., X. Ding, Sajjad, M. Sajjad, and S. Abbas. 2019. Three Decades of Coastal Changes in Sindh, Pakistan (1989–2018): A Geospatial Assessment. Remote Sensing. https://doi.org/10.3390/rs12010008

Figure 36: The Indus Delta Region

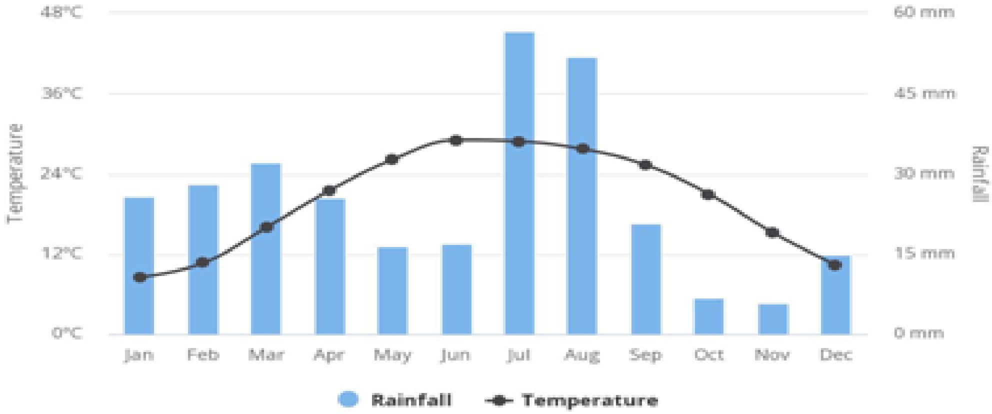


Source Kanwal et al. (2018)

3. Current and Future Climate

Pakistan is a very large and climatically diverse country. The annual average climate is shown in **Figure 37**, but is stressed that there is considerable variation across the country due to elevation and climatological differences. Pakistan has distinct climate zones, with high altitude mountains in the north and west, arid deserts in the south, the hot and dry Indus River Valley in the centre and south, and a humid coastline. Most of the country receives very little rainfall, with the majority occurring in the summer monsoon season.

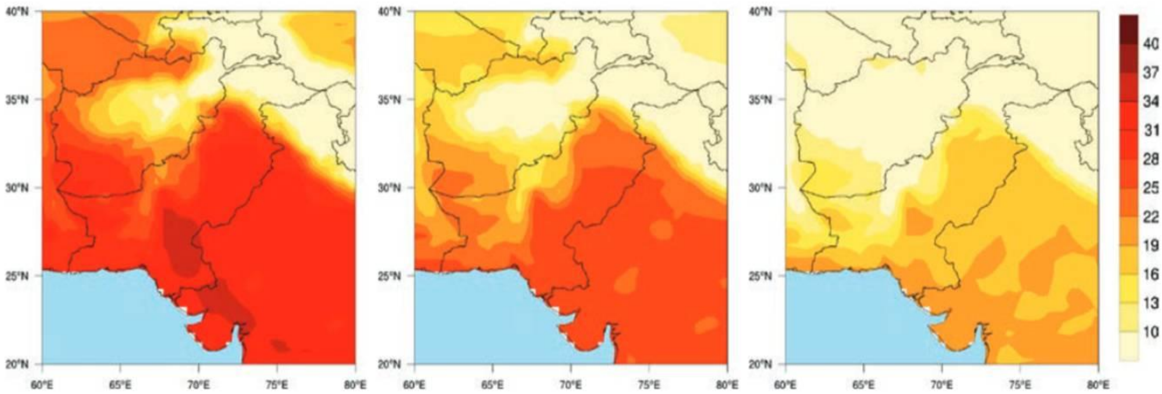
Figure 37: Average monthly temperature and rainfall in Pakistan, 1901-2016



Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical.* https://climateportal.worldbank.org.

It is generally dry and hot near the coast and along the lowland plains of the Indus river, becoming progressively cooler in the northern uplands and Himalayas (**Figure 38** and **Figure 39**). There are generally four seasons in Pakistan: (i) a cool, dry winter from December to February; (ii) a hot, dry spring from March through May; (iii) the summer rainy season, also known as the southwest monsoon period, occurring from June to September; and (iv) the retreating monsoons from October to November.

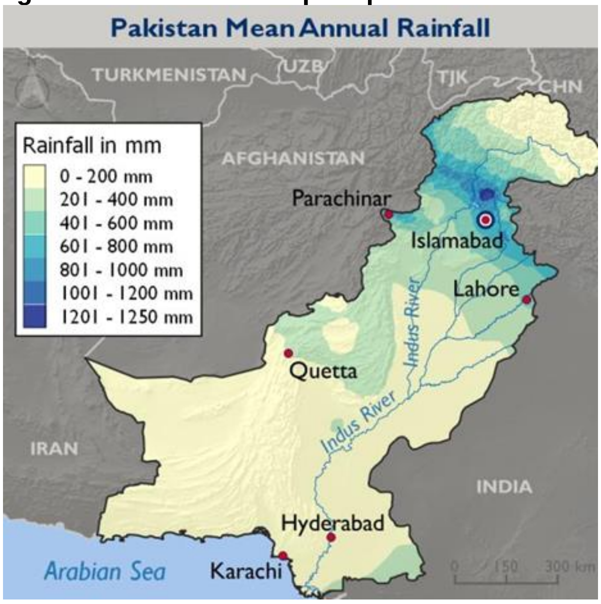
Figure 38: Average maximum temperature (left), annual mean temperature (center), and average minimum temperature in Pakistan (right), 1901–2016



There are large rainfall differences across the country. The majority of the country receives very little rainfall, with the exception of the Northern regions, where monsoons can bring upwards of 200 mm a month from July to September. The South receives very little rainfall (less than 200 mm/year on average). However, there is also high Inter-annual rainfall, which often leads to successive patterns of floods and drought. El Niño and La Niña cycles have a significant influence on climate variability in Pakistan, with anomalies in both temperature Fand flood frequency and impact[231] correlated to its cycle.

[231] del Río, S. et al. 2013. *Recent mean temperature trends in Pakistan and links with teleconnection patterns.* International Journal of Climatology, 33, 277–290.

Figure 39: Annual mean precipitation in Pakistan



Source: USAID (2018).

In terms of coastal regions, Pakistan ranks among the top-25 countries in terms of population in the low elevation coastal zone (LECZ). In the year 2000, around 5 million people were living in low-lying coastal areas,[232] however, because of the strong population growth it is projected that the LECZ population could increase six-fold to reach 30 million people by 2060.

Climate Trends

Recent observations show that the climate of Pakistan and Sindh region are changing already. There is a clear warming trend, which has accelerated since the 1960s, and higher numbers of heatwaves and hot days. However, a review of difference profiles and academic papers (2nd NC, 2018, USAID, 2018, GERICS, 2015, ADB, 2017, WB, 2020, del Río, S., et.al. 2013; Dehlavi, et al., 2015) finds differences reported in the exact levels of warming, and on the relative increases in different regions. Across the studies, there is a reported warming of 0.5 to 1°C of warming over the last century, but this has been driven by an accelerated warming since the 1960s.

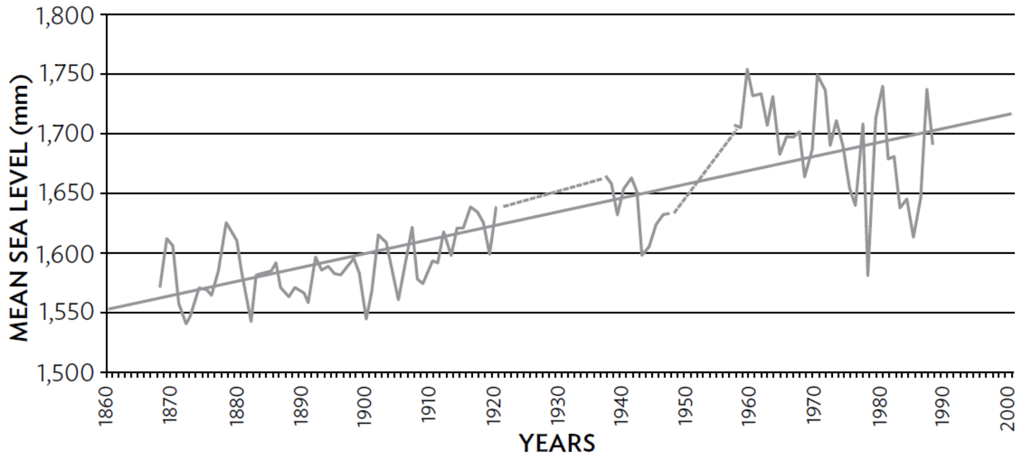
The patterns of rainfall trends are more uncertain, and differ across the country and by season. The trends are difficult to pick out due to the high inter-annual variability, and a review of multiple sources finds differences in reported trends. However, there are some consistently reported trends that mean rainfall in the arid plains of Pakistan and the coastal belt has decreased by 10-15% since the 1960s (ADB, 2017, USAID, 2018, WB, 2020), whereas most other regions indicate a possible slight increase. However, heavy rainfall events have increased, with the heaviest rain intensities recorded over the last decade, which is exacerbating flood risks. The number of heavy rainfall events has increased since 1960, and the nine heaviest rains recorded in 24 hours were recorded in 2010.

Coastal areas of Pakistan have experienced changes in mean sea level in the past, with observations at Karachi indicating an increase in the mean sea level of about 1 mm/yr during the 20th century (GERICS, 2015 Rabbani, 2008).

[232] Neumann B., A.T. Vafeidis, J. Zimmermann, and R.J. Nicholls. 2015. Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. PLoS ONE 10(3): e0118571. https://doi.org/10.1371/journal.pone.0118571

There is also some information that highlights that due to warmer ocean temperatures, cyclone risks are rising in the Arabian sea,[233] and attribution studies report that climate change has likely increased the probability of late-season cyclones.

Figure 40: Mean Sea Level Rise Recorded along Karachi Coast, Pakistan, 1850–2000



Source: Rabbani M.M. et al. 2008. The Impact of Sea Level Rise on Pakistan's Coastal Zones - In a Climate Change Scenario. 2nd International Maritime Conference at Bahria University, Karachi.

Climate Change Projections

This annex has compiled climate model projections. A number of studies have been considered, but the data focuses on the information from World Bank climate portal data. This uses multi-model data from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) included in the IPCC's Fifth Assessment Report (AR5). The data is derived from 35 available global circulation models (GCMs) used by the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report. Data and downscaled through bi-linear interpolation (World Bank, 2021[234]). There are some regional climate modelling runs for Pakistan, but only for a limited number of models, and given the very high challenges in climate projections for the country, the multi-model ensemble data is preferred.

Temperature Changes. The projected temperature increases for Pakistan indicate increases above the global average. By mid-century (2050s) a further rise of broadly 1.5°C to 2.5°C (central estimate), relative to a baseline 1986-2005 period is projected, depending on scenario and model. Temperature is projected to rise after this time under high emission scenarios (with no global mitigation), and could reach 5°C (central estimate) by the end of the century. There are also projected increases in hot and very hot days. The data from the World Bank downscaled analysis is shown below. Projections for future temperature change are presented as the changes (or anomalies) in maximum and minimum temperatures over the given time period, as well as changes in the average temperature. Unless otherwise stated the global projections shown here represent changes against the 1986-2005 baseline.

[233] Murakami, H., Vecchi, G.A. & Underwood, S. Increasing frequency of extremely severe cyclonic storms over the Arabian Sea. Nature Clim Change 7, 885–889 (2017). https://doi.org/10.1038/s41558-017-0008-6

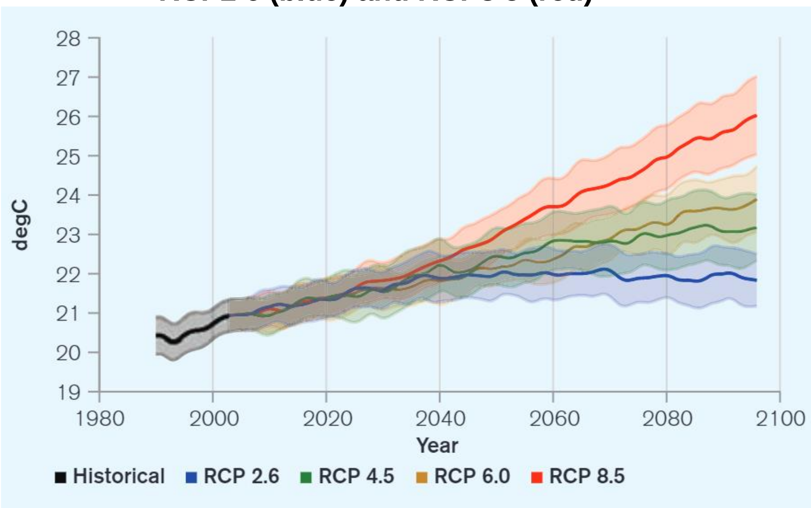
[234] Metadata for the Climate Change Knowledge Portal (CCKP). https://climateknowledgeportal.worldbank.org/themes/custom/wb_cckp/resources/data/CCKP_Metadata_Final_January2021.pdf

Figure 41: An overview of Pakistan's temperature projections (anomaly °C) over different time horizons, emissions pathways, and measures, showing the median estimates of the full CCKP model ensemble and the 10th and 90th percentiles in brackets.

Scenario	Annual average of monthly maximum		Annual average		Annual average of monthly minimum	
	2040–2059	2080–2099	2040–2059	2080–2099	2040–2059	2080–2099
RCP2.6	1.36 (0.74, 2.17)	1.4 (0.62, 2.49)	1.36 (0.7, 2.07)	1.26 (0.51, 2.33)	1.48 (0.74, 2.45)	1.37 (0.48, 2.48)
RCP4.5	1.94 (1.1, 2.84)	2.73 (1.72, 4.01)	1.86 (1.1, 2.71)	2.52 (1.62, 3.52)	1.95 (1.05, 2.86)	2.71 (1.57, 3.85)
RCP6.0	1.64 (0.88, 2.42)	3.31 (2.29, 4.49)	1.5 (0.95, 2.22)	3.05 (2.05, 4.16)	1.75 (0.9, 2.53)	3.37 (2.43, 4.7)
RCP8.5	2.46 (1.58, 3.35)	5.24 (3.86, 6.75)	2.36 (1.68, 3.19)	4.9 (3.71, 6.65)	1.75 (1.68, 3.73)	5.6 (4.14, 7.13)

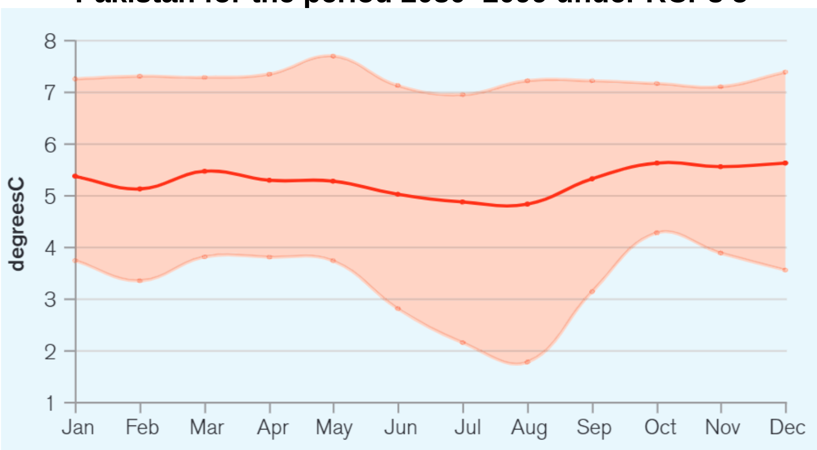
Source WB/ADB, 2020

Figure 42: Historic and projected average annual temperature in Pakistan under RCP2 6 (blue) and RCP8 5 (red)



Note: The values shown represents the median of 30+ GCM model ensemble with the shaded areas showing the 10–90th percentiles.
Source: WBG Climate Change Knowledge Portal. 2019. Climate by Sector. https://climateknowledgeportal.worldbank.org/country/pakistan

Figure 43: Projected change (anomaly) in monthly temperature, shown by month, for Pakistan for the period 2080–2099 under RCP8 5

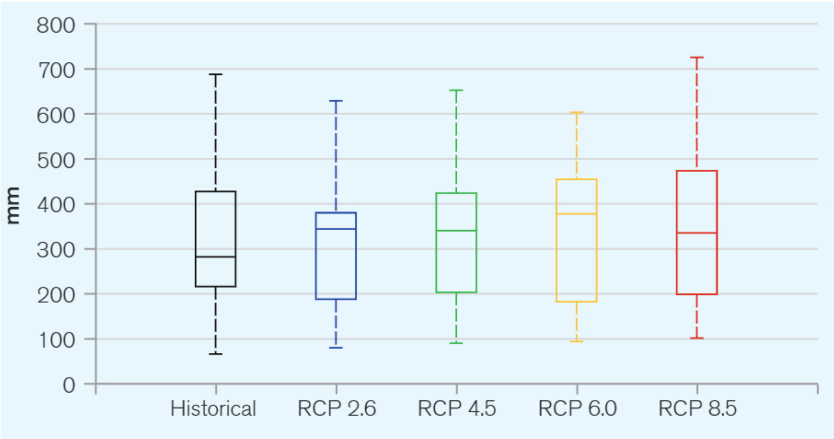


Note: The values shown represents the median of 30+ GCM model ensemble with the shaded areas showing the 10–90th percentiles.
Source: WBG Climate Change Knowledge Portal (2019). Climate by Sector. https://climateknowledgeportal.worldbank.org/country/pakistan

Precipitation Changes. There is lower confidence in the changes in precipitation, because it is extremely difficult to model rainfall changes in Pakistan. The climate models generally project modest changes in rainfall by the mid-century (2050s). There is more confidence that heavy precipitation events will increase, which could have implications for floods. **Figure 44** shows the projections of future precipitation in Pakistan. The changes on an annual basis for the full model ensemble are not statistically significant. However, studies such as Amin et al. (2018)[235] also highlights the risk of increased frequency and intensity of flood and drought events due to changes in the seasonality, regularity, and extremes of precipitation. This fits with a global trend, described by Westra et al. (2014),[236] of increased intensity of sub-daily extreme rainfall events.

The poor and inconsistent performance of climate models in projecting precipitation trends in Pakistan[237] links in part to their weak performance simulating future changes in the South Asian monsoon[238] Uncertainty also remains regarding the future dynamics of the El Niño Southern Oscillation.

Figure 44: Boxplots showing the projected average annual precipitation for Pakistan, 2080-2099



Source: WBG Climate Change Knowledge Portal. 2019. Climate by Sector. https://climateknowledgeportal.worldbank.org/country/pakistan

4. Natural Hazard Risk

Pakistan faces some of the highest disaster risk levels in the world, ranked 18 out of 191 countries by the 2020 Inform Risk Index[239] (**Table 17**). This risk ranking is driven particularly by the nation's exposure to earthquakes, but Pakistan also has high exposure to flooding (ranked jointly 8th), including, riverine, flash, and coastal, as well as some exposure to tropical cyclones and their associated hazards (ranked jointly 40th) and drought (ranked jointly 43rd). Disaster risk in Pakistan is also driven by its social vulnerability. Pakistan's vulnerability ranking (37th) is driven by its high rates of multidimensional poverty. Pakistan scores slightly better in terms of its coping capacity (ranked 59th). The section which follows analyses climate change influences on the exposure component of risk in Pakistan.

[235] Amin, A., et.al. 2018. Regional climate assessment of precipitation and temperature in Southern Punjab (Pakistan) using SimCLIM climate model for different temporal scales. Theoretical and Applied Climatology: 131: 121–131.
[236] Westra, S. et al. 2014. *Future changes to the intensity and frequency of short-duration extreme rainfall.* Reviews of Geophysics, 52, 522–555.
[237] Latif, M., A. Hannachi, and F.S. Syed. 2018. *Analysis of rainfall trends over Indo-Pakistan summer monsoon and related dynamics based on CMIP5 climate model simulations.* International Journal of Climatology, 38, e577-e595.
[238] Sperber, K.R. et al. 2013. *The Asian summer monsoon: an intercomparison of CMIP5 vs. CMIP3 simulations of the late 20th century.* Climate Dynamics, 41, 2711–2744.
[239] https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk

Table 17: Selected indicators from the INFORM Index for Risk Management for Pakistan

Flood	Tropical Cyclone	Drought	Vulnerability	Lack of Coping Capacity	Overall Inform Risk Level	Rank
(0-10)	(0-10)	(0-10)	(0-10)	(0-10)	(0-10)	(1-191)
8.8	3.8	5.5	5.4 [4.7]	5.9 [5.0]	6.3 [5.1]	18

Note: For the sub-categories of risk (e.g. "Flood") higher scores represent greater risks. Conversely the most at-risk country is ranked 1st. Regional average scores are shown in brackets.
Source: Emergency Events Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters (CRED). *The International Disaster Database.* 2020. URL: https://www.emdat.be/

Table 18) show its impact on Pakistan. Flooding events are among the most destructive natural hazards affecting a huge area in the country as well as the socially vulnerable population. Other hazards also impact Pakistan considerably given the large share of its vulnerable population.

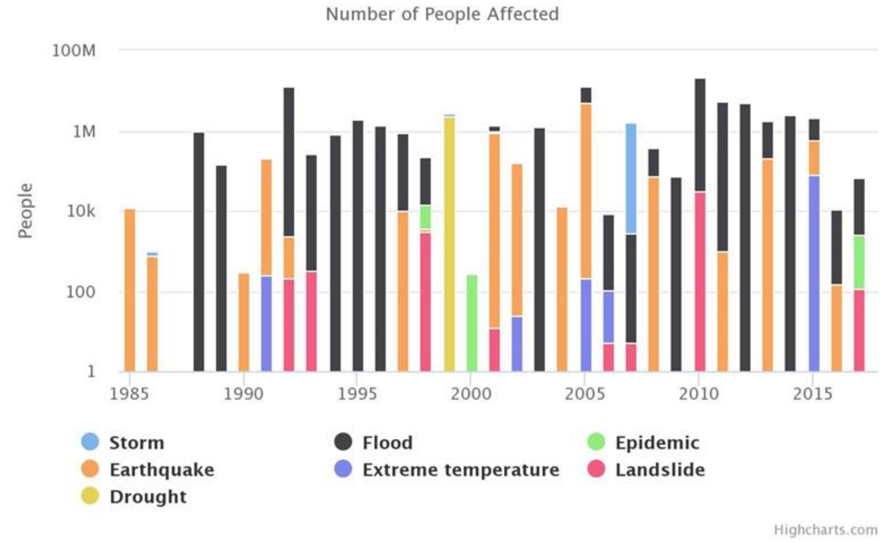
Table 18: Summary of Natural Hazards in Pakistan, 1900–2018

Disaster Type	Disaster Subtype	Events Count	Total Deaths	Total Affected	Total Damage ('000 US$)
Drought	Drought	1	143	2,200,000	247,000
Earthquake	Ground movement	31	143,734	7,275,388	5,329,755
Epidemic	Bacterial disease	3	142	11,103	0
	Parasitic disease	1	0	5,000	0
	Viral disease	2	35	2,504	0
	Others	5	131	371	0
Extreme temperature	Cold wave	3	18	0	0
	Heat Wave	15	2,936	80,574	18,000
Flood	Flash flood	20	3,412	22,108,546	10,184,118
	Riverine flood	43	9,229	34,967,357	9,727,030
	Others	31	4,751	22,307,919	1,170,030
Landslide	Avalanche	12	567	4,435	0
	Landslide	8	206	29,707	18,000
	Mudslide	2	16	12	0
Storm	Convective storm	13	256	1,771	0
	Tropical cyclone	7	11,555	2,599,940	1,715,036
	Others	7	184	2,988	0

Source:
INFORM (2019). Index for Risk Management. Inter-Agency Standing Committee Reference Group on Risk, Early Warning and Preparedness. Available at: http://www.inform-index.org/

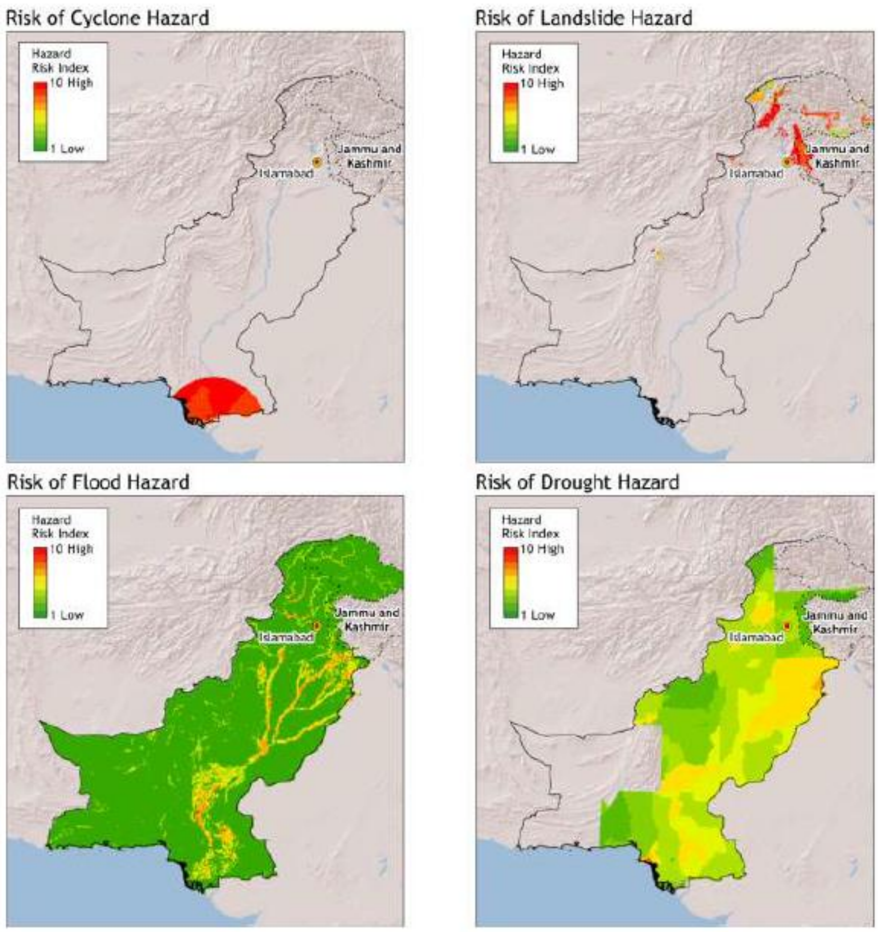
The data shows the high and repeated patterns of natural climate hazards, as below. The profile of these hazards varies across the country. The coastal zone is particularly vulnerable to cyclone risk, and flood risk.

Figure 45: Number of People Affected by Natural Hazards, 1985 – 2018



Source: WB Climate Portal.

Figure 46: Exposure to climate-related hazards across Pakistan



Source: GFDRR. http://www.gripweb.org/

Flood. The World Resources Institute's AQUEDUCT Global Flood Analyzer can be used to establish a baseline level of flood exposure to large-scale river flooding. As of 2010, assuming protection for up to a 1-in-25-year event, the population annually affected by flooding in Pakistan was estimated at 1.5 million people and expected annual urban damage is estimated at $1.4 billion.[240] Development and climate change are both likely to increase these figures. The climate change component can be isolated and by 2030 is expected to increase the annually affected population by 400,000 people, and urban damage by $6.1 billion under the RCP8.5 emissions pathway. UNISDR (2014)[241] place Pakistan's average annual losses to flood at around $1 billion. Work by Willner et al. (2018)[242] estimates that by 2035–2044 an additional five million people will be affected by extreme river flooding annually (**Table 19**).

Table 19: Estimated number of people in Pakistan affected by an extreme river flood (extreme river flood is defined as being in the 90th percentile in terms of numbers of people affected) in the historic period 1971-2004 and the future period 2035-2044

Estimate	Population exposed to extreme flood (1971–2004)	Population exposed to extreme flood (2035–2044)	Increase in affected population
16.7 Percentile	4,158,091	9,220,336	5,062,245
Median	5,709,314	11,238,400	5,529,086
83.3 Percentile	7,929,955	13,378,717	5,448,762

Note: Figures represent an average of all four RCPs and assume present day population distributions.
Source: Willner, S., A. Levermann, F. Zhao, and K. Frieler. 2018. *Adaptation required to preserve future high-end river flood risk at present levels.* Science Advances: 4:1. https://advances.sciencemag.org/content/4/1/eaao1914

Cyclones and storm surges. The lowland plains of Sindh and Baluchistan, which include the urban regions of Karachi and Hyderabad, are vulnerable to the impacts of cyclones. While the Arabian Sea is comparatively less prone to cyclonic storms than the Bay of Bengal, and cyclones do not hit landfall as commonly as the sea has a colder temperature, there is an occurrence of one extremely severe cyclone on average in every four-five years in the Arabian sea. There are recorded incidents affecting Pakistan recorded in international databases (EM-DAT)[243]. For example, a strong cyclone hit Pakistan in 1999, killing some 6200 people, and there have been major storms recorded in 2004, 2007 and 2010, all of which affected the project area. In 2007, storm surges caused by Cyclone Yemyin had significant impacts on lives and property.

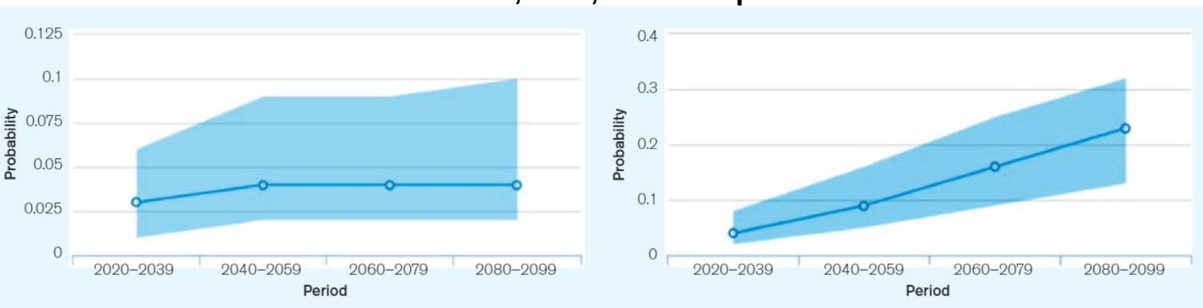
There is some uncertainty over the future patterns of tropical cyclones. The IPCC SROCC (2019)[244] projects that the average intensity of tropical cyclones, the proportion of Category 4 and 5 tropical cyclones and the associated average precipitation rates are projected to increase for a 2°C global temperature rise above any baseline period (medium confidence). This, combined with rising mean sea levels will contribute to higher extreme sea levels associated with tropical cyclones (very high confidence). Coastal hazards will also be exacerbated by an increase in the average intensity, magnitude of storm surge and precipitation rates of tropical cyclones.

Heat Waves. Pakistan regularly experiences some of the highest maximum temperatures in the world, with an average monthly maximum of around 27°C and an average June maximum of 36°C. The current median annual probability of a heat wave occurring in any given location in Pakistan is around 3%.308F308F[245] Pakistan experienced 126 heat waves between 1997-2015, around 7 per year, and there is an increasing trend. Over 1,200 heat-related deaths resulted from a severe heatwave in 2015, primarily focused on Sindh Province.[246] Matthews

[240] World Resource Institute (WRI). 2018. *AQUEDUCT Global Flood Analyzer.* https://floods.wri.org/#
[241] United Nations International Strategy for Disaster Reduction (UNISDR). 2014. *PreventionWeb: Basic country statistics and indicators.* https://www.preventionweb.net/countries [accessed 14/08/2018]
[242] Willner, S., A. Levermann, F. Zhao, and K. Frieler. 2018. *Adaptation required to preserve future high-end river flood risk at present levels.* Science Advances: 4:1.
[243] EM-DAT, CRED / UCLouvain, Brussels, Belgium www.emdat.be
[244] IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (eds.)]. In press.
[245] WBG Climate Change Knowledge Portal. 2018. *Climate Data: Projections.* https://climateportal.worldbank.org.
[246] Nasim, W., et.al. 2018. *Future risk assessment by estimating historical heat wave trends with projected heat accumulation using SimCLIM climate model in Pakistan.* Atmospheric Research: 205: 118–13. 2018.

et al. (2017)[247] identify both Karachi and Lahore as among the cities with most vulnerability to increases in extreme heat, even under lower emissions pathways. This indicates high mortality risk could become a regular occurrence. The multi-model ensemble projects an increase in the median annual probability of a heatwave in any given region from 3% to 4–23% depending on the emissions pathway.[248] This estimated change in probability as a percentage increase over the probability in 1995, albeit with a different and smaller set of models, showing probability increases in the range of 62–140% depending on emissions pathway, with the highest increases always seen under RCP8.5.[249]

Figure 47: Projected change in the probability of observing a heat wave in Pakistan under RCP2.6 (left figure) RCP8.5 (right figure) estimated by the full IPCC model ensemble in 10th, 50th, and 90th percentiles

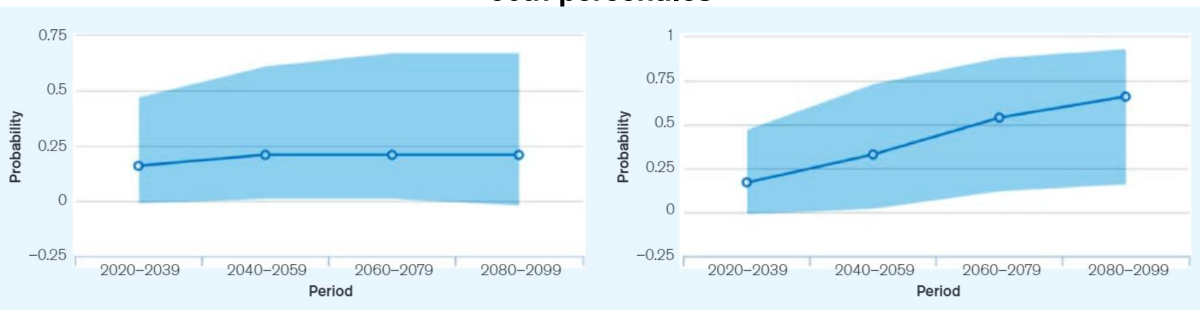


Note: In this model a 'Heat Wave' is defined as a period of 3 or more days where the daily temperature is above the long-term moving 95th percentile of daily mean temperature.
Source: WBG Climate Change Knowledge Portal. .2019. Climate by Sector.
https://climateknowledgeportal.worldbank.org/country/pakistan

Drought. Two primary types of drought may affect Pakistan, meteorological (usually associated with a precipitation deficit) and hydrological (usually associated with a deficit in surface and subsurface water flow, potentially originating in the region's larger river basins). At present Pakistan faces an annual median probability of severe meteorological drought of around 3% as defined by a standardized precipitation evaporation index (SPEI) of less than –2.314F314F250 . The probability of meteorological drought is projected to increase under all emissions pathways, and with very strong increases. While uncertainty is high, the CMIP5 ensemble projection would suggest that severe drought conditions (SPEI <–2) may be experienced with an annual probability of 25–65% across Pakistan, with higher probability under higher emissions. As reported by Ahmed et al. (2018)[251] drought frequency is increasing in already arid and semi-arid areas. Droughts are in some cases associated with El Niño events and can cause significant damage to crop and livelihoods, as in the consecutive droughts of 1999 and 2000, which caused crop failure and mass famine in Pakistan.

[247] Matthews, T., R.L. Wilby, and C. Murphy. 2017. *Communicating the deadly consequences of global warming for human heat stress.* Proceedings of the National Academy of Sciences, 114, 3861–3866.
[248] WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org
[249] Matthews, T., R.L. Wilby, and C. Murphy. 2017.*Communicating the deadly consequences of global warming for human heat stress.* Proceedings of the National Academy of Sciences, 114, 3861–3866.
[250] WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org
[251] Ahmed, K., S. Shahid, & N. Nawaz. *Impacts of climate variability and change on seasonal drought characteristics of Pakistan.* Atmospheric Research, 214, 364–374. 2018.

Figure 48: Projected change in the annual probability of experiencing at least severe drought conditions (–2 SPEI index) in Pakistan under RCP2.6 scenario (left) and RCP8.5 scenario (right) estimated by the full CMIP5 model ensemble in 10th, 50th, and 90th percentiles



Source: WBG Climate Change Knowledge Portal (CCKP, 2019). Climate Projections. URL: https://climateknowledgeportal.worldbank.org/country/pakistan/climate-data-projections

5. Climate Change Impacts

It is clear that climate change will have a major impact on Pakistan. The ND-GAINS[252] ranking highlights Pakistan is vulnerable to climate change due to its vulnerable population (36th most vulnerable country in the world) and low coping mechanisms (36th least ready country). It is ranked as 152th (out of 181) in the ND-GAIN country index ranking.

Notre-Dame GAIN Index Ranking (2018)	
152th	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 (University of Notre-Dame, 2018).

There are a combination of potential risks to the coastal region that is the focus of the study. The primary threat is from sea-level rise, and the potential impacts of storms surges. These impacts could be exacerbated by the projected increase in cyclones. However, the livelihoods of the area will be affected by other changes, notably changing patterns in extremes, which mean that multiple climate risks need to be considered.

Sea-level rise is a major threat to all coastal regions, including Pakistan. It is one of the main threats to the proposed project area. Coastal erosion and storm surge waves are already threatening towns and farms situated along the coast. Work by the UK Met Office (2014) estimated that without adaptation, around one million people will face coastal flooding annually by the period 2070–2100. Geographically, the largest area of vulnerability is the Indus Delta, around 4,750 km^2 of which sits below 2m above sea-level.[253] It is estimated that around one million people live in the delta. Saline intrusion[254] continues to be a major challenge in the coastal zone, degrading land quality and agricultural yields.[255] These issues are likely to intensify, affecting many marginal and deprived communities.

[252] https://gain.nd.edu/
[253] Syvitski, J. P. M. et al. 2009. *Sinking deltas due to human activities.* Nature Geoscience, 2(10), 681–686.
[254] Zeng, L. and M.C. Shannon. 1986.*Salinity effects on seedling growth and yield components of rice*. Crop Sci. 40, 996–1003. 2000.
[255] Letey, J. and A. Dinar. *Simulated crop-water production functions for several crops when irrigated with saline waters.* Hilgardia. 54, 1–32.

Figure 49: 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.

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		1.84m (0.98-2.47)

Source: Le Bars, D., S. Drijhout, and H. de Vries. *A high-end sea level rise probabilistic projection including rapid Antarctic ice sheet mass loss.* Environmental Research Letters: 12:4. 2017.

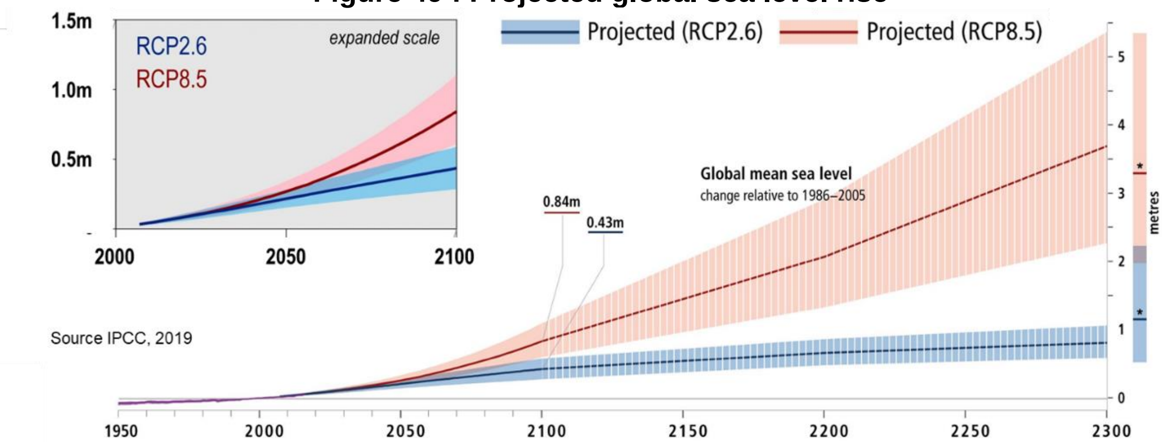
Figure 50: The average number of people experiencing flooding per year in the coastal zone in the period 2070–2100 under different emissions pathways (assumed medium ice-melt scenario) and adaptation scenarios for Pakistan

Scenario	Without adaptation	with adaptation
RCP2.6	950,300	1,040
RCP8.5	1,207,740	2,190

Source: UK Met Office. 2014. *Human dynamics of climate change: Technical Report*

More recently, the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate report has reassessed the likely levels of future sea-level rise (Oppenheimer et al., 2019)[256]. This includes the addition of ice sheet contributions and projects much higher levels of SLR globally. It reports a much higher upper range, with 0.6 to 1.1 meters likely by 2100 under a high-emission scenario, due to the increased ice loss from the Greenland and Antarctic ice sheets. Even under low emission scenarios, it is likely that the coastal areas will experience at least 1-metre of sea level rise over the long-term.

Figure 49 : Projected global sea level rise



Sources IPCC SROCC (2019).

Recent expert elicitations[257,258] raises the possibility of even higher increases under high-emission scenarios, with conceivably 2 meters by 2100. Sea level will continue to rise for

[256] Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

[257] Garner, A.J. et al. 2018. Evolution of 21st Century Sea Level Rise Projections. Earth's Future, 6(11), 1603-1615, doi:10.1029/2018ef000991.

[258] Bamber, J.L. et al. 2019. Ice sheet contributions to future sea-level rise from structured expert judgment. Proceedings of the National Academy of Sciences, 116(23), 11195, doi:10.1073/pnas.1817205116.

centuries, even if the Paris agreement is achieved, due to the thermal inertia of the oceans (the 'commitment to sea-level rise').

Furthermore, extreme sea-level event – that historically occurred once per century – are projected to occur much more frequently, potentially becoming annual events by the end of the century under high warming scenarios. As highlighted above, the average intensity of tropical cyclones, the proportion of higher intensity cyclones, and associated average precipitation rates are also projected to increase, although with local variations. As well as an increase in wind related storm damage, this leads to an increased risk of extreme sea level events, i.e. high-water level heights from mean sea level, storm surges and tides. As sea level rises, there is an increased risk of river banks being overtopped and of flooding of adjacent land further up the estuaries. Saltwater will penetrate further upstream and inland.

Recent modelling with the new extreme sea level rise scenarios reports potential population migration in Asia by the end of the century due to coastal flooding[259], which could affect coastal regions of Pakistan.

Water. The climate projections indicate increases in the severity of extreme events of both flood and drought, although there is some uncertainty regarding the long-term outlook for water resources in Pakistan including the change in annual rainfall. A useful overview of the potential impacts of climate change on the Indus Basin was provided by Archer et al. (2010).[260] Issues highlighted include the declining and insufficient capacity of Pakistan's reservoirs to provide for its needs under future development and climate change scenarios, and the likely pressure this will place on groundwater. In particular, the Indus River system surface water availability per capita was 5,260 m^3 in 1951 and by 2016, that had fallen to close to 1,000m^3, a trend that is expected to continue and worsen.[261] With this, the current water extraction rate of Pakistan is approximately 61 km^3 from its aquifers each year, which far exceeds the sustainable limits.[262] As such, Pakistan is commonly considered to be both water-stressed (high water withdrawals relative to availability) and water-scarce (low water availability per capita). This suggests that Pakistan's economy is more water-intensive than any other country, making its GDP directly dependent on water resources. A key issue for the project area is the potential increase in salt water intrusion affecting water supplies, coupled with broader issues of water availability from the changes due to climate change and demand increases. The second national communication (GoP, 2018) reports that the Sindh area will suffer the most from water logging and salinity because of poor drainage systems.

Biodiversity and Land Use. Issues of land degradation, desertification and dryland expansion are a major concern in Pakistan. Around 80% of Pakistan's area is arid or semi-arid, processes linked to human development such as overgrazing, over exploitation of water resources and over-cultivation, and excessive use of fertilizers are combining to degrade land quality and expand drylands. MOCC/IUCN (2017) reports on the challenges. For the project region, a key issue is the impacts on coastal ecosystems, especially because of the ecosystem services these provide (provisioning services; regulating services; cultural services and supporting services). The Indus Delta has a large area of total mangrove forests, with an area of around 98,128 ha (Salik et al, 2015[263]). The mangrove ecosystems along the coast are

[259] COACCH. 2019. The Economic Cost of Climate Change: Synthesis Report on COACCH Interim Results. Analysis by Lincke et al. using the DIVA model. www.coacch.eu

[260] Archer, D. R., N.Forsythe, H.J. Fowler, and S.M. Shah. 2010. *Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions:* Hydrology and Earth System Sciences, 14, 1669–1680.

[261] Sleet, P. *Water Resources in Pakistan: Scarce, Polluted and Poorly Governed.* Strategic Analysis Paper, Global Food and Water Crises Research Programme. Future Directions International, Australia. 2019.

[262] Church, J. A., et.al. 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.

[263] Salik, K.M., S. Jahangir, W. ul Zafar Zahdi, and S. ul Hasson. 2015. Climate change vulnerability and adaptation options for the coastal communities of Pakistan, Ocean & Coastal Management, Volume 112, 2015, Pages 61-73, ISSN 0964-5691, https://doi.org/10.1016/j.ocecoaman.2015.05.006.

already facing severe impacts from increased sediment loads, reduced fresh water inflows, a growing number of invasive species, clear felling of forests, and pollution from human activities. Sea-level rise and delta flooding are already severely impacting the coastal zone, leading to water shortages, declining property values, loss of invaluable archeological sites, and a decline in tourism (GFDRR, 2011).A study identified the major threats to biodiversity (specifically, the Uchalli complex and the Indus Delta) where combined impacts of climate change, drought, encroachments of land, agriculture, use of agrochemicals, decrease in wetlands vegetation, deforestation, ground water extraction, illegal hunting and lack of implementation of Wildlife Protection Laws[264] play synergistic roles. In support to this, the forests, which cover only 4.2 million of the 85 million hectares of the land, are shrinking at one of the highest rates in the world (2.5–3.1% annually), resulting in severe reduction in biological diversity, and threatening not only the ecological balance but adding to the perils faced by threatened and endangered species and the back-fire effects to the livelihoods directly linked with these resources.[265]

Agriculture. Climate change will influence food production via direct and indirect effects on crop growth processes. Direct effects include alterations to carbon dioxide availability, precipitation and temperatures. Indirect effects include through impacts on water resource availability and seasonality, soil organic matter transformation, soil erosion, changes in pest and disease profiles, the arrival of invasive species, and decline in arable areas due to the submergence of coastal lands and desertification.

Agriculture employs 42.3% of the Pakistan's workforce and contributes 21% to gross domestic product (GDP), making potential climate impacts and adaptation needs in the sector a high priority. The five most important crops in the country, wheat, rice, cotton, sugarcane, and maize, are grown predominantly by subsistence farmers, and a large proportion of the nation's agricultural land is degraded. Around 80% of Pakistan's agricultural production area is irrigated.[266] Damage to key cash crop yields, such as cotton, is a particular concern. Pakistan is the fifth largest producer of cotton in the world—the industry contributes 10% of the country's GDP and employs approximately 30% of the country's farmers, many of whom are rural women. Studies suggest Pakistan's crops are highly sensitive to changes in temperature and water availability, and that temperature rises in the region of 0.5–2°C could lead to around an 8–10% loss in yield (Dehlavi et al.,2015).[267] Declines are projected, particularly for crops such as cotton, wheat, sugarcane, maize, and rice.[268] Yu et al. (2013)[269] suggest rice and sugarcane are worst affected under a high emissions scenario, experiencing 25% and 20% yield reductions respectively. The impacts of climate change on the livestock sub-sector are less clear and further study is required. However, the impact of the extended drought period in 2015–2017 which reduced livestock output by 48% in the worst affected districts highlighted the potential threat of future increases in drought frequency.

The impact of extreme climate events on the agricultural sector in Pakistan can be very significant, raising concerns regarding the projected increase in their frequency attributed to climate change. A major flood in 2010 led to an estimated 2.4 million hectares of unharvested crops being lost, worth approximately $5.1 billion. Droughts can be equally devastating to rural livelihoods, from 1999–2002, droughts in the Sindh and Baluchistan provinces killed two

[264] Qureshi, N.A. & Z. Ali. 2011. Climate Change, Biodiversity Pakistan's Scenario. The Journal of Animal and Plant Sciences, 21(2 Suppl.): 2011, Page: 358-363 ISSN: 1018-7081.

[265] Khan, H., E. Inamullah & K. Shams. 2009. Population, environment and poverty in Pakistan: linkages and empirical evidence. Environ Dev Sustain 11:375–392. DOI 10.1007/s10668-007-9119-y

[266] ADB. 2017. *Climate Change Profile of Pakistan.* https://www.adb.org/publications/climate-change- profile-pakistan

[267] Dehlavi, A., A. Gorst, B. Groom, F. Zaman. *Climate change adaptation in the Indus ecoregion: A microeconomic study of the determinants, impacts and cost effectiveness of adaptation strategies*. WWF-Pakistan. 2015.

[268] Asian Development Bank (ADB). *Climate Change Profile of Pakistan*. ADB Publication. Manila, Philippines. 2017. URL: https://www.adb.org/ publications /climate-change-profile-pakistan

[269] Yu, W., et.al. *The Indus Basin of Pakistan: The impacts of climate risks on water and agriculture*. The World Bank. Washington, DC. 2013.

million livestock and necessitated emergency relief to provide drinking water and food aid to farming communities.

A further influence of climate change on agricultural production is through its impact on the health and productivity of the labor force. Work by Dunne et al. (2013)[270] suggests that 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 2050 under the highest emissions pathway (RCP8.5). Studies have projected that climate change-induced loss of wheat and rice crop production by 2050 could total $19.5 billion dollars on Pakistan's Real GDP coupled with an increase in commodity prices followed by a notable decrease in domestic private consumption. This decline in crop production not only impacts the economic agents involved in the agriculture sector of the country, but also its multiplier effect on industrial and business sectors.[271]

Poverty and Inequality. Many of the climate changes projected are likely to disproportionately affect the poorest groups in society. As mentioned earlier, food insecurity puts the marginalized sectors further down in attaining a quality of living that a huge rise in commodity prices will create a great challenge for the livelihood of the whole country, especially for urban households.[272] Also, heavy manual labor jobs are commonly among the lowest paid whilst also being most at risk of productivity losses due to heat stress (Kjellstrom et al., 2016).[273] In rural settings, poorer farmers and communities are least able to afford local water storage, irrigation infrastructure, and technologies for adaptation. Rural groupings include those who are owners of small farms (20%), those who are landless farmers (10%) and agricultural laborers (12%) all of whom are likely to be among the most affected by the above pressures.

Around 20% of Pakistan's population remains undernourished and climate change looks likely to challenge Pakistan's attempts to alleviate undernourishment, poverty and deprivation. Moreover, it suggests all of Pakistan's provinces will experience some living standards declines associated with temperature increases, with Sindh province the worst affected.[274]

Finally, migration may post concerns to South Asia region as work by the World Bank (Rigaud et al., 2018)[275] suggests South Asia will experience an estimated 17–36 million internal climate migrants by 2050 as a result of slow-onset climate changes. The range in this estimate reflects different future development pathways with differing levels of emissions reduction and inequality in development outcomes. Under all scenarios, the poorest and most climate-vulnerable communities are likely to be the hardest hit. Without significant adaptation and mitigation actions, beyond 2050 the climate-induced migration rate is likely to accelerate considerably. It is expected that 'hotspots' of in and out-migration are likely to form. Large majority of migrants in South Asia are expected to come from communities dependent on rain-fed croplands for their livelihoods.

Human Health and Nutrition. The World Food Programme (2015)[276] estimate that without adaptation action the risk of hunger and child malnutrition on a global scale will increase by

[270] Dunne, J. P., R.J. Stouffer, and J.G. John. 2013. *Reductions in labour capacity from heat stress under climate warming.* Nature Climate Change, 3(6), 563–566.
[271] Khan, M.A. et al. 2020. *Economic Effects of Climate Change-Induced Loss of Agricultural Production by 2050: A Case Study of Pakistan.* Sustainability, *12*(3). DOI: 1216; https://doi.org/10.3390/su12031216.
[272] Ibid
[273] Kjellstrom, T., et.al. 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.
[274] Ibid
[275] Rigaud, K., et.al. 2015. *Groundswell: Preparing for internal climate migration*. World Bank Group, Washington DC. 2018.
[276] World Food Program (WFP). *Two minutes on climate change and hunger: A zero hunger world needs climate resilience.* The World Food Programme.

20% respectively by 2050. The work by Springmann et al. (2016)[277] has assessed the potential for excess, climate-related deaths associated with malnutrition. The authors identify two key risk factors which are expected to be the primary drivers: a lack of fruit and vegetables in diets and health complications caused by increasing prevalence of people underweight. They project that there will be approximately 9.32 climate-related deaths per million population per year linked to lack of food availability in Pakistan by the year 2050 under RCP8.5, which is comparatively better than many other developing nations. This estimate does not include the impact of potential climate-related changes on the nutritional content of food.

In terms of the heat-related mortality, a research has identified 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 (Im et al., 2017).[278] 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 and intensified heat waves. Matthews et al. (2017)[279] identify both Karachi and Lahore as cities likely to face extreme exposure to deadly temperatures even on lower emissions pathways. Work by Honda et al. (2014),[280] which utilized the A1B emissions scenario from CMIP3 (most comparable to RCP6.0), estimates that without adaptation, annual heat-related deaths in the South Asian region, will increase 139% by 2030 and 301% by 2050.

The occurrence of diseases is also probable as coarse estimates of changes in the distribution of a small number of diseases according to the World Health Organization (WHO)[281] projects that, under a high emissions scenario (RCP8.5), 46 million people in Pakistan will be at risk of contracting malaria by 2070. However, if global emissions are decreased significantly (RCP2.6) this number is projected to be around 12 million by 2070. Diarrheal-related deaths are projected to decrease significantly by 2050, but the proportion of those attributable to climate change is expected to rise, under a high emissions scenario this will be from 11.7% in 2030 to 17% by 2050.

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[277] Springmann, M., et.al. *Global and regional health effects of future food production under climate change: a modelling study.* The Lancet: 387: 1937–1946. 2016.

[278] Im, E. S., J.S. Pal, and E.A.B. Eltahir. 2017. *Deadly heat waves projected in the densely populated agricultural regions of South Asia.* Science Advances, 3(8).

[279] Matthews, T., R.L. Wilby, and C. Murphy. 2017. *Communicating the deadly consequences of global warming for human heat stress*. Proceedings of the National Academy of Sciences, 114, 3861–3866.

[280] Honda, Y. et al. 2014. *Heat-related mortality risk model for climate change impact projection*. Environmental Health and Preventive Medicine 19: 56–63.

[281] World Health Organization (WHO). 2015. *Climate and Health Country Profile: Pakistan*. WHO publication. http://apps.who.int/iris/bitstream /handle/10665/246150/WHO-FWC-PHE-EPE-15.28-eng.pdf;jsessionid=C6 5C70B12A378437312D491DAD93E531?sequence=

G. PAPUA NEW GUINEA CLIMATE RISK PROFILE

1. Summary of Climate Rationale

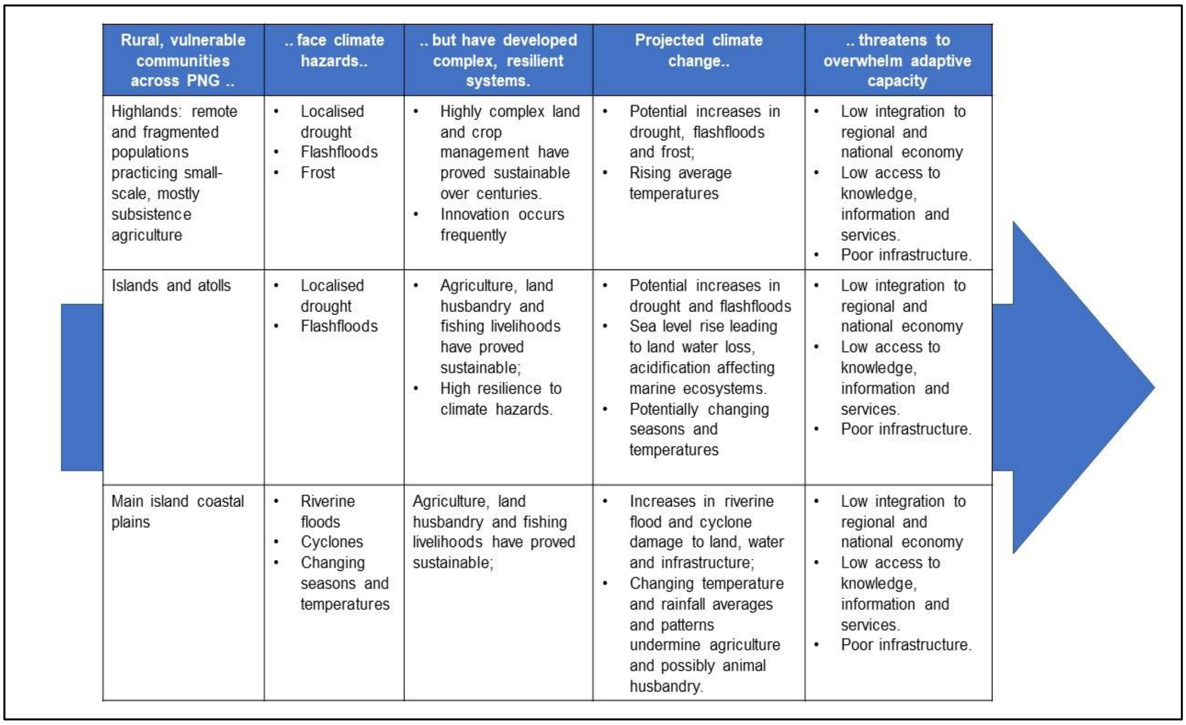
Papua New Guinea (PNG) is one of the most geographically, environmentally and culturally diverse countries on the planet. The country's ecosystems include mountain glaciers, humid tropical rainforests, swampy wetlands, and coral reefs which span across an archipelago of islands where more than 850 different languages are spoken. The countries climate risk is characterized by high vulnerability and low adaptive capacity. PNG is a member of the "Vulnerable Twenty (V20)" group and is ranked 149th out of 181 countries globally on the ND-GAIN Index (2018) reflecting its vulnerability to, and low readiness for, climate change challenges. This heightened vulnerability is largely due to widespread poverty, lack of basic infrastructure, and poor access to basic services. Poverty rates of between 30-40% have been reported along with adult literacy rates of around 50%. Agriculture provides the main source of livelihoods for 85% of the population and approximately 70% of households in PNG remain dependent on subsistence agriculture. The prevalence of stunting in children aged 5 years or younger is 50% in rural areas and 35.3% in urban areas. The Gender Inequality Index for PNG is 0.611, ranking 140th out of 155 countries. Women's share in waged employment is only 5.3%, the lowest in the Pacific region, and only 9.5% of adult women have reached secondary level of education. The heavy reliance on natural assets and large gaps in human capital means that these communities are highly vulnerable to climate-related hazards and their impacts on livelihoods and food security and have limited capacity for adaptation to a rapidly changing climate.

Papua New Guinea has a monsoonal climate characterized by high temperatures and humidity throughout the year. It experiences one of the wettest climates in the world with annual rainfall in many areas of the country exceeding 2,500 mm. Most projections suggest the frequency and intensity of extreme rainfall events will increase and there is medium confidence for projected future trend of increased annual average precipitation. Maximum and minimum temperatures are projected to rise notably faster than average temperatures. The warming and increased climate variability associated with climate change are projected to dramatically increase the frequency of heatwaves in future and PNG may transition to a chronically heat-stressed environment.

The impact of climate change on agriculture - and thus the livelihoods and food security of the majority of its people - is highly nuanced. Climate change will present specific risks and opportunities to different communities and be largely dependent on the ecological zone that they live in and the type of agriculture they practice (**Figure**). Major droughts associated with ENSO have highlighted the nation's food insecurity and saline intrusion resulting from sea-level rise has already been documented damaging the production of small-holder farmers. A decline in agricultural yields as a result of increasing maximum and minimum temperatures is a particular concern. Even increases in the range of 9-26 days above 35^{o}C under the three lower emissions pathways represent a potential hazard to livelihoods in the country. Coastal, river (fluvial), and surface (pluvial) flooding also represent a major risk and estimates suggest that the population affected by an extreme flood could increase by 35,000-56,000 people by 2035-2044 (assuming present day population distributions) as a result of climate change, destroying crops and productive assets and trapping households in a cycle of poverty and food insecurity. Population growth and poorly planned development have the potential to increase these estimates further.

Farmers from small island states such as PNG, have learnt to work with highly variable climate and weather extremes. However, changes outside of their sphere of knowledge and experience can have significant implications for production and food security. Further, the magnitude and intensity of any extreme climatic event are compounded by pre- and post-conditions surrounding that event, so that farmer experience based on familiarity is less valuable in managing the impact of the event. All this highlights the need for building local level skills and understanding of how to adapted to changing conditions with tailored actions specific to the socio-ecological system context.

Figure 50: Diagram summarizing climate rational justifying CRPP investment in rural communities in PNG



Rural, vulnerable communities across PNG ..	.. face climate hazards..	.. but have developed complex, resilient systems.	Projected climate change..	.. threatens to overwhelm adaptive capacity
Highlands: remote and fragmented populations practicing small-scale, mostly subsistence agriculture	• Localised drought • Flashfloods • Frost	• Highly complex land and crop management have proved sustainable over centuries. • Innovation occurs frequently	• Potential increases in drought, flashfloods and frost; • Rising average temperatures	• Low integration to regional and national economy • Low access to knowledge, information and services. • Poor infrastructure.
Islands and atolls	• Localised drought • Flashfloods	• Agriculture, land husbandry and fishing livelihoods have proved sustainable; • High resilience to climate hazards.	• Potential increases in drought and flashfloods • Sea level rise leading to land water loss, acidification affecting marine ecosystems. • Potentially changing seasons and temperatures	• Low integration to regional and national economy • Low access to knowledge, information and services. • Poor infrastructure.
Main island coastal plains	• Riverine floods • Cyclones • Changing seasons and temperatures	Agriculture, land husbandry and fishing livelihoods have proved sustainable;	• Increases in riverine flood and cyclone damage to land, water and infrastructure; • Changing temperature and rainfall averages and patterns undermine agriculture and possibly animal husbandry.	• Low integration to regional and national economy • Low access to knowledge, information and services. • Poor infrastructure.

2. Country Overview

Papua New Guinea (PNG) is located in the South West Pacific and comprises half of the large Southwest Pacific Island of New Guinea and an archipelago of other islands, ranging in size from New Britain (38,000 square km^2) down to tiny atolls. The main island is dominated by a rugged spinal mountain range rising to 5,000 meters above sea level – known as the Highlands.

PNG is recognized as one of the world's most culturally and geographically diverse countries in the world. Over 850 languages are spoken by people of various ethnicities and mountain glaciers, humid tropical rainforests, swampy wetlands, and coral reefs can all be found in the country. In addition to harbouring abundant natural resources such as gold, copper, oil and natural gas, PNG boasts 7% of the world's biodiversity.[282] The Highlands of PNG are drained by major rivers that flow for up to 1,100 km across the coastal lowlands to the sea in the North and South.[283]

Table 20: PNG Key Indicators

Indicator	2015 (or as stated)	2019 (or as stated)
GDP per capita ($, current)	2630	2685
GDP growth (%, constant prices)	9.5	5
GDP growth (agriculture)	-2.7	2.5
Population (million)	7.5 (2014)	9.3

[282] UNEP/GEF. *Papua New Guinea's Fourth National Report to the Convention on Biological Diversity*. United Nations Environment Programme. 2010

[283] AUS-PNG Network. *Environment of Papua New Guinea. Website accessed 16/02/2021*

Indicator	2015 (or as stated)	2019 (or as stated)
Urban population (% of total population)	12.6 (2012)	13.2 (2018)
Infant mortality rate (below 1 year/per 1000 live births)	48.4 (2012)	42.4 (2016)
Population with at least some secondary education (% of people aged 25 and older)	11.1 (2010)	12.2 (2017)
Population with access to safe water	39.7 (2012)	39.6 (2015)

Source: ADB. 2020. Country Partnership Strategy PNG 2021-2025.

PNG is classified as a fragile and conflict-affected situation (FCAS) country and a small island developing state (SIDS). Governance is considered weak and corruption widespread, and these affect the state's ability to carry out basic functions such as the delivery of public services and poverty reduction. The mineral and petroleum sector, upon which PNG is reliant for growth and revenue, is a key driver of fragility—economic, political and environmental—and has, at times, been a source of conflict.[284]

Economic growth has been relatively solid in recent years - Gross Domestic Product (GDP) has seen positive growth since the early 2000 and has averaged over 4.2% for the period 2015-2019. However, this growth has been largely driven by minerals exploitation, and growth excluding minerals was below 1%. As a result, poverty and low development status remain widespread and persistent. The last official poverty rate was recorded in 2009, at 38%, worse than in 1996 (30%). Life expectancy at birth remains low, improving only to 64.3 years in 2018, from 62.0. years in 2010. Most other socio-economic indicators remain persistently low and among the weakest in the Pacific (see **Table 20).**

PNG's population of 9.3 million (2019 estimate)[285] remains predominantly rural. In 2020, only 8 urban areas had an estimated population over 60,000.[286] All other places can be considered to be a very small town, village, rural or remote. An estimated eighty-five per cent of the population live in such rural areas, which is also the home for 80% of the poor.[287] In addition, many recent migrants live in informal settlements around urban areas and have an essentially rural existence.

The predominant economic activity in rural areas is agriculture. Agriculture provides the main source of livelihoods for 85% of the PNG population (although providing less than 30% of GDP).[288] Subsistence food production through small-holder farming is the most important part of PNG agriculture. It provides most of the food consumed in the country – an estimated 83% of food energy and 76% of protein.[289] It is noteworthy that less than 4% of land is used for commercial production – demonstrating the subsistence nature of livelihoods that are dependent on natural resources and agriculture. For example, some 40% of the population relies almost entirely on subsistence sweet potato production, grown in the Highlands. Subsistence agriculture is the most common form of any employment for both men and women.[290] Farm domestic animals are also important in rural economies, notably pigs, but also chickens, cattle, sheep, goats, and others. Finally, rural communities in swamplands and on islands and in coastal areas are commonly involved in small-scale fishing activities.[291]

Agriculture has a long history in PNG, some experts suggesting up to 10,000 years. Over the millennia, the inhabitants have developed highly complex and highly resilient food production systems. Despite this long history, agriculture in PNG has been and remains characterised by

[284] ADB. 2020. *Country Partnership Strategy: Papua New Guinea, 2021-2025.* Manila
[285] ADB. 2020. *Country Partnership Strategy: Papua New Guinea, 2021-2025.* Manila
[286] Data Extracted from 2011 National Population and Housing Census of Papua New Guinea -- Final Figures. National Statistical Office. Papua New Guinea. 2011
[287] UN. PNG - Common Country Analysis. 2016
[288] ADB. 2020. *Country Partnership Strategy: Papua New Guinea, 2021-2025.* Manila
[289] Introduction in *Food and agriculture in Papua New Guinea* (edited by R. Michael Bourke and Tracy Harwood.). 2009.
[290] UN. PNG - Common Country Analysis. 2016
[291] FAO. 2018. Fishery and Aquaculture Country Profiles.

a high degree of innovation and openness to change. New crops are regularly adopted and old ones discarded or their importance reduced. Further, notably in recent times, many new techniques have been adopted or invented, such as composting, planting tree in fallows and crop rotations, particularly as people have intensified land use in response to population increase.[292]

Analysis reveals a strong nexus linking poverty, vulnerability and geographical location in present times in PNG. Typically, the rural population and the population dependent on small-scale agriculture (including animal husbandry and fishing) are vulnerable. Firstly, rural people face at least one severe environmental constraint – such as annual flooding, steep slopes, high rainfall, poor soils, high altitude or high cloud cover. Further, they are geographically isolated - on a small offshore island; or are isolated by sea; or have no road connection and as a result have very poor access to markets or services; or they lie in provincial border areas and province or district administration takes responsibility for them. Many rural people also face additional socio-economic challenges, such as low adult literacy, low school enrolment, long distances to walk from home to the nearest primary school, low rates of immunization, few household assets, and constant threat of insect borne disease due to 'basic bush house' accommodation, and typically they have very few well educated people in positions of influence to argue on their behalf. Although recent data is scarce, the 2009–2010 Household Income and Expenditure Survey indicated that poverty is worse in rural areas, with for example the prevalence of stunting in children aged 5 years or younger is 50% in rural areas and 35.3% in urban areas.[293,294].

Specific vulnerable groups include women, the internally displaced, youth, elderly and displaced, as illustrated in the following paragraphs.

Socially and culturally constructed norms and roles have shaped attitudes to gender, leading to unequal power relations in PNG. The Gender Inequality Index for PNG is 0.611, ranking 140th out of 155 countries. Women's share in waged employment is only 5.3%, the lowest in the Pacific region, and only 9.5% of adult women have reached secondary level of education. The maternal mortality ratio is among the worst in Asia and the Pacific (see Table 20). The adolescent birth rate is 62.1 per 1,000 women age 15-19 (2014). Women have substantially less access to health care and education services than men, and are vastly underrepresented at all levels of government. Two in three women in PNG experience gender-based violence at some point in their lifetime.[295]

As of September 2016, there were over 44,500 Internally Displaced Persons (IDPs) in PNG. Internal displacement occurs as a result of tribal fights and land disputes, and natural disasters. Displacement in turn affects access to government services such as health, food security, shelter, water, sanitation, hygiene, social protection and education. Displacement in PNG is often protracted, with households living in temporary living situations for more than a year. These displaced populations are more vulnerable to development challenges as they have less access to basic services, including protection. Women and girls are especially susceptible to abuse, from both within their communities and outside.

The population of PNG is relatively young. Around 51.5 per cent of the 7.05 million people inhabiting the country in 2011 were younger than 19 years of age.[296] NSO, last census, website). PNG's rural areas have considerably younger populations, with 42 per cent of the population under the age of 15 compared to 37 per cent in urban areas. And Youth unemployment is about three times higher than that of the general population. Papua New

[292] Various sections in *Food and agriculture in Papua New Guinea* (edited by R. Michael Bourke and Tracy Harwood.). 2009.
[293] ADB. Country Partnership Strategy PNG 2021-2025. 2020
[294] Papua New Guinea National Statistical Office. 2009–2010 Household Income and Expenditure Survey. 2010
[295] UN. PNG - Common Country Analysis. 2016
[296] Papua New Guinea National Statistical Office. National Population and Housing Census 2011. 2011

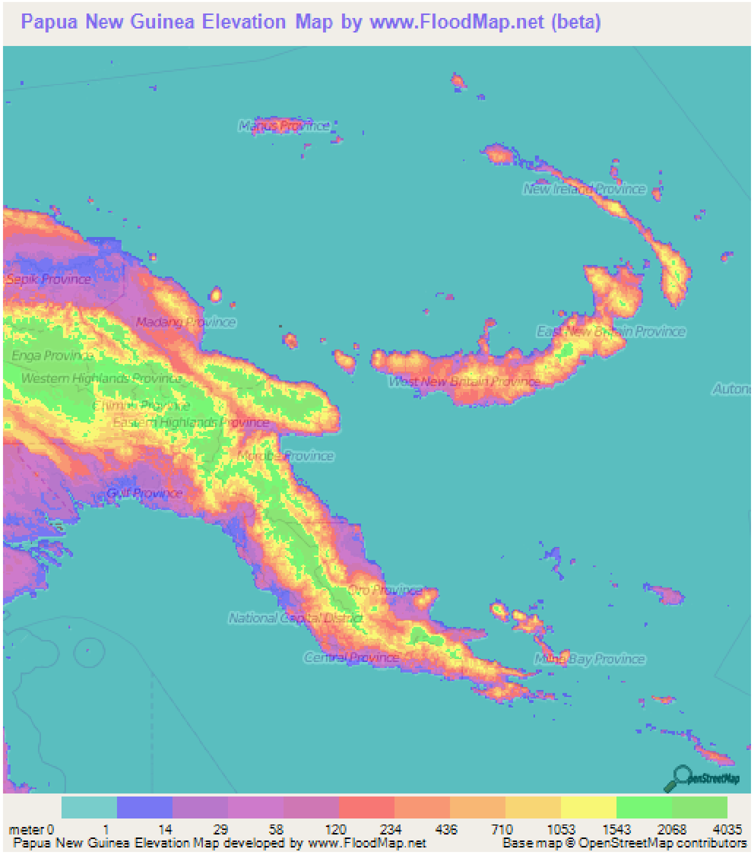
Guinean children and youths are exposed to the highest rate of violence in the East Asia and Pacific region – and available small-scale studies indicate that up to 75 per cent of children in PNG experience physical abuse, with even more experiencing verbal abuse. In a recent study in Bougainville, 85.6 per cent of the fathers surveyed reported beating their children.[297]

The population of PNG is distributed across the various ecosystems, with notably the following ecosystem categories:

- Approximately 36% living in the Highlands hilly/mountain chain stretching northwest to south east on the main island;
- Approximately estimated 26% living on the main island's coastal plains;
- Approximately 16% in the island archipelagos, including larger islands, smaller island and atolls.

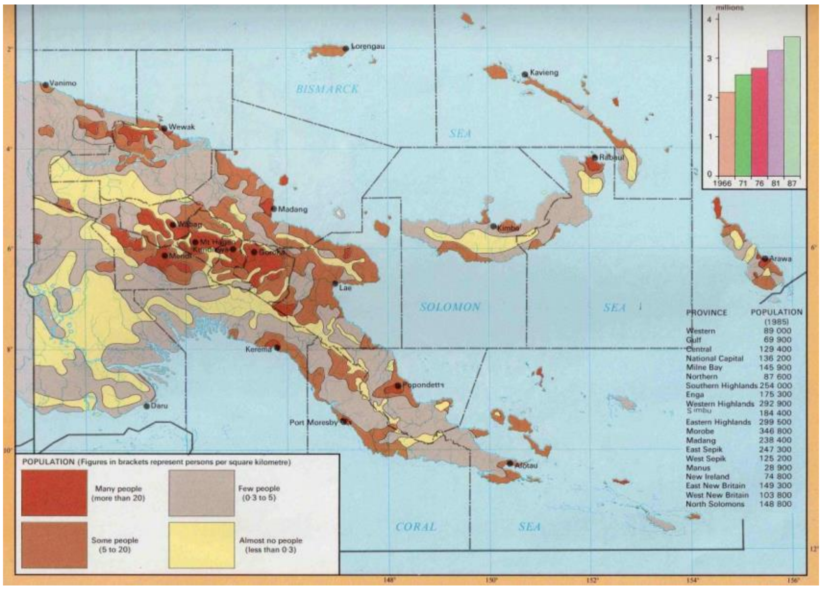
The following maps illustrate the basic geographical factors behind the distribution of population.

Figure 51: Topographic map, showing the location of the highlands region, as well as the coastal plains on the main island (and the many small islands)



[297] UN. PNG - Common Country Analysis. 2016

Figure 52: map of population densities, showing that the highland regions are amongst the mostly highly populated, despite the steep and fragile terrain.



The following sections indicate some of the key economic, agricultural and ecological characteristics of the three ecosystem categories.

The Highlands: Probably the most studied of all regions of PNG, with best data, particularly regarding agricultural systems. The Highlands of PNG is a chain of mountains and high valleys stretching in a generally west to east direction from the border with Indonesia in the center of the island to the eastern coast. The mountain valleys of the Highlands have been relatively densely populated for a long time and remain so. The Highlands have many unique geographical characteristics including an extreme tropical climate, highly fragmented watersheds and a predominantly steep relief. The population is highly dispersed in villages across the valleys. Drinking water for rural communities is drawn mostly from unprotected sources. The steep slopes, fragile soils and heavy rainfalls mean there is low connectivity between valleys and it is often challenging for villagers to connect to modern services. The population engage predominantly in rainfed agriculture on the mild to steep slopes, with high levels of local consumption and low integration into regional or national economy.

Typical staple crops include sweet potato (often dominant), banana, cassava and yam. Other crops include beans, cabbage, cucumber, peanuts, sugarcane, betelnut, tobacco. Irrigation is typically absent, although land is drained. Most agriculture is rotational, with short fallow periods, and use of burning to increase short-term production. Pig husbandry is always very important.[298] The features of the smallholder sector are that it is fractured and small-scale. Smallholders may grow crops to sell, and the informal business operators may collect and aggregate crops, but there is in general a poor coordination of market access, crop quality, crop management and crop marketing.[299]

Island Archipelagos: The level of remoteness decreases with island size, with populations on atolls and very small islands highly dependent on infrequent, vulnerable and small-scale shipping services. Food production is mainly for domestic use, and agricultural inputs are highly limited on the smallest islands. Generally, the diversity of food production increases with the island size. Atolls will be largely dependent on swamp taro and coconuts, with slightly

[298] R. Michael Bourke and Bryant Allen. Village Food Production Systems, in *Food and agriculture in Papua New Guinea* (edited by R. Michael Bourke and Tracy Harwood.). 2009
[299] UN. PNG - Common Country Analysis. 2016

larger islands having more diverse home gardens and possibly sweet potato as a staple. Sweet potato is an important staple on the larger islands, which will have a range of crops including cash crops such as cocoa and oil palm. The larger islands have regular connections to main land and a higher proportion of food produced is commercial – although this is often limited to a few large-scale operations, with most of the population remaining economically non-integrated. Fishing and chicken raising are important, and pig husbandry is very important.[300] Coastal communities depend heavily on shallow groundwater wells for domestic consumption.

Main island coastal plains: PNG has a total coastline of over 5,000km, most of which is on the main island. In general, this consists of flat lands leading to the steep hills that surround the highlands. Around the island, these coastal plains vary in width from a few hundred meters (e.g. on the northern coast where the sea lies close to rising hills) to up to several hundred km to the south. These coastal plains contain many large swamps and floodplains, which are also the home for considerable populations – although less densely populated than the Highlands and the islands.   Although there are many areas with relatively large populations, particularly along the northern coast which is mostly villages and small town.

The coastal communities depend heavily on shallow groundwater wells for domestic consumption. They practice a wide range of lowland, tropical agriculture, including fishing and fish farming in swampy areas. Cash crops are produced, but mainly by larger-scale operation which are not the subject of this study. Typical crops include rice, coconuts, cassava and home-gardens.

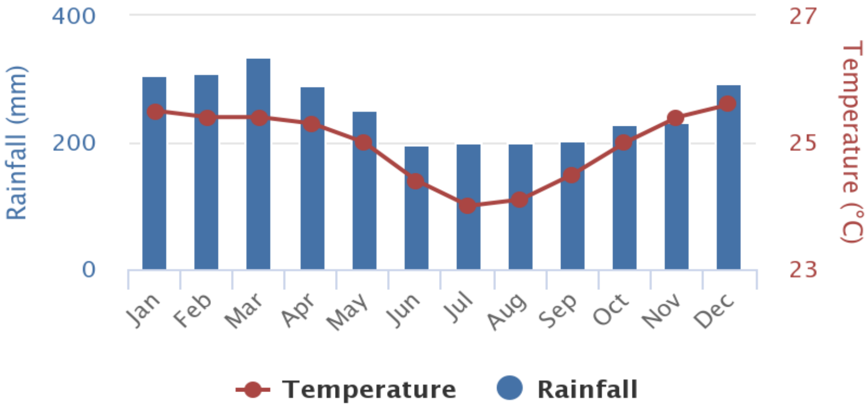
3. Current and Future Climatology

Papua New Guinea has a monsoonal climate characterized by high temperatures and humidity throughout the year. Mean temperatures in Port Moresby range between 26°C and 28°C, with maximum temperatures of 30ºC to 32ºC all year round (**Figure 53**). Two monsoon seasons are recognized: the northwest monsoon, which occurs from December to March, and the southwest monsoon, which occurs from May to October. PNG experiences one of the wettest climates in the world with rainfall in many areas of the country exceeding 2,500 mm, and the heaviest events occurring in the highlands. While PNG recognizes a wet season from November to April, and drier months in July, August and September, precipitation takes place all-year round, typically in the range of 200-400 mm/month - see **Figure 54**, for more detail on regional precipitation differences. Areas with a more pronounced wet and dry season include: Markham Valley, Bulolo Valley, Maprik—Angoram area, Eastern highlands, and coastal areas near Cape Vogel, Port Moresby, and Daru.

Climate in this part of the Pacific is governed by several factors, including the trade winds and the movement of the South Pacific Convergence Zone (SPCZ), a zone of high pressure and rainfall that migrates across the Pacific south of the equator. Year to year variability in climate is strongly influenced by the El Niño Southern Oscillation (ENSO) system in the southeast Pacific, which usually delays the start of the monsoon season and brings drought conditions to PNG, especially in the southern areas of the main island.

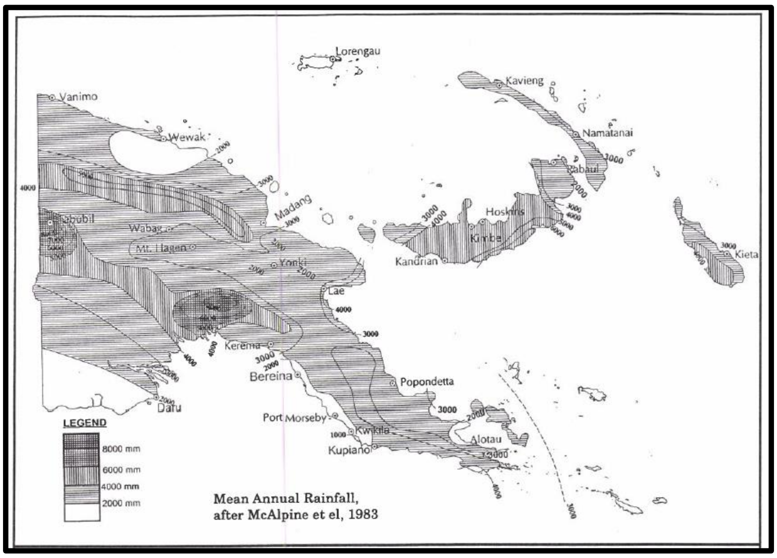
[300] (for example), Food and Agriculture in Papua New Guinea. R.M. Bourke and T. Harwood (eds). 2009

Figure 53: Average monthly temperature and rainfall in Papua New Guinea, 1901–2016



Source: WBG Climate Change Knowledge Portal. 2018. Climate Data: Historical. https://climateportal.worldbank.org.

Figure 54: Annual rainfall. Although generally high, there is much diversity, and some coastal flood plain areas have less than 2000mm/year



Climate Trends

Temperature. The Berkeley Earth dataset can be used to estimate temperature changes over the 20th century. Warming over New Guinea's land surface, as measured in the difference between average temperature in 1900-1917 and 2000-2017, has been approximately 0.8-0.9°C. Warming over New Ireland is similar, in the range of 0.9-1.0°C during the same time period. The Climate Research Unit (CRU) historical data suggest that this temperature rise has been fastest in the minimum temperatures, with daily maximum temperatures rising broadly in line with the average.[301]

Precipitation. Inter-annual variation in precipitation can be very high. Annual precipitation in Port Moresby is typically lower than other areas and regularly fluctuates between 700mm and

[301] Australian Bureau of Meteorology and CSIRO. *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. 2014.

1,400mm. This variation is influenced by El Niño Southern Oscillation, with El Niño events typically associated with below average annual rainfall[13] and drought[302]. No change in precipitation trends has thus far been attributed to historical climate change but the research into historical climate change in PNG has been very limited.

Climate Change Projections

Projections for future temperature change are presented in three primary formats. **Table 21** shows the changes (anomalies) in daily maximum and daily minimum temperatures over the given time period, as well as changes in the average temperature, **Table 22** shows projections of average temperature anomaly (ºC) in Papua New Guinea for different seasons (3-monthly time slices) and **Figures 58** and **59** display only the monthly average temperature projections. While similar, these three indicators can provide slightly different information. Annual average temperatures are most commonly used for general estimation of climate change, but the monthly 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.

Table 21 and Table 22 provides information for temperature change 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 the primary focus. Unless otherwise stated projections shown here represent changes against the 1986-2005 baseline.

Table 21: Overview of Papua New Guinea's temperature anomaly projections (ºC) over different time horizons, emissions pathways, and measures of temperature, showing the median estimates of the full CCKP model ensemble and the 10th and 90th percentiles in brackets

Scenario	Annual average of monthly maximum		Annual average		KNMI	Annual average of monthly minimum	
	2040–2059	2080–2099	2040–2059	2080–2099	2080–2099	2040–2059	2080–2099
RCP2.6	0.9 (0.5, 1.5)	0.8 (0.5, 1.5)	0.8 (0.5, 1.3)	0.7 (0.5, 1.5)	1.1	0.9 (0.6, 1.4)	0.9 (0.5, 1.4)
RCP4.5	1.2 (0.8, 1.7)	1.6 (1.1, 2.4)	1.1 (0.8, 1.6)	1.4 (1.1, 2.2)	1.9	1.2 (0.8, 1.7)	1.7 (1.2, 2.4)
RCP6.0	1.1 (0.7, 1.7)	2.1 (1.4, 3)	1 (0.8, 1.4)	1.7 (1.5, 2.7)	2.3	1.1 (0.8, 1.6)	2.1 (1.6, 2.9)
RCP8.5	1.6 (1.1, 2.2)	3.5 (2.5, 4.6)	1.4 (1.2, 2.1)	2.9 (2.5, 4.3)	3.6	1.6 (1.2, 2.3)	3.5 (2.7, 4.6)

Note: Also shown, statistically downscaled projected annual average temperature rises derived from the KNMI Climate Explorer, which project at a finer spatial resolution and therefore reduce the influence of ocean cover in the projections. (World Meteorological Organization. 2019. *KNMI Climate Explorer CMIP5 projections*.)
Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Projection*. https://climateportal.worldbank.org

Table 22: Projections of average temperature anomaly (ºC) in Papua New Guinea for different seasons (3-monthly time slices) over different time horizons and emissions pathways, showing the median estimates of the full CCKP model ensemble and the 10th and 90th pe percentiles in brackets

Scenario	2040-2059		2080-2099	
	Jun-Aug	Dec-Feb	Jun-Aug	Dec-Feb
RCP2.6	0.8 (0.6, 1.3)	0.8 (0.5, 1.3)	0.7 (0.6, 1.6)	0.7 (0.5, 1.5)
RCP4.5	1.1 (0.9, 1.7)	1 (0.8, 1.6)	1.4 (1.2, 2.3)	1.3 (1.1, 2.3)

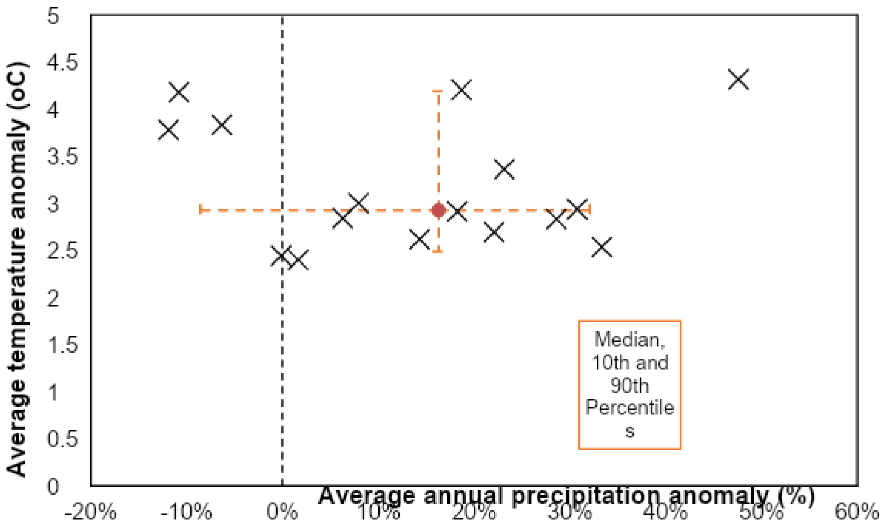
[302] Lyon, B. *The strength of El Nino and the spatial extent of tropical drought*. Advances in Geosciences, 31. 2004.

Scenario	2040-2059		2080-2099	
	Jun-Aug	Dec-Feb	Jun-Aug	Dec-Feb
RCP6.0	1 (0.8, 1.4)	1 (0.8, 1.5)	1.8 (1.6, 2.7)	1.7 (1.4, 2.7)
RCP8.5	1.4 (1.2, 2.1)	1.4 (1.1, 2.1)	3.1 (2.5, 4.4)	2.9 (2.3, 4.3)

Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Projection*. https://climateportal.worldbank.org.

The range of projections from 16 GCMs on the indicators of average temperature anomaly and annual precipitation anomaly for PNG under RCP8.5 is shown in **Figure 55**.

Figure 55: 'Projected average temperature anomaly' and 'projected annual rainfall anomaly' in Papua New Guinea



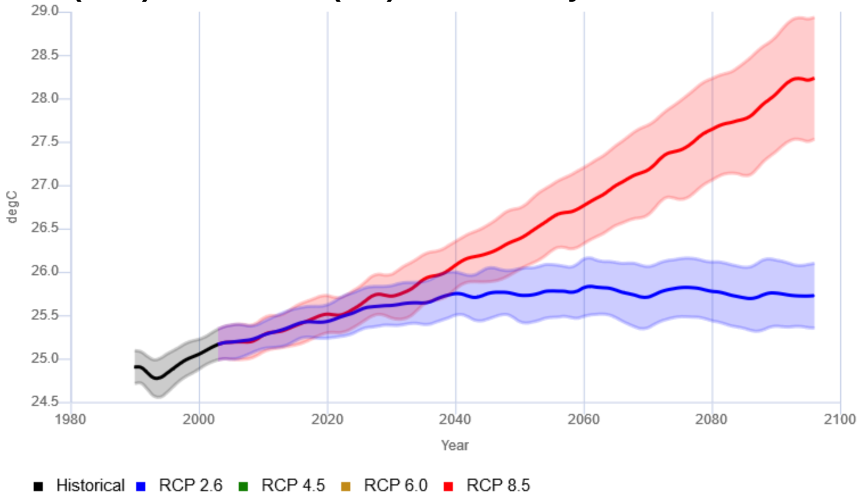
Note: Outputs of 16 models within the ensemble simulating RCP8.5, 2080–2099. Models shown represent the subset of models within the ensemble which provide projections across all RCPs and therefore are most robust for comparison. Three models are labelled.

Projections of temperature rise over PNG are influenced by the coarse spatial resolution of the GCMs used in CMIP5. As with other Pacific islands, the changes projected are influenced by the neighboring ocean cover. Work by the Australian Bureau of Meteorology and CSIRO[13] utilizing dynamical downscaling suggests that temperature rises will be approximately 0.4°C higher over land surfaces compared to the ocean surface. This may mean the temperature projections produced by the CCKP model ensemble represent conservative estimates of the change that will be experienced by PNG's communities.

The CCKP model ensemble projects median warming of 2.9°C by 2080-2099 under the highest emissions pathway (RCP8.5) relative to the 1986-2005 baseline. This projection falls to 0.7°C under the lowest emissions pathway (RCP2.6). Projected rates of warming are typically 20-30% lower than the global average, but should be treated with extreme caution. The CCKP's projected rates of warming are similar to those projected in the PACCSAP country climate profiles,[303] but notably less than the statistically downscaled projections from the KNMI Climate Explorer,[304] which might be regarded as more reliable in the context of small islands nations. Maximum and minimum temperatures are projected to rise notably faster than average temperatures, pointing towards a less stable and more frequently heat stressed climate in the future.

[303] WBG Climate Change Knowledge Portal. 2018. *Climate Data: Projection*. https://climateportal.worldbank.org.
[304] World Meteorological Organization (WMO). 2019. *KNMI Climate Explorer CMIP5 projections*. https://climexp.knmi.nl/start.cgi

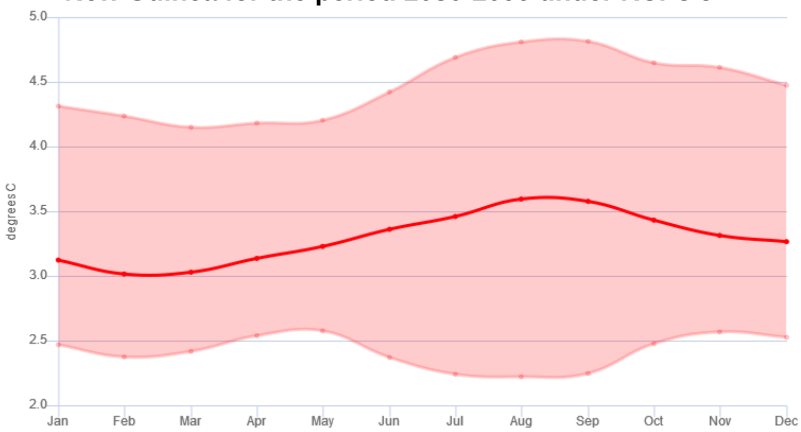
Figure 56: Historic and projected average annual temperature in Papua New Guinea under RCP2.6 (blue) and RCP8.5 (red) estimated by the CCKP model ensemble



Note: Shading represents the standard deviation of the model ensemble.
Source: WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org.

The CCKP model ensemble also projects warming slightly biased towards the months of August and September (**Figure 57Error! Reference source not found.**), but uncertainty remains high.

Figure 57: Projected change (anomaly) in monthly temperature, shown by month, for Papua New Guinea for the period 2080-2099 under RCP8.5



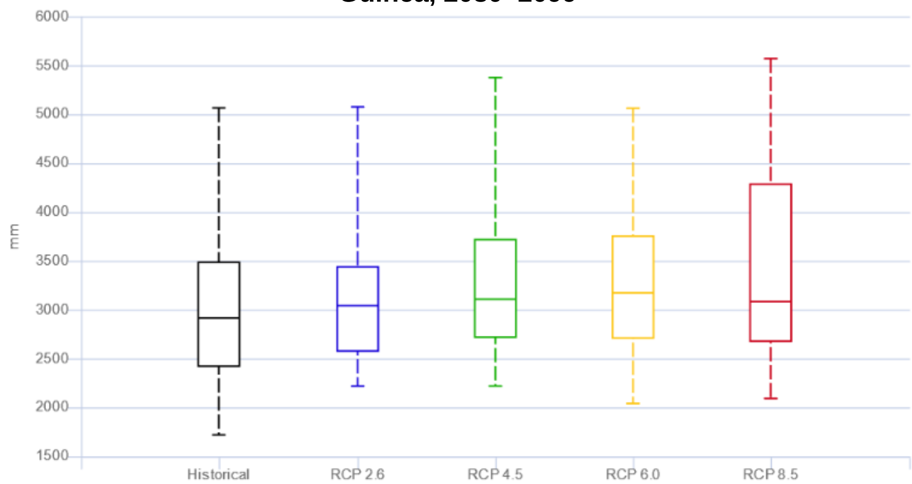
Note: The value shown represents the median of the model ensemble with the shaded areas showing the 10th – 90th percentiles.
Source: WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org.

Figure 55) uncertainty remains high, as indicated by the range and inter-quartile ranges shown in **Figure 58**. Lafale et al. (2018) suggest medium confidence should be placed in the projected future trend of increased annual precipitation.[305] In contrast the projections which suggest the frequency and intensity of extreme rainfall events will increase are associated with high confidence. This view is supported by the CCKP model ensemble's projections for PNG and is consistent with global trends. The intensity of sub-daily extreme rainfall events appears to be increasing with temperature, a finding supported by evidence from different

[305] Lafale, P., H. Diamond and C. Anderson. 2018. *Effects of climate change on extreme events relevant to the Pacific Islands.* Science Review 2018: 50-73.

regions of Asia and the Pacific.[306] However, as this phenomenon is highly dependent on local geographical contexts further research is required to constrain its impact on PNG. The uncertainty around precipitation projections stems particularly from the poor ability of climate models to simulate the variability driven by the ENSO phenomenon, and their inability to project how climate change will influence its cycles.[307,308]

Figure 58: Boxplots showing the projected average annual precipitation for Papua New Guinea, 2080–2099



Source: WBG Climate Change Knowledge Portal. 2018. Climate by Sector: Interactive Climate Indicator Dashboard. https://climateportal.worldbank.org.

4. Climate Change Risk

PNG is exposed to a wide range of climate hazards. The country experiences significant flooding and landslides, due to its extreme topographic features, and is highly vulnerable to the impacts of the El Niño-Southern Oscillation. Parts are also exposed to the impacts of cyclones. On average, the country experiences 2-3 events annually that require a national-level response, in addition to numerous smaller events at the local level.[309] The following figures illustrate the disaster impacts, including from climate related hazards, faced by PNG:

- According to IMF analysis from 1980 to 2016, suggested reductions due to disasters in PNG occurred in: (i) GDP of 0.13-0.22 percentage point per year, (ii) fiscal balance of 0.09-0.12 percentage points, and (iii) trade balance of 0.34-0.44 percentage points.[310]
- PNG experiences an average annual loss[311] (AAL) of $94.2 million, equivalent to 0.6% of GDP (2014 figures), as a consequence of floods;[312]
- UNDP suggests that 18% of PNG's landmass is either permanently or regularly inundated, due to coastal, river (fluvial), and surface (pluvial) flooding.[313]

[306] Westra, S. et al. 2014. *Future changes to the intensity and frequency of short-duration extreme rainfall*. Reviews of Geophysics, 52, 522–555.
[307] Yun, K.S., S.W. Yeh, and K.J. Ha. 2016. *Inter-El Niño variability in CMIP5 models: Model deficiencies and future changes*. Journal of Geophysical Research: Atmospheres, 121, 3894-3906.
[308] Chen, C., M.A. Cane, A.T. Wittenberg, and D. Chen. 2017. *ENSO in the CMIP5 simulations: life cycles, diversity, and responses to climate change*. Journal of Climate, 30, 775-801.
[309] World Bank. 2009. *Reducing the risk of Disaster and Climate Variability in the Pacific Islands: PNG Country Assessment*. Washington DC.
[310] International Monetary Fund. 2018. *Economic Impact of Natural Disasters in Pacific Island Countries*. Washington DC.
[311] Average annual loss is the expected loss per year based on both historic and modeled potential future hazards averaged over many years.
[312] PreventionWeb. Papua New Guinea Disaster & Risk Profile (accessed 16 Feb 2021)
[313] United Nations Development Programme. *National Adaptation Plan process in focus: Lessons from Papua New Guinea.* 2018

- The country's Second National Communication suggests that at least 22,000 people are affected annually by river flooding, causing average damage of over $8 million, whereas modelling undertaken by The World Resources Institute suggests that the population annually affected by 1-in-10 year river flooding in PNG is estimated at 33,000 people.[314]
- PNG's Second National Communication suggests a further 8,000 people are affected by coastal flooding every year, causing over $10 million in damages.

Recent major disasters in PNG highlight the hazards and impacts (see Box 1 for more information) from severe food shortages to large-scale flooding and storm damage, affecting tens, sometimes, hundreds of thousands. Although it is the large-scale or extreme events which attract attention, the cumulative impact of many small-scale natural disasters - notably flash floods, landslides and coastal storms - can cause the biggest impact to rural communities, and collectively cause more damage than the large-scale events. Accurate and comprehensive data on this is lacking, and most events are not officially recorded. The high levels of disaster risk faced in PNG are reflected in its ranking in the 2019 INFORM Risk index (28th out of 191 countries). PNG's ranking is driven by moderate levels of exposure to floods, drought and cyclone, but particularly by its lack of coping capacity (on this indicator PNG is ranked as having the 11th lowest coping capacity in the world).[315] Critically, the changing nature of climate hazards will disproportionately impact vulnerable groups and populations, as illustrated in Box 2.

Box 1: Providing information and examples of specific climate hazards

Intensive rain and landslides. PNG's topography results in significant landslide risk, given the combination of steep mountain ranges, volcanism, high seismicity, and high levels of rainfall. Three of the world's largest landslides recorded in the last 120 years occurred in PNG. The World Bank ranks PNG among the countries with the highest landslide hazard profiles in the world.

Cyclones. The southern part of PNG is at particular risk from frequent and intense cyclones accompanied by storm surge between the months of October and May. Recent events include cyclones Justin (1997) and Guba (2007) that brought torrential rain resulting in widespread flooding and landslides. 150,000 people were affected, and damages and losses were between $300 to $500 million, and this caused the deaths of between 180 and 260 people. Direct losses from cyclones are caused by wind and flooding due to rain and storm surge. AAL attributed to cyclones is $22.7 million, according to analysis by PCRAFI. For return periods of 50 and 100 years, direct losses of $218 million and $432 million, respectively, are expected.

Droughts. Resulting in cool, dry air and reduced rainfall, Drought incidents have historically been linked to the La Niña and in turn these events are known to cause serious food shortages through their impact on crop productivity. El Niño events are frequent in PNG and result in drought. Since the late 19th century, El Niño has had severe impacts in PNG in 1902, 1914, 1941, 1997, and 2015. In years unaffected by El Niño, crops are cultivated throughout the year with rainfall peaking between December and April, followed by a drier period from July to August.

Severe frosts. Associated with drought conditions and El Niño events, severe frosts occur in the Highlands region, home to 40% of the population, with significant impact of food security. The worst effects on subsistence crops, primarily sweet potato, occurs at altitudes above 1,700m. During the 2015-2016 El Nino, a nationwide government-led assessment found that up to 2.2 to 2.4 million people were affected by the drought and frost, while a World Food Programme food security assessment, vulnerability analysis and mapping, in early 2016, identified around 700,000 people affected, with 180,000 people experiencing severe food insecurity. A previous El Niño event in 1997/98 affected 1.24 million people with over 336,000 classed as food insecure Those affected include populations in the high-altitude areas of the Highlands, some inland lowland areas and some

[314] World Resources Institute (WRI). *AQUEDUCT Global Flood Analyzer.* 2018. URL: https://floods.wri.org/#
[315] World Bank and ADB. 2019. Climate Risk Country Profile Papua New Guinea.

islands. The destruction of crops was also reported as a factor in families migrating to lower altitudes. (WFP, 2015)

Sources: ADB. 2018. Papua New Guinea - Background Note on Disaster Risk Management. Background document to the preparation of *Country Partnership Strategy PNG 2021-2025.* 2018; World Food Programme. 2015. *Papua New Guinea El Niño 2015-16.* 2015

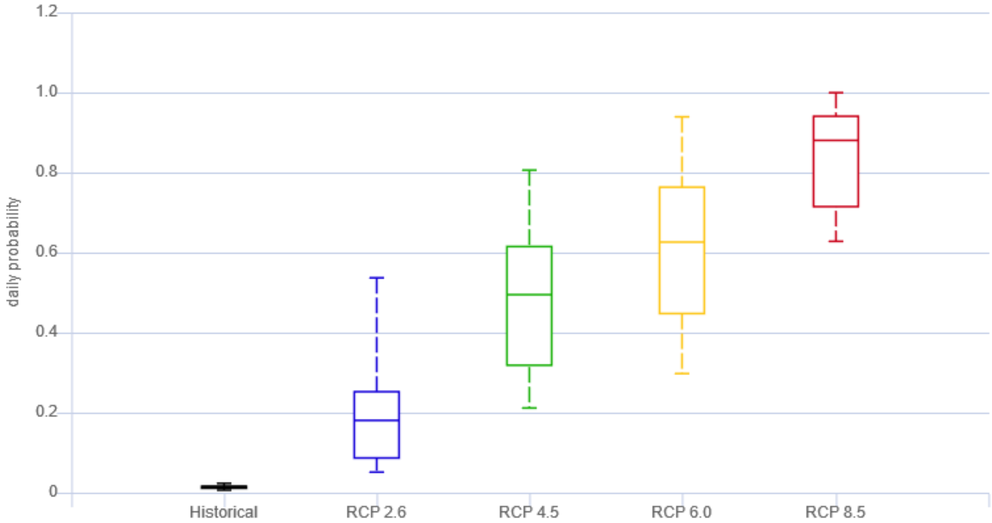
Box 2: An illustration of how climate hazards can impact specific vulnerable groups, using the example of gender and droughts

Women are particularly adversely affected by drought in PNG. For example, during the 2015/16 El Niño drought the following was reported (https://iwda.org.au/women-continue-to-bear-the-brunt-of-the-png-drought/) "Voice for Change, a local organisation that tackles gender-based violence and advocates for women's leadership in the Highlands of PNG, has been active in drought relief efforts. The organisation has reported increased security, sanitation, water, and food concerns for women given their gendered responsibilities for household water collection and providing food for their families. Women have had to travel further for water which increases risk of violence or arrest. Often they've needed to infringe onto another clan's land to access a river, and have been charged for it." In addition to this information there were undocumented reports of women and girls being raped during the 2015/16 drought. These reports arose from situations where highly vulnerable families from high-altitude highlands moved to be with extended family in lower altitude areas … a common coping strategy during drought. In these situations, girls in particular were vulnerable to the approaches of their hosts with their families having little power to protect them given the circumstances of the drought. This is a particularly sensitive subject in PNG, with no documented evidence.

This situation was exacerbated by the fact that women lack power in decision making, and so their unique needs were not adequately addressed in relief efforts.

Heat waves. PNG regularly experiences high maximum temperatures, with an average monthly maximum of around 31°C and an average November maximum of 32°C. The current median probability of a heat wave (defined as a period of 3 or more days where the daily temperature is above the long-term 95th percentile of daily mean temperature) is around 1%.[18] This value reflects PNG's very stable present-day climate. Heat waves represent anomalous high temperatures based on historical trends. As such, if the baseline against which heat waves are measured remains unchanged (1986-2005), the warming and increased climate variability associated with climate change is projected to dramatically increase the frequency of heat waves in future. As shown in **Figure 59** by 2080-2099 PNG sees a considerable increase in the likelihood of a heat wave under all emissions pathways. In addition, under higher emissions pathways (particularly RCP8.5) PNG may transition to a chronically heat-stressed environment, with the CCKP model ensemble projecting a potential 100 day increase in the number of days surpassing 35°C by 2080-2099. Even increases in the range of 9-26 days above 35°C (ensemble median estimate) under the three lower emissions pathways represent a potential health hazard to PNG's communities.

Figure 59: Projected change in the probability of observing a heat wave in PNG, 2080–2099



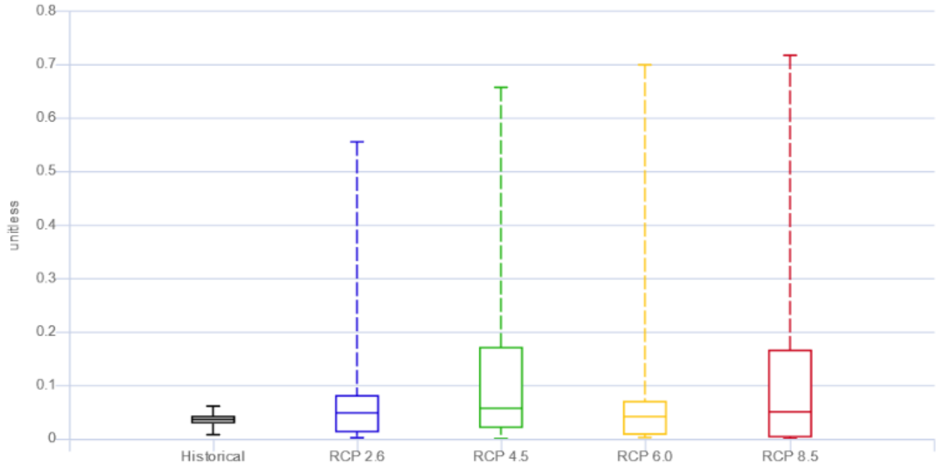
Note: A 'Heat Wave' is defined as a period of 3 or more days where the daily temperature is above the long-term 95th percentile of daily mean temperature.
Source: WBG Climate Change Knowledge Portal. 2018. Climate by Sector: Interactive Climate Indicator Dashboard. URL: https://climateportal.worldbank.org.

Drought. Two primary types of drought may affect PNG, meteorological (usually associated with a precipitation deficit) and hydrological (usually associated with a deficit in surface and subsurface water flow, potentially originating in the region's wider river basins). At present PNG faces an annual median probability of severe meteorological drought of around 4%, as defined by a standardized precipitation evaporation index (SPEI) of less than -2. Past drought incidents in PNG have led to significant disaster events, with a notable drought in 1997 resulting in widespread famine.[316] Severe drought caused by strong El Niño event in 2015–2016 affected about 40% of the population, with almost half a million people experiencing food shortages.[317]

The CCKP model ensemble presents an uncertain future for drought in PNG, with a wide variety of model estimates. The model ensemble median estimate would indicate no change in annual probability under all emissions pathways but a small subset of climate models suggests significant increases in the probability of drought (**Figure 60**). Naumann et al., who provide regionalized estimates of future drought frequency, suggests a large increase in drought frequency in the Oceania region.[318] These estimates may, however, be biased by the dramatically different climatology of Australia. Lafale et al. (reporting findings of the Pacific-Australia Climate Change Science and Adaptation Planning Program) conversely suggest there is medium confidence that droughts will decline in frequency.[319] In part this uncertainty reflects our poor understanding of how climate change will impact on the ENSO phenomenon which can drive drought in PNG.[320] Further research is urgently required to constrain projections of future drought severity and frequency.

[316] McVicar, T.R. & P.N. Bierwirth. *Rapidly assessing the 1997 drought in Papua New Guinea using composite AVHRR imagery.* International Journal of Remote Sensing, 22(11), pp.2109-2128. 2001.
[317] United Nations Office for the Coordination of Humanitarian Affairs (OCHA). 2015. *Papua New Guinea El Nino 2015-16*. Reliefweb News. https://reliefweb.int/sites/reliefweb.int/files/resources/PNG%20Brief%20Sep2015.pdf
[318] Naumann, G., et.al. *Global Changes in Drought Conditions Under Different Levels of Warming*. Geophysical Research Letters, 45(7), 3285–3296. 2018.
319 Lafale, P., H. Diamond, & C. Anderson. *Effects of climate change on extreme events relevant to the Pacific Islands.* Science Review 2018: 50-73. 2018.
[320] Chen, C., M.A. Cane, A.T. Wittenberg, & D. Chen. *ENSO in the CMIP5 simulations: life cycles, diversity, and responses to climate change*. Journal of Climate, 30, 775-801. 2017.

Figure 60: Boxplots showing the annual probability of experiencing a 'severe drought' in PNG (-2 SPEI index) in 2080-2099 under four emissions pathways



Source: WBG Climate Change Knowledge Portal. 2018. Climate by Sector: Interactive Climate Indicator Dashboard. https://climateportal.worldbank.org.

Flood and landslide. Flood represents a major risk in PNG. The UNDP suggest that 18% of PNG's landmass is either permanently or regularly inundated.[321] PNG experiences coastal, river (fluvial), and surface (pluvial) flooding. The country's Second National Communication with the UNFCCC suggests that at least 22,000 people are affected annually by river flooding, causing average damage of over $8 million. The World Resources Institute's AQUEDUCT Global Flood Analyzer[322] can be used to establish a baseline level of river flood exposure. As of 2010, assuming protection for up to a 1-in-10 year event, the population annually affected by river flooding in PNG is estimated at 33,000 people and the damage to GDP is estimated at $73 million. The discrepancy in the modelled versus reported damage may be explained either by model deficiencies, and/or by a lack of reporting of more minor flood events. PNG's Second National Communication suggests a further 8,000 people are affected by coastal flooding every year, causing over $10 million in damages. The UNISDR estimate a total average annual loss to flood in the region of 0.5% of annual GDP.[323]

Population growth, development and climate change are both likely to increase these figures. The climate change component can be isolated and by 2030 under the RCP8.5 emissions pathway (AQUEDUCT Scenario B) is expected to increase the annually affected population by 20,000 people, and the GDP impact by $90 million.

Paltan et al. (2018) demonstrate that even under lower emissions pathways coherent with the Paris Climate Agreement almost all Asian countries face an increase in the frequency of extreme river flows. In PNG what would historically have been a 1-in-100-year flow, could become a 1-in-50 year or 1-in-25-year event.[324] There is good agreement among models on this trend. As shown in **Table 23,** Willner et al. (2018) estimate that the population affected by an extreme flood could increase by 35,000-56,000 people by 2035-2044 (assuming present day population distributions) as a result of climate change. Population growth and poorly planned development have the potential to increase this figure further.

[321] United Nations Development Programme (UNDP). 2018. *National Adaptation Plan process in focus: Lessons from Papua New Guinea.* United Nations Development Programme Publication.
[322] World Resources Institute (WRI). 2018. *AQUEDUCT Global Flood Analyzer.* https://floods.wri.org/#
[323] United Nations International Strategy for Disaster Reduction (UNISDR). 2014. *PreventionWeb: Basic country statistics and indicators.* https://www.preventionweb.net/countries
[324] Paltan, H. et al. 2018. *Global implications of 1.5°C and 2°C warmer worlds on extreme river flows Global implications of 1.5°C and 2°C warmer worlds on extreme river flows.* Environmental Research Letters, 13.

Table 23: Estimated number of people in Papua New Guinea affected by an extreme river flood (extreme flood is defined as being in the 90th percentile in terms of numbers of people affected) in the historic period 1971-2004 and the future period 2035-2044

Estimate	Population exposed to extreme flood (1971-2004)	Population exposed to extreme flood (2035-2044)	Increase in affected population
16.7 Percentile	112,459	168,642	56,183
Median	130,208	181,406	51,198
83.3 Percentile	167,719	203,010	35,291

Note: Figures represent an average of all four RCPs and assume present day population distributions.
Source: Willner, S., A. Levermann, F. Zhao, and K. Frieler. 2018. Adaptation required to preserve future high-end river flood risk at present levels. Science Advances: 4:1.

A further and poorly documented risk in PNG is that of landslides. While many smaller-scale events go unreported, fatalities and infrastructure damage are known to take place annually, and multiple medium-high impact events are reported most years.[325] PNG is exposed to earthquakes on a regular basis, with 10 earthquakes of magnitude 7.0 and above experienced between 2014-2018,[326] these have been known to trigger some of the highest impacts, i.e., high fatality, events. Earthquakes are most likely to trigger landslide events when occurring in combination with heavy rainfall which saturates the soil. Landslides may also occur directly as a result of flash flooding, particularly when ecosystems and soil are degraded. Indeed, one study suggested around 60% of landslides are triggered by rainfall. These phenomena link landslide risk to climate change and to expected increases in rainfall intensity. The CCKP model ensemble projects increase in both the intensity of high rainfall events and the frequency of wet days.[20] Research has linked short-duration, high intensity, rainfall to increased probability of moderate to high impact landslide events in PNG,[327] signifying the potential for climate change to exacerbate landslide risk.

Cyclones and storm surge. Every decade around 15 tropical cyclones pass through PNG's exclusive economic zone, around a quarter of which is category 3 or stronger (severe events). A 1-in-100-year cyclone landfall was estimated to cost around 8.4% of GDP as of 2011.[328] However even cyclones passing a long way from PNG's land mass can have a significant local impact, with flooding and inundation of low-lying islands documented as a result of elevated water levels.[329] Climate change is expected to interact with cyclone hazards 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 windspeed and precipitation intensity. The 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 extreme events.[330] This finding is supported for Papua New Guinea by modelling conducted by Australian Aid.[331] While the frequency of moderate intensity tropical cyclones may decline the increase in wind speeds associated with category 5 cyclones is projected to increase. Consequentially, the average economic losses experienced during a 1-in-50 year event are expected to rise in the range of 14-66% and the average annual economic losses to tropical cyclones may also rise by around 5%. For further discussion of the future probabilities of cyclone genesis see work by the

[325] Robbins, J. C. and M.G. Petterson. 2015. *Landslide inventory development in a data sparse region: spatial and temporal characteristics of landslides in Papua New Guinea.* Natural Hazards and Earth System Sciences Discussions, 3, 4871–4917.
[326] United States Geological Survey (USGS). 2020. *Climate Data.* https://earthquake.usgs.gov/.
[327] Robbins, J. C. 2016. *A probabilistic approach for assessing landslide-triggering event rainfall in Papua New Guinea, using TRMM satellite precipitation estimates*. Journal of Hydrology, 541, 296–309.
[328] Lafale, P., H. Diamond and C. Anderson. 2018. *Effects of climate change on extreme events relevant to the Pacific Islands.* Science Review 2018: 50-73.
[329] Smithers, S.G. and R.K.Hoeke. 2014. *Geomorphological impacts of high-latitude storm waves on low-latitude reef islands—Observations of the December 2008 event on Nukutoa, Takuu, Papua New Guinea*. Geomorphology, 222, pp.106-121.
[330] Walsh, K. et al. 2015. *Tropical cyclones and climate change.* WIREs Climate Change: 7: 65-89.
[331] Australian Aid. 2013. *Current and future tropical cyclone risk in the South Pacific.* Pacific Catastrophe Risk Assessment and Financing Initiative.

Australian Bureau of Meteorology and CSIRO. More 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.

Table 24 below summarizes some of the climate risks that vulnerable rural populations are exposed to in the three main ecological zones in PNG.

Table 24: Examples of the impacts of climate hazards on vulnerable rural populations in the three main ecological zones of PNG

Typical site	Hazard	Risk
Highlands	Rainfall variability	Agricultural droughts that contribute to reduced production or loss of production, and subsequent food insecurity. This has likely affected up to one million or more in the past. This is often in combination with frost events. However, on a more regular basis, as all agriculture is rainfed, regular localised droughts affect small numbers of the more vulnerable people.
	Intensive rainfall	Flash floods and landslides are very common in the highlands, due to steep terrain and unstable soils. These regularly, and all through the year, cause infrastructure damage and cut communication links, and damage agricultural land. Almost all areas are exposed to this hazard.
	Maximum and minimum and average temperatures	High temperatures facilitate plant, animal and human disease, although this has been less of a problem in the past in the Highlands. Frost contributes to reduced agricultural production, often in combination with droughts during La Nina.
	Humidity	Can facilitate plant disease.
Islands	Intensive rainfall	These are an issue at some sites, especially where coastlines are narrow. Flash floods cause infrastructure damage and cut off communication links, and damage agricultural land.
	Extreme sea level	Storm surge and wave action lead to flooding, coastal erosion and damage to water sources and loss of agricultural land.
	Mean sea level	No risk currently
	Ocean acidity	Acidity levels have increased in recent years. This is thought to contribute to undermining marine ecosystem health. No data is available to impacts on fish stocks and local fishing.
Coastal Plains	Short- and medium-term upstream rain fall	Upstream rainfall, prolonged and intensive, lead to large scale downstream flooding. These riverine floods, sometimes large scale, cause infrastructure damage and can contribute to health epidemics
	Cyclones	In particular in southern parts of the main islands, these have regular impacts, exacerbating floods. These can also cause infrastructure damage and cut off communication links, increase coastal erosion and loss of agricultural land.
	Maximum and average temperatures and humidity	Temperatures, combined with humidity, can facilitate plant, animal and human disease.
	Extreme sea level	For sites very close to the coast, storm surge and wave action can lead to flooding, coastal erosion and damage to water sources
	Mean sea level	No risk currently
	Ocean acidity	Levels have increased in recent years. This is thought to contribute to undermining marine ecosystem health. No data is available to impacts on fish stocks and local fishing.

5. Climate Change Impacts

Climate change will likely have an effect on the frequency and intensity of climate extremes and exacerbate climate variability and uncertainty in Papua New Guinea. The types of risk faced and their impacts are highly contextual and will differ across the country and the ecological zones discussed in the previous sections. However, in more general terms it is clear that Papua New Guinea's demographic characteristic of a predominantly rural agrarian society creates a unique climate change risk context in terms of vulnerability and coping capacities and impacts from climate change on the population's livelihoods and well-being will be significantly felt across the country.

Water. The water sector in PNG faces major challenges. A report by Water Aid in 2018 suggested PNG's population had the second lowest rate of access to a basic safe water supply in the world, at only 37%.[332] The report emphasized that climate change threatens to slow progress in addressing this issue. Known risks include the increased probability of coastal and river flooding, both of which threaten human lives, livelihoods and infrastructure, but are also likely to degrade water quality spreading salt contamination and water-borne diseases.

One assessment by ADB suggested that by 2070 PNG could face annual water shortages of 124 mm due to combined climate change and human development.[333] However, this estimate was based on outdated climate modelling. Drought incidents have historically been linked to the El Niño and in turn these events are known to cause serious food shortages through their impact on crop productivity.[334] The high uncertainty about future precipitation trends[335] and particularly future ENSO and drought occurrence are unhelpful for planning future water resources management and highlight the need for disaster risk reduction measures. Such a situation is experienced in some regions where an estimated 3 million people may be affected in Papua New Guinea, with a projected 1.9 million of these in the highlands.[336]

The coastal zone and ecosystems. Sea-level rise threatens significant physical changes to coastal zones around the world. Global mean sea-level rise was projected to be in the range of 0.44-0.74m by the end of the 21st century by the IPCC's Fifth Assessment Report[337] but some studies published more recently have highlighted the potential for more significant rises (**Table 25**). Sea-level rise can vary spatially, and work by the Australian Bureau of Meteorology and CSIRO has suggested that end-of-century sea-level rise could vary by as much as 10cm across the South Pacific region, meaning countries such as PNG should be prepared for above average sea-level rises.[338]

PNG has already documented the impacts of sea-level rise on its communities. The Carteret islands were among the first Pacific islands from which environmental refugees were documented, as a result of sea-level rise. National policy is to relocate half of the island's population of around 2,500 by 2020.[339] The UK Met Office (2014) estimate that around 34,000-44,000 PNG residents face permanent inundation by 2070-2100, but the coarse resolution of this modelling may mean this figure is an underestimate and further research is required (**Table 26**). Other impacts of sea-level rise include saline intrusion, which has already been documented damaging the production of small-holder farmers.[340] Sea-level rise also threatens the integrity of PNG's coastal resources and biodiversity. Notably, the mangrove forests found

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[332] Water Aid- Australia. *WaterAid report reveals nations with lowest access to water*. 2018. URL: https://www.wateraid.org/au/articles/wateraid-report-reveals-nations-with-lowest-access-to-water

[333] Asian Development Bank (ADB). *Economic of Climate Change in the Pacific. Brochure: August 2013.* ADB Publication. Manila, Philippines. 2013.

[334] Ibid

[335] The Guardian. *Pacific's fight against Covid-19 hamstrung by lack of clean water.* 2020. URL: https://www.theguardian.com/world/2020/aug/29 /pacifics-fight-against-covid-19-hamstrung-by-lack-of-clean-water

[336] Oxfam International . *Powerful El Niño brings droughts and food insecurity to millions in Papua New Guinea.* N.D. URL: https://www.oxfam.org/en /powerful-el-nino-brings-droughts-and-food-insecurity-millions-papua-new-guinea

[337] Church, J. A., et.al. *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. 2013.

[338] Australian Bureau of Meteorology and CSIRO. *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. 2014.

[339] Intergovernmental Panel on Climate Change (IPCC). *Reported at UN Climate Change Conference COP23.* 2017. URL: https://cop23.com.fj/ papuanewguinea/

[340] Government of Papua New Guinea. *Papua New Guinea Second National Communication to the UNFCCC*. 2014.

along New Guinea's north coast have been identified as vulnerable to submergence and loss.[341]

Table 25: 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)

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		1.84m (0.98-2.47)

Source: Le Bars, D., S. Drijhout, and H. de Vries. *A high-end sea level rise probabilistic projection including rapid Antarctic ice sheet mass loss.* Environmental Research Letters: 12:4. 2017.

Table 26: The average number of people experiencing flooding per year in the coastal zone in the period 2070-2100 under different emissions pathways (assumed medium ice-melt scenario) and adaptation scenarios for Papua New Guinea (UK Met Office, 2014)

Scenario	Without adaptation	with adaptation
RCP2.6	34,310	130
RCP8.5	44,260	270

Source: UK Met Office. 2014. *Human dynamics of climate change: Technical Report*. Met Office, UK Government.

The challenge that coral reefs around PNG faces directly relates to growing pressures from human development in upstream river basins and in the vicinity of the coast.[342] As outlined in the IPCC's 5th Assessment Report, Pacific coral reefs face a negative outlook under all climate change scenarios.[343] Ocean acidification and warming represent a dual risk, and there is high certainty that both will continue under all emissions pathways. RCP2.6 represents the only emissions pathway under which ocean acidity conditions remain suitable for healthy coral reefs in PNG. Under RCPs 4.5, 6.0 and 8.5 the ocean conditions around PNG are expected to transition to a state only marginally suitable for coral by 2030. Under RCP4.5 conditions remain in this state but under RCP8.5 conditions transition to a state in which corals have not historically been found.[344] At the same time ocean warming is likely to increase the frequency of coral bleaching events. One study estimates that a 2°C rise in mean sea surface temperature could increase the frequency of coral bleaching events from once every 30 years to once every four months.[345] Further research is required to constrain the possible future scenarios of coral bleaching, and their impact on the viability of coral in PNG, as projections of sea-surface temperature changes currently hold high uncertainty.

The unfavorable outlook for coral reefs in PNG is likely to have negative impacts on the health of coastal fisheries. Further research is required to constrain this impact and establish the size of the potential threat to one of PNG's largest protein sources. Gillett estimates PNG's average per capita fish consumption at 18.2-24.9 kilogram (kg) per year.[346] Further research is also required to better understand the climate change impacts on ocean fisheries. One study

[341] Lovelock, C. E., et.al. *The vulnerability of Indo-Pacific mangrove forests to sea-level rise.* Nature, 526, 559. 2015.
[342] Tulloch, V.J. et al. 2016. *Improving conservation outcomes for coral reefs affected by future oil palm development in Papua New Guinea.* Biological Conservation, 203, pp.43-54.
[343] Nurse, L. et al. 2014. *Small islands.* In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY , USA, pp. 1613-1654.
[344] WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical.* https://climateportal.worldbank.org.
[345] 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. Melbourne, Australia.
[346] Gillett, R. 2009. *Fisheries in the Economies of the Pacific Island Countries and Territories.* Asian Development Bank Publication. Manila, Philippines.

suggested PNG may experience a 30% decline in Skipjack Tuna catch by the end of the century under a high emissions scenario.[347]

Biodiversity, Forestry and Land-use. Papua New Guinea is world renowned for its biologically rich and diverse forests. These forests also hold an unusually large amount of above-ground biomass, and hence can be significant carbon stores.[348] The forests sustain an estimated 85 percent of the country's population with food and shelter.[349] About 1,035 different plant species are known to be used for various purposes in PNG. Wildlife plays an important part in traditional diets, supplying the primary intake of proteins and fats in many highland areas and other isolated areas of the country.[350] As such, forest products represent a major source of both household food security and export income.

Over recent decades PNG has experienced major challenges in the forestry sector. Illegal and unsustainable logging, facilitated by poor governance, has led to rapid deforestation, and the benefits of forest exports have accrued disproportionately to the wealthiest groups in society.[351] Data are scarce on the precise scale of deforestation but losses in forest area have historically proceeded at a rate of over 1% per year.[352] Governance and the management of growing development pressures are likely to remain the largest determinant of future forest health and biodiversity in PNG, but climate change may also have an impact. Empirical evidence is limited, but the available research suggests PNG's mid-elevation species may fare best under future climates, and upland species may experience a contraction of their viable ranges which may threaten the long-term survival of many endemic species.[353] Another study reveals that the analysis of 2353 endemic plant species distributions in New Guinea island shows that 63% of species are expected to have smaller geographic ranges by 2070 making ecoregions in PNG having an average of −70 ± 40 fewer species by 2070. Future geographic range contractions, as impacts, include 720 endemic plant species that are used by indigenous people.[354] Such a contraction in biodiversity and potential for loss of non-timber forest products that are critical for nutritional diversity of many communities in remote areas of Papua New Guinea has significant implications for food security.

Agriculture. Climate change is predicted to adversely affect food systems in the entire Pacific Region, including the supply of food from agriculture and fisheries[355]. Any changes or shifts in the climate will affect the physiology and output of food crops, as the growth, development and production of crops depend on both climatic (e.g. rainfall, temperature, humidity) and environmental (e.g. soil, water availability and topography) variables being sufficiently available, and that there is adequate protection from external factors (invasive species, pest and disease)[356]. The threats to agricultural production from climate change thus arise largely from changes in temperature and precipitation, both long-term and slow-changing (slow-onset

[347] ADB. 2013. *The Economics of Climate Change in the Pacific*. Full Report. Asian Development Bank Publication. Manila, Philippines.
[348] Venter, M. et.al. 2017. *Optimal climate for large trees at high elevations drives patterns of biomass in remote forests of Papua New Guinea*. Global change biology, 23(11), pp.4873-4883.
[349] Oxfam International. *Powerful El Niño brings droughts and food insecurity to millions in Papua New Guinea.* N.D. URL: https://www.oxfam.org/en/powerful-el-nino-brings-droughts-and-food-insecurity-millions-papua-new-guinea
[350] Department of Agriculture & Livestock. 2016. *Report on The State of Biodiversity for Food and Agriculture in Papua New Guinea*. http://www.fao.org/3/CA3422EN/ca3422en.pdf
[351] Laurance, W. F. et al. 2011. *Predatory corporations, failing governance, and the fate of forests in Papua New Guinea*. Conservation Letters, 4(2), 95–100.
[352] Shearman, P. L. et al. 2009. *Forest Conversion and Degradation in Papua New Guinea 1972–2002*. Biotropica, 41(3), 379–390.
[353] Maiguo, E., R. Keenan, and C. Nitschk. 2013. *Assessment of Vulnerability and Impacts of Climate Change on Forests in Papua New Guinea.* In Proceedings of the 7th Huon Seminar-2013 (pp. 130–141).
[354] Cámara-Leret, R., et.al. *Climate change threatens New Guinea's biocultural heritage*. Science Advances 27 Nov 2019:Vol. 5, no. 11, eaaz1455 DOI: 10.1126/sciadv.aaz1455. 2019.
[355] Barnett, J. 2011. Dangerous climate change in the Pacific Islands: food production and food security. *Regional Environmental Change*, 11 (Suppl. 1), pp. 229-237, 10.1007/s10113-010-0160-2
[356] Iese, V. et al. (2015) Farming adaptations to the impacts of climate change and extreme events in Pacific Island Countries W.G. Ganpat, W.-A.P. Isaac (Eds.*), Impacts of Climate Change on Food Security in Small Island Developing States*, IGI Global, United States of America (2015), pp. 166-194, 10.4018/978-1-4666-6501-9.ch006

changes), as well as changes in the frequency and intensity of extreme weather events. Extreme events are likely to be more damaging, especially if their timing coincides with a crucial developmental stage in the life cycle of a crop or livestock species, as well as because of their potentially damaging impact on the communities working in the sectors and the supporting infrastructure.[357] Severe droughts, intense floods, salt water inundation and intrusion and tropical cyclones reduce both crop yields and total production, increasing the risks of food insecurity in communities[358]. As agriculture is the main source of food, livelihood and income for the majority of PNG communities - the UNDP (2018) estimate that 70% of households in PNG remain dependent on subsistence agriculture[359] - the impacts of climate change on this sector are highly critical to food security and sustainable development in the country. 83% of food consumed is produced in country, thus, any disruption to local food production (from climate or other shocks) has an immediate and significant impact on food security.

A review of multiple studies conducted by ADB suggested that major staple crops for communities in PNG such as sweet potato, cassava, maize and taro are likely to show negative yield trends as a result of climate change, with sweet potato declining as much as 10% by 2050. This is a particular concern as PNG's population is particularly dependent on sweet potato production, with its Second National Communication to the UNFCCC suggesting 63% of calories in rural areas derive from this source - sweet potato is particularly important in the highlands, where the crop contributes to the food security and cash incomes of more than 90% of the highland population.[360] Sweet potato, despite its resilient features, can be vulnerable to pests, diseases and impacts of climate change, and studies suggest that climate change is already impacting production. Excess water logging and soil moisture encourages above-ground growth but reduces growth of the storage root. Sweet potato has also been impacted by severe frosts as experienced in the highlands of Papua New Guinea, and has also been affected by salinity[361].

Some of the lesser considered impacts of climate change on agriculture are pests and diseases and the quality of the crops. Crop quality can be affected by a warming temperature. Higher temperatures have been shown to reduce vitamin content in fruit and vegetable crops,[362] having significant impacts on nutrition security. Root crops such as sweet potatoes, taro, yam and pana have also been reported to have lost their flavor as a consequence of receiving too much rain, which has been suggested to be closely linked to the nutrient content. A study by Iese et al. (2015) indicates that increased water infiltration or percolation promotes the washing away of nutrients, minerals or elements that influence the taste or flavor of the tubers - although this area requires further study. Evidence also suggests that climate change is likely to be an effective dissemination mechanism for pests and diseases. As pest and disease incidence and distribution are influenced by temperature and precipitation patterns, projected changes in the climate are likely to have an impact, with potential for new threats from pathogens or pests that are considered unimportant today in some agro-ecological zones[363], which will have implication for yields and quality of crops.

Table 27 below highlights some of the direct and indirect risks from climate change for some of the most important staple crops in PNG.

[357] McGregor, A. et al. 2016. Vulnerability of staple food crops to climate change. M. Taylor, A. McGregor, A., Taylor,M., B. Dawson, B (Eds.), Vulnerability of Pacific Island Agriculture and Forestry to Climate Change, Pacific Community (SPC), Noumea, New Caledonia, pp. 161-238

[358] Iese, V., Holland, E., Wairiu, M., Havea, R., Patolo, S., Nishi, M., Hoponoa, T., Bourke, M., Dean, A., and Wangainbete, I. 2018 Facing food security risks: The rise and rise of the sweet potato in the Pacific Islands. *Global Food Security.* Vol 18. Pp 48-56

[359] United Nations Development Programme (UNDP). 2018. *National Adaptation Plan process in focus: Lessons from Papua New Guinea.* United Nations Development Programme.

[360] ADB. 2013. *The economics of climate change in the Pacific.* Manila.

[361] ibid Iese et al, (2018)

[362] Ibid Mcgregor et al 2016

[363] Ibid McGregor et al 2016

Climate change will also present opportunities for agriculture and rural livelihoods. A warming temperature will enable crops to be cultivated in locations currently unsuitable, and thus provide an opportunity for crop diversification and improved nutrition and income generation - banana cultivation in areas of higher altitude for example[364]**.** Currently, rainfed maize yields appear not to do well in the Highlands. Yields generally appear to be high in most of the rest of the country. Under climate change, maize results indicate yield losses in most of the country, and yield gains in the highlands – thus rainfed maize could be grown in areas previously not planted to that crop, with yields in the Highlands even surpassing current yields. Rainfed taro could also potentially be grown on the fringes of the Highlands region[365]. The capacity to adapt to climate change and bring about climate resilient sustainable development is thus very much dependent on the ability of households to reduce risk of losses of yields of some crops and take advantage of potential opportunities. This will require improved knowledge and skills on climate smart production practices that are context specific.

[364] Ibid McGregor et al 2016
[365] ADB. 2015. *Climate change, food security, and socioeconomic livelihood in Pacific Islands.* Manila.

Table 27: Impacts of climate change on key staple crops in Papua New Guinea

Type of risk	Examples of impacts	Climate projections for PNG[366]
Temperature rise and extreme Heat: Depending on their intensity and duration, short episodes of high temperatures can be very damaging if they occur at a critical time of development, and can affect growth and yield independently of any substantial changes in mean temperature. Where temperatures are already close to the physiological maximum, higher temperatures are likely to increase both the heat stress on crops and water loss by evaporation. High temperature stress can be exacerbated by the high relative humidity found in tropical locations. Models indicate that in tropical and subtropical regions temperature increases of only 1°–2°C are likely to depress yields as heat tolerance levels are exceeded.	**DIRECT IMPACTS** **SWEET POTATO -** Tuber production is reduced significantly at temperatures above 34°C. An increase of 1°–2°C (very high emission scenario) by 2050 would affect production in lowland locations in PNG where temperatures are currently around 32°C within one or two generations, which would have major food security implications. Beyond 2050, the food security implications under all emission scenarios except RCP2.6 could be serious. The impact would depend on the timing and duration of the event, as well as soil moisture levels. **BANANA** - Temperatures in excess of 35°C (heatwaves) are likely to affect flowering and bunch filling. By 2050 and beyond, temperature could be a significant constraint on banana production at low altitudes in PNG, especially if warming proceeds according to the very high emissions scenario (RCP8.5), where 1°–2°C will be reached by 2050, and 2°–4°C by 2090. **INDIRECT IMPACTS** **TARO** – A rise in minimum night-time temperature increases the likelihood of Taro Leaf Blight spreading to locations currently free of the disease higher elevation areas of PNG. Extreme heat days are likely to pose a threat in this regard. Temperature and humidity have directly been linked with outbreaks, pointing to the influence of minimum (night) temperature on TLB outbreaks. In PNG, TLB is less severe a few hundred meters above sea level and is rarely found	Warming over New Guinea's land surface, as measured in the difference between average temperature in 1900-1917 and 2000-2017, has been approximately 0.8-0.9ºC. Warming over New Ireland is similar, in the range of 0.9-1.0ºC during the same time period. The Climate Research Unit (CRU) historical data suggest that this temperature rise has been fastest in the minimum temperatures. The CCKP model ensemble projects median warming of 2.9ºC by 2080-2099 under the highest emissions pathway (RCP8.5) relative to the 1986-2005 baseline. This projection falls to 0.7ºC under the lowest emissions pathway (RCP2.6). Projected rates of warming are typically 20-30% lower than the global average, but should be treated with extreme caution. Maximum and minimum temperatures are projected to rise notably faster than average temperatures, pointing towards a less stable and more frequently heat stressed climate in the future. By 2080-2099, PNG sees a considerable increase in the likelihood of a heat wave under all emissions pathways. In addition, under higher emissions pathways (particularly RCP8.5) PNG may transition to a chronically heat-stressed environment, with the CCKP model ensemble projecting a potential 100 day increase in the number of days surpassing 35ºC by 2080-2099. Even increases in the range of 9-26 days above 35ºC (ensemble median estimate) under the three lower emissions pathways could impact agricultural yields.

[366] Summary of projections set out in previous section.

Type of risk	Examples of impacts	Climate projections for PNG[366]
	above the altitude of 1300 m (Bourke 2010), suggesting sensitivity of the oomycete to a small rise in temperature. **BANANA -** Higher temperatures could encourage the spread of black leaf streak disease to higher altitudes.	
Droughts and associated frosts: Droughts can result in the death of crops, early maturity, and reduction in size of fruits and tubers, as well as, decline in yield and nutritional quality.	**SWEET POTATO:** The temperature in major growing areas in the PNG highlands can fall below the minimum threshold (10°C), particularly during drought periods, with severe consequences for food security. In the highlands of PNG, where sweet potato is the dominant staple, it is susceptible to frosts that accompany ENSO-induced droughts. Drought can also exacerbate micronutrient deficiency (e.g. zinc) due to reduced transpiration rates.	Large uncertainty surrounds the potential for increase in drought due to climate change with some studies indicating increases and others decreases. In part this uncertainty reflects the poor understanding of how climate change will impact on the ENSO phenomenon which can drive drought in PNG. Further research is urgently required to constrain projections of future drought severity and frequency. Nonetheless, severe drought caused by strong El Niño event in 2015–2016 affected about 40% of the population, with almost half a million people experiencing food shortages and so a conservative approach would follow the likelihood of increased drought. Although there remains uncertainty over how the ENSO cycle will change under climate change, current understanding suggests that severe El Niño events will become more common over the course of the century,[367] and there may also be an increase in the frequency of El Niño events,[368] with the result that the likelihood of severe drought in the country will increase.
Increased rainfall extremes: Total annual rainfall is just one aspect of the impact of rainfall on plant growth. Important factors are seasonal distribution (timing), variation between years, extremes and intensity. High levels of precipitation at critical times such as harvesting can have serious effects. Excess water results in waterlogging, and soil saturation and oxygen deficiency (hypoxia) which can occur over a few days. Nutrient uptake is reduced and therefore transient waterlogging can lead to decreased yields if crops. Hypoxia can also	**SWEET POTATO** - Sweet potato is vulnerable to extended periods of wet weather and so increased extreme rainfall is a concern for sweet potato. It has been reported to negatively affect tuber formation and production as a result of increases or changes in rainfall. Excessively high soil moisture, particularly during initiation (6–10 weeks after planting) reduces tuber yield and is a major cause of food shortages in the PNG highlands. Where rainfall is already very high, most growers will find it difficult to counter a significant rainfall increase — an increase in rainfall,	The intensity of sub-daily extreme rainfall events appears to be increasing with temperature, a finding supported by evidence from different regions of Asia and the Pacific. Medium confidence should be placed in the projected future trend of increased annual precipitation. However projections that suggest the frequency and intensity of extreme rainfall events will increase are associated with high confidence.

367 McPhaden, M. J., A. Santoso, and W. Cai (2019), Understanding ENSO in a changing climate, Eos, 100, HYPERLINK "https://doi.org/10.1029/2019EO124159"https://doi.org/10.1029/2019EO124159. Published on 23 May 2019.
368 Wang, B. et al. (2019) Historical change of El Niño properties sheds light on future changes of extreme El Niño. *Proceedings of the National Academy of Sciences* 116 (45) 22512-22517

Type of risk	Examples of impacts	Climate projections for PNG[366]
increase the concentration of toxic ions, metals, fatty acids, phenolic compounds and ethylene found in the soil.	particularly between October and March, would result in yield reductions in many locations. **TARO -** The lower limit for mean annual rainfall is 1500 mm with 5000 mm as the upper limit. Taro is not tolerant of waterlogging. In PNG giant taro is grown successfully across locations with rainfall of 2000–4000 mm per year. Increases in annual rainfall from climate change may exceed the 5000mm limit in these areas making Taro cultivation problematic. **CASSAVA** - Higher rainfall levels can reduce root growth, but despite this, it remains an important food crop in some very high rainfall locations, such as the PNG lowlands with rainfall around 6000 mm/year. As with Taro, increases in annual rainfall from climate change may exceed the limit in these areas making cultivation problematic. **Indirect Impacts** **Disease -** A wetter climate could increase problems with sweet potato scab. Excess water in soil also provides ideal conditions for the proliferation of Bongu on taro. **Pests:** Increases in weeds as a consequence of change and increased rainfall is also an issue. This may be because the prolonged days of rainfall prevent farmers from attending to their gardens thus resulting in reduced labor input. For example, increased rainfall and more rainy days prevent farmers from burning their gardens for new cultivation, which further increases the need for more labour input as the weeds and shrubs recolonize the once cleared land. Excess water also enhances the rotting of not only tubers and corms but other dead vegetation like tree trunks and twig leaves which are favorable habitats and microhabitats for pests, facilitating increased reproduction and distribution.[369] Heavy rainfall leading to flooding can also delay farming operations, wipe out entire crops over wide areas, damage	In PNG what would historically have been a 1-in-100-year river flow, could become a 1-in-50 year or 1-in-25-year event. There is good agreement among models on this trend and estimates suggest that the population affected by an extreme flood could increase by 35,000-56,000 people by 2035-2044 (assuming present day population distributions) as a result of climate change. It is important to note that any percentage change in rainfall should be considered in the context of the current baseline, so that large projected increases, for countries where current rainfall levels are already considered high (such as in parts of lowland PNG), are likely to have a significant impact on productivity.

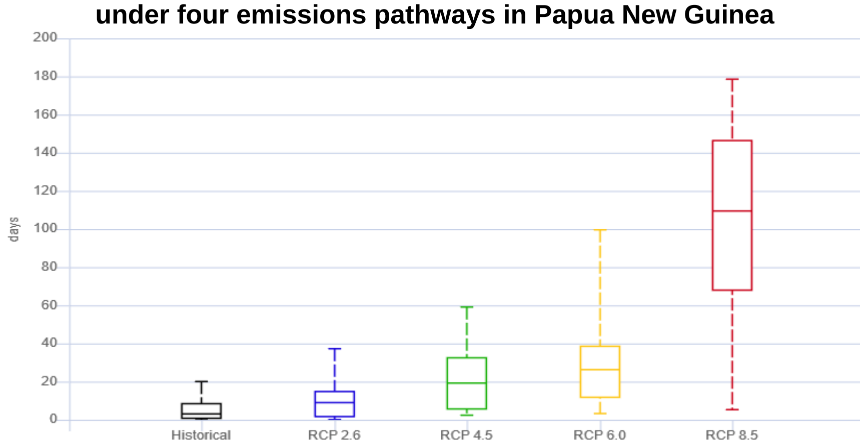
[369] Ibid Ises *et al.* (2015)

Type of risk	Examples of impacts	Climate projections for PNG[366]
	seedling availability and restrict access to planting material and markets.	
Cyclones, storm surge and sea-level rise: Sea-level rise, cyclones and associated storm surge can impact on agriculture through coastal erosion with some areas of land under increased risk of permanent inundation. Other known risks include the action of sea-level rise to enhance the damage caused by cyclone-induced storm surges, and the possibility of increased windspeed and precipitation intensity. These events periodically contaminate the freshwater lens and through the infiltration of salt water into rivers during dry seasons, which can increase the level of salt in the soil. Production losses are already being experienced in coastal areas due to saltwater contamination of soil and groundwater. Damage to crops and vegetation tends to increase exponentially with wind speed; for example, 180km/hr winds are four times more damaging than 90km/hr winds. The level of damage to infrastructure important for the agriculture sector, such as roads and markets, will obviously depend on the pre-cyclone status of that infrastructure and how well it has been maintained.	**SWEET POTATO -** Saline intrusion is likely to affect tuber growth in the atolls and low-lying coastal locations. Most countries in the region are already reporting losses in swamp taro due to salinity toxicity, and this trend is likely to continue and intensify. Some genotypes of swamp taro, sweet potato and cassava appear to be more tolerant of salinity than others, but more field data are necessary for confirmation. The intense amount of rainfall associated with cyclones is said to induce rotting of tubers and corms of root crops, as well as, the physical washing away of newly planted or young crops such as sweet potato, cassava, water melon, slippery cabbage and corn. Aroids such as **TARO** generally have a low tolerance to salinity. **CASSAVA** is particularly susceptible to waterlogging and to high winds (>30 knots) which can cause lodging of the plants. Lodging results in severe root damage which is rapidly translated into root rots and loss of the whole plant.	Climate change is expected to interact with cyclone hazards in complex ways which are currently poorly understood. The 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 extreme events. This finding is supported for Papua New Guinea by modelling conducted by Australian Aid. While the frequency of moderate intensity tropical cyclones may decline the increase in wind speeds associated with category 5 cyclones is projected to increase. A mean sea level rise of at least 73cm by 2100 is also projected.

Note: Unless otherwise stated, examples of impacts are taken from McGregor (2016).

The discussion above has focused mainly on the staple crops important for subsistence farming among rural communities. However, PNG's high value commercial crops such as cacao[370] and coffee are equally sensitive to changing climate (temperature and rainfall).[371] Such crops will impact around 60,000 coffee and cocoa farmers and their families and also the GDP contribution of Agriculture.[372] Also, a study looked at the influence of climate change on agricultural production is through its impact on the health and productivity of the labor force, it suggests 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 2050 under the highest emissions pathway (RCP8.5).[373] This phenomenon demands further investigation in the PNG context, given the expected increase in maximum temperatures towards dangerous levels (**Figure 61**). 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.

Figure 61: Ensemble estimate of the annual number of very hot (Tmax >35oC) days in 2080–2099 under four emissions pathways in Papua New Guinea



Source: WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org.

The impact of climate change on agriculture in PNG is highly nuanced. Climate change will present specific risks and opportunities to different communities and be largely dependent on the ecological zone that they live and the type of crops that they grow. Farmers, from small island states such as PNG, have learnt to work with highly variable climate and weather extremes. However, changes outside of their sphere of knowledge and experience can have significant implications for agricultural production, creating challenges for food production. Further, the magnitude and intensity of any extreme climatic event are compounded by pre- and post-conditions surrounding that event, so that farmer experience based on familiarity is less valuable in managing the impact of the event. All this highlights the need for building local level skills and understanding of how to adapted to changing conditions with tailored actions specific to the socio-ecological system context.

[370] De Almeida J, W. Tezara W, & A. Herrera. 2016. *Physiological responses to drought and experimental water deficit and waterlogging of four clones of cacao (Theobroma cacao L.) selected for cultivation in Venezuela.* Agric Water Management 171:80–88. DOI: https://doi.org/10.1016/j.agwat.2016.03.012

[371] UNFCCC. 2014. *Papua New Guinea Second National Communication to the Under the United Nations Framework Convention on Climate Change.* https://unfccc.int/sites/default/files/resource/Pngnc2.pdf

[372] World Bank. 2014. *60,000 Coffee and Cocoa Farmers in Papua New Guinea to Benefit from Major Agriculture Project*. https://www.worldbank.org/en/news/press-release/2014/02/28/coffee-cocoa-farmers-papua-new-guinea-agriculture-project

[373] Dunne, J. P., R.J. Stouffer, and J.G. John. 2013. *Reductions in labour capacity from heat stress under climate warming*. Nature Climate Change, 3(6), 563–566.

Poverty, Inequality, and Vulnerability to climate-related disaster. Understanding the vulnerability and deprivation in PNG can be challenging due to the very low availability of reliable data. The UNDP report poverty rates of between 30-40% and an adult literacy rate of around 50% (dates unclear) and PNG has consistently ranked among the lowest 30 countries in the Human Development Index. Access to basic service infrastructure, such as electricity and clean water, is known to be extremely limited. Urbanization in PNG is comparatively low, and many communities live in remote and inaccessible locations. While potentially important to the many unique local cultures and ways of life found in PNG, low levels of connectivity are among the factors which contribute to very significant disaster risk. This disaster risk is amplified by social vulnerability and high exposure to natural hazards. Income and wealth inequality are also believed to be very high in PNG, exacerbated by the monopolization of natural resources by a wealthy minority, and recent global research suggests this may also contribute to reduced resilience to disasters.

UNISDR place the average annual economic losses to disaster at around 1% of GDP,[374] with major contributions from flood and earthquake. However, these estimates are based on very poor-quality data from the EM-DAT database which does not capture many lower profile disaster events. One assessment suggests the true financial burden may be as much as three times higher, i.e., nearer 3% of GDP. That same study estimates the number of people affected by natural hazards at 7 million between 1990-2012. Given the inequalities within PNG, neither of these estimates captures the distributional impacts of disaster which will ultimately determine the health and wellbeing impacts experienced by communities. Further research is urgently required to better understand the vulnerability component of the disaster risk equation in PNG.

As shown in the preceding sections, climate change is likely to increase hazards, and without adaptation the exposure, faced by PNG's communities. Many of the climate changes projected are likely to disproportionately affect the poorest groups in PNG. 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. Poorer businesses are least able to afford air conditioning - an increasing need given the projected increase in cooling days. Poorer farmers and communities are least able to afford local water storage, irrigation infrastructure, and technologies for adaptation. In PNG, key concerns relate to the potential increase in flood and landslide hazards associated with more intense rainfall events. One study conducted in the central highlands region, where many key cash crops are produced, has highlighted the very significant proportion of villages (71%) found to have high or very high flood risk. This also includes the majority of public infrastructure in the area. A very significant adaptation and resilience building challenge is faced by PNG as it aims to protect its poorest communities from climate-related disasters.

On the other hand, with many rivers and creeks drying up, villagers are forced to use alternative water sources, compromising hygiene practices and causing diarrhea, dysentery and typhoid. Women have to walk for several hours to get water and schools are open only half the day in response to the heat and lack of water. Communities relying heavily on farming are suffering severe food shortages. Some communities say their food supplies will last two to three months. [375]

Poverty and inequality in Papua New Guinea's urbanized areas are captured by the huge presence of informal settlements, making up about half of Port Moresby's residences.[376] These

[374] United Nations International Strategy for Disaster Reduction (UNISDR). 2014. *PreventionWeb: Basic country statistics and indicators.* https://www.preventionweb.net/countries

[375] Oxfam International. N.D. *Powerful El Niño brings droughts and food insecurity to millions in Papua New Guinea.* https://www.oxfam.org/en/powerful-el-nino-brings-droughts-and-food-insecurity-millions-papua-new-guinea

[376] Connell, J. 2018. *Effects of climate change on settlements and infrastructure relevant to the Pacific islands.* Pacific Marine Climate Change Report Card. Commonwealth Marine Economies Programme.

areas often lack basic infrastructure and due to low enforcement of spatial planning often develops in hazard prone areas. PNG is increasingly experiencing what is often termed 'coastal squeeze' - the overdevelopment of coastal areas vulnerable particularly to flood and storm damage. This includes much of PNG's service and industrial sectors, which as of 2017 contributed almost 80% of GDP. A supporting study confirms that combination of factors makes informal settlements particularly vulnerable to shocks and stresses, including: limited infrastructure and access to services, low levels of adaptive capacity, and losing their access to land and livelihoods after a disaster.[377]

Furthermore, the physical impacts of increased climate-hazard exposure PNG's urban economy may experience slow-onset pressures. Research has established a reasonably well constrained relationship between heat stress and labor productivity, household consumption patterns, and (by proxy) household living standards (Mani et al., 2018).[378] In PNG an increase in temperatures will almost certainly reduce productivity and hence living standards. Urban living in PNG is largely centered around Port Moresby, a city which is expected to surpass a population of one million before 2050,458F379 wherein the effects of heat stress in urban centers may amplify if the phenomenon of Urban Heat Island (UHI) develops with growth of built-up areas.

Accessibility also drives resilience among the human population. Poor inter-regional and international transport connectivity have been identified as key factors hindering PNG's development progress, including the ability to address poverty, malnutrition, and provision of basic services. Hazards associated with climate represent one of a number of challenges faced by policy makers attempting to improve and extend transport infrastructure. The belt of highlands which spans PNG's main island has been identified as a target area for improving connectivity in the Government's 2018-2022 Medium Term Development Plan. This region also represents a hotspot of landslide risk.[380] Given the potential for increased hazard from both flash flooding and landslide due to climate change, disaster risk reduction considerations will need to be made in future development initiatives.

Given the past challenges PNG has faced with illegal and unplanned exploitation of natural resources a systems approach to transport planning will also be necessary. The extension of transport networks into lesser exploited regions of the country may extend these issues to new areas. There is potential for downstream implications on disaster risk, for example through poor land and soil management practices which may further increase flood and landslide risk. Forest ecosystems in upland areas are also known to be among the most vulnerable to climate change impacts and opening these areas up to new exploitation and extraction may reduce their resilience to climate change. These issues are not only ecological. As reported above, the costs of overexploitation of natural resources are often borne by poorer communities, while the benefits accrue to a wealthy minority. If new development of resources means the poorest have less diverse income streams their resilience to climate-linked hazards is likely to suffer. The evolution of PNG's transportation network has often been linked to the exploitation of mining resources. As well as generating controversy for its negative impacts on the natural environment and the unequal distribution of benefits generated, the mining industry holds its own vulnerabilities to

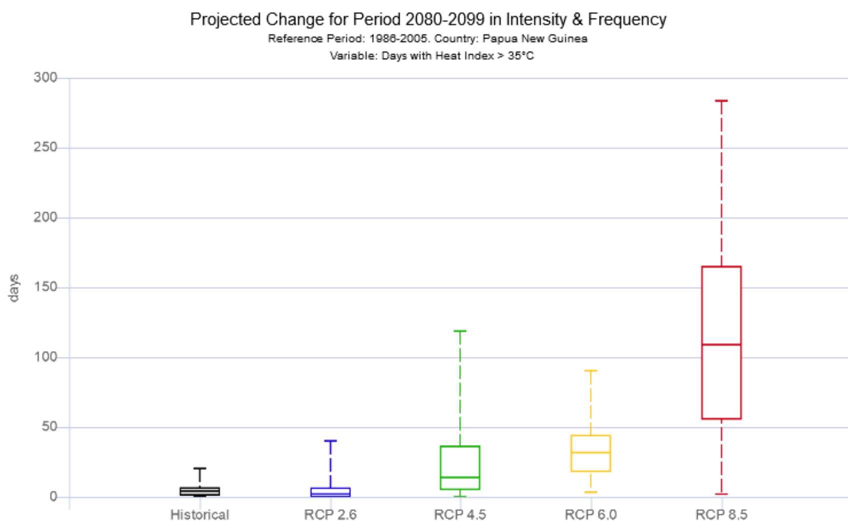
[377] Royal Institute of Chartered Surveyors (RICS). 2016. *The implications of land issues for climate resilient informal settlements in Fiji and Papua New Guinea.* London: Royal Institute of Chartered Surveyors.
[378] Mani, M. et al. 2018. *South Asia's Hotspots: The Impact of Temperature and Precipitation changes on living standards*. South Asian Development Matters. World Bank, Washington DC.
[379] UNFCCC. 2014. *Papua New Guinea Second National Communication to the Under the United Nations Framework Convention on Climate Change*. https://unfccc.int/sites/default/files/resource/Pngnc2.pdf
[380] Robbins, J. C. 2016. *A probabilistic approach for assessing landslide-triggering event rainfall in Papua New Guinea, using TRMM satellite precipitation estimates*. Journal of Hydrology, 541, 296–309.

climate change. Mining relies on plentiful water supplies, and like the transport network is susceptible to landslide impacts.

Human Health and Nutrition. The World Food Program estimate that without adaptation the risk of hunger and child malnutrition on a global scale could increase by 20% respectively by 2050. Work by Springmann et al. has assessed the potential for excess, climate-related deaths associated with malnutrition. The authors identify two key risk factors that are expected to be the primary drivers: low diet diversity (primacy of carbohydrate intake with less fats and protein intake460F[381] and a lack of fruit and vegetables in diets), and health complications caused by increasing prevalence of people underweight.

In terms of health-related mortality, research has placed a threshold of 35ºC (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. Temperatures significantly lower than the 35ºC 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 and intensified heat waves. As shown in **Figure 62,** days surpassing the 35ºC threshold (Heat Index) are likely to become more frequent under all emissions pathways except RCP2.6 in PNG.

Figure 62: Historical (1986-2005) and projected (2080-2099) annual count of days with Heat Index >35oC under four emissions pathways in Papua New Guinea



Source: WBG Climate Change Knowledge Portal. 2018. *Climate by Sector: Interactive Climate Indicator Dashboard.* https://climateportal.worldbank.org.

Work by Honda et al., which utilized the A1B emissions scenario from CMIP3 (most comparable to RCP6.0), estimates that without adaptation, annual heat-related deaths in the Australasian region could increase 211% by 2030 and 437% by 2050. The potential reduction in heat-related deaths achievable by pursuing lower emissions pathways is significant, as demonstrated by Mitchell et al.

[381] World Food Program (WFP). 2015. *Papua New Guinea Country Profile. WFP Regional Bureau for Asia & the Pacific and the Food Security, Markets and Vulnerability Analysis unit (OSZAF)*. https://reliefweb.int/sites/reliefweb.int /files/resources/PNG%20Brief%20Sep2015.pdf

Climate change pressures, such as increased incidence of extreme rainfall, drought, and flood, as well as higher temperatures, represent environmental drivers of vector and water-borne disease. Diarrheal disease is a significant health risk in PNG. Around three in every 1,000 children die before the age of five as a result of diarrheal disease, and it is the cause of around 5% of hospital admissions. A primary driver is the lack of basic clean water supply and sanitation services but global research also links both flood and drought to increased incidence of diarrheal disease. Aside from this, the burden of malaria is likely to increase in PNG with climate change. Malaria has been diagnosed as the major indicator of mortality rates in Papua New Guinea, with around 1.7 million cases in 2003 and 700 mortality cases in 2007. WHO reports that since many cases in remote/rural areas are not recorded properly, the number of cases could be even higher.[382] Also, a related study has shown that women living in poorer-quality environments in PNG produce less food, suffered chronic malnutrition, and had children with lower birth weight,[383] making the double burden of malnutrition increasingly significant to its population.

The table below summarizes how climate change will impact livelihoods and vulnerable communities in the three main socio-ecological systems in the country. As can be seen from the table, each system will have a unique set and unique degree of climate change threats. Further, the exact nature of the threats at any site is unknown, due to lack of data and lack of certainty with climate change projections. These threats will cross many economic and social sectors. However, clearly, at many sites in all three potential areas, climate change may be an existential threat by reversing recent socio-economic gains, undermining food security, and causing multiple damage to health and infrastructure. Although high levels of vulnerability can be assumed, there will be a basis on which to develop adaptive capacity – given the complex systems the communities have created and manage. However, that basis will also be unique from site to site, meaning strategies to develop adaptive capacity must be site specific.

Table 28: Projected impact on vulnerable communities (in the absence of adaptation measures)

Changing climate hazard	Highlands	Coastal floodplains	Small islands
Rainfall variability	Any increases in drought, and shifts in rainy season, will negatively affect agricultural production and food security. Increases in drought may also affect domestic water availability and health. Some crops will be negatively impacted, although some opportunities to increase production may appear. Food security challenges will increase. According to Bourke[384]: the populations in the central highlands have	Although less likely than in highlands due to presence of large amounts of surface and ground water, increases in drought, and shifts in rainy season, may negatively affect agricultural production and food security. In places where rainfall is already high (that is most locations in this zone), increased rainfall is likely to reduce the production of many food crops (e.g. banana, cassava, taro, yam and cocoa)[385].	Increases in drought, and shifts in rainy season, may negatively affect agricultural production and food security. Crops may be affected by both increase in drought and increase in rain during rainy seasons. Crops to be affected include, possibly, banana, cassava, taro, yam and cocoa. This is particularly an issue at the smaller islands where food security is particularly an issue.

[382] Regmi S. 2015. *Gender and Health Adaptation Measures to Climate Change in the Pacific: A Case Study of Papua New Guinea*. In: Leal Filho W. (eds) Handbook of Climate Change Adaptation. Springer, Berlin, Heidelberg. DOI: https://doi.org/10.1007/978-3-642-38670-1_53
[383] Allen, B.J. 2002. *Birthweight and environment at Tari'*. P N G Med J 45(1–2):88–98.
[384] R. M. Bourke. Impact of climate change on agriculture in Papua New Guinea, 2020 (personal communication?)
[385] Ibid

Changing climate hazard	Highlands	Coastal floodplains	Small islands
	three major vulnerabilities with climate change. The first is the likelihood that sweet potato yields will be reduced by significant increases in rainfall. The second, less certain impact is that of higher temperatures on development of coffee leaf rust and consequent reduction of coffee yield. The third and potentially the most important is that the environment at 1600 - 2000m altitude will become less productive.		Increases in drought may also affect domestic water availability and health.
Intensive rainfalls	Most of the high mountainous regions of the country experience landslides, which destroys villages and gardens and major infrastructures, including communications. Increased intensive rainfall leads to Increased landslides notably cut communication routes, decreasing access to services. The increased probability of river flooding which threatens human lives, livelihoods and infrastructure, and is also likely to degrade water quality and spread water-borne diseases, affecting health and mortality.	Increases in upstream short- and medium-term rainfall may lead to riverine flooding, causing damage to buildings, infrastructure and agricultural land. Health and food security and mortality may be negatively impacted.	The increased probability of coastal flooding will threaten human lives, livelihoods and infrastructure and is also likely to degrade water quality, spreading salt contamination and water-borne diseases, affecting health and mortality.
Maximum and minimum and average temperatures	Increases in maximum (average, extreme) temperatures may facilitate animal, plant and even human diseases, and even mortality. Direct effects include alterations to carbon dioxide availability, precipitation and temperatures. Indirect effects include through impacts on water resource availability and seasonality, soil organic matter transformation, soil	Increases in maximum (average, extreme) temperatures may facilitate animal, plant and even human diseases, and even mortality. As discussed in Bourke et al (2009)[386]: • For example, in PNG it is observed that Taro blight, is caused by a fungus that is less severe at lower temperatures. Likewise, coffee rust is observed to do less	Increases in maximum (average, extreme) temperatures may facilitate animal, plant and even human diseases, and even mortality. This will negatively affect agricultural production and food security.

[386] R. Michael Bourke and Bryant Allen. Village Food Production Systems, in *Food and agriculture in Papua New Guinea* (edited by R. Michael Bourke and Tracy Harwood.). 2009

Changing climate hazard	Highlands	Coastal floodplains	Small islands
	erosion, changes in pest and disease profiles, the arrival of invasive species. Increases in frost days may negatively affect agricultural production and food security. The above will negatively affect agricultural production and food security.	damage at lower temperatures in PNG. Increasing temperatures may lead to reduce yields of these two important crops. • Diurnal temperature ranges also have an important influence on productivity. In PNG, the diurnal temperature range is greater in the highlands – potentially one reason why crop yields are higher in the highlands. Yet, the IPCC reports that, for most of the planet, diurnal range has been decreasing. If this is also occurring in PNG, it will tend to reduce crop yields to an unknown extent. The above will negatively affect food security.	
Cyclones	No anticipated impact	In areas close to southern coast, increased intensity of cyclones may lead to increased storm damage, increases in intensive rainfall and storm surge along the coast. Increased damage to infrastructure can notably cut communication routes, decreasing access to services.	In islands lying in or close to the typhoon belt, the increased intensity of cyclones may lead to increased storm damage and flooding or erosion. Widespread flooding may become more common, leading to damage and potential health impacts. Increased storm activity, and damage to infrastructure, will impair communication routes, decreasing access to services.
Mean sea level The impacts of rising sea levels and increased extreme events have been documented in nearby Solomon Islands, see for example Hiriasia	No potential impact	In areas along the coast, this may cause loss of coastal land, salinization of agricultural land and water, and regular flooding. This will threaten to undermine some communities' existence, and threaten to exacerbate many socio-economic and health challenges in many others. Livelihoods, food	This may cause loss of limited land, salinization of agricultural land and water, and regular widespread flooding. This will threaten to undermine some communities' existence, and threaten to exacerbate many socio-economic and health challenges in many others. Livelihoods, food security and health will be

Changing climate hazard	Highlands	Coastal floodplains	Small islands
(2007)[387] and Kauhiona and Fugui (2008).[388]		security and health will be negatively affected. Outward migration is a possibility. This includes the decline in arable areas due to the submergence of coastal lands. Many people in these areas depend on shallow groundwater for domestic use and garden irrigation. Salinization will undermine these practices, thereby contributing to food security and health challenges.	negatively affected. Outward migration to other rural/urban areas is likely for some sites, thereby exacerbating socio-economic challenges at the receiving sites. This includes the decline in arable areas due to the submergence of coastal lands. Many people in these areas depend on shallow groundwater for domestic use and garden irrigation. Salinization will undermine these practices, thereby contributing to food security and health challenges. Note, the Carteret islands of PNG were among the first Pacific islands from which environmental refugees were documented, as a result of sea-level rise damaging land and water resources. Although many other factors were involved,[389] it is accepted that climate change and rising sea levels are a factor in rendering the islands unsuitable for agriculture and sustainable communities.[390]
Extreme sea level	No potential impact	This is likely to contribute to increased coastal erosion and exacerbate flooding events, overall increasing the negative impacts associated with mean sea level rise. Extreme 'events', such as storm surge and overtopping, will damage	This is likely to contribute to increased coastal erosion and exacerbate flooding events, overall increasing the negative impacts associated with mean sea level rise. Extreme 'events', such as storm surge and overtopping, will damage

[387] Hiriasia, D (2007). "Climate Change and Sea Level Rise in the Happy Isles: Document about the effects of enhanced green house in Solomon Islands, Solomon Islands Meteorological Services, Solomon Islands Government.
[388] Kauhiona, H. and Fugui, G. (2008). "Impact of High Swells and Climate Change on Luaniua and Pelau, Ontong Java Atolls, Malaita Province Outer Islands", Report, Climate Change Division, Ministry of Environment, Conservation and Meteorology, Solomon Islands Government
[389] John Connell. Nothing There Atoll? "Farewell to the Carteret Islands. 2018.
[390] International Office for Migration (IOM). Assessing the Evidence: Migration, Environment and Climate Change in Papua New Guinea. 2014.

Changing climate hazard	Highlands	Coastal floodplains	Small islands
		communications and WSS infrastructure, breaking communication links and potentially contributing to health events.	communications and WSS infrastructure, breaking communication links and potentially contributing to health events.
Ocean Acidity	No potential impact	This may damage marine and coastal ecosystems (mangroves and reefs), and will have the two following negative impacts on coastal communities: (i) reducing the protection from storms provided by mangroves and reefs; (ii) undermining the health of coastal fisheries, thereby negatively affecting livelihoods and food security.	This may damage marine and coastal ecosystems (mangroves and reefs), and will have the two following negative impacts on coastal communities: (i) reducing the protection from storms provided by mangroves and reefs; (ii) undermining the health of coastal fisheries, thereby negatively affecting livelihoods and food security. See, for example, Union of Concerned Scientists (2019)[391]

[391] Union of Concerned Scientists. 2019. O2 and Ocean Acidification: Causes, Impacts, Solutions. https://www.ucsusa.org/resources/co2-and-ocean-acidification (website accessed 7 February 2021).

H. TIMOR-LESTE CLIMATE RISK PROFILE

1. Summary of Climate Risk

Timor-Leste occupies the eastern half of the island of Timor, and has a mountainous inland topography, extensive coastline and a short, fast-flowing, and highly seasonal river system. The climate is tropical hot and humid and is influenced by the Western Pacific monsoon and the mountainous relief of the island. The El Niño Southern Oscillation (ENSO) also exerts a strong influence over rainfall variability. The population of Timor-Leste is estimated at 1,383,723, with a median age of just 19.6, and 40% of the population under the age of 14. Agriculture accounts for almost half of employment, and plays a significant role in the economy. Most agriculture is subsistence, and rural areas suffer from food insecurity, due to a combination of low productivity, high population growth and unpredictable rainfall coupled with extreme climate events. Surveys show that over 40% of Timor-Leste's population live below the poverty line, 30% of adults can't read and 70% of people live in rural areas with limited health services.

Historic climate trends show that average annual temperatures have increased and projections estimate that average annual temperatures are likely to increase with climate change around 1°C for the 2036-2065 period for RCP4.5, and 1.1-1.6°C for the 2066-2095 period, while for RCP8.5 increases are larger, with 1.2°C -1.6°C expected for 2036-2065, and 2.2-3.0°C for 2066-2095, all relative to 1986-2005. There is broad agreement among the models for an increase in annual precipitation, with larger increases expected in the higher emissions scenario RCP8.5, and higher increases towards the end of the century. While overall annual precipitation may increase, there are indications that the onset of the rainy season may be delayed, with increased rainfall occurring during a shorter rainy season. The months of Jun-Sep, largely corresponding to the current dry season, are likely to become even drier. Larger increases in extreme rainfall is expected towards the end of the century - under RCP4.5 there is a clear signal of increased heavy rainfall, with an average +14.5% increase in the number of days exceeding the 99th percentile by mid-century, and a 38.6% increase in days for the 2066-2095 period. In terms of sea level, a mean increase of 25cm, and increases of 37cm at the top of the range of projections are expected to mid-century under regardless of RCP used, while in the high emissions scenario sea level rise could exceed 1m by 2100.

Climate change poses a major threat to efforts to improve the food security situation in the country, with poor, rural populations relying on subsistence agriculture particularly at risk, Timor-Leste is among the countries with the lowest levels of food security. The significant inter-annual variability in rainfall, potential changes in the seasonality of rainfall, and a growing population, mean that water availability will continue to be a challenge for Timor-Leste. Agricultural livelihoods are particularly vulnerable to drought, and water scarcity arising from intermittent and unreliable rainfall, and the strong seasonality of water sources in the country. The likely increases in the dry season will increase water stress in many areas. Combined with higher temperatures (and higher rates of evapo-transpiration), longer dry seasons will likely be an increase in soil moisture deficits. Many rural communities are highly reliant on groundwater resources, which can be highly seasonal, and in some cases run dry during the dry season. Staple crops, in addition to cash crops, are also sensitive to rising temperatures and the impacts associated with extreme rainfall, seawater inundation and salinization of coastal aquifers. Further, amplification effects from climate change on existing environmental degradation, loss of agricultural land and reductions in soil fertility especially the supply of water (particularly water scarcity during the dry season) will likely compound to create constraints on agricultural output.

2. Country Overview

Timor-Leste occupies the eastern half of the island of Timor, which it shares with the Indonesian province of East Nussa Tengura. The country has an area of approximately 14,954km^2, which includes main land area of 13,989km^2, the Oecusse enclave of 817km^2 and two islands, Atauro island and Jaco island, respectively. The island has an extensive coastline stretching 700km, while inland the topography is mountainous, with the central mountain range above 2000m, and culminating in Folo Tatamailau, at 2963m.[392]

The country's river systems are short, fast-flowing and highly seasonal, with many intermittent in the dry season[393]. There is only one major lake, Ira Lalalo, in Los Palos province. Although Timor-Leste retains relatively high forest cover, at 45.4%, it is estimated that during the period of 1990-2016 a further 30% of land area was deforested.

The population of Timor-Leste is estimated at 1,293,120 in 2019, with a median age of just 19.6, and 40% of the population under the age of 14[394] The demographic structure suggests rapid population growth over the coming decades, and is currently estimated at annual rate of 2.2%. Timor-Leste ranks 141 on the Human Development Index, with a GNI per capita of $4,440 and life expectancy of 69.5[395] Data for 2016 estimate that 30.7% of the population were living on less than the internationally recognised poverty line of $1.90/day, and 45.8% were classified as living in multi-dimensional poverty.[396] The population is concentrated around the capital, Dili, which has 281,000 people.

Agriculture accounts for 9% of GDP, and 41% of employment, however, excluding oil revenue agriculture plays a much more significant role in the economy than these percentages suggest.[397] Most agriculture is subsistence, with coffee the only major crop grown for export, and major food crops including rice, maize, cassava, sweet potato, legumes, banana, squash, beans, peanuts, and white potato. The predominant food crops in the areas around Aileu and Ainaro are sweet potato and cassava, while rice can be grown in the lowlands around Dili.[398] Rural areas suffer from food insecurity, due to a combination of low productivity, high population growth and unpredictable rainfall coupled with extreme climate events.[399]

The major climate risks for the country include drought, flooding (flash flooding and river flooding), landslides, sea-level rise and saline intrusion, and cyclones. Such events drastically shape the poverty and malnutrition context of the country (**Table 29**). Timor-Leste is assessed as having high vulnerability and low readiness based on its scores on the ND-GAIN Index. Although the vulnerability score has decreased over time, the country's readiness has also decreased since 2015, and the overall country score of 43.8 ranks Timor-Leste as position number 111 – the 47th most vulnerable, and 89th least ready country on the index. Agricultural livelihoods are particularly vulnerable to drought, and water scarcity arising from intermittent and unreliable rainfall, and the strong seasonality of water sources in the country. In addition, with rising temperatures, heat

[392] Center for Excellence in Disaster Management and Humanitarian Assistance. *Timor-Leste Disaster Management Reference Handbook.* 2019.
[393] World Bank. 2020. *Timor-Leste Country Climate Profile.*
[394] The Central Intelligence Agency (CIA). *CIA Factbook: Timor-Leste* (population estimate for July 2020).
[395] UNDP http://www.hdr.undp.org/en/countries/profiles/TLS. Accessed February 2021
[396] United Nations Development Program (UNDP). Development Index 2020. 2020. URL: www.hdr.undp.org
[397] The World Bank. *Timor-Leste Water Sector Assessment and Roadmap.* 2019.
[398] Center for Excellence in Disaster Management and Humanitarian Assistance. *Timor-Leste Disaster Management Reference Handbook.*
[399] *Timor-Leste National Communication*. 2014.

stress is adversely affecting agricultural production.[400] The combined risks of these events form the vulnerability of the population to food security issues and poverty.

Table 29: Timor-Leste Key Indicators

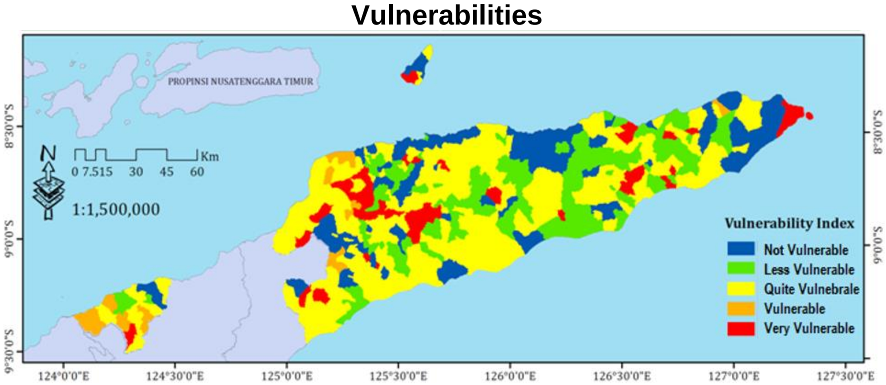
Indicator	Value	Source
Population undernourished[401]	26.9% (2014-2016)	GHI, 2015
National poverty rate[402]	41.8% (2014)	ADB, 2020
Share of wealth held by bottom 20%[403]	9.4% (2014)	World Bank, 2018
Net Annual migration rate[404]	-4.3% (2015-2020)	UNDESA, 2019
Infant mortality rate (between age 0 and 1)	4.73% (2015-2020)	UNDESA, 2019
Average annual change in urban population[13]	3.35% (2015-2020)	CIA, 2020
Dependents per 100 independent adults	69.8 (2019)	UNDESA, 2019
Urban population as % of total population[405]	31.3% (2020)	CIA, 2020
External debt ratio to GNI	83.6% (2019)	World Bank, 2019
Government expenditure ratio to GDP[406]	-4.8% (2018)	NSD, 2019

Notre-Dame GAIN Index Ranking (2018)	
111th	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 (University of Notre-Dame, 2018).

The Initial Nationally Determined Contribution (INDC) carried out a *suco*-level vulnerability assessment, which concluded that 59% of *sucos* were at least ‘quite vulnerable’ on a 5-point scale, based on current exposure, sensitivity and adaptive capacity.[407] As illustrated in

Figure 66, a number of *sucos* in Aileu and Ainaro were assessed as quite vulnerable, including some in the central mountainous areas which fall into the ‘very vulnerable’ category.

Figure 66: Spatial Distribution of Sucos (village) in Timor-Leste and their consequent Vulnerabilities



[400] United States Agency for International Development. *Timor-Leste Climate Change Factsheet*. 2017.
[401] International Food Policy Research Institute. *Global Hunger Index: Armed Conflict and the Challenge of Hunger*. 2015. URL: https://reliefweb.int/sites/reliefweb.int/files/resources/global-hunger-index_2015_english.pdf
[402] Asian Development Bank (ADB). *Basic Statistics*. 2020. URL: https://www.adb.org/countries/timor-leste/poverty#:~:text=In%20Timor%2DLeste %2C%2041.8%25,access%20to%20electricity%20in%202017.
[403] The World Bank. *Income share held by lowest 20%.* 2018. URL: https://data.worldbank.org/indicator/SI.DST.FRST.20?locations=TL [accessed 21/11/20].
[404] United Nations Department of Economic and Social Affairs (UNDESA). *World Population Prospects 2017.* 2017. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 11/01/19].
[405] The Central Intelligence Agency (CIA). *The World Factbook*. Central Intelligence Agency. 2018. Washington DC. URL: https://www.cia.gov/library/publications/the-world-factbook/geos/ch.html
[406] National Statistic Directorate, Timor-Leste. *East Timor Government Budget.* 2019. URL: https://tradingeconomics.com/east-timor/government-budget#:~:text=Government%20Budget%20in%20East%20Timor,percent%20of%20GDP%20in%202016.
[407] Government of Timor-Leste. *Timor-Leste Initial National Communication to the UNFCCC.* 2014. A *suco* is the equivalent of a village unit.

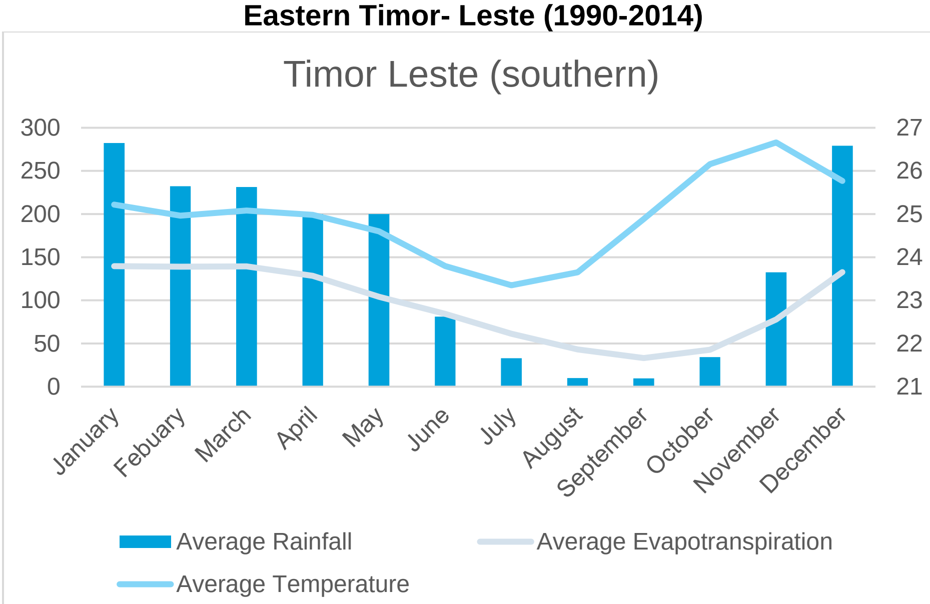
Note: A *suco* is the equivalent of a village unit. Source: Government of Timor-Leste. Timor-Leste Initial National Communication to the UNFCCC. 2014.

3. Current and Future Climatology

Timor-Leste has a hot and humid tropical climate influenced by the Western Pacific monsoon and the mountainous relief of the island. Average annual temperatures vary little throughout the year, but altitude exerts a strong influence, with average annual temperatures ranging from 27°C on the coast, to 15°C in the central mountainous areas.[408,409]

There is significant inter-annual variability in rainfall, with the El Niño Southern Oscillation (ENSO) exerting a strong influence over rainfall variability. El Niño conditions bring drier conditions and shorter, delayed wet seasons, often causing droughts, whilst La Niña conditions cause higher rainfall even in the dry season and are linked to higher tropical cyclone activity. For the period 1950-1999 Dili recorded its two record low rainfall totals during the El Niño events of 1982-83 and 1997-98, and provinces such as Ainaro can see rainfall totals reduce by up to 50% of the annual average.[410] Rainfall also varies significantly from north to south, with parts of the north of the island receiving as little as 500mm/year, whereas the western mountainous areas can receive up to 2800mm/year[411]. The wet season lasts from Dec-March in the north of the island, with a prolonged 8-month dry season, but extends from November to June or July in the south of the island, as shown in **Figure 63** and **Figure 64**.

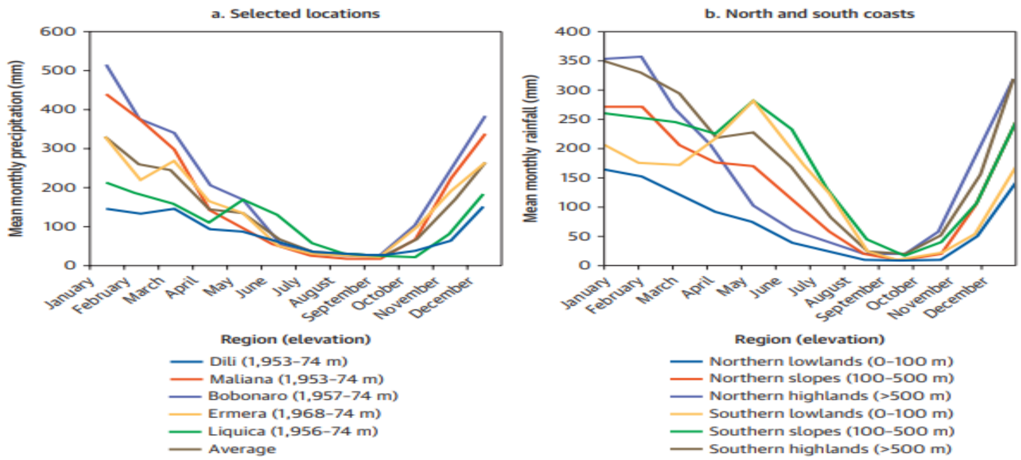
Figure 63: Mean monthly rainfall, temperature and evapo-transpiration for Southern and Eastern Timor- Leste (1990-2014)



Note: https://ewgis.org/catchx-global/. Data provided through Catch-X is as follows: Precipitation data is from the global MSWEP dataset, modelled runoff, temperature and evapo-transpiration from the EU-funded eartH2observe dataset.

[408] United States Agency for International Development. *Timor-Leste Climate Risk Profile*. 2017.
[409] Government of Timor-Leste. *Timor-Leste Disaster Management Reference Handbook*. 2019
[410] Government of Timor-Leste. *National Adaptation Programme of Action.* 2010.
[411] Government of Timor-Leste. *Timor-Leste Disaster Management Reference Handbook*. 2019

Figure 64: Distribution of annual precipitation for locations across Timor-Leste

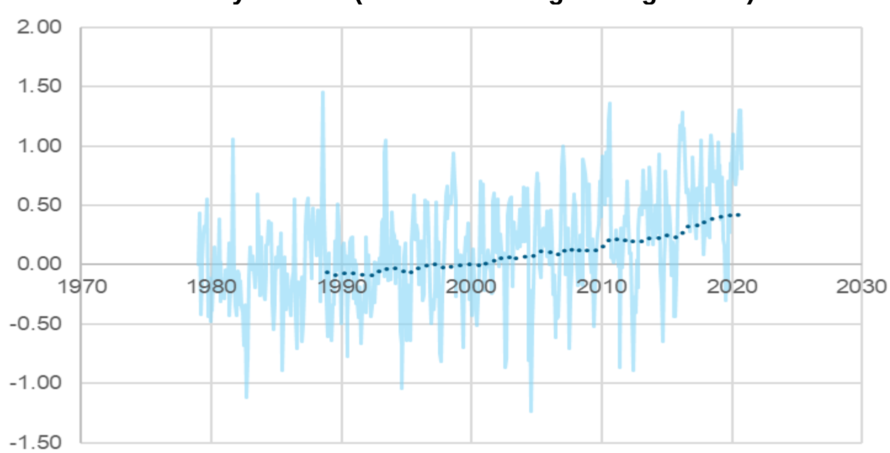


Source: World Bank. 2018. *Timor-Leste Water Sector Assessment and Roadmap.*

Climate trends

Historical trends in climate are difficult to estimate because of the discontinuous nature of many meteorological records, although it is clear that average annual temperatures have increased. Estimates of the rate of change vary from 0.16C/decade since 1950[412] to a more modest 0.11C/decade from 1979-2005[413]. **Figure 65** displays the trend in temperature since 1980 around Dili, in the North, based on reanalysis data to provide continuity. The increase since around 2000, in particular, has been pronounced.

Figure 65: Monthly anomalies with respect to long term average temperature based on ERA5 reanalysis data (decadal moving average trend)



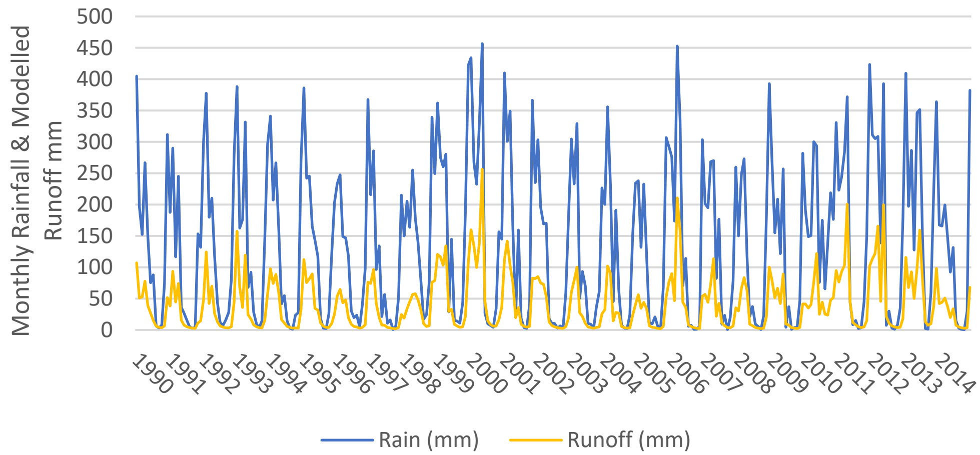
Source: KNMI Data Explorer.

Estimates of trends in precipitation also vary. The Timor Leste National Adaptation Programme of Action (NAPA) estimates a decrease in rainfall from 1961-90, whereas USAID suggest an overall increase from 1901-2009, but decreasing rainfall for many areas since 1990[414]. Analysis

[412] USAID. 2017. Timor Leste Climate Risk Profile
[413] Timor Leste National Adaptation Programme of Action (NAPA)
[414] USAID. 2017. Timor Leste Climate Risk Profile.

of the rainfall data for southern and eastern Timor from Catch X (**Figure 66**), meanwhile, shows no clear trend in rainfall over the period 1990-2014.

Figure 66: the monthly rainfall and runoff in Southern and Eastern Timor-Leste for the period 1990-2014



Note: https://ewgis.org/catchx-global/. Data provided through Catch-X is as follows: Precipitation data is from the global MSWEP dataset, modelled runoff, temperature and evapo-transpiration from the EU-funded eartH2observe dataset.

Climate projections

This assessment has reviewed future climate projections based on Coupled Model Inter-comparison Project Phase 5 (CMIP5) including analysis of statistically downscaled climate projections from the U.S. National Aeronautics and Space Administration (NASA), the World Bank Climate Change Knowledge Portal (CCKP) and other sources as noted[415,416]. The CMIP5 experiments support the IPCC Fifth Assessment Report (AR5), released in 2014[417]. Climate projections are summarised for both RCP4.5 and RCP8.5, for the future time periods 2036-2065 and 2066-2095, with changes evaluated relative to an historical baseline of 1986-2005. RCP4.5 represents a medium-low scenario in which the concentration of greenhouse gasses is stabilised by 2100, whereas RCP8.5 is a high emissions scenario, with no effective mitigation measures. Climate projections are summarized for both RCP4.5 and RCP8.5, for the time period 2036-2065[418].

Table 29 summarise climate model projections from the CMIP5 ensemble for Timor-Leste, showing the 25th, 50th and 75th percentile of the ensemble of climate projections, with models sorted from least warming to greatest warming and from greatest reduction in precipitation to greatest increase in precipitation.

Temperature: Minimum, Maximum and Average temperatures will all increase under all scenarios, but increases in Timor-Leste are likely to be lower than the global average. For RCP4.5 average annual temperatures are likely to increase around 1°C for the 2036-2065 period, and

[415] NEX-GDDP (Global Daily Downscaled Projections) dataset, prepared by the Climate Analytics Group and NASA Ames Research Center using the NASA Earth Exchange, and distributed by the NASA Center for Climate Simulation (NCCS).
[416] WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections.* https://climateknowledgeportal. Worldbank .org /country/timor-leste/climate-data-projections.
[417] The model runs under the CMIP6 experiments, supporting the pending IPCC Sixth Assessment Report, are in most cases complete, and CMIP results will become increasingly available as model evaluation work progresses, but at this point the CMIP5 output provides the most complete and scientifically vetted climate projections data available.
[418] Ibid

1.1-1.6°C for the 2066-2095 period, while for RCP8.5 increases are larger, with 1.2C-1.6°C expected for 2036-2065, and 2.2-3.0°C for 2066-2095, all relative to 1986-2005.

Table 29: An overview of temperature change (ºC) projected Timor-Leste over different time horizons, emissions pathways, and measures of temperature, showing the median estimates of the full CCKP model ensemble and the 25th, 50th and 75th percentiles

Scenario		Annual average of monthly maximum		Annual average		Annual average of monthly minimum		Annual Precipitation %	
		2036-2065	2066-2095	2036-2065	2066-2095	2036-2065	2066-2095	2036-2065	2066-2095
RCP4.5	25th	0.86	1.18	0.79	1.09	0.72	1.00	2.26	2.70
	50th	0.95	1.29	0.92	1.26	0.96	1.23	6.13	5.80
	75th	1.14	1.58	1.19	1.58	1.10	1.54	12.28	16.11
RCP8.5	25th	1.19	2.26	1.24	2.25	1.23	2.24	0.99	9.55
	50th	1.33	2.60	1.30	2.47	1.33	2.46	9.54	16.87
	75th	1.59	3.00	1.56	2.93	1.55	2.94	17.01	28.09

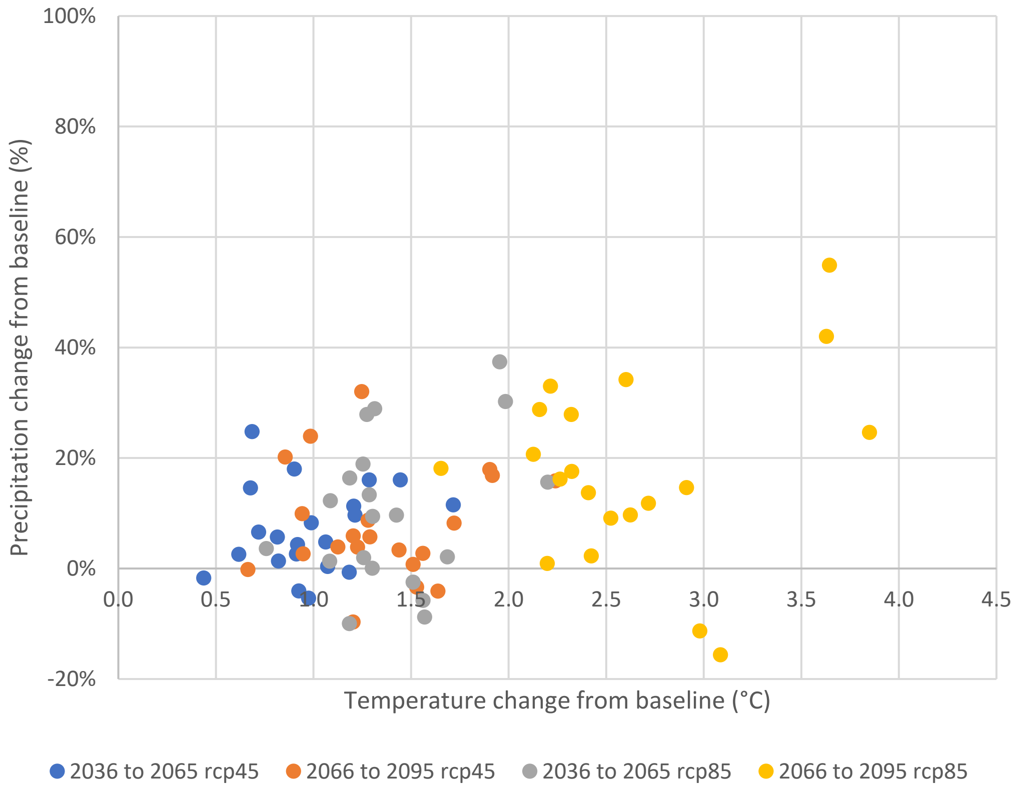
Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections.*

Precipitation: There is broad agreement among the models for an increase in annual precipitation, with larger increases expected in the higher emissions scenario RCP8.5, and higher increases towards the end of the century. It is important to note, however, that there are several models which suggest decreases in annual precipitation, as illustrated in **Figure 67**. **Figure 67** depicts the variation in GCM outputs with respect to projected changes in temperature (ºC) on the horizontal axis and changes in precipitation (% relative to baseline) on the vertical axis, for both RCP4.5 and RCP8.5, and for projection periods 2036-2065 and 2066-2095, respectively. Figure 8 shows the distribution of monthly rainfall changes throughout the year corresponding to RCP4.5 for 2036-2065. The months of Jun-Sep, largely corresponding to the current dry season, are likely to become even drier, and there is a clear signal for increases in rainfall from February-May.

Importantly, while overall annual precipitation may increase, there are indications that the onset of the rainy season may be delayed, with increased rainfall occurring during a shorter rainy season[419]. For example, analysis in the 2nd National Communication notes a likely delay to the onset of the rainy season[420]. Rainfall variability in Timor Leste is driven by the ENSO cycle, and the evolution of ENSO under climate change will play an important role in determining drought and inter-annual variability in rainfall in the country. Changes in the ENSO cycle are still not well captured by climate models, however, the latest research indicates that El Niño events may become both more frequent and more severe over the course of the century[421].

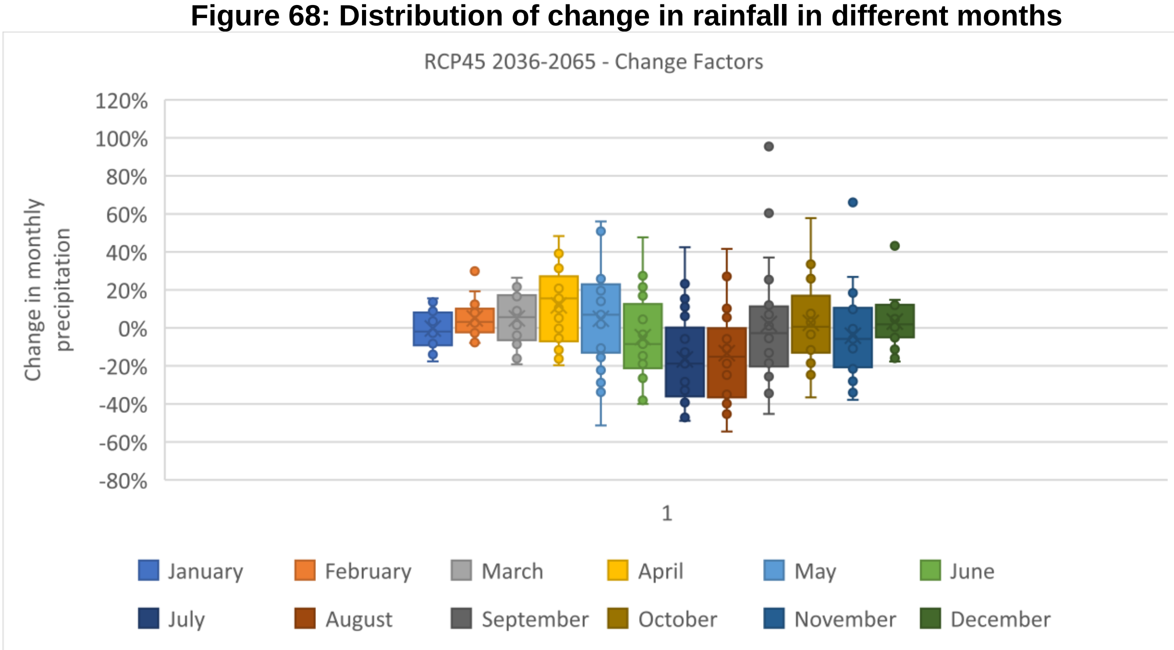
[419] Government of Timor Leste. 2014. Initial National Communication the UNFCCC.
[420] Government of Timor Leste. 2020. 2nd National Communication the UNFCCC.
[421] McPhaden, M. J., A. Santoso, and W. Cai. 2019. Understanding ENSO in a changing climate, Eos, 100, https://doi.org/10.1029/2019EO124159. Published on 23 May 2019.

Figure 67: 'Projected average temperature anomaly' and 'projected annual rainfall anomaly' in Timor-Leste. Outputs of 16 models within the ensemble simulating RCP 4.5 and RCP8.5 over the period 2036-2065 and 2066-2095



Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections.* https://climateknowledgeportal. Worldbank .org /country/timor-leste/climate-data-projections.

Figure 68: Distribution of change in rainfall in different months



Rainfall intensity: The intensity of rainfall is expected to increase in Timor Leste, with larger increases in extreme rainfall towards the end of the century. Analysis of changes in the proportion of days exceeding the historical 95th and 99th percentile values, is summarised in **Table 30**. Under RCP4.5 there is a clear signal of increased heavy rainfall, with an average +14.5% increase in the number of days exceeding the 99th percentile by mid-century, and a 38.6% increase in days for the 2066-2095 period.

Table 30: Changes in number of days exceeding 95th and 99th percentile for RCP 4.5. 25th, 50th and 75th percentiles of the ensemble of climate models

Scenario	2036–2065		2066–2095	
	95th	99th	95th	99th
25th	-4.38	-2.73	18.25	19.55
50th	2.01	14.55	27.37	38.64
75th	17.15	25.45	32.76	72.50

The 2nd National Communication also presents analysis of changes in a variety of indicators of extreme rainfall. There is a clear increase in the intensity and frequency of heavy rainfall events, including both annual maximum 5-day precipitation, and annual maximum daily precipitation. This is evident across all of the selected municipalities, with changes likely to be most pronounced in Manatuto and Manufahi, and increases lower for Dili and Atauro.[422]

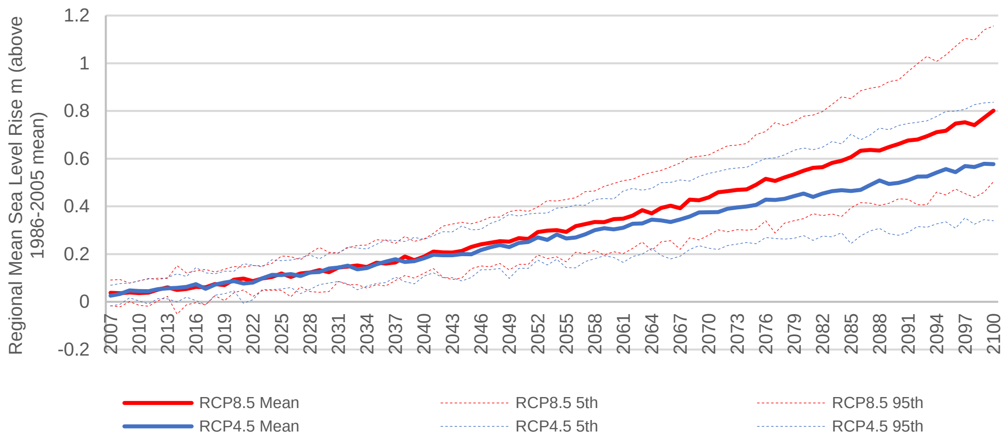
Sea level rise. To mid-century, mean sea level rise for Timor-Leste follows a similar trajectory regardless of whether RCP4.5 or RCP8.5 is used, as illustrated in **Figure 69**, with a mean increase of 25cm, and increases of 37cm at the top of the range of projections. Beyond that there is significant divergence; the mean value for the higher emissions RCP8.5 shows an increase of 80cm by 2100, while the mean value for RCP4.5 is 58cm. It is important to note that even under the lower emissions scenario, increases of just over 80cm are possible, while in the high emissions scenario sea level rise could exceed 1 meter.

From a risk assessment perspective, it is also worth noting that recent research and modelling of sea level rise has tended to increase the amount of sea level rise expected, as a result of improved understanding of ice sheet dynamics,[423] so, it may be prudent to assume higher values.

Among the most significant potential impacts of sea level rise in Timor-Leste is the threat to coastal aquifers, used both as domestic water supply and in some areas as sources of supplementary irrigation. Sea level rise, particularly in locations where coastal aquifers are being over-extracted (withdrawals exceeding recharge), can lead to saline intrusion into the aquifers, potentially rendering them unsuitable as sources of domestic and irrigation water supply.

[422] Government of Timor Leste. 2020. 2nd National Communication the UNFCCC.
[423] Intergovernmental Panel on Climate Change (IPCC). 2018. *Special Report on the Ocean and Cryosphere in a Changing Climate*; Garner A.J. et al. 2018. Evolution of 21st Century Sea Level Rise projections. Earth's Future, 6(11): 1603-1615.

Figure 69: Mean Sea Level Rise to 2100 for Timor-Leste



4. Natural Hazard Risk

According to the World Risk Report, which generates rankings based on exposure and vulnerability to Natural Hazards, Timor-Leste ranks 28th globally (**Table 31**), further breakdown this ranking shows that among all the risks, the lack of coping capacity turns out as the greatest contributing factor to Timor-Leste's global ranking (54th in exposure, 48th in vulnerability and 15th coping capacity).[424]

Table 31: Selected indicators from the INFORM 2020 Index for Risk Management for Timor-Leste

Flood (0-10)	Tropical Cyclone (0-10)	Drought (0-10)	Vulnerability (0-10)	Lack of Coping Capacity (0-10)	Overall Inform Risk Level (0-10)	Rank (1-191)
5.0 [4.5]	2.6 [1.7]	2.5 [3.2]	5.7 [3.2]	7.8 [4.5]	5.7 [3.9]	28

Note: For the sub-categories of risk (e.g. "Flood") higher scores represent greater risks. Conversely, the most at-risk country is ranked 1st. Regional average scores are shown in brackets.

Floods, droughts, landslides and cyclones are the major natural hazards in Timor-Leste and could potentially be exacerbated by the effects of climate change.[425]

Flooding is the most frequent disaster, with riverine and flash flooding both occurring during periods of extreme rainfall; significant flood events were recorded in 2001, 2003, 2006, 2013, 2019 and 2020[426]. La Niña events are frequently associated with heavy rainfall and increased flooding. In addition to the direct impact of flooding, for example on crops and infrastructure, there are frequently secondary effects such as increases in water-borne and vector-borne diseases.[427] Floods in 2013 displaced around 20,000 people, and led to school closures and the contamination of the drinking water supply. Flood risk is expected to increase in the future as extreme rainfall events become more common, and the increasing population means that more people live in flood-prone areas. Cyclones also lead to flooding; however, these are more common in the east of the island.

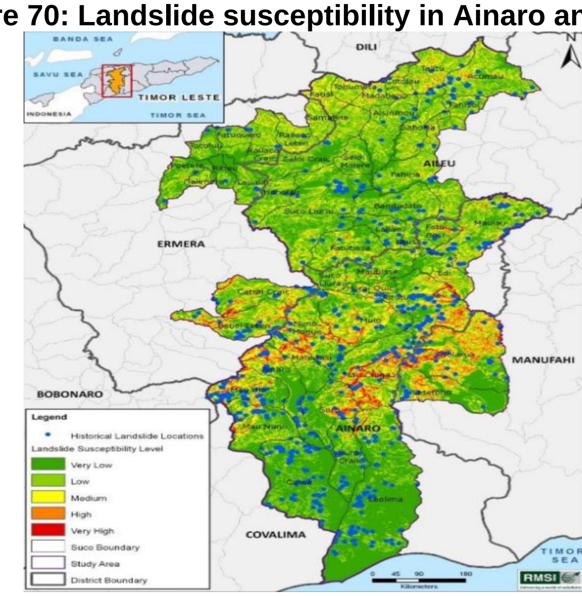
[424] Ibid.
[425] Center for Excellence in Disaster Management and Humanitarian Assistance. *Timor-Leste Disaster Management Reference Handbook.*
[426] Timor-Leste Disaster Risk Management Handbook. 2019.
[427] Ibid.

Drought: Droughts occur regularly in Timor-Leste, and these drought conditions can be made more extreme or extended under El Niño conditions, with significant decreases in the yield of major agricultural crops. The country experienced a major drought from 2015-2017. It is estimated that the 2015/16 El Nino drought impacted approximately half the area of maize and rice planted in the country, with 50% of households reporting loss of livestock, and 50% suffering from food insecurity as a result of the drought[428]. Although there remains uncertainty over how the ENSO cycle will change under climate change, current understanding suggests that severe El Niño events will become more common over the course of the century[429], and there may also be an increase in the frequency of El Niño events[430], with the result that the likelihood of severe drought in the country will increase.

Landslides: Landslides are a major hazard in Timor-Leste, triggered either by heavy rainfall, or seismic activity. The World Bank carried out a detailed mapping of natural hazards as part of the *Building Climate and Disaster Resilience in Communities along Dili-Ainaro and Linked Road Corridor* Project[431]. This assessment evaluated natural hazards and risks across 49 *sucos* along the proposed route of the road, with a focus on floods, landslides, and high winds. Landslides were a major risk to road infrastructure and residential buildings, and the project documented over 800 historical landslides in the area in question, as shown in **Figure 70**. Landslide susceptibility is concentrated in the central mountainous areas, with high-risk areas particularly common in the north of Ainaro District.

Deforestation and unsustainable land practices have destabilized many slopes, and increased soil erosion, thus increasing landslide risk. Landslide risk will increase in the future as the intensity of rainfall increases.

Figure 70: Landslide susceptibility in Ainaro and Aileu



Source: World Bank (2015)

[428] Government of Timor Leste. 2020. 2nd National Communication to the UNFCCC
[429] McPhaden, M. J., A. Santoso, and W. Cai. 2019. 2019. Understanding ENSO in a changing climate, Eos, 100, https://doi.org/10.1029/2019EO124159.
[430] Wang, B. et al. 2019. Historical change of El Niño properties sheds light on future changes of extreme El Niño. *Proceedings of the National Academy of Sciences* 116 (45) 22512-22517
[431] World Bank. 2015. *Natural Hazard Synthesis Report*. Building Climate and Disaster Resilience in Communities along Dili-Ainaro and Linked Road Corridor Project. https://www.gfdrr.org/sites/default/files/publication/Final%20Hazard%20 Risk%20Assessment%20Synthesis%20Report_ %20Timor%20Leste.pdf

5. Climate Change Impacts

Climate change is expected to exacerbate exiting natural hazard risk in Timor-Leste through its effect on increasing frequency and/or intensity of extreme events, as well as the "slow onset" gradual changes in the suitability of the climate and environment for current livelihood practices. Timor-Leste's high vulnerability and low readiness for climate change, particularly in terms of agricultural livelihoods in the context of drought, and water scarcity are likely to result in significant negative impacts on food security issues and poverty, and thus sustainable development. This section outlines the main impacts from climate change on key sectors, with a specific focus on rural livelihoods and poverty.

Water. Available water resources in Timor-Leste will be placed under increased stress as a result both rapid population growth and increasing demand, as well as changes in changes in rainfall patterns and temperatures.[432] Although overall rainfall may increase, the likely increases in the dry season will increase water stress in many areas, while the combination of higher temperatures (and higher rates of evapo-transpiration) and longer dry seasons will increase soil moisture deficits.

Many rural communities are highly reliant on groundwater resources, which can be highly seasonal, and in some cases run dry during the dry season. Groundwater resources are replenished by rainfall in the wet season, providing storage for use throughout the year. However, increased demand for domestic, industrial and agricultural use is straining ground water. Increased seasonality in rainfall, coupled with higher temperatures may negatively affect the quality and quantity of groundwater resources, in the future and in coastal areas sea-level rise will lead to increased saline intrusion into coastal aquifers. Additionally, increased temperatures and evaporation are negatively impacting the country's 12 river systems, which are generally short, fast flowing and intermittent. Changes in surface water flow have significant impacts on people and livelihoods, especially those reliant on agriculture (which accounts for more than 90 percent of freshwater withdrawals).[433]

Furthermore, increases in extreme rainfall events, and associated flooding and landslides, have the potential to damage water infrastructure and polluting surface water sources if this is not appropriately designed to ensure it is resilient to these risks.[434] **Table 32** summarizes the risks to water sources from the impacts of climate change.

Table 32: Climate sensitivity of water sources

Drought	Heavy Rainfall; flooding	Extreme heat	Cyclones, storms	Landslides
• Seasonality impacts the water sources. Rivers can have dry/low flows during dry season and flash flooding and high river flows in the wet season	• Increased rainfall intensity causes increased rates of runoff leading to reduced groundwater recharge. • Contamination of water sources	• Timor-Leste rivers are short, fast-flowing and intermittent so are very sensitive to increased temperatures	• Combined sewer storm water over-flows contaminate local surface waters.	• Contamination of water sources e.g. increased turbidity. • High sediment loads combined with water pollution can make water unfit

[432] Government of Timor-Leste. 2014. *Initial National Communication to the UNFCCC*.
[433] USAID. 2017. Timor-Leste Climate Risk Profile. https://www.climatelinks.org/sites/default/files/asset/document/2017_Climate%20Change%20Risk%20Profile%20-%20Timor%20Leste.pdf
[434] Australia Department of Climate Change and Energy Efficiency. 2012. *Vulnerability assessment of climate change impacts on groundwater in Timor-Leste*; FAO. 2012. *Aqaustat: Timor-Leste*; Government of Timor-Leste. *Initial National Communication to the UNFCCC.* 2014; and International Federation of Red Cross (IFRC). 2016. *What happens when the water runs out?*

Drought	Heavy Rainfall; flooding	Extreme heat	Cyclones, storms	Landslides
• Depletion of groundwater aquifers due to reduce groundwater recharge from intermittent/reduced rainfall • Shallow well systems run dry • Changes in rainfall patterns undermine the viability of critical water supply infrastructure in communities • Localised aquifers located in mountain areas have low potential yields and limited opportunities for development. • Aquifers susceptible to rainfall changes, responding rapidly (seasonally).	from floodwater and animal faeces • Borehole pumping control and treatment installation failure within flooded area.	and evaporation. • Lower DO and reduced water quality from upstream STW effluent.		for consumption and can lead to regular urban water shortages in some areas.

Source: ADB; Atkins Consulting, Climate Risk and Vulnerability Assessment for Timor Leste Water Supply and Sanitation Investment Project. ADB TA9414, September 2020.

Forest, Biodiversity and Land Use and Coastal Environment. Climate and weather variability threatens Timor Leste's terrestrial and aquatic ecosystems, which are part of the Coral Triangle, a marine area in the western Pacific Ocean home to nearly 600 different species of reef-building corals and 2,000 species of reef fish. Damage to mangrove forests, which some reports suggest decreased from 90 km² in the early 1900s to 18 km² in 2008, has accelerated the impacts of climate change on coastal landscapes. Without a mangrove buffer, coral reefs, beaches, and the coastal population and infrastructure are increasingly exposed to storm surges. Rising sea surface temperatures cause reef fish and other species to migrate to areas farther offshore with more suitable environmental conditions. Rising sea-levels, and increased cyclone risk will also exacerbate other stressors on the coastal and marine environment, and could accelerate damage to fragile ecosystems.[435]

Forest resources play a key role in smallholder activities in Timor-Leste. A study shows that in Lacluta (Viqueque municipality) forest resources were used for farming (such as wood and bamboo fencing) with albeit the supply was declining.[436] FAO (2010) estimated that 93% of the energy consumed by households in Timor-Leste came from wood.[437] Also, a forest resources analysis identifies that 53% of Timorese households collected wood for construction, 42% for income generation and 39% collected forest products for food.[438] In addition to reducing the amount of land suitable for agricultural production, hotter drier conditions are likely to adversely

[435] Ibid (see No. 57)
[436] Moore A, T . Dormody, D. Van Leeuwen and A. Harder. 2014. *Agricultural sustainability of small-scale farms in Lacluta, Timor Leste.* International Journal Agriculture Sustainability. 12(2):130-145.
[437] Food and Agriculture Organisation (FAO). 2010. *Global Forest Resources Assessment 2010 country report Timor-Leste.* Rome: FAO. http://www.fao.org/3/al643E/al643E.pdf
[438] Hosgelen M, & U. Saikia. 2014. *Forest reliance as a livelihood strategy in Timor-Leste* In: Loney H, da Silva AB, Mendes NC, da Costa Ximenes A, Fernandes C, editors. Proceedings of the Understanding Timor-Leste 2013 Conference, Liceu Campus, National University of Timor-Lorosa'e (UNTL), Avenida Cidade de Lisboa, Dili, Timor-Leste, 15 – 16 July 2013. Timor-Leste Studies Association. p. 66-73.

affect forest productivity, and will increase the areas affected by forest fires. Climatic changes will exacerbate the existing stresses to forests from agricultural expansion and habitat fragmentation.

Agriculture. Agricultural systems in Timor-Leste, including the livelihood conditions and food insecurity issues, will be affected both by increases in extreme events, as well as changes in temperature and rainfall[439]. The majority of agriculture in the country is rain-fed, and as such is vulnerable to changes in the timing and amount of rainfall, and increasing variability. Production of maize and rice as the country's main staple crops, for example, is already insufficient to meet current domestic demand, forcing the government to rely on imports. These staple crops, in addition to peanuts, are sensitive to rising temperatures and the impacts associated with extreme rainfall, seawater inundation and salinization of coastal aquifers.[440] Further, amplification effects on existing environmental degradation, loss of agricultural land and reductions in soil fertility especially the supply of water (particularly water scarcity during the dry season) will likely compound to create constraints on agricultural output[441]. **Table 33** provides an overview of the potential impacts of climate change on crop-based agriculture.

Table 33: Potential impacts of climate change on crop-based agriculture

Climatic Variables Subject to Change	Potential Impacts on Crop-based Agriculture
Increases in mean growing season temperatures	• Reduced yield • Reduced time to maturity • Increase in seasonal water demand[(a)] • Reduced exposure to climatic hazards (flood, windstorm, hail, etc.) • Increased or altered risks from pests, diseases[(b)] • Potential changes in competition with weeds[(b)] • Increased risk from wildfire
Increases in temperature, frequency of very hot days	• Increased heat stress • Increased water demand • If during critical stages (flowering, pollination, fruiting, grain filling) yield reduction or loss
Increases in minimum temperatures; decreased frequency of cold days and nights	• Extended growing season in cold environments • Increased yield in cold environments • Reduced risk of frost damage in cold environments • Potential changes in competition with weeds
Increases in intense precipitation events	• Direct damage to crops (particularly if hail) • Increased waterlogging, constraints to timely cultivation • Damage to drainage systems • Increased extent and intensity of erosion and waterlogging • Increased pest incidence
Increase in drought conditions	• Lower yields from crop damage, stress, and/or failure • Loss of arable land as a result of land degradation and wind erosion • Increased risk of wildfires
Increase in flood conditions	• Direct damage to; loss of standing crops • Loss of soil through erosion • Waterlogging of soil, delay in planting
Changes in seasonal precipitation accumulation	• Dependent on direction of change – potentially favorable if precipitation increases in historically water-constrained region • Potential changes in competition with weeds, pests[(b)]
Increase in frequency, severity of tropical storms	• Direct damage to crops from high wind speeds; intense precipitation

[439] United States Agency for International Development. 2017. *Climate Risk Profile: Timor-Leste*. https://www.climatelinks.org/sites /default/files/asset/document/2017_Climate%20Change%20Risk%20Profile%20-%20Timor%20Leste.pdf
[440] Government of Timor Leste. 2020. 2nd National Communication to the UNFCCC
[441] Scherer, N. and D. Tänzler. 2018. *The Vulnerable Twenty – From Climate Risks to Adaptation: A compendium of climate fragility risks and adaptation finance needs of the V20 countries*. Federal Foreign Office, Berlin Germany. October 1, 2018. Aldephi. https://www.adelphi.de /de/system/files/mediathek/bilder/The%20Vulnerable%20Twenty%20%E2%80%93%20From%20Climate %20Risks%20to%20Adaptation%20-%20adelphi.pdf

Climatic Variables Subject to Change	Potential Impacts on Crop-based Agriculture
Increase in atmospheric concentration of CO_2	• Increased biomass production and increased physiological efficiency of water use in both crops and weeds • Increased efficiency of water use by crops • Potential for increased weed competition with crops(b) • Photosynthesis, growth, and yield of C_3 plants (e.g., wheat and rice) likely to increase(c) • Impact on C_4 plants (e.g., maize, sugarcane) less significant • Possible re-partitioning of biomass away from grain to leaves, stem and roots • Possible changes in assimilation of nitrogen fertilizer • Possible changes in nutrient content
Increase in atmospheric concentration of ozone	• Suppression of yield for many major crops

Source: Various sources, by authors.
Notes:
(a) may be off-set by shorter growing period.
(b) poorly understood at present.
(c) observed responses in free atmosphere CO_2 exchange (FACE) experiments are often significantly less than predicted by theory or model simulation.

Major crops produced in Timor-Leste include coffee, maize, rice, coconuts, dry beans, cassava, other root crops, peanuts, and vegetables. Maize and rice, the two staple grain crops, are both sensitive to the projected impacts of climate change. **Table 34** summarizes several of the physiological impacts of temperature increase on wheat and rice.

Table 34: Climate change risk factors for maize and rice

Crop	Crop-specific Climate Risks and Benefits
Maize	• each degree day spent above 30°C reduces yield by 1% under optimal rainfed conditions, and by 1.7% under drought conditions • Possible gains in yield with warming at relatively cool sites. • Significant yield losses at sites where temperatures commonly exceed 30°C (corresponding to areas where the growing season average temperatures = 23°C or maximum temperatures = 28°C). • Daytime warming is more harmful to yield than night-time warming. • Drought increases yield susceptibility to warming even at cooler sites
Rice (paddy)	Heat stress at key developmental stages can result in: • reduced duration of crop growth, • increased spikelet sterility, • reduced duration of grain-filling, • increased respiratory losses leading to lower yields and lower grain quality • elevated night temperatures have larger impact on yield than day-time highs • 1°C increase in temperature above critical threshold (>24°C) can result in a 10% reduction in grain yield

Source: Thornton P, Cramer L (editors). 2012. Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate. CCAFS Working Paper 23. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark.

Modelling of maize indicates reductions in yield in the range of 5-20% in the absence of adaptation, noting that much of this loss could be offset by supporting agricultural water supply through activities such as irrigation and water harvesting[442]. These losses may be conservative, as they do not attempt to capture any increase in losses from extreme events. Coffee, a major

[442] Government of Timor Leste. 2014. Initial National Communication to the UNFCCC.

export crop, faces challenges from rising temperatures and increasing extreme rainfall events, which can damage crops during growth periods, and affect overall yield and quality of the crop[443]. A significant source of losses during El Niño years is false starts to the rainy season, where the initial onset of rains is followed by an abnormal dry period before the season reliably starts. These false starts can cause crop failure as there is not enough rainfall to support crop growth following planting, for example in Manatuto, farmers reported frequent false starts during previous El Niño events, and having to plant 3-4 times due to the losses suffered. The 2016-17 El Niño event caused sharp reductions in agricultural yields, with a decrease of 40% in Maize production, and 57% in Rice production[444], and subsequently increased food insecurity. Oecusse and Dili are both important rice-producing areas and there is clear need to address these losses; for example if water storage is developed, for example through water harvesting, it might be possible to reduce the impacts of these false starts on crop development.

Sea-level rise will exacerbate problems with coastal erosion, and saline intrusion in coastal aquifers. Given the importance of the coastal lowlands for production of both Rice and Maize, these impacts could negatively affect production of staple crops. Climate change poses a major threat to efforts to improve the food security situation in the country, with poor, rural populations relying on subsistence agriculture particularly at risk.

Livestock, including cattle, pigs and chickens, are an important asset for 75% of the population. Animal health, however, is at risk from increased heat stress and changes in water and feed availability[445]. The fisheries subsector of Timor-Leste is already stressed by illegal fishing, which accelerates crop failures. While sea surface temperatures are projected to rise, reefs may be protected from coral bleaching by the cooling influence of the Indonesia Through Flow (an ocean current). If this cooling remains consistent, water around Timor-Leste may provide a cool water buffer and refuge against further temperature increases[446,447].

Poverty and Inequality. Statistics show that over 40% of Timor-Leste's population live below the poverty line, 30% of adults can't read and 70% of people live in rural areas with limited health services. Such deplorable conditions make them all the more vulnerable to the impact of climate change. As resource dependent as this rural population is, gender analysis shows that for women, these circumstances are felt even more acute.[448]

Climate change poses a major threat to efforts to improve the food security situation in the country, with poor, rural populations relying on subsistence agriculture particularly at risk. In the 2014 Global Hunger Index, Timor-Leste is among the countries with the lowest levels of food security, due to instability of its government, especially due to territorial conflict.[449]

Other aspects of morbidity relate to extreme humidity and temperature levels linked to heat stress and more severe respiratory infections, such as pneumonia, asthma, and other lung and nasal diseases. Indirect impacts include an increased risk of crop failure and livestock mortality, potentially undermining food security and increasing malnutrition rates.[450]

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[443] USAID. 2017. Timor Leste Climate Risk Profile.
[444] Ibid.
[445] Ibid
[446] ADB. 2014. *State of the Coral Triangle.* Manila.
[447] USAID. 2013. *A Marine Biological Assessment of Timor-Leste. Map adapted from Timor-Leste Climate Zones*. CartoGIS, College of Asia and the Pacific, and The Australian National University.
[448] CARE-Timor-Leste. *Explore Timor-Leste*. N.D. URL: care-international.org/where-we-work/timor-leste
[449] International Food Policy Research Institute. 2015. *Global Hunger Index: Armed Conflict and the Challenge of Hunger*. https://reliefweb.int/sites/reliefweb.int/files/resources/global-hunger-index_2015_english.pdf
[450] Ibid.

Although the Timor-Leste people have some capacity to adapt to these complex changes, such coping strategies are still reliant on climate-sensitive natural resources, aggravated by their limited access to alternative livelihoods. As mentioned above, traditional gender roles exacerbate the risks for women in a changing climate, while minimal access to weather and climate forecasting hinders adaptive actions. For instance, the decision-making power of rural communities, down to family's resource use and survival also plays a strong role, and women have been unequally empowered. Women in Liquica, for example, have much less say than men over the use of resources, and by extension, over ways to adapt.[451]

Climate change is a stress multiplier, and its effects will be most pronounced among groups which are already poor and marginalized. Rural communities which are relatively isolated and reliant on rain-fed, subsistence agriculture have limited access to resources, and limited capacity to cope with, and recover from, climate-related hazards. In the absence of adaptation, the increased variability in rainfall, and increases in extreme events such as flooding and landslides will pose a significant challenge to poverty-reduction efforts.

Human Health and Nutrition. The impacts on health and nutrition range from injuries and death arising from climate-related disasters such as floods and cyclones, to changes in the spread of vector-borne diseases, and adverse health outcomes from the impact of climate change on food security, malnutrition and poverty. More than 450,000 households suffer annually from displacement, diminished water quality, injury and mortality due to floods and landslides– a number likely to rise with increased rainfall intensity.[452]

Analysis from the WHO shows that 75% of the population in Timor-Leste, primarily those living along the coast, are at risk[453] and has direct exposed to Malaria and Dengue. It is expected to increase from around 600,000 in the baseline period to 2.76M by 2070, driven both by population growth and increasingly favorable climatic conditions for Malaria transmission.[454] As temperatures increase, the range of these and other vector-borne diseases is likely to expand and spread into the central highlands. Malaria remains a leading cause of death for children under five. The districts of Viqueque and Lautem have the highest malaria rates and greatest risk of future increases, while Manatuto is most exposed to dengue.[455]

Undernutrition is a significant issue facing the country, and the likely adverse effects on agricultural production, as well as the expected lower nutritional value of food grown under elevated levels of CO_2 will pose a challenge to efforts to ensure that the population of Timor-Leste is food secure.[456] Also, flooding and other natural disasters often compromise the quality of potable water sources, leading to outbreaks of waterborne diseases such as diarrhea and typhoid.[457] Such double burden of malnutrition in the totality of human well-being and its direct relationship to poverty is a challenge aggravated by the combined impacts of climate change.

[451] Eucker, D. & P. Bolte. 2015. *Food, water, rain, risk: the uphill struggle to adapt Final evaluation of the MAKA'AS project on community-based adaptation in Timor-Leste*. https://careclimatechange.org/wp-content/uploads/2019/05/CBA-Portfolio-Evaluation_MAKAAS_Evaluation-Report_FINAL1.pdf
[452] USAID. 2017. Timor-Leste Climate Risk Profile.
[453] Ibid.
[454] WHO. 2015. Climate and Health Profile Timor-Leste.
[455] Ibid.
[456] Ibid.
[457] USAID. 2017. *Timor-Leste Climate Risk Profile.*

I. VANUATU CLIMATE RISK PROFILE

1. Summary of Climate Rationale

The climate rational for GCF investment in Vanuatu is based on the increased risks faced by certain population groups and socio-economic subsectors in Vanuatu as a result of climate change. This increased risk is a function of the increases in frequency and intensity of climate hazards due to climate change, and of increases in the levels of vulnerability and exposure to those hazards. It is noted that climate change also increases some factors of vulnerability or exposure, thereby providing a second pathway to increasing risk. The key vulnerable groups considered are the rural population, the semi-urban population, and the urban population, and within those groups, there is a particular focus on women. The key affected socio-economic sectors are agriculture (and food production), tourism, disaster risk management/reduction, human health and nutrition, and island ecology and biodiversity. The key climate related hazards are droughts, cyclones, flooding and coastal erosion.

It is noteworthy that, by one index, Vanuatu is considered the most at-risk country on the planet, and Port Vila the world's most exposed city to natural hazard-related disasters.The key finding is that, although the Vanuatu people have been managing the effects of climate extremes throughout history and have established a range of traditional coping strategies, increases in hazards and increases in exposure/vulnerability could likely lead to large population groups and part of the economy not being able to cope at all with future climate change.

Although facing the same hazards, the impacts on the different population groups are very different, specifically:

- **The rural population.** Although a large group, in general they all face similar hazards, exposures and vulnerabilities. The challenges are very similar. There is a progressive increase in impact level as remoteness grows;
- **Urban.** Not all members of the urban population are equally affected, with some highly resilient and only a few affected. The vulnerable groups are highly affected – including the poor, women headed households, many women, the elderly and disabled. The principal impact is from cyclones, followed by flooding and sea level rise, but some members of the urban population are also affected by secondary impacts on food production from drought;
- **Peri-urban population** is affected by both rural and urban issues, and is probably the most at risk, due also to its high vulnerability and limited access to services. This population is affected by cyclone, droughts, flooding and coastal impacts of sea action.

Vulnerable people at all sites will be affected through the impacts of climate change on agriculture, food production, tourism and access to services and infrastructure and for many, climate change is likely to be an existential threat by reversing recent socio-economic gains, undermining food security, and causing multiple damage to health and infrastructure and service. The complex, uncertain and inter-related nature of the climate change threats mean that there is no single shot nor single sector solution. The optimal solutions would appear to be to increase climate change adaptive capacity and reduce vulnerability to climate hazards so that vulnerable groups have the agency to understand, plan for and adapt to the climate change threats.

2. Country Overview: the people and their vulnerability

The climate rational for GCF investment in Vanuatu is based on the increased risks faced by certain population groups and subsectors as a result of climate change. This increased risk is a function of the increases in the climate hazards due to climate change, and the levels of vulnerability and exposure to those hazards. It is noted that that climate change also increases some factors of vulnerability or exposure, thereby providing a second pathway to increasing risk. This note aims to further define the climate rationale by providing additional understanding on: (i) which population groups and sectors are at risk from climate hazards; (ii) how the climate hazards are projected to evolve with climate change; (iii) how risk levels will change for certain population groups and across key sectors as a result of the changing hazards, but also as a result of changing exposure/vulnerabilities where relevant.

The societal costs of disasters around the world are continuing to increase and Pacific Island countries are considered some of the most vulnerable. This is primarily due to a combination of high hazard exposure coupled with a range of social, economic, physical, and political vulnerabilities. In the South Pacific, there is a growing conjunction of high hazards and high exposure/vulnerability in certain groups. Understanding this exposure and vulnerability is crucial to identifying interventions.

People in Vanuatu have long-held traditional practices to deal with temperature and rainfall variability, cyclones and geological hazards.[458] In recent decades, Vanuatu has experienced a range of social changes, including a widespread conversion to Christianity, changing and declining *kastom*[459], increased settlement of coastal areas, population growth, urbanisation, and increasing participation in the cash economy.[460] However, there is also evidence that vulnerability is reaching breaking points, with pressure from climate change is breaking social connections, rendering existing information and knowledge obsolete. Hence where there was complex resilience and agency, there may now be growing weaknesses, especially in vulnerable groups.[461]

The Republic of Vanuatu is an island nation located in the Western Pacific Ocean, lying in the tropics between latitudes 12º to 23º South. It is an archipelago of over 80 islands, of which 65 are inhabited, stretching 1,300 km from North to South in the Western Pacific Ocean. The archipelago is of volcanic origin. It is remote, some 1,750 km East of Northern Australia although nearer to New Guinea island. The terrain across the islands is mostly mountainous with narrow coastal plains. The total land area is 12,336 km^2 and the maritime exclusive economic zone covers of 680,000 km^2. The total coastline is approximately 2,500 km long.[462] And the highest peak is Mount Tabwemasana on Espiritu Santo, at 1,877 m above sea level.

The dominant economic activity is small-scale agriculture. This provides a living for about two thirds of the population. However, in GDP terms, the economy is based predominantly on the service sector (67% of GDP value added, notably through tourism), followed by agriculture (22%) and industry (11%).[463] In 2017, 330,000 tourists visited the island. Fishing—both artisanal (in which a large proportion of the population participates) and commercial—and offshore financial services are other mainstays of the economy.[464]

[458] Government of the Republic of Vanuatu. 2015. Vanuatu Climate Change and Disaster Risk Reduction Policy, 2016–2030.
[459] can be defined as the ni-Vanuatu ways of life that originated from the period before European contact.
[460] Savage A., H. Bambrick and D. Gallegos. 2021. Climate extremes constrain agency and long-term health: A qualitative case study in a Pacific Small Island Developing State. Weather and Climate Extremes. Volume 31, March 2021, 100293
[461] Jackson, G. et al. A Framework for Disaster Vulnerability in a Small Island in the Southwest Pacific: A Case Study of Emae Island, Vanuatu. 2017.
[462] Republic of Vanuatu. Second National Communication to the United Nations Framework Convention on Climate Change. 2014
[463] World Bank and ADB. 2019. Climate Risk Country Profile Vanuatu.
[464] CIA website. https://www.Cia.gov (accessed 18/02/2021)

Table 35: Country at a glance

Indicator	2010 (or as stated)	2018 (or as stated)
GNI per capita ($, current)	2,710	3,120
GDP growth (%, constant prices)	1.6	2.9
GDP agriculture, forestry and fishing (%ge of GDP)	21	26
Population (million)	0.24	0.29
Poverty ratio (at $1.9/per day, 2011 figures)	13.2	
Infant mortality rate (below 5 year/per 1000 live births)	30	27
Urban population (as % of total population)		25.5[465]
Urbanization rate	2.55%, 2015–2020 (estimate)[466]	

Source: World Bank data. https://data.worldbank.org/country/VU, unless stated.

The population is characterised by its rapid growth rates, high growth in urbanization rates (**Table 35**), and high levels of migration, both internal and international. As of 2020, the total population was estimated at 303,000. In total there are over 100 languages, although almost 97% of the population is officially considered either Bislama or English speaking. 99.2% of the population is of Melanesian descent. The population is young, with approximately 34% of the population under 15 and the median age is 23. Three-quarters of the population are considered to live in rural areas—the urban populace lives primarily in two cities, Port-Vila (the capital, on Efate island) and Luganville (on Espiritu Santo). More than 50% of the population resides on the three largest islands—Espiritu Santo, Malakula, and Efate.[467] It is also of note that most of the population reside in low-ling coastal locations, and that is also where most infrastructure is located.[468]

In addition to the rural and urban populations, there is a significant 'peri-urban' population, located around Port Vila and Luganville. Typically, the peri-urban areas are the most densely populated, experience large immigration, the highest population growth. This population is relatively new. These areas are sometimes referred to as rural areas, and the population as the rural population in the urban areas. For example, BECA reported in 2015 that the '*rural areas in the greater Port Vila urban area have a combined population of 16,653'*. It is noted that this was a significant proportion part of Port Vila's overall population.[469]

The populations in the rural, peri-urban and urban zones have highly differentiated exposure to climate hazards and very different adaptive capacities and vulnerabilities. For example, and notably, access to services (energy, water, education, etc.) and to land and to employment depends very much on geographical location[470], rather than on socio-economic conditions or status. Accordingly, this note considers the three different geographical stereotypes separately.

The Rural Population

The rural population ranges from small villages on the main islands to more remote villages on smaller islands to very isolated island communities. Typically, the population is in small, remote settlements, several hours drive or boat trip to nearest large settlement, with relatively high transport costs.

[465] CIA website. https://www.Cia.gov (accessed 18/02/2021)
[466] CIA website. https://www.Cia.gov (accessed 18/02/2021)
[467] CIA website. https://www.Cia.gov (accessed 18/02/2021)
[468] Tonkin and Taylor. 2018. Disaster Assessment/Climate Risk and Vulnerability Assessment – Port Vila Integrated Urban Improvements Project.
[469] BECA consultants. Urban Growth Trends Report – Port Vila and Luganville: Risk Mapping and Planning for Urban Preparedness. Prepared for Vanuatu Meteorological and Geo-Hazard Department (2015)
[470] Vanuatu National Statistics Office and UNDP Pacific Centre. 2011. Vanuatu Hardship and Poverty Report: Analysis of the 2010 Household Income and Expenditure Survey .

Economic activities: In addition to farming subsistence crops, economic activities typically include fishing, handicrafts and providing basic services to tourism. Approximately 90% of all households, and 97% of rural households, engage in crop production, all rain-fed, mostly subsistence. The main agricultural products are copra, kava[471], cocoa, coffee, taro, yams, fruits and vegetables.[472] The production of beef, pork, poultry, sheep and goat for local consumption forms an essential part of the rural economy. Animal husbandry practices have undergone changes in recent years, and for example, commercialized operations now providing the bulk of the beef consumed locally. Coastal small-scale fisheries contribute significantly to the rural income, nutrition and self-reliance.

Access to services: Typically, access to social services, including education and health care may be difficult or expensive for the rural population, although this varies enormously depending on geographical location, with rural population on the two main islands being the least affected. Intra-island transport is difficult/costly, as is inter-island outside the main islands[473] (NAP 2007). Water supply and electricity supply are decentralized, typically to household level e.g., in the form of a solar household units. 91% of cooking is done using coconut shells or wood in rural areas.[474, 475] Food security is closely tied to the ability to grow crops and to utilize traditional fishing grounds.[476]

Land and water: Generally, the rural population has access to Vanuatu's considerable fertile land resources. At the annual level, access to water is also good, due to high rainfalls. Water may be typically supplied by a combination of seasonal river, rooftop harvesting and shallow wells. However, many households and most agriculture are dependent on seasonal rainfall, and seasonal shortages are common.

Adaptive capacity: The capacity of rural Vanuatu communities to cope with extreme climate hazards is considered low. This low capacity results from a complex interplay of several factors, covering historical, social, economic, physical, cultural, environmental, and institutional dimensions.[477] However, the population may have many positive aspects that have ensured resilience to previous hazards, notably access to range of natural marine, coastal and terrestrial ecosystems, well developed knowledge and history of coping with adverse conditions.[478]

The Peri-Urban Population

Peri-urban housing can be defined as housing to which the occupant has no legal claim, or is occupying illegally. It may also refer to unplanned settlements, or settlements that are not in compliance with planning and building regulations. This can and does include buildings in land designated as disaster zones.[479]

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[471] Or Piper methysticum. Kava is an important agricultural commodity in many Pacific countries and used for making traditional beverage.
[472] FAO. 2008. An Assessment of the Impact of Climate Change on Agriculture and Food Security - A Case Study in Vanuatu, In "Climate change and food security in Pacific Island Countries".
[473] Government of Vanuatu. 2007. National Adaptation Programme for Action.
[474] See, e.g., Savage A., H. Bambrick and D. Gallegos (2021).
[475] Vanuatu National Statistics Office and UNDP Pacific Centre. 2011. Vanuatu Hardship and Poverty Report: Analysis of the 2010 Household Income and Expenditure Survey.
[476] USAID. 2018. Pacific Islands Climate Risk Profile.
[477] Jackson, G. et al. 2017. A Framework for Disaster Vulnerability in a Small Island in the Southwest Pacific: A Case Study of Emae Island, Vanuatu.
[478] Pacific Community. RESCCUE – Climate Change Impacts in North Efate, Vanuatu. 2016
[479] BECA consultants. Urban Growth Trends Report – Port Vila and Luganville: Risk Mapping and Planning for Urban Preparedness. Prepared for Vanuatu Meteorological and Geo-Hazard Department (2015)

Peri-urban population refers to residents living in informal settlements in and around the two major urban areas of Port Vila and Luganville. These are densely populated areas, physically close to urban areas with good social services nearby, although not always easily or affordably accessible. Peri-urban areas are the areas where most migrants from rural areas first arrive, as they do not have access to planned and formal settlements. Hence, these areas experience high population growth, and are characterised by a large number of recent arrivals, and by a high ethnic and cultural diversity.

Economic Activities: Although the majority of households engage in subsistence agriculture, and in sales of surplus, increasing numbers also engage in services and paid work in the nearby urban area. Typically, this is low paid, unreliable work, meaning many employed people continue to live in poverty.

Access to basic services: Typically, water and electricity is supplied or is available nearby. The connections may be semi-legal, and are often limited and relatively costly, or unreliable. Access to the social services is also possible, compared to rural areas, but less reliable or more costly than for true urban population.

Land and water: Notably, the peri-urban population face uncertain land tenure, and this is a key challenge. The land is often more marginal – i.e. on steep slopes or close to river beds subject to flooding. The majority of the peri-urban population also engage in crop production on small plots, typically less fertile and more marginal than rural counterparts. These small food gardens play a key role in providing household food but are less resilient. [480] Residents of peri-urban areas obtain water from a variety of sources: some have access to mains supply of variable quality or price. Many supplement this source with more direct sources—rooftop harvesting, small streams and shallow wells—all of which may be seasonal.

Adaptive capacity: Weak institutional anchoring, less access to land, disconnect from network and home lands all increase vulnerability. The social political make up makes governing the ecosystems a challenge. High population growth means many are forced to live in marginal areas, including flood zones.[481]

The Urban Population and Vulnerable Urban Groups (note: Figures and analysis of Port Vila and Luganville sometimes include the peri-urban areas)

Vanuatu has two main urban areas, Port Vila and Luganville. Their combined population was just over 57,000 in 2009. During 1999-2009, Port Vila grew at a rate of 4.1%, whilst Luganville grew at 2.1%. According to the 2016 Mini Census, the population of Port Vila was 51,437 people in area about 12 km^2.[482] Port Vila has been identified as the 'world's most exposed city to natural hazard related disasters' with27% of households live in makeshift or temporary material housing.[483]

Although the cash economy dominates in urban areas, the population is diverse and includes highly integrated, well-educated and skilled workforce as well as recent migrants who may still be

[480] See, e.g., Savage A., H. Bambrick and D. Gallegos (2021)
[481] BECA consultants. Urban Growth Trends Report – Port Vila and Luganville: Risk Mapping and Planning for Urban Preparedness. Prepared for Vanuatu Meteorological and Geo-Hazard Department (2015)
[482] Government of the Republic of Vanuatu. 2016. 2016 Post TC Pam: Mini Census Report. Ministry of Finance and Economic Management. Vanuatu National Statistics Office. https://vnso.gov.vu/index.php/component/advlisting/?view=download&fileId=4542
[483] Rey, T. et al. 2017. An integrative approach to understand vulnerability and resilience post-disaster. The 2015 cyclone Pam in urban Vanuatu as case study.

transitioning from subsistence based to cash-based economies. This latter group notably continues to experience unemployment and poverty.[484] According to the 2010 Household Income and Expenditure Survey (HIES), the main sources of employment in the urban centres are formal employment from private sector (45%) followed by the government (19%).[485] For example, in Luganville, the main economic activities are wholesaling, retailing, banking, restaurant and hotel related. However, by international standards, the economy is not diverse, and technical capacity is limited. Both Port Vila and Luganville have several wharves and an international airport. Port Vila has the country's only container port.

For this study, true urban areas differ from peri-urban (and rural) areas in the following important ways:

- Unlike rural areas, urban areas contain considerable office space, small businesses and industry, and government buildings (especially Port Vila), as well as residential areas;[486]
- The urban population live and work in legal and planned settlements, with fixed and more reliable (often less costly) electricity and water supply – although the rapid growth of the urban population can mean that meeting the needs of the population in the two main urban centres is a constant challenge.[487]

Another important difference is that, unlike rural and peri-urban areas, urban areas include population tranches that are characterised by low vulnerability and are more resilient to the impact of external shocks and stresses. The urban population generally has good access to services, although for the poor it can be relatively expensive.

In urban areas, unlike rural areas, vulnerability and poverty is highly complex and multi-dimensional (see Box 3), and can change from year to year, and more in-depth studies are required to analyse and determine appropriate support measures.

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[484] Rey, T. et al. 2017. An integrative approach to understand vulnerability and resilience post-disaster. The 2015 cyclone Pam in urban Vanuatu as case study. 2017.

[485] Vanuatu National Statistics Office and UNDP Pacific Centre. 2011. Vanuatu Hardship and Poverty Report: Analysis of the 2010 Household Income and Expenditure Survey

[486] BECA consultants. Urban Growth Trends Report – Port Vila and Luganville: Risk Mapping and Planning for Urban Preparedness. Prepared for Vanuatu Meteorological and Geo-Hazard Department (2015)

[487] World Bank/GFDRR. Vulnerability, Risk Reduction and Adaptation to Climate Change – Vanuatu. 2011.

Box 3: Vulnerability in urban areas is complex – vulnerable groups have to be defined, described and understood

Illustrative findings from Vanuatu National Statistics Office (2011),

- One in eight households in Port Vila are female headed;
- Across Vanuatu, households produce 58% of their own food, this is not possible in urban areas. And, as the cost of food is much higher in urban areas, particularly in Port Vila, food security amongst the poor is low;
- Food poverty levels are higher than national levels – as high as 8.7% in Luganville;
- In urban areas, the number below the Basic Needs Poverty Line (BNPL) is double that of rural areas, and the 'depth'[488] is greater (6% in urban areas, c.f. 2.3 % in rural areas);
- The gap between female and male unemployment levels is far higher in urban areas;
- Given the higher costs of living, having employment does not necessarily mean escaping poverty in urban areas – in Port Vila 16.8% of government employees and 17.1% of private sector employees were BNPL;
- The situation with regards to women, elderly and disabled is complex. In some sites, these groups occupy a disproportionately high amount of the BNPL group, but less in other sites less;
- Women's' vulnerability to poverty varies considerably, and not all women-headed households are poor;
- Food and basic needs poverty is significantly higher among people with low levels of education;
- Gender-based inequality is deeper in urban areas and, to some extent, is reflected in wage inequality;
- For example, in Luganville, market vendors (classified here as producing goods for sale) are one of the most vulnerable groups with 22.7% below the BNPL and 27.3% very vulnerable to falling below the BNPL;
- Retirees and people with disability, particularly women, are among the most vulnerable.

A more recent case-study by Rey et al. (2017)

- Female-headed households particularly struggled after Tropical Cyclone Pam (2015);
- There is a strong correlation between vulnerability status and education level in urban areas;
- There is a strong three-way relationship between gender, low education and poverty in urban areas - vulnerability and poverty needs are higher among females than males with limited or no schooling;
- Males and females aged over 60 are more vulnerable in urban areas - over 20% are BNPL;
- Men dominate most formal employment in most sectors;
- Retirees and people with disabilities in Port Vila are particularly vulnerable to being below the BNPL;
- Households headed by elderly are, therefore, among the highly vulnerable groups.

Source: Vanuatu National Statistics Office and UNDP Pacific Centre. 2011. Vanuatu Hardship and Poverty Report: Analysis of the 2010 Household Income and Expenditure Survey; and Rey, T. et al. 2017. An integrative approach to understand vulnerability and resilience post-disaster. The 2015 cyclone Pam in urban Vanuatu as case study.

The urban areas have many health challenges, many of which are climate related, including nutritional deficiencies, and diarrheal and vector-borne diseases. These particularly impact the poor.

[488] Gap between revenue and poverty line

Gender

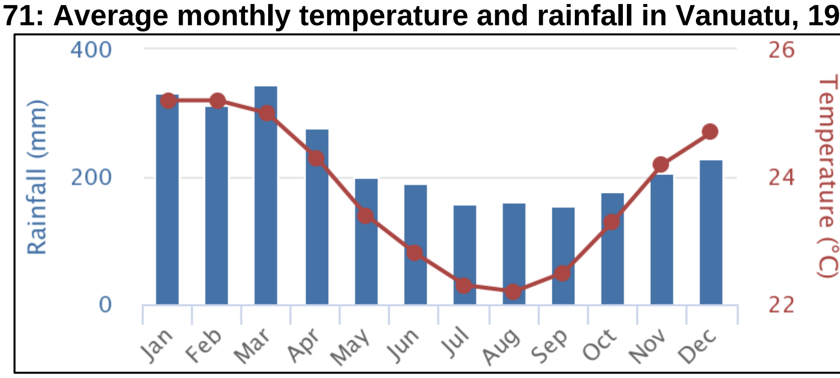
Notwithstanding variations across areas, gender factors increase vulnerability at all sites. Women are particularly vulnerable: women enjoy far less access to education, to disaster and climate information, to assets, to mobile phones and to decision-making. Notably, the prevalence rates of violence against women in Vanuatu are one of the highest in the world (60% of adult women experience some form of partner violence in their lifetime).[489] In past disasters, it was observed that women and women-headed households suffered disproportionately after the disaster, including reduced access to food, to health services and to basic security. Increases in gender-based violence are also observed. Female-headed households are amongst the most vulnerable.[490]

3. Current and Future Climatology

Vanuatu's climate is typical of a Pacific Island nation, with low seasonal variation in temperature (average temperatures varying just 4ºC throughout the year) and relatively high precipitation totals (**Figure 71**). Variations in climate, and particularly precipitation, are influenced strongly by the El Niño-Southern Oscillation (ENSO). ENSO has a complex relationship with climate but can be a driver of both drought and flood events as well as of regional sea-levels.

Vanuatu's Second National Communication to the UNFCCC suggests temperatures have been rising in the region at around 0.1ºC per decade since the 1970s. However, the Berkeley Earth Dataset suggests a slightly more complex picture. Up to the 1990s there was limited warming in the region, but from 1995 the warming accelerated, and temperatures between 2014 and 2018 were averaging around 0.5–0.6ºC above the long-term average. [491] A separate study pointed to significant natural multi-decadal rainfall variability in the South Pacific Convergence Zone (in which Vanuatu is situated). Observing records over 400 years, abrupt changes in the order of ~1800mm possibly occurring during wet seasons were observed.[492] However, in recent decades, no changes in rainfall patterns significantly outside the range of normal inter-annual variation have been documented and linked to human-induced climate changes.

Figure 71: Average monthly temperature and rainfall in Vanuatu, 1901–2016



Source: WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical.*

Table 36, based on the four Representative Concentration Pathways, provides an overview of temperature change (ºC) projected for Vanuatu over different time horizons, emissions pathways,

[489] Megan Williams (CARE). 2020. Rapid Gender Analysis - COVID-19 - Vanuatu.
[490] Government of Vanuatu. 2020. Vanuatu Recovery Strategy 2020-2023.
[491] WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical.* https://climateportal.worldbank.org.
[492] Partin, J.W., et.al. *2013. Multidecadal rainfall variability in South Pacific Convergence Zone as revealed by stalagmite geochemistry.* Geology, 41(11), pp.1143-1146.

and measures of temperature, showing the median estimates of the full CCKP model ensemble and the 10th and 90th percentiles in brackets.[493]

Table 36: Projected temperature scenarios for Vanuatu

Scenario	Annual average of monthly maximum		Annual average		Annual average of monthly minimum	
	2040–2059	2080–2099	2040–2059	2080–2099	2040–2059	2080–2099
RCP2.6	0.7 (0.5, 1.1)	0.7 (0.3, 1.2)	0.7 (0.2, 0.9)	0.7 (0.3, 0.9)	0.6 (0.2, 1)	0.6 (0.1, 0.9)
RCP4.5	0.9 (0.6, 1.5)	1.3 (0.8, 2)	0.9 (0.5,1.2)	1.3 (0.7, 2)	1 (0.3, 1.2)	1.3 (0.7, 1.8)
RCP6.0	0.9 (0.6, 1.3)	1.6 (1.2, 2.5)	NA	NA	NA	NA
RCP8.5	1.3 (0.8, 2)	2.7 (1.9, 4)	1.4 (0.7, 2)	2.9 (1.9, 4.2)	1.4 (0.9, 1.8)	3 (2.1, 3.9)

Note: in **Error! Reference source not found.**, the projected temperatures are above a baseline period of 1986-2005. An additional 0 .61ºC of global warming is estimated to have taken place between the periods 1850-1900 and 1986-2005.

Figure 72 and **Figure 73** display only the average temperature projections. While similar, these three indicators can provide slightly different information. Monthly/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.[494]

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 on 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 Vanuatu under RCP8.5 is shown in **Figure 72**. However, it should be noted that concerns have been raised about the realism of some of the more extreme outlier models labelled in **Figure 72**.[495]

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 on 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 the nearby ocean than to the island itself. Caution should therefore be applied to interpreting results.

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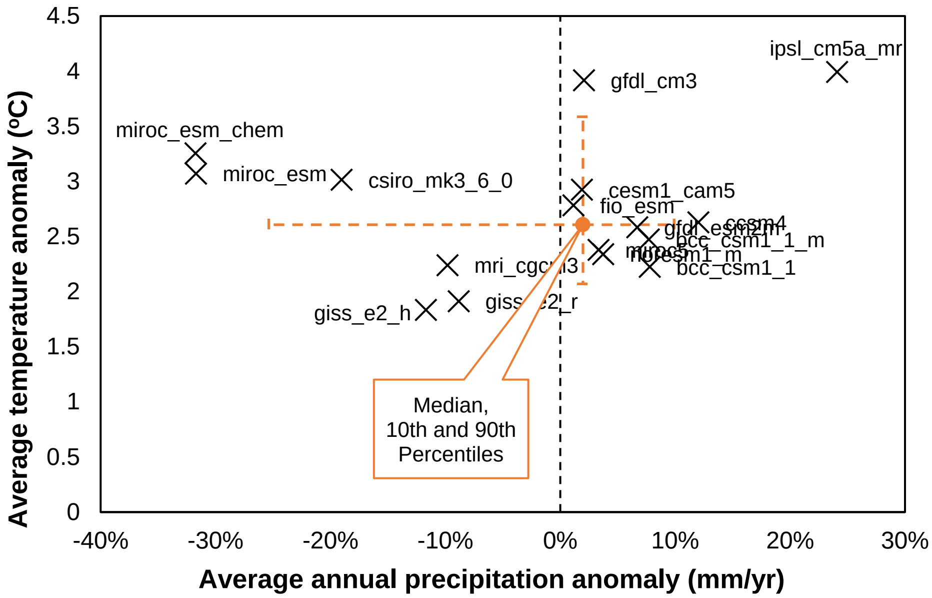
[493] WBG Climate Change Knowledge Portal. 2018. *Climate Data: Historical.* https://climateportal.worldbank.org.

[494] Models shown in **Figure 72** and **Figure 73** represent the subset of models within the ensemble which provide projections across all RCPs and therefore are most robust for comparison.

[495] McSweeney, C.F., R.G. Jones, R.W. Lee, and D.P. Rowell. 2015. *Selecting CMIP5 GCMs for downscaling over multiple regions*. Climate Dynamics, 44(11-12), pp.3237-3260.

Figure 72: 'Projected average temperature anomaly' and 'projected annual rainfall anomaly' in Vanuatu. Outputs of 16 models within the ensemble simulating RCP8.5, 2080–2099



Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections.*

Figure 73: Historical and simulated surface air temperature time series for the region surrounding Vanuatu

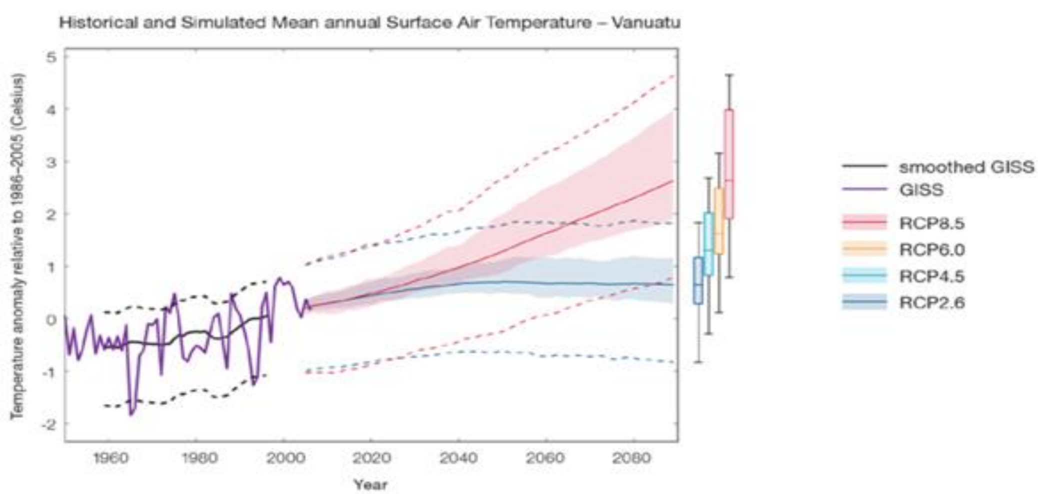


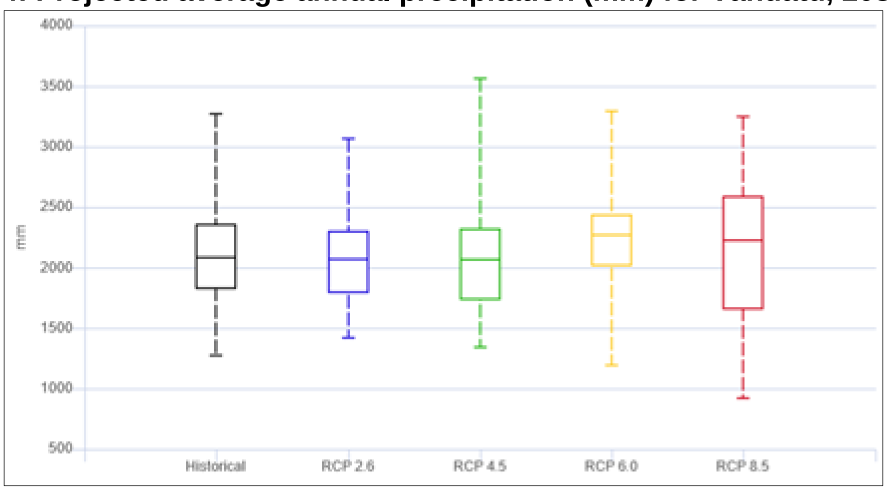
Figure 73 shows the anomaly (from the base period 1986–2005) in surface air temperature from observations (the GISS dataset, in purple), and for the CMIP5 models under the very high (RCP8.5, in red) and very low (RCP2.6, in blue) emissions scenarios. The solid red and blue lines show the smoothed (20-year 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 inter annual 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 centered on 2090 are shown by the bars on the right for RCP8.5, 6.0, 4.5 and 2.6.[496]

There is relatively good agreement among models that future temperature rises over Vanuatu's islands will be below the global average. Under the highest emissions pathway temperatures are projected to reach around 2.9ºC by 2090, compared to around 3.7ºC globally, this reflects the moderating effect of large amounts of nearby ocean cover. However, this 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; as such these projections should be approached with caution.

Considerable uncertainty surrounds projections of local long-term future precipitation trends in Vanuatu, and little can be said regarding changes in average annual rainfall (see **Figure 74**).

Figure 74: Projected average annual precipitation (mm) for Vanuatu, 2080-2099



Source: WBG Climate Change Knowledge Portal. 2019. *Climate Data: Projections.*

However, the intensity of sub-daily extreme rainfall events appears to be increasing with temperature.[497] Although, this phenomenon is highly dependent on local geographical contexts and further research is required to constrain its impact on Vanuatu, most projections suggest the frequency and intensity of extreme rainfall events will increase, with high confidence. This view is supported, for example, by the CCKP model ensemble's projections for the region. The CCKP model ensemble projects increases in both the intensity of high rainfall events and the frequency of wet days. The intensity of sub-daily extreme rainfall events appears to be increasing with temperature, a finding supported by evidence from different regions of Asia and the Pacific.[498]

4. Climate Risk in Vanuatu

The South Pacific is currently considered one of the most hazard prone regions in the world. This is attributed to high levels of exposure to hazards coupled with a range of vulnerabilities that include low economic development, weak formal governance structures and social protection, and a dependence on exposed assets and entire industries, such as agriculture and fisheries,

[496] 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. Melbourne, Australia.
[497] Westra, S. et al. 2014. *Future changes to the intensity and frequency of short-duration extreme rainfall*. Reviews of Geophysics, 52, 522–555.
[498] Ibid.

that are crucial for livelihoods. [499] In the 2020 edition of the World Risk Index, Vanuatu leads the index as the country with the highest disaster risk.[500] This section looks at climate hazards in Vanuatu and provides the best understanding of how they will be affected by climate change.

Heat Waves. Vanuatu regularly experiences high maximum temperatures, with an average monthly maximum of around 27.2ºC and an average February maximum of 28.8ºC. The historic temperature regime in Vanuatu was very stable. Projected climate changes are expected to push temperatures above 30ºC on a regular basis: heatwaves and extremely high temperatures are to be more frequent, more sustained; 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 heatwaves. For Vanuatu, the number, and temperature, of extremely hot days is expected to increase (*very high confidence*).[501]

An additional issue is the potential for marine heatwaves. Research has identified the Western Tropical Pacific as a global hotspot for climate change impacts on marine heatwaves. Marine heatwaves are projected to extend their spatial footprint and to grow in duration and intensity.[502] The consequences of this trend may be serious for marine ecosystems in the region (and the livelihoods dependent on them), which are adapted to survive under very stable temperature regimes.

Droughts. Two types of drought may affect Vanuatu, meteorological (usually associated with a precipitation deficit) and hydrological (usually associated with a deficit in surface and subsurface water flow). Whereas high islands receive higher rainfall that channels down mountains into extensive networks of streams and rivers, low islands lack such resources and are often entirely reliant on shallow and limited groundwater lenses and rainwater catchments as fresh water sources. On average, both annually and for one-time events, precipitation falls in smaller amounts on low islands, making them highly vulnerable to drought of any severity. Additionally, low islands face significant risk from storm surge and coastal flooding, both with potential impacts on water resource availability and quality. Having adequate freshwater reserves is also a challenge for high islands, as they also rely on rainfall to balance out groundwater discharge.[503]

There has been a 5% increase in the frequency of droughts in Vanuatu between the years 1951 and 2010. The duration and magnitude of these droughts has also experienced a slight upward trend.[504]

According to USAID, the El Niño event of 1997/98 was one of the most pronounced drought periods in this region of the Pacific, causing significant declines in agricultural productivity and exports. Then, for example, in 2015, a severe El Nino event commenced across the Pacific Ocean. This was reported as "one of the three strongest El Nino events since 1950" and categorised as 'very strong', the highest-ranking of the US National Oceanic and Atmospheric Administration categories. On several islands, including Efate, people experienced water shortages and food crop failure, contributing to food and nutrition insecurity and malnutrition.[505]

[499] Jackson, G. et al. 2017. A Framework for Disaster Vulnerability in a Small Island in the Southwest Pacific: A Case Study of Emae Island, Vanuatu.
[500] Bündnis Entwicklung Hilft and Ruhr University Bochum Institute for International Law of Peace and Armed Conflict (IFHV). 2020. World Risk Report 2020.
[501] 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. Melbourne, Australia.
[502] Frölicher, T. L., E.M. Fischer, and N. Gruber. 2018. *Marine heatwaves under global warming.* Nature, 560(7718), 360–364. 2018.
[503] USAID. 2018. Pacific Islands Climate Risk Profile.
[504] Fraser Thomas Partners. 2018. Port Vila Integrated Urban Improvements Project, Volume 1, Draft. Asian Development Bank.
[505] USAID. 2018. Pacific Islands Climate Risk Profile.

While the impacts of climate extremes on food availability are well documented, the experiences and consequences of food and nutrition insecurity at the village and household level are less understood.[506] In early 2020, Vanuatu's southern islands were once again reportedly in the grip of a meteorological drought.[507]

Drought events in Vanuatu are highly dependent on ENSO cycles. The western islands of Vanuatu tend to experience drought during El Niño as the rainfall moves east, following the warm waters of the western equatorial Pacific flow.[508] The above appear to be recent examples demonstrating how El Nino driven droughts lead to endangered freshwater supplies and insecure food supplies across the region.[509] These are particularly damaging in the more remote islands lacking sufficient harvesting/storage capacity.[510]

For the future, meteorological drought may increase in frequency, with one study conducted for ADB suggesting a potential doubling in the frequency of severe and extreme droughts by 2080 under RCP8.5.[511] Other more recent research also suggests that climate change will result in an increased frequency of extreme ENSO-driven events - related to drought conditions in the South Western Pacific; however, the confidence of these projects is uncertain.[512] This represents a major risk to those areas highly dependent on rainwater for domestic use or agriculture.[513]

Cyclones Vanuatu is located in a region just south of the equator known for the regular occurrence of tropical cyclones with damaging winds, rains and storm surge. Tropical cyclones affect the country during the warmer-wet season between November and April, as the high rainfall brings associated low-pressure systems.[514] Between 1981 and 2018, 33 of the 74 tropical cyclones that passed through the country were severe events – Category 3 or stronger.[515] According to its Second National Communication to the UNFCCC around 20-30 cyclones pass over Vanuatu every decade, around 3-5 of which will cause severe damage.

Vanuatu has very high exposure and vulnerability to the impact from tropical cyclones and storm surge which can strike in combination or isolation. Cyclones bring coastal and flash flooding even when only passing in the vicinity of the island. The high winds associated with cyclones damage assets, livelihoods and lives. In 2015 Cyclone Pam, a category 5 tropical cyclone, struck Vanuatu, killing 11 people, destroying or damaging over 17,000 buildings and displacing 65,000 people. The economic damages associated with the incident were estimated to be equivalent to around 64% of GDP.[516] Just five years later, in April 2020, Tropical Cyclone Harold struck (just after the declaration of the COVID Pandemic). Harold tore across the northern and central islands of

[506] Savage A., H. Bambrick and D. Gallegos. 2021. Climate extremes constrain agency and long-term health: A qualitative case study in a Pacific Small Island Developing State. Weather and Climate Extremes. Volume 31, March 2021, 100293
[507] RNZ News. & January 2020.
[508] Tonkin and Taylor. 2018. Disaster Risk Assessment/Climate Risk and Vulnerability Assessment - Port Vila Integrated Urban Improvements Project.
[509] Annamalai, H. et al. 2015. El Nino Strengthens in the Pacific: Preparing for the Impacts of Drought. AsiaPacific Issues, No. 122.
[510] World Bank/GFDRR. 2011. Vulnerability, Risk Reduction and Adaptation to Climate Change – Vanuatu.
[511] Y. Li. and P. Urich. 2017. *Climate Change Impact Assessment for Luganville, Vanuatu.* ADB/CLIMsystems Ltd.
[512] Savage A., H. Bambrick and D. Gallegos. 2021. Climate extremes constrain agency and long-term health: A qualitative case study in a Pacific Small Island Developing State. Weather and Climate Extremes. Volume 31, March 2021, 100293
[513] Foster, T. and J. Willetts. 2018. *Multiple water source use in rural Vanuatu: are households choosing the safest option for drinking?*. International Journal of Environmental Health Research, 28(6), pp.579-589.
[514] Tonkin and Taylor. 2018. Disaster Assessment/Climate Risk and Vulnerability Assessment – Port Vila Integrated Urban Improvements Project.
[515] 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. Melbourne, Australia.
[516] National Advisory Board on Climate Change and Disaster Risk Reduction (NABCCDRR). 2015. *Cyclone Pam post disaster needs assessment*. https://www.nab.vu/cyclone-pam-post-disaster-needs-assessment [accessed 16/05/2019]

Vanuatu with sustained winds up to 270km/hour. The Post Disaster Needs Assessment estimated the cost of losses and damages associated with Harold to be approximately $500mn.[517]

Research suggests that cyclone impacts in urban areas on Vanuatu may be greater than in rural areas. Rural areas experience some damage and crop loss, but quickly recover. Urban areas experience total breakdown in services, high costs, and loss of access to affordable food, in a situation which can last some time. [518,519]

Climate change is expected to interact with cyclone hazards 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. The 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.[520,521] Trends emerging from scientific literature in regard to tropical cyclone genesis and tracks in the Pacific point towards a climate change-driven westward shift in the genesis location of cyclones.[522] Evaluation of climate change implications for severe wind hazards has thus far produced inconclusive results.[523] Other characteristics, such as maximum wave height, have been shown to be strongly linked to El Niño-Southern Oscillation, and as such will depend upon the poorly understood relationship between climate change and ENSO.[524] One study has suggested that under future climates, cyclone generation will become more frequent during El Niño events, but less frequent during La Niña events.[525] 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.

Riverine/pluvial flooding: Cumulatively, the very high number of localized and flash floods is of great importance, particularly in urban areas. These may be by sea overtopping, intense rainfall, cyclones or some combination of all three. All have a particular impact in urban areas where land is limited, infrastructure is dense and exposed, and infiltration/drainage is limited. In addition, standing water resulting from poor drainage systems has implications for human health, including outbreaks of dengue fever and malaria.

Both urban flooding and coastal flooding are considered primary hazards for Vanuatu and classified as high risk by the Global Facility for Disaster Reduction and Recovery. As extreme rainfall and weather events increase in frequency and intensity, urban and coastal flooding will

[517] Government of Vanuatu. 2020. Post-Disaster Needs Assesment, TC Harold and Covid=19.
[518] Rey, T. et al. 2017. An integrative approach to understand vulnerability and resilience post-disaster. The 2015 cyclone Pam in urban Vanuatu as case study.
[519] Jackson, G. et al. 2017. A Framework for Disaster Vulnerability in a Small Island in the Southwest Pacific: A Case Study of Emae Island, Vanuatu.
[520] Walsh, K. et.al. 2015. Tropical cyclones and climate change. WIREs Climate Change. 7: 65-89.
[521] Widlansky, M. J., et.al. 2019. Tropical Cyclone Projections: Changing Climate Threats for Pacific Island Defense Installations. Weather, Climate, and Society, 11(1), 3–15.
[522] Wu, L., C. Wang, & B. Wang. *Westward shift of western North Pacific tropical cyclogenesis*. Geophysical Research Letters, 42(5), 1537–1542. 2015. DOI: https://doi.org/10.1002/2015GL063450.
[523] Siquera, A., A. Arthur, & M. Woolf. 2014. *Evaluation of severe wind hazard from tropical cyclones – current and future climate simulations.* Pacific-Australia Climate Change Science and Adaptation Planning Program.
[524] Stephens, S. A., & D.L. Ramsay. 2014. *Extreme cyclone wave climate in the Southwest Pacific Ocean: Influence of the El Niño Southern Oscillation and projected climate change*. Global and Planetary Change, 123, 13–26. DOI: https://doi.org/https://doi.org/10.1016/j.gloplacha.2014.10.002
[525] Chand, S. S., K.J. Tory,H. Ye, and K.J.E. Walsh. 2016. *Projected increase in El Niño-driven tropical cyclone frequency in the Pacific*. Nature Climate Change, 7, 123. DOI: https://doi.org/10.1038/nclimate3181

consequently increase. Both hazards present moderate to very high levels of potential damage to the local infrastructure. [526]

The research undertaken on Port Vila by Tonkin and Taylor (2018) [527] showed that:

- Localized (pluvial) flooding can occur even with average rainfall levels, particularly in the flooding hotspots. Insufficient drainage systems and degraded watersheds compromise Port Vila's ability to cope with this localized flooding. An increase in rainfall or storm surges will exacerbate this issue.
- The northern part of Port Vila is also prone to flooding from the two rivers flowing through Mele.
- In the future, increased flooding is expected to occur due to higher sea levels and possibly more intense rainfall events. The most vulnerable locations are likely to be around the lower reaches of the rivers, particularly in places where mangroves and other vegetation have been removed. Flooding in this area impacts agriculture, particularly traditional wealth crops such as sugar cane, yam and rice.
- Climate change is also likely to alter slope and bedrock stability through changes in precipitation and/or temperature.

As mentioned above, potential super-cycle of intense rainfall could lead to very high increases in extreme rain events, exacerbating all flooding events.

Mean Sea Level Rise, Extreme Sea Levels, Coastal Flooding and Erosion

As an island nation, Vanuatu is highly exposed to mean and extreme sea levels, as well as to extreme wave energies. Rises in mean sea levels may lead to inundation, loss of land, erosion and permanent damage of marine and freshwater ecosystems (including drinking water supplies). These affects will be exacerbated by extreme sea level events, and by high energy wave events. These effects can combine with droughts (further affecting water resources and freshwater ecosystems) and cyclone (storm surges).

Global mean sea level is just one component of *local mean* sea levels, which are just one component of *local extreme* sea levels.

Global changes Global mean sea-level rise was projected to be in the range of 0.44-0.74m by the end of the 21st century by the IPCC's Fifth Assessment Report but some studies published more recently have highlighted the potential for more significant rises (**Table 37Table 37**).

Table 37: Estimates of global mean sea-level rise by rate and total rise compared to 1986-2005 including likely range shown in brackets where applicable

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)

[526] Tonkin and Taylor. 2018. Disaster Assessment/Climate Risk and Vulnerability Assessment – Port Vila Integrated Urban Improvements Project.
[527] Tonkin and Taylor. 2018. Disaster Assessment/Climate Risk and Vulnerability Assessment – Port Vila Integrated Urban Improvements Project.

Scenario	Rate of global mean sea-level rise in 2100	Global mean sea-level rise in 2100 compared to 1986-2005
Estimate inclusive of high-end Antarctic ice-sheet loss[528]		1.84m (0.98-2.47)
High end scenario, considering low probability tail for SLR distribution[529]		2m
Scenarios to be considered plausible[530]		2.0m -2.5m

Source: for RCP scenarios, data from Chapter 13 of the IPCC's Fifth Assessment Report[531], others as referenced.

Hence, global mean sea level rises of up to 1.5 m and over by 2100 are credible.

Local levels. Local mean sea levels are also driven by the regional variation in global mean sea levels due to ocean dynamics; the regional variation in mean sea level due to redistribution of mass between land and oceans; and local vertical land movement. Local 'extreme' sea levels are also driven by tidal levels, storm surges and waves.[532,533] Localized sea-level rise can in fact be an extremely complex phenomenon to measure and model, notably due to the influence of large-scale climate phenomena such as ENSO. Some studies have suggested that the western Pacific has been experiencing above average rates of sea-level rise, but the extent to which this is attributable to human-driven climate change and/or likely to continue requires further research.[534]

Sea-level rise can vary spatially, and work by the Australian Bureau of Meteorology and CSIRO has suggested that end-of-century sea-level rise could vary by as much as 10cm across the South Pacific region, meaning countries should be prepared for above average sea-level rises[535].

Vanuatu's Second National Communication reports sea-level rise at a rate of around 6 mm/yr between 1990 and 2010 – slightly faster than the global average over the same period. Notably, the net rate at which the sea is encroaching on Vanuatu's islands can be significantly accelerated by the simultaneous subsidence of the land driven by tectonic movements. Within the period 1997-2009 such movements almost doubled the rate of net sea-level rise.[536] Tectonic movements can hamper efforts to monitor sea-level rise.[537] One study has modelled the expected rates of coastal erosion under rising sea-levels.[538] In the long run, coastal infrastructure may be threatened by permanent inundation.

[528] Le Bars, D., S. Drijhout, and H. de Vries. 2017. *A high-end sea level rise probabilistic projection including rapid Antarctic ice sheet mass loss*. Environmental Research Letters: 12:4.
[529] Nichols, R. J. et al. Integrating new sea-level scenarios into coastal risk and adaptation assessments: an on-going process. 2021 (forthcoming)
[530] NOAA. 2017. Global and Regional Sea Level Rise Scenarios for the United States. USA National Oceanic and Atmospheric Administration (NOAA) Technical Report NOS CO-OPS 083. 75 pages (quoted from Kiem, A., 2018, literature review prepared for ADB).
[531] 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.
[532] Nichols, R. J. et al. Integrating new sea-level scenarios into coastal risk and adaptation assessments: an on-going process. 2021 (forthcoming)
[533] Widlansky, M. J., A. Timmermann, and W. Cai. 2015. *Future extreme sea level seesaws in the tropical Pacific*. Science Advances, 1(8). DOI: https://doi.org/10.1126/sciadv.1500560
[534] Peyser, C. E., J. Yin, F.W. Landerer, and J.E. Cole. 2016. *Pacific sea level rise patterns and global surface temperature variability*. Geophysical Research Letters, 43(16), 8662–8669. 2016. DOI: https://doi.org/10.1002/2016GL069401
[535] 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. Melbourne, Australia.
[536] Ballu, V. et al. 2011. *Comparing the role of absolute sea-level rise and vertical tectonic motions in coastal flooding, Torres Islands (Vanuatu)*. Proceedings of the National Academy of Sciences, 108(32), pp.13019-13022.
[537] Deo, M.N., R. Govind, & A. El-Mowafy. 2013. *The Stability of Tide Gauges in the South Pacific Determined from Multiepoch Geodetic Levelling, 1992 to 2010.* Marine Geodesy, 36(3), pp.261-284.
[538] Sahin, O. et al. 2019. *Spatial Bayesian Network for predicting sea level rise induced coastal erosion in a small Pacific Island.* Journal of environmental management, 238, pp.341-351. 2019.

USAID reported that should sea levels rise by only 20 cm above current levels, a coastal flooding event that historically occurred once every 100 years would occur, on average, every 10 years.[539]

The return period of exceptionally high sea-levels, driven by climate circulations, is expected to reduce and low-lying pacific island nations are particularly at risk.[540] Studies have shown that the extent of wave-driven flooding is impacted by coral reef height and health, highlighting the importance of coral conservation.[541]

As a result, rising sea levels, both on average and during extreme events such as storm surge, king tides, and wind waves, are likely to steadily degrade coastal areas in coming decades, affecting land, water and infrastructure.

Ocean Acidification Calcium carbonite is used for the external skeletons of multiple marine organisms – for instance, plankton, coral reefs, and shellfish. 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. **Figure 75** shows the projected aragonite saturation state under three emission scenarios for Vanuatu.[542] Worryingly under RCP4.5 and RCP8.5 the saturation state is expected to decrease below the threshold needed to sustain healthy coral reefs.

Accordingly, species living in and around coral reefs, either permanently or in their juvenile period, and particularly larger species, face an extinction threat.[543] As a result of changes in temperature, dissolved oxygen, and acidity, the maximum catch potential of currently resident species has been forecast to decline significantly in Vanuatu.[544]

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[539] USAID. 2018. Pacific Islands Climate Risk Profile.

[540] Vitousek, S. et al. 2017. *Doubling of coastal flooding frequency within decades due to sea-level rise.* Scientific Reports, 7(1), 1399. DOI: https://doi.org/10.1038/s41598-017-01362-7

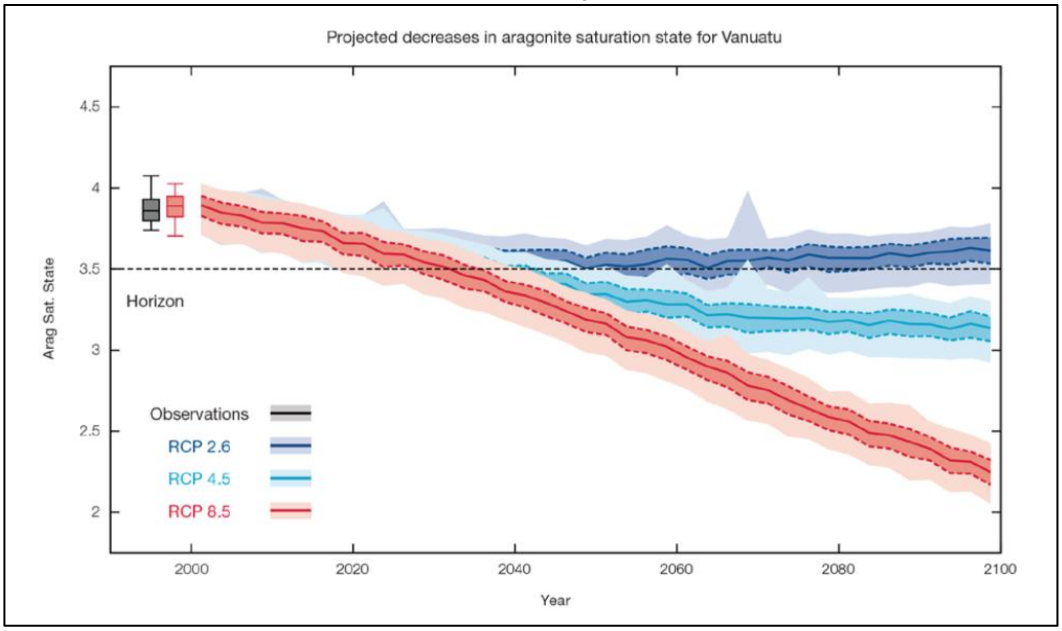
[541] Beetham, E., P.S. Kench, and S. Popinet. 2017. *Future Reef Growth Can Mitigate Physical Impacts of Sea-Level Rise on Atoll Islands*. Earth's Future, 5(10), 1002–1014.

[542] Orr, J. C. et al. 2005. *Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms*. Nature, 437(7059), 681.

[543] Mellin, C. et al. 2016. *Humans and seasonal climate variability threaten large-bodied coral reef fish with small ranges*. Nature Communications, 7(1), 10491. DOI: https://doi.org/10.1038/ncomms10491

[544] Asch, R. G., W.W. Cheung, and G. Reygondeau. 2018. *Future marine ecosystem drivers, biodiversity, and fisheries maximum catch potential in Pacific Island countries and territories under climate change*. Marine Policy, 88, 285–294.

Figure 75: Projected changes in aragonite saturation state in Vanuatu from CMIP5 models under RCP2.6, 4.5 and 8.5



Note: 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.

Of key importance, is the role coral reefs play in dissipating wave energy through a range of factors like the bottom roughness and the bed shear stress. The significant wave height is highly influenced by the tide over the reef flat. Hence, depletion of coral reefs through sea level rise and acidification will have direct impacts on the frequency and intensity of extreme events from waves and storm surge (especially on lagoons). Consequently, future projections of increasing water levels are likely to change wave transformation and dissipation over the reef. Waves and storm surges will face less resistance from coral and reach land more frequently, more intensely.[545] And this will combine with SLR.

5. Climate Change Impacts

The three vulnerable group profiles in Vanuatu are the rural, the peri-urban and the urban. Although each includes a very diverse set, they each have a defining combination of lifestyles, resources, challenges and strengths. In particularly they each have a particular exposure/vulnerability profile. The next section then introduced the climate, climate hazards and projected climate changes experienced across Vanuatu. This section summarizes the projected impacts of climate change on Vanuatu. First **Table 38** provides a summary of how climate change will impact the three population groups. Subsequently, this section describes how climate change is projected to impact key socio-economic sectors on Vanuatu.

[545] Faivre, G. et al. 2020. Coastal Processes within a Coral Reef Lagoon System: Erakor Lagoon, Efate Island, Vanuatu.

Table 38: Details of how climate change will impact the three population profiles on Vanuatu

Population group	Relevant climate hazard	Direct or primary impacts	Secondary impacts
Rural The threats are mostly to food production and to livelihoods, but also to support services	Drought/rainfall variability	• Temporary reduction in rainwater for agriculture; • Temporary reduction in recharge of groundwaters; • Temporary reduction flow in surface waters; • Temporary reduction storage of drinking water (small dams, rooftop harvesting). [546]	• Loss of crops and agricultural yields, and subsequent loss of revenue and food security. • Damage to groundwater and surface waters; • Health impacts of water shortage; • Health impact of loss of food; • Loss of indigenous knowledge and agency; • Poor farmers and communities are least able to afford local water storage, irrigation infrastructure, and technologies for adaptation; • More remote have less access to support, to services and face increased costs.
	Rising mean and extreme sea levels, rising sea temperatures and acidity	• Increase in severe reef and seagrass damage further exacerbating other impacts, notably exposure to wave action and storm surge; Increased damage to agricultural crops; • Increased damage to aquaculture facilities and other infrastructure; • Possible mangrove loss.[547]	• Loss of agricultural land to erosion and/or overtopping (leading to salinization). • Temporary or permanent damage to groundwater and surface water to salinization; • Loss of coastal and marine ecosystems lead to loss of fisheries (and other, e/g/ mangrove) resources; • Loss of local infrastructure, including tourism infrastructure, meaning loss of tourism revenue.
	Cyclones	• Damage to crops and to equipment and to assets • Difficulty getting to services and markets due to damaged transport infrastructure (ports and roads)	In the past, rural areas have suffered less proportionally than urban areas, and many have recovered more quickly.

[546] See, e.g., (i) Savage A., H. Bambrick and D. Gallegos (2021), (ii) Annamalai, H. et al. (2018), (iii) Faivre, G. et al (2020), (iv) FAO (2008), (v) RNZ News. Vanuatu's Southern Islands in drought. 7/January/2021.
[547] Pacific Community. RESCCUE – Climate Change Impacts in Orth Efate, Vanuatu. 2016

Population group	Relevant climate hazard	Direct or primary impacts	Secondary impacts
	Multi-hazard	• As demonstrated in 2015, the combination of Tropical Cyclone Pam followed by strong drought led to combined impacts.	Savage A., H. Bambrick and D. Gallegos (2021)found that climate extremes affected the food and nutritional security (FNS) of people in the two study villages directly, with effects on gardens and food production, and indirectly, by exacerbating the nutrition transition, a shift away from traditional diets energy-dense imported food that is already progressing in Vanuatu. These effects undermine long-term FNS and health. Climate extremes also eroded food-related cultural practices and traditions and constrained local agency to make food choices.
Peri-urban	Drought/rainfall variability	• Temporary reduction in rainwater for agriculture, drinking water, etc.	• Crops may be lost, and revenue. Population will be obliged to purchase food at extra costs. Poverty and food poverty to increase. Likely health impacts of weakened diet. • Increase in population due to likely arrival of migrants.
	Rising mean and extreme sea levels, rising sea temperatures and acidity	• Most peri-urban population is away from direct coast, and less involved in fishing, hence direct impacts are likely to be less.	• Mostly due to impacts in rural areas, peri-urban population to be faced with: • Less access to fish and protein in markets. • Increase in population due to likely arrival of migrants. • Losses of opportunity for employment in tourism sector.
	Pluvial/riverine floods	• Damage to houses and infrastructure • Damage to water supply • Reduced access to transport, markets and to social services	• High cost could push families into poverty, as could loss of revenue due to loss of access to work/markets • Health impacts of loss of drinking water and standing waters • Costs of loss of access to services • Increases in gender disparities.

Population group	Relevant climate hazard	Direct or primary impacts	Secondary impacts
	Cyclones (For example: BECA (2015) found that for 5,000 buildings, a change in winds from those associated with a 1:100 year event to those associated with a 1:500, would lead to half the buildings experiencing 'very heavy damage' as opposed to only 'heavy' damage, with major financial implications. This is the kind of change that could be affected by climate change on cyclone winds.)	• Damage to infrastructure. • Breakdown in services: energy, water, transport, education, health, etc. crops and loss of food production • Health impacts, due to changed diet • Loss of indigenous knowledge and agency • Negative impact on fisheries activities and firewood and basket making activities. [548]	• Increased vulnerability. • More population likely to fall into poverty. • Health impacts of weakened water supply, energy supply, access to health services, etc. • Losses of opportunity for employment in tourism sector.
Urban (with focus on vulnerable groups) [549] The threats mostly to infrastructure and assets, which reduce access to jobs and services, lead to increased costs, and push more people into poverty.	Drought/rainfall variability	Little direct impact.	• Cost of food to rise, leading to increase in food and absolute poverty; • Possibly increase in population due to likely arrival of migrants – leading to stress on services and potential health hazards; • Water shortages unlikely in urban areas.[550]
	Sea levels and storm surge Floods: Vanuatu already has a significant population and asset base exposed to flooding of different types. Over 10,000 people and several thousand infrastructure assets are exposed to riverine flooding and several hundred people and infrastructure assets are exposed to storm surge. This exposure is expected to increase as climate change causes the sea-level to rise.	• The investigations reveal that living in an urban area increases a population's exposure to hydrological, weather and sea-related risks.[551] • Storm surge to combine with cyclones, SLR to increase level of permanent and temporary flooding. • Coastal erosion leads to loss of land, infrastructure and water resources.	• Damage to water supplies and sanitation (and resulting negative impact on tourism, and health)[552] • Damage to coastal/tourism infrastructure; • Currently, large areas, large proportion of population and large proportion of assets are exposed 'low-medium' to river flooding and/or coastal inundations. These percentage will increase considerably given projections for extreme rainfall and SLR, and many people/assets will move into the 'medium- high' and 'ultimate-extreme' exposure groups.[553]
	Pluvial/riverine floods	• Damage to houses and infrastructure • Damage to water supply • Reduced access to transport, markets and to social services	• Costs could push families into poverty, as could loss of revenue due to loss of access to work/markets • Health impacts of loss of drinking water and standing waters

[548] See, e.g., Savage A., H. Bambrick and D. Gallegos (2021), Annamalai, H et (2018).

[549] Sourced from T+T amongst many others – a full hazard assessment for PV

[550] Tonkin and Taylor. 2018. Disaster Assessment/Climate Risk and Vulnerability Assessment – Port Vila Integrated Urban Improvements Project.

[551] Rey, T. et al. 2017. An integrative approach to understand vulnerability and resilience post-disaster. The 2015 cyclone Pam in urban Vanuatu as case study.

[552] See, e.g., Rey T.. et al (2017)

[553] Tonkin and Taylor. 2018. Disaster Assessment/Climate Risk and Vulnerability Assessment – Port Vila Integrated Urban Improvements Project.

Population group	Relevant climate hazard	Direct or primary impacts	Secondary impacts
			• Costs of loss of access to services • Increases in gender disparities.
	Cyclones	• Significant wind and storm surge damage to infrastructure – transport, energy and tourism (and resulting negative impact on tourism) • Assets destroyed • Economic activities stopped or curtailed.	• As evidence in recent cyclones (Pam), the economic impacts are very considerable, and force many people directly into poverty, causing many businesses to fail; • The breakdown in regular life has a major impact across sector. Post cyclone migration may also lead to population growth in urban areas.
	Temperature	Rising temperatures (mean and extreme)	• Heavy manual labour jobs are commonly among the lowest paid whilst also being most at risk of productivity losses due to heat stress.[554] • Poorer businesses are least able to afford air conditioning, an increasing need given the projected increase in (very) hot days.

6. Climate Change Impacts on Key Socio-Economic Sectors

This section notably looks at the socio-economic sectors that are pertinent to the vulnerable populations. For example, it does not look into finance or industrialised fishing, as these sectors have very little interaction with the vulnerable. The socio-economic sectors considered are: Agriculture; Tourism; Disaster Risk Management/Reduction; Human Health and Nutrition; Island Ecology and biodiversity

Agriculture (and food security). Vanuatu's economy remains strongly oriented towards agriculture (particularly in rural areas). Food products constituted around 85% of exports in 2011. Simultaneously, Vanuatu has a food trade deficit and dependence on imports for food security equivalent to over $50 per capita in 2011 giving it high vulnerability to price shocks and disaster events.[555] Copra, which is the kernel inside coconuts, accounted for 35% of Vanuatu's exports in 2007, and coconuts are also used as a source of food, drink, animal feed, and as a construction material by the islands' communities.[556]

Table 39: Climate Stressors and Climate Risks Agriculture and Food Security

Stressors	Risk
Sea level rise Increased temperatures Increased drought frequency and duration	Soil erosion and soil fertility loss
	Saltwater intrusion into aquifers and cropland
	Reduced crop yields
	Crop failures
	Decreased nutritional health

[554] Kjellstrom, T. et al. 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.
[555] World Trade Integrated Solution (WITS). *Vanuatu Trade overview*. Supported by World Bank. 2019. URL: https://wits.worldbank.org/
[556] MALFFB, Vanuatu. *Agriculture*. N.D. URL: https://malffb.gov.vu/index.php?id=1

Stressors	Risk
Increased storm frequency and intensity	

Source: USAID. 2018 Pacific Islands Climate Risk Profile.

Climate change could influence food production via direct and indirect effects on crop growth processes. Direct effects include alterations to carbon dioxide availability, precipitation and temperatures. Indirect effects include through impacts on water resource availability and seasonality, soil organic matter transformation, soil erosion, changes in pest and disease profiles, the arrival of invasive species, and decline in arable areas due to the submergence of coastal lands. In Vanuatu, the combined impacts of climate change, population growth and soil fertility declines will exert a growing cumulative pressure on the remaining lowland forests of Vanuatu to be converted to agricultural land to suffice for the increasing demand for food production.[557] Multiple climate-linked drivers threaten the productivity of Vanuatu's agricultural sector. Given the significance of agriculture to Vanuatu's economy, saltwater intrusion poses a present danger to food production with much of the land currently cultivated situated in coastal areas.[558] Saltwater intrusion, which allows salt from seawater to be absorbed into the soil, has been observed to cause reduced crop efficiency and even lead to crop failure.[559,560] Cyclones can also cause devastating damage to agricultural products[561] but, as mentioned previously, there is uncertainty surrounding how their intensity and frequency might change in the future.

The fisheries subsector also contributes to the full potential for food security in Vanuatu in terms of the protein diet source, however, the population's consumption is only 20 kg per capita per year.[562]

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 2050 under the highest emissions pathway (RCP8.5).[563] Vanuatu currently operates an agricultural system highly dependent on physical labor input and hence is potentially vulnerable to higher temperatures without adaptation.[564] In combination, it is highly likely that the above processes will have a considerable impact on national food consumption.

Tourism. Over 40% of GDP in Vanuatu is linked to the tourism sector. In one critical review of literature examining the dynamics between climate change and tourism, there appeared to be multiple indications that the tourism sectors of small island states, such as Vanuatu, are particularly vulnerable to climate change.[565] In the long-term, the dual threats of rising sea levels

[557] Pouteau, R. and P. Birnbaum. 2016. *Island biodiversity hotspots are getting hotter: vulnerability of tree species to climate change in New Caledonia.* Biological Conservation, 201, 111–119.
[558] Vanuatu National Redd+ Programme. *Malekula.* 2017. URL: http://reddplus.vu/vanuatu-national-redd-program/redd-selected-islands/malekula/
[559] Nhung, T. T., P. Le Vo, V. Van Nghi, and H.Q. Bang. 2019. *Salt intrusion adaptation measures for sustainable agricultural development under climate change effects: A case of Ca Mau Peninsula, Vietnam*. Climate Risk Management, *23*, 88-100.
[560] Bartels, D. and R. Sunkar. 2005. *Drought and salt tolerance in plants*. Critical reviews in plant sciences, *24*(1), 23-58.
[561] McKenzie, E., B. Prasad, and A. Kaloumaira. 2005. *Economic impacts of natural disasters on development in the pacific:* Volume 2: Economic assessment tools. Pacific Islands Applied Geoscience Commission (SOPAC).
[562] Ibid.
[563] Dunne, J. P., R.J. Stouffer and J.G. John. 2013. *Reductions in labour capacity from heat stress under climate warming*. Nature Climate Change, 3(6), 563–566.
[564] Lebot, V. and P. Siméoni. 2015. *Community Food Security: Resilience and Vulnerability in Vanuatu*. Human Ecology, 43(6), 827–842.
[565] Scott, D., S. Gössling and C.M. Hall. 2012. *International tourism and climate change.* Wiley Interdisciplinary Reviews: Climate Change, 3(3), 213-232.

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 valuable recreational diving sector, which is threatened by environmental degradation, loss of reeds, and coastal erosion.[566] One study has identified an explicit need for the Government of Vanuatu to take an active and direct role in adapting the nation's tourism sector to climate change.[567] At present, tourism can come into conflict with other sectors and research has pointed towards a need to actively pursue greater co-ordination, sustainability and benefit sharing. Agro-ecological tourism additionally has the potential to support traditional practices and preserve cultural knowledge.[568]

Table 40: Climate Stressors and Climate Risks Tourism

Stressors	Risk
Increased storm frequency and intensity, SLR Increased air and sea-surface temperatures Increased drought frequency and duration Ocean acidification	Loss of coastal and ocean ecosystems and biodiversity
	Reduced interest in tourism
	Reduced water availability
	Damage to hard and soft infrastructure
	Fewer products to sale to tourists

Source: USAID. 2018 Pacific Islands Climate Risk Profile.

In addition to direct physical impacts, climate change may affect the tourism sector in Vanuatu through global efforts to mitigate climate change. One possible manifestation is the increased cost of international flights. One study estimated that while the cost of achieving an emissions-target compatible tourism sector may be proportionately low (3.6%). Nonetheless the necessary increase in trip costs (estimated at $11 when averaging across every global trip but potentially higher on a long-haul destination such as Vanuatu) may reduce Vanuatu's attractiveness as a tourist destination.[569]

Disaster Risk Management/Reduction. Not only do Pacific islands such as Vanuatu face multiple hazards but, as climate change drivers hazard intensify, so the risk of simultaneous hazard or 'compound' hazard exposure.[570] At the same time Pacific nations face very considerable uncertainty around future changes which are enhanced by deficiencies in the current suite of climate models. In this context a focus on reducing vulnerability and alleviating the underlying drivers of risk is essential. One study has attempted to develop a framework for understanding and targeting resources at such drivers in Vanuatu.[571]

Vanuatu has been making progress in its disaster risk management, as evidenced by the effective advance warning systems which saved lives when Cyclone Pam struck in 2015.[572] Preparing for disaster both in terms of risk reduction and response can be challenging for the Pacific Islands

[566] Klint, L. M. et al. 2012. *Dive tourism in Luganville, Vanuatu: Shocks, stressors, and vulnerability to climate change.* Tourism in Marine Environments, 8(1–2), 91–109.
[567] Klint, L. M. et al. 2012. *Climate change adaptation in the Pacific Island tourism sector: analysing the policy environment in Vanuatu*. Current Issues in Tourism, 15(3), pp.247-274.
[568] Addinsall, C., B. Weiler, P. Scherrer, and K. Glencross. 2017. *Agroecological tourism: bridging conservation, food security and tourism goals to enhance smallholders' livelihoods on South Pentecost, Vanuatu*. Journal of Sustainable Tourism, 25(8), pp.1100-1116.
[569] Scott, D., S. Gössling, C.M. Hall, and P. Peeters. 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.
[570] Matthews, T., R.L. Wilby and C. Murphy. 2019. *An emerging tropical cyclone-deadly heat compound hazard*. Nature Climate Change, in press.
[571] Jackson, G., K. McNamara, and B. Witt. 2017. *A framework for disaster vulnerability in a small island in the Southwest Pacific: a case study of Emae island, Vanuatu*. International Journal of Disaster Risk Science, 8(4), pp.358-373. 2017.
[572] Handmer, J. & H. Iveson. *Cyclone Pam in Vanuatu: Learning from the low death toll*. Australian Journal of Emergency Management, The, 32(2), p.60.

with extremely limited resources. As of 2015, Vanuatu had a budget for disaster management of around $265,000 per year, and a disaster insurance facility of around $17 million. Analysis suggests that there is an annual probability of 91% and 22% respectively that demand will exceed these resources.[573] A lack of state and individual resource to cope with natural hazards is a particular issue with regards to food availability and the nation's dependence on imports, leading to frequent food poverty[574]

Studies have highlighted the need to better understand the health and well-being risks of climate-driven migration.[575]

Human Health and Nutrition. Human health is to be negatively affected through multiple, complex pathways related to climate change impacts. In most cases, climate change is expected to amplify existing health problems rather than introducing new ones. Direct health impacts, such as injury and death from increasingly frequent and or severe storms and heat exhaustion, will affect most Pacific Island nations, particularly for young children, older persons, and those in poverty. Indirect impacts related to water and food security are likely to affect all countries in the region to varying degrees. Increased frequency and intensity of storms can lead to worsening floods, which can damage infrastructure critical to health service delivery (e.g., hospitals, roads, clean water, and electricity). Additionally, flooding of coastal plains and mangroves and increases in extreme rainfall events could result in a corresponding increase in vector-borne illness, such as dengue fever. [576]

The broad human health risks of climate change in Pacific Island Countries were assessed in a 2016 study. Specifically flagged in Vanuatu were the health impacts of extreme weather events, heat-related illness, water security and safety, food security and malnutrition, vector-borne diseases, respiratory illnesses, non-communicable diseases, and a variety of other disorders.[577]

Table 41: Climate Stressors and Climate Risks: Health and Nutrition

Stressors	Risk
Increased temperatures Increased drought frequency and duration Increased storm frequency and intensity, SLR	Shifts in vector- and waterborne diseases
	Decreased nutrition and food security
	Reduced availability or increased disruption of health services
	Reduced water quality and availability
	Difficulty maintaining sanitation systems and practices.

Source: USAID. 2018 Pacific Islands Climate Risk Profile.

In terms of heat-related mortality research has placed a threshold of 35^{o}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.[578] Temperatures significantly lower than the 35^{o}C threshold of 'survivability' can still represent a major threat to human health. Climate change is expected to push global temperatures closer to this temperature 'danger zone' both through slow-onset warming and intensified heat waves.

[573] Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) and World Bank. 2015. *Vanuatu Country Note*.
[574] Feeny, S., et.al. 2013. *Household vulnerability and resilience to shocks: findings from Solomon Islands and Vanuatu.* Australian National University. Working Paper.
[575] Dannenberg, A.L., H. Frumkin, J.J. Hess and K.L. Ebi. 2019. *Managed retreat as a strategy for climate change adaptation in small communities: public health implications.* Climatic Change, pp.1-14.
[576] USAID. 2018 Pacific Islands Climate Risk Profile.
[577] Lachlan, M. et al. 2016. *Health Impacts of Climate Change in Pacific Island Countries: A Regional Assessment of Vulnerabilities and Adaptation Priorities*. Environmental Health Perspectives, 124(11), 1707–1714.
[578] Im, E. S., J.S. Pal and E.A.B. Eltahir. 2017. *Deadly heat waves projected in the densely populated agricultural regions of South Asia.* Science Advances, 3(8), 1–8.

Honda et al. (2014) utilized the A1B emissions scenario from CMIP3 (most comparable to RCP6.0) to estimate that without adaptation, annual heat-related deaths in the Australasian region, could increase by 211% by 2030 and 437% by 2050.[579] The potential reduction in heat-related deaths achievable by pursuing lower emissions pathways is significant, as demonstrated by Mitchell et al (2018).[580] Further research is required to better constrain estimates of Vanuatu's geographical range.

Sea-level rises pose a serious threat to the water security of Pacific nations due to the potential salinization of potable water sources. Saline intrusion to drinking water sources has been linked to the increased prevalence of hypertension during pregnancy[581] and, as 57% of the adult population in Vanuatu is overweight,[582] could contribute to increased levels of hypertension more generally. Fish related diet is also not as usual for Vanuatu as the present-day average levels of fish consumption (20 kg per person per year) must be increased up to 35 kg of fish per person each year to diversify their protein-diet sources.[583]

Multiple studies have found that increased temperatures, drought, and rainfall are correlated with increases in reported levels of diarrheal disease,[584] including specifically in the Pacific Island region.[585] 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. Research by Singh et al. (2001)[586] demonstrated a clear link between annual average temperature and average reporting rates of diarrheal disease specifically amongst Pacific island states.

Island Ecology and biodiversity. Sea-level rise does not only threaten humans residing on Pacific islands, but also their unique island ecosystem functions and ecology. Indeed, island biodiversity faces a variety of human pressures.[587] Research has shown that inundation of low-lying islands has the potential to remove important refuges for migrating sea birds.[588] 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 about the terrestrial ecology of low-lying Pacific islands, for example endemic lizards, which may become trapped in a shrinking habitat.[589] Research has also highlighted the risks to biodiversity

[579] Honda, Y. et al. 2014. *Heat-related mortality risk model for climate change impact projection*. Environmental Health and Preventive Medicine 19: 56-63.

[580] Mitchell, D. et al. 2018. *Extreme heat-related mortality avoided under Paris Agreement goals*. Nature Climate Change, 8(7), 551–553.

[581] Khan, A.E. et al. 2011. *Drinking water salinity and maternal health in coastal Bangladesh: implications of climate change*. Environmental health perspectives, 119(9), 1328-1332.

[582] World Health Organization (WHO). 2020. *Global Health Observatory Repository*. https://www.who.int/gho/ncd/risk_factors/overweight/en/

[583] Pouteau, R. and P. Birnbaum. 2016. *Island biodiversity hotspots are getting hotter: vulnerability of tree species to climate change in New Caledonia.* Biological Conservation, 201, 111–119.

[584] Zhou, X. et al. 2013. *High temperature as a risk factor for infectious diarrhea in Shanghai, China.* Journal of epidemiology, JE20130012; and Wu, X. et al. 2016. *Impact of climate change on human infectious diseases: Empirical evidence and human adaptation.* Environment International, 86, 14–23.

[585] Singh, R. B. et al. 2001. *The influence of climate variation and change on diarrheal disease in the Pacific Islands.* Environmental health perspectives, 109(2), 155-159.

[586] Singh, R. B. et al. 2001. *The influence of climate variation and change on diarrheal disease in the Pacific Islands.* Environmental health perspectives, 109(2), 155-159.

[587] Jupiter, S., S. Mangubhai and R.T. Kingsford. 2014. *Conservation of Biodiversity in the Pacific Islands of Oceania: Challenges and Opportunities*. Pacific Conservation Biology, 20(2), 206–220.

[588] Reynolds, M. H., et.al. 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

[589] Taylor, S. and L. Kumar. 2016. *Global Climate Change Impacts on Pacific Islands Terrestrial Biodiversity: A Review*. Tropical Conservation Science, 9(1), 203–223.

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%.[590]

Marine and coastal ecosystems provide benefits for all people in Vanuatu. Yet, these ecosystem services often remain invisible.[591] Only through fisheries, as the population's livelihood, are these resources appreciated. Impacts on the actual harvest of these fresh marine/ reef goods are severely affected by factors such as coral bleaching and destruction of the coral reef system.[592]

[590] Pouteau, R. and P. Birnbaum. 2016. *Island biodiversity hotspots are getting hotter: vulnerability of tree species to climate change in New Caledonia.* Biological Conservation, 201, 111–119.
[591] Marine and Coastal Biodiversity Management in Pacific Island Countries (MACBIO). *Vanuatu Profile*. N.D.http://macbio-pacific.info/vanuatu/#prettyPhoto
[592] Pouteau, R., & P. Birnbaum. 2016. *Island biodiversity hotspots are getting hotter: vulnerability of tree species to climate change in New Caledonia.* Biological Conservation, 201, 111–119.