CLIMATE RISK COUNTRY PROFILE

PAPUA NEW GUINEA

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ACKNOWLEDGEMENTS

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

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

CONTENTS

FOREWORD

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

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

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

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

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

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

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

KEY MESSAGES

- Projections suggest warming in Papua New Guinea (PNG) could be similar to, or very slightly below, the global average. Warming of around 3.6°C is projected by the 2090s, compared to the 1986–2005 baseline under the highest emissions pathway (RCP8.5).
- Minimum and maximum temperatures are expected to rise considerably faster than average temperatures, potentially amplifying risks to human health and ecosystems.
- Understanding of climate-related risks in PNG is hindered both by the lack of study of localized historical and future climate changes, and by the limited data on many aspects of social vulnerability.
- Available evidence suggests that without significant global mitigation and local adaptation action PNG's communities face very significant increases in disaster risk as a result of climate change. These risks are likely to disproportionately burden the poorest communities.
- Hazards such as flash flooding, landslide, and coastal flooding are all likely to intensify. The population affected by river flooding, and its economic damages, are both projected to double by 2030.
- Exposure to hazards is significant and likely to increase, with many rural communities living in flood and landslide risk areas, and coastal communities and infrastructure exposed to sea-level rise with potential amplification of future storm surges.
- Extreme heat is very likely to present a human health risk in PNG as temperatures will move closer to unsafe levels under even lower emissions pathways. Health risks associated with potential new exposure to diseases are poorly understood.
- The degradation of natural resources is likely, as well as shifts in the viable ranges for plant and animal species, potentially reducing agricultural yields, and accelerating the decline of PNG's unique ecosystems.

COUNTRY OVERVIEW

Located in the South West Pacific, Papua New Guinea (PNG) comprises the eastern half of New Guinea island, four additional islands (Manus, New Ireland, New Britain, and the Autonomous Region of Bougainville), and around 600 smaller islets and atolls. PNG is home to a diverse range of ecosystems, including mountain glaciers, humid tropical rainforests, swampy wetlands, and coral reefs. In addition to harboring abundant natural resources such as gold, copper, oil and natural gas, PNG boasts 7% of the world's biodiversity.[1] Agriculture, fishing, community forestry, and small-scale mining are primary livelihood activities in rural areas. PNG is undergoing economic and social transformation and with such a highly dispersed and remote population with 87% of Papua New Guineans living in rural areas, poverty, poor infrastructure, corruption, safety and security concerns, among other factors, all heighten the vulnerability of the local population (**Table 1**).

Widespread poverty, poor infrastructure, corruption, safety and security concerns, among other factors, all heighten the vulnerability of the local population across PNG. PNG ranked 155rd out of 189 countries surveyed in the 2020

[1] UNEP and GEF (2010). Papua New Guinea's Fourth National Report to the Convention on Biological Diversity. United Nations Environment Programme. URL: https://www.sprep.org/attachments/VirLib/PNG/fourth-report-cbd-2010.pdf

UNDP Human Development Report.[2] PNG is already prone to numerous natural hazards, and climate variability and change may increase their incidence. Landslides, soil erosion, deforestation, loss of biodiversity, as well as increase occurrence of recurrent floods and droughts.

The Climate Change and Development Authority (CCDA)[3] is the coordinating body for all climate change related policies and is tasked with ensuring a path of climate-compatible growth. Towards this goal, the government launched a 40-year development strategy in October 2009 called "PNG Vision 2050" to develop sustainable development measures in all sectors and increase resilience to the impacts of climate and environmental changes. In May 2015, the PNG Government passed the Climate Change Bill, to become the first nation in the Pacific region to implement a law that will, among other things, minimizes the effects of climate change as a result of infrastructural development. PNG ratified the Paris Climate Agreement on September 21, 2016 and submitted its Intended Nationally Determined Contribution (NDC) to the UNFCCC in 2016 and its Enhanced Nationally Determined Contribution in 2020. PNG also published its Second National Communication (NC2) in 2014, which identifies sea level rise, agriculture and food security, landslides and risks to public health as the greatest impacts to the country from climate change.[4]

TABLE 1. Key indicators

Indicator	Value	Source
Population Undernourished[5]	Unknown (2017–2019)	FAO, 2020
National Poverty Rate[6]	37.5% (2017)	ADB, 2020a
Share of Income Held by Bottom 20%[7]	5.1% (2009)	World Bank, 2021
Net Annual Migration Rate[8]	–0.01% (2015–2020)	UNDESA, 2019
Infant Mortality Rate (Between Age 0 and 1)[9]	4.2% (2015–2020)	UNDESA, 2019
Average Annual Change in Urban Population[10]	2.5% (2015–2020)	UNDESA, 2018
Dependents per 100 Independent Adults[11]	63 (2020)	UNDESA, 2019
Urban Population as % of Total Population[12]	13.2% (2019)	CIA, 2020
External Debt Ratio to GNI[13]	78.4% (2018)	ADB, 2020b
Government Expenditure Ratio to GDP[14]	19.5% (2019)	ADB, 2020b

2 UNDP (2020). Human Development Reports: 2020 Statistical Update. United Nations Development Programme. URL: http://hdr.undp.org/en/countries/profiles/PNG
3 CCDA replaced the Office of Climate Change and Development (OCCD) in January, 2016.
4 Papua New Guinea (2014). Second National Communication. URL: https://unfccc.int/sites/default/files/resource/Pngnc2.pdf
5 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/
6 ADB (2020a). Basic Statistics 2020. URL: https://www.adb.org/publications/basic-statistics-2020 [accessed 27/01/21]
7 World Bank (2021). Income share held by lowest 20%. URL: https://data.worldbank.org/ [accessed 25/10/2021]
8 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 CIA (2020). The World Factbook. Central Intelligence Agency. Washington DC. URL: : https://www.cia.gov/the-world-factbook/
13 ADB (2020b). Key Indicators for Asia and the Pacific 2020. Asian Development Bank. URL: https://www.adb.org/publications/key-indicators-asia-and-pacific-2020
14 ADB (2020b). Key Indicators for Asia and the Pacific 2020. Asian Development Bank. URL: https://www.adb.org/publications/key-indicators-asia-and-pacific-2020

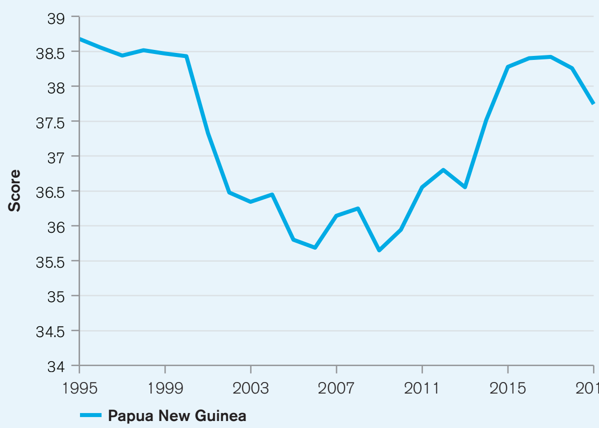
Green, Inclusive and Resilient Recovery

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

This document aims to succinctly summarize the climate risks faced by PNG. This includes rapid onset and long-term changes in key climate parameters, as well as impacts of these changes on communities, livelihoods and economies, many of which are already underway. This is a high-level synthesis of existing research and analyses, focusing on the geographic domain of PNG, therefore potentially excluding some international influences and localized impacts. The core data presented is sourced from the database sitting behind the World Bank Group's Climate Change Knowledge Portal (CCKP), incorporating climate projections from the Coupled Model Inter-comparison Project Phase 5 (CMIP5). This document is primarily meant for WBG staff to inform their climate actions. The document also aims to direct the reader to many useful sources of secondary data and research.

Due to a combination of political, geographic, and social factors, PNG is recognized as vulnerable to climate change impacts, ranked 153rd out of 182 countries in the 2020 ND-GAIN Index.[15] The ND-GAIN Index ranks 182 countries using a score which calculates a country's vulnerability to climate change and other global challenges as well as their readiness to improve resilience. The more vulnerable a country is the lower their score, while the more ready a country is to improve its resilience the higher it will be. Norway has the highest score and is ranked 1st. **Figure 1** is a time-series plot of the ND-GAIN Index showing PNG's progress.

FIGURE 1. The ND-GAIN Index (Score 0–100) summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. It aims to help businesses and the public sector better prioritize investments for a more efficient response to the immediate global challenges ahead.



[15] University of Notre Dame (2020). Notre Dame Global Adaptation Initiative. URL: https://gain.nd.edu/our-work/country-index/

Climate Baseline

Overview

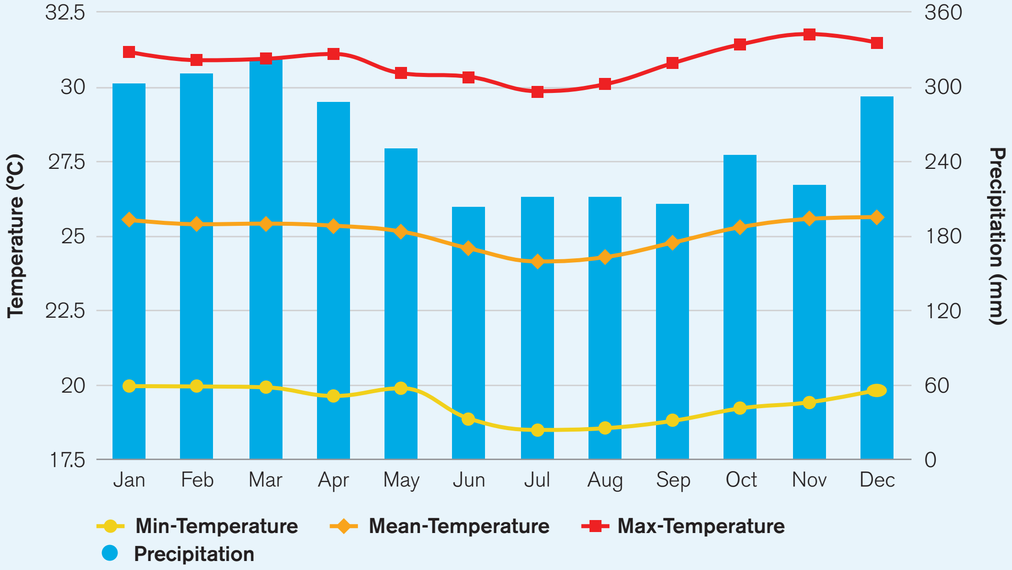
PNG has a monsoonal climate characterized by high temperatures and humidity throughout the year. Mean temperatures in Port Moresby range between 26°C and 28°C, with maximum temperatures of 30°C to 32°C year-round, for the latest climatology, 1991–2020 (**Figure 2**). Two monsoon seasons are recognized: 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. 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.[16] **Figure 3** shows the spatial differences of observed historical temperature and rainfall in PNG.

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.

[16] Papua New Guinea (2014). Second National Communication. URL: https://unfccc.int/sites/default/files/resource/Pngnc2.pdf

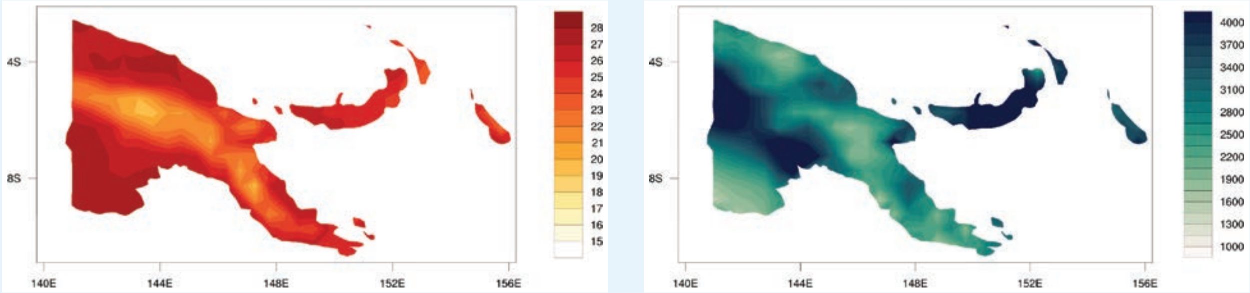
Annual Cycle

FIGURE 2. Average monthly mean, max, and min temperatures and rainfall in PNG (1991–2020)[17]



Spatial Variation

FIGURE 3. Annual mean temperature (°C) (left), and annual mean rainfall (mm) (right) in PNG over the period 1991–2020[18]



[17] WBG Climate Change Knowledge Portal (CCKP, 2021). Papua New Guinea Climate Data: Historical. URL: https://climateknowledgeportal.worldbank.org/country/papua-new-guinea/climate-data-historical

[18] WBG Climate Change Knowledge Portal (CCKP, 2021). Papua New Guinea Climate Data: Projections. URL: https://climateknowledgeportal.worldbank.org/country/papua-new-guinea/climate-data-projections

Key Trends

Temperature

The Berkeley Earth dataset can be used to estimate temperature changes over the 20th century. Warming over PNG'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.[19,20]

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 700 mm and 1,400 mm. This variation is influenced by El Niño Southern Oscillation, with El Niño events typically associated with below average annual rainfall[18] and drought.[21] 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.

> **A Precautionary Approach**
>
> Studies published since the last iteration of the IPCC's report (AR5), such as Gasser et al. (2018), have presented evidence which suggests a greater probability that earth will experience medium and high-end warming scenarios than previously estimated.[22] Climate change projections associated with the highest emissions pathway (RCP8.5) are presented here to facilitate decision making which is robust to these risks.

Climate Future

Overview

The main data source for the World Banks' Climate Change Knowledge Portal (CCKP) is the Coupled Model Inter-comparison Project Phase 5 (CMIP5) models, which are utilized within the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), providing estimates of future temperature and precipitation. Four Representative Concentration Pathways (i.e. RCP2.6, RCP4.5, RCP6.0, and RCP8.5) were selected and defined by their total radiative forcing (cumulative measure of GHG emissions from all sources) pathway and level by 2100. In this analysis RCP2.6 and RCP8.5, the low and high emissions pathways, are the primary focus RCP2.6 represents a very strong mitigation scenario, whereas RCP8.5 assumes a high-emissions scenario. For more information, please refer to the RCP Database.

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

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

21 Lyon, B. (2004). The strength of El Nino and the spatial extent of tropical drought. Advances in Geosciences, 31. URL: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2004GL020901

22 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. URL: http://pure.iiasa.ac.at/id/eprint/15453/

For PNG, these models show a trend of consistent warming that will be more significant for inland regions as compared to coastal areas. Rainfall projections are less certain. **Tables 2** and **3** below, provide information on temperature projections and anomalies for the four RCPs over two distinct time horizons; presented against the reference period of 1986–2005.

TABLE 2. Projected anomaly (changes °C) for maximum, minimum, and average daily temperatures in PNG for 2040–2059 and 2080–2099, from the reference period of 1986–2005 for all RCPs. The table is showing the median of the CCKP model ensemble and the 10–90th percentiles in brackets[23]

	Average Daily Maximum Temperature		Average Daily Temperature		Average Daily Minimum Temperature	
Scenario	**2040–2059**	**2080–2099**	**2040–2059**	**2080–2099**	**2040–2059**	**2080–2099**
RCP2.6	0.8 (0.1, 1.8)	0.8 (0.0, 1.8)	0.9 (0.3, 1.6)	0.9 (0.2, 1.6)	0.9 (0.3, 1.5)	0.9 (0.2, 1.6)
RCP4.5	1.1 (0.4, 2.0)	1.5 (0.7, 2.6)	1.1 (0.6, 1.8)	1.6 (1.0, 2.4)	1.2 (0.6, 1.8)	1.6 (1.0, 2.4)
RCP6.0	1.0 (0.2, 2.3)	1.9 (1.0, 3.3)	1.0 (0.5, 1.8)	2.0 (1.3, 3.0)	1.1 (0.5, 1.7)	2.1 (1.3, 2.9)
RCP8.5	1.5 (0.7, 2.5)	3.2 (2.1, 4.7)	0.5 (0.9, 2.3)	3.3 (2.4, 4.5)	1.6 (1.0, 2.3)	3.4 (2.5, 4.5)

TABLE 3. Projections of average temperature change (°C) in PNG 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.[22]

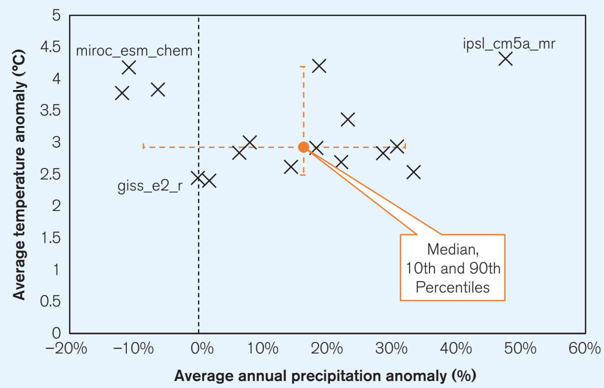
	2040–2059		2080–2099	
Scenario	**Jun–Aug**	**Dec–Feb**	**Jun–Aug**	**Dec–Feb**
RCP2.6	0.9 (0.1, 1.7)	0.8 (0.4, 1.4)	0.9 (0.0, 1.8)	0.8 (0.3, 1.4)
RCP4.5	1.2 (0.5, 1.9)	1.1 (0.6, 1.7)	1.6 (0.8, 2.5)	1.5 (1.0, 2.3)
RCP6.0	1.1 (0.3, 1.8)	1.0 (0.6, 1.7)	2.1 (1.1, 3.0)	1.9 (1.3, 2.9)
RCP8.5	1.6 (0.8, 2.5)	1.5 (0.9, 2.2)	3.5 (2.3, 4.6)	3.1 (2.5, 4.3)

[23] WBG Climate Change Knowledge Portal (CCKP, 2021). Papua New Guinea Climate Data: Projections. URL: https://climateknowledgeportal.worldbank.org/country/papua-new-guinea/climate-data-projections

Model Ensemble

Climate projections presented in this document are derived from datasets available through the CCKP, unless otherwise stated. These datasets are processed outputs of simulations performed by multiple General Circulation Models (GCM) (for further information see Flato et al., 2013).[24] 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. The range of projections from 16 GCMs for annual average temperature change and annual precipitation change in PNG under RCP8.5 is shown in **Figure 4**. Spatial variation of future projections of annual temperature and precipitation for mid and late century under RCP8.5 are presented in **Figure 5**.

FIGURE 4. 'Projected average temperature anomaly' and 'projected annual rainfall anomaly' in PNG. Outputs of 16 models within the ensemble simulating RCP8.5 over the period 2080–2099. Models shown represent the subset of models within the ensemble which provide projections across all RCPs and therefore are most robust for comparison.[25] Three models are labelled.

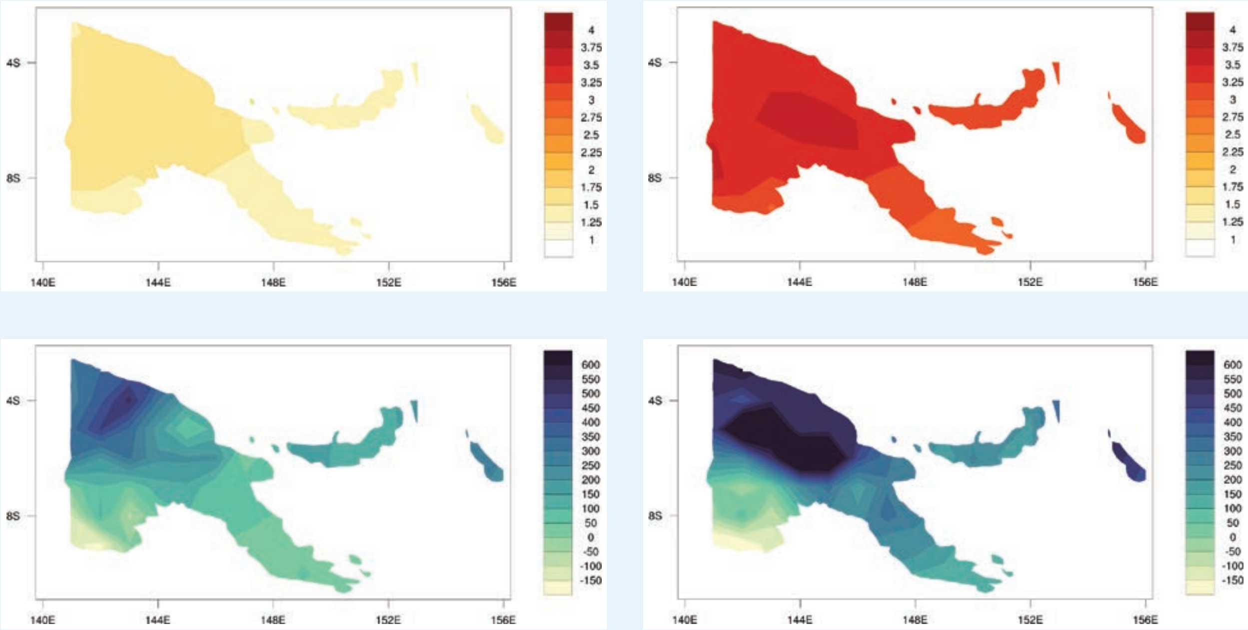


[24] Flato, G., Marotzke, J., Abiodun, B., Braconnot, P., Chou, S. C., Collins, W., . . . Rummukainen, M. (2013). Evaluation of Climate Models. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 741–866. URL: http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf

[25] WBG Climate Change Knowledge Portal (CCKP, 2021). Climate Data: Projections. URL: https://climateknowledgeportal.worldbank.org/country/papua-new-guinea/climate-data-projections.

Spatial Variation

FIGURE 5. CMIP5 ensemble projected change (32 GCMs) in annual temperature (top) and precipitation (bottom) by 2040–2059 (left) and by 2080–2090 (right) relative to 1986–2005 baseline under RCP8.5[26]



Temperature

Projections of future temperature change are presented in three primary formats. Shown in **Table 2** are the changes (anomalies) in daily maximum and daily minimum temperatures over the given time period, as well as changes in the average temperature. **Figures 6** and **7** display the monthly and annual average temperature projections. While similar, these three indicators can provide slightly different information. Monthly and annual average temperatures are most commonly used for general estimation of climate change, but the daily maximum and minimum can explain more about how daily life might change in a region, affecting key variables such as the viability of ecosystems, health impacts, productivity of labor, and the yield of crops, which are often disproportionately influenced by temperature extremes.

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 neighboring ocean cover. Work by the Australian Bureau of Meteorology and CSIRO[18] 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.

[26] WBG Climate Change Knowledge Portal (CCKP, 2021). Climate Data: Projections. URL: https://climateknowledgeportal.worldbank.org/country/papua-new-guinea/climate-data-projections.

FIGURE 6. Historic and projected average annual temperature in PNG under RCP2.6 (blue) and RCP8.5 (red) estimated by the CCKP model ensemble. Shading represents the standard deviation of the model ensemble.[27]

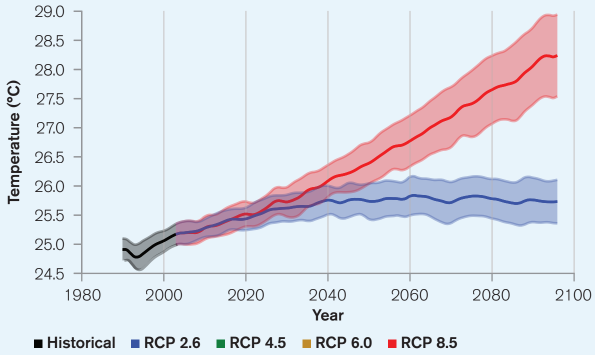
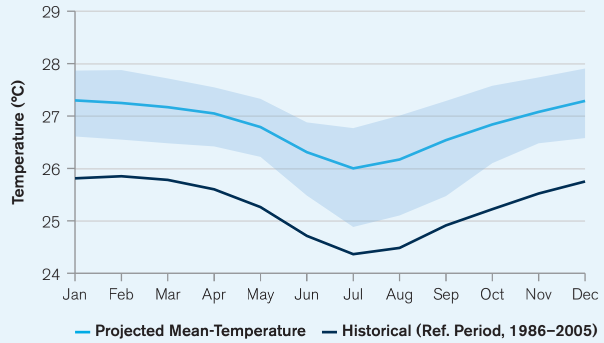


FIGURE 7. Projected monthly temperature, in relation to the Historical Reference Period, 1986–2005, for PNG for the period 2040–2059 under RCP8.5. The value shown represents the median of the model ensemble with the shaded areas showing the 10th–90th percentiles.[26]

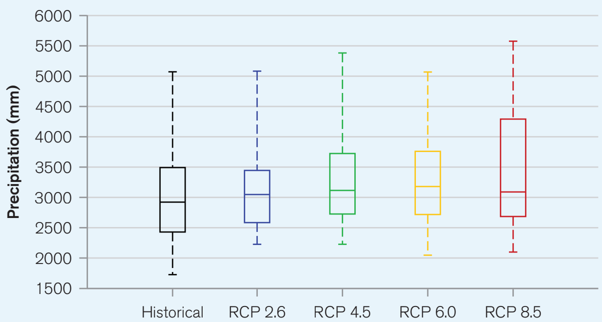


The CCKP model ensemble projects median warming of 3.3°C by the 2090s under the highest emissions pathway (RCP8.5) relative to the 1986–2005 baseline. This projection falls to 0.9°C under the lowest emissions pathway (RCP2.6). Projected rates of warming are typically 20–30% lower than the global average, but should be treated with extreme caution. 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. As seen in **Figure 7**, warming is projected to increased throughout the year.

Precipitation

While most models project an increase in the average annual precipitation in PNG (**Figure 3**) uncertainty remains high, as indicated by the range and interquartile ranges shown in **Figure 8**. Lafale et al. (2018) suggest medium confidence should be placed in the projected future trend of increased annual precipitation.[28] 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

FIGURE 8. Boxplots showing the projected average annual precipitation for PNG in the period 2080–2099[26]



[27] WBG Climate Change Knowledge Portal (CCKP, 2021). Papua New Guinea Climate Data: Projections. URL: https://climateknowledgeportal.worldbank.org/country/papua-new-guinea/climate-data-projections

[28] Lafale, P., Diamond, H., Anderson, C. (2018). Effects of climate change on extreme events relevant to the Pacific Islands. Science Review 2018: 50–73. URL: https://reliefweb.int/sites/reliefweb.int/files/resources/1_Climate_change_overview.pdf

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 regions of Asia and the Pacific.[29] However, as this phenomenon is highly dependent on local geographical contexts further research is required to constrain its impact in 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.[30,31]

CLIMATE RELATED NATURAL HAZARDS

PNG is one of the countries most at-risk to climate change and natural disasters. The high levels of disaster risk faced in PNG are reflected in its ranking in the 2019 INFORM Risk Index,[32] ranking 28th out of 191 countries (**Table 4**). PNG's ranking is driven by moderate levels of exposure to flood, 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. The section that follows explores the exposure component of risk in PNG. As seen in **Figure 1**, the ND-GAIN Index presents an overall picture of a country's vulnerability and capacity to improve its resilience. In contrast, the Inform Risk Index identifies specific risks across a country to support decisions on prevention, preparedness, response and a country's overall risk management.

TABLE 4. Selected indicators from the INFORM 2019 Index for risk management for PNG. For the sub-categories of risk (e.g. "Flood") higher scores represent greater risks. Conversely the most at-risk country is ranked 1st. Global average scores are shown in brackets.

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]	5.1 [3.6]	7.3 [4.5]	5.7 [3.8]	28

29 Westra, S., Fowler, H. J., Evans, J. P., Alexander, L. V., Berg, P., Johnson, F., Kendon, E. J., Lenderink, G., Roberts, N. (2014). Future changes to the intensity and frequency of short-duration extreme rainfall. Reviews of Geophysics, 52, 522–555. URL: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014RG000464

30 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. URL: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016JD024964

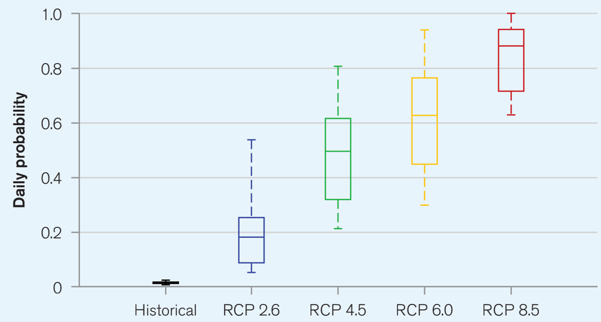
31 Chen, C., Cane, M.A., Wittenberg, A.T. and Chen, D. (2017). ENSO in the CMIP5 simulations: life cycles, diversity, and responses to climate change. Journal of Climate, 30, 775–801. URL: https://journals.ametsoc.org/jcli/article/30/2/775/96236/ENSO-in-the-CMIP5-Simulations-Life-Cycles

32 European Commission (2019). INFORM Index for Risk Management. Timor-Leste Country Profile. URL: https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk/Country-Profile/moduleId/1767/id/386/controller/Admin/action/CountryProfile

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%.[26] 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 are projected to dramatically increase the frequency of heat waves in future. As shown in **Figure 9** by the 2090s 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 the 2090s. 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 9. Projected change in the probability of observing a heat wave in PNG for the period 2080–2099. 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.[26]



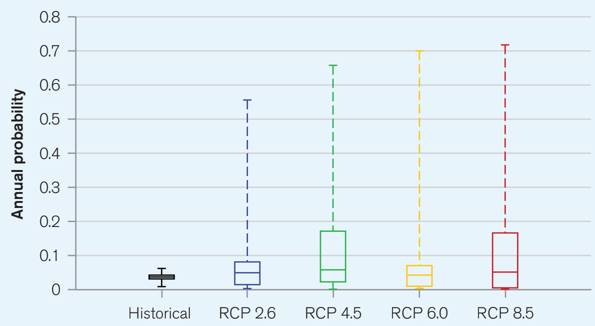
Drought

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.[33]

[33] McVicar, T.R. and Bierwirth, P.N. (2001). Rapidly assessing the 1997 drought in Papua New Guinea using composite AVHRR imagery. International Journal of Remote Sensing, 22(11), pp. 2109–2128. URL: https://www.tandfonline.com/doi/abs/10.1080/01431160120728

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 suggest significant increases in the probability of drought (**Figure 10**). Naumann et al., who provide regionalized estimates of future drought frequencies, suggest a large increase in drought frequency in the Oceania region.[34] 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.[27] In part this uncertainty reflects our poor understanding of how climate change will impact on the ENSO phenomenon which can drive drought in PNG.[30] Further research is urgently required to constrain projections of future drought severity and frequency.

FIGURE 10. Boxplots showing the annual probability of experiencing a 'severe drought' in PNG (–2 SPEI Index) in 2080–2099 under four emissions pathways[26]



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.[35] PNG experiences coastal, river (fluvial), and surface (pluvial) flooding. The country's NC2 suggests that at least 22,000 people are affected annually by river flooding, causing average damages of over $8 million.[36] The World Resources Institute's AQUEDUCT Global Flood Analyzer[37] 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 damages 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 estimates a total average annual loss to flood in the region of 0.5% of annual GDP.[38]

[34] Naumann, G., Alfieri, L., Wyser, K., Mentaschi, L., Betts, R. A., Carrao, H., . . . Feyen, L. (2018). Global Changes in Drought Conditions Under Different Levels of Warming. Geophysical Research Letters, 45(7), 3285–3296. URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2017GL076521

[35] UNDP (2018). National Adaptation Plan process in focus: Lessons from Papua New Guinea. United Nations Development Programme. URL: https://www.undp.org/content/undp/en/home/librarypage/climate-and-disaster-resilience-/national-adaptation-plan-process-in-focus—lessons-from-Papua-New-Guinea.html

[36] Papua New Guinea (2014). Second National Communication. URL: https://unfccc.int/sites/default/files/resource/Pngnc2.pdf

[37] WRI (2018). AQUEDUCT Global Flood Analyzer. URL: https://floods.wri.org/# [Accessed: 22/11/2018]

[38] UNISDR (2014). PreventionWeb: Basic country statistics and indicators. URL: https://www.preventionweb.net/countries

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.[39] There is good agreement among models on this trend. As shown in **Table 5** 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.

TABLE 5. Estimated number of people in PNG 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. Figures represent an average of all four RCPs and assume present day population distributions.[40]

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

A further and poorly documented risk in PNG is that of landslide. 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.[41] PNG is exposed to earthquakes on a regular basis, with 10 earthquakes of magnitude 7.0 and above experienced between 2014–2018,[42] these have been known to trigger some of the highest impact, 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 soils are degraded. Indeed, one study suggested around 60% of landslides are triggered by rainfall.[40] These phenomena link landslide risk to climate change and to expected increases in rainfall intensity. The CCKP model ensemble projects increases in both the intensity of high rainfall events and the frequency of wet days.[26] Research has linked short-duration, high intensity, rainfall to increased probability of moderate to high impact landslide events in PNG,[43] signifying the potential for climate change to exacerbate landslide risk.

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[39] Paltan, H., Allen, M., Haustein, K., Fuldauer, L., & Dadson, S. (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. URL: https://iopscience.iop.org/article/10.1088/1748-9326/aad985/meta

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

[41] Robbins, J. C., & Petterson, M. G. (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. URL: https://nhess.copernicus.org/preprints/nhess-2015-203/

[42] USGS (2019). Earthquake Data. URL: https://earthquake.usgs.gov/ [accessed 30/01/2019]

[43] 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. URL: https://www.sciencedirect.com/science/article/pii/S0022169416304140

Cyclones and Storm Surge

Every decade around 15 tropical cyclones pass through PNG's exclusive economic zone, around a quarter of which are 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.[27] 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.[44] 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 windspeed and precipitation intensity. Modelling of climate change impacts on cyclone intensity and frequency conducted across the globe points to a general trend of reduced cyclone frequency but increased intensity and frequency of the most extreme events.[45] This finding is supported for PNG by modelling conducted by Australian Aid.[46] 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 Australian Bureau of Meteorology and CSIRO.[18] 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.

CLIMATE CHANGE IMPACTS

Natural Resources

Water

The water sector in PNG faces major challenges. A report by Water Aid in 2018[47] suggested PNG's population had the second lowest rate of access to a basic safe water supply in the world, at only 37%. The report emphasized that climate change threatens to slow progress on 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.

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[44] Smithers, S.G. and Hoeke, R.K. (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. URL: https://www.sciencedirect.com/science/article/pii/S0169555X14001767

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

[46] Australian Aid (2013). Current and future tropical cyclone risk in the South Pacific. Pacific Catastrophe Risk Assessment and Financing Initiative. URL: https://www.pacificclimatechange.net/document/current-and-future-tropical-cyclone-risk-south-pacific-south-pacific-regional-risk

[47] Water Aid (2018). The State of the World's Water 2018. URL: https://washmatters.wateraid.org/sites/g/files/jkxoof256/files/The%20Water%20Gap%20State%20of%20Water%20report%20lr%20pages.pdf

Other aspects of the climate change's impact on the water sector are less clear. One assessment suggested that by 2070 PNG could face annual water shortages of 124 mm due to combined climate change and human development.[48] However, this estimate was based on outdated climate modelling. 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. The high uncertainty around future precipitation trends, and particularly future ENSO and drought occurrence are unhelpful for planning future water resources management and highlight the need for disaster risk reduction measures. Effective water and flood management are vital to livelihoods in PNG, as well as human health, with a large proportion of the country directly or indirectly dependent on agriculture. PNG's Second National Communication sets out a wide variety of proposed adaptation strategies to protect against river and coastal flooding. Many of these strategies involve traditional 'hard' infrastructure development, such as dykes and sea-walls. Given the great intrinsic and ecosystem service value found in PNG's biodiversity nature-based adaptation strategies, such as upland afforestation, require further research and development.[49]

The Coastal Zone

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 0.44–0.74 m by the end of the 21st century by the IPCC's Fifth Assessment Report[50] but some studies published more recently have highlighted the potential for more significant rises (**Table 6**). 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 10 cm across the South Pacific region, meaning countries such as PNG should be prepared for above average sea-level rises.[18]

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.[51] The UK Met Office (2014) estimates 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 7**). Other impacts of sea-level rise include saline intrusion, which has already been documented damaging the production of small-holder farmers.[52] Sea-level rise also threatens the integrity of PNG's coastal resources and biodiversity. Notably, the mangrove forests found along New Guinea's north coast have been identified as vulnerable to submergence and loss.[53]

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[48] ADB (2013). Economic of Climate Change in the Pacific. Brochure: August 2013. Asian Development Bank. URL: https://www.adb.org/sites/default/files/publication/30372/economics-climate-change.pdf

[49] Papua New Guinea (2014). Second National Communication. URL: https://unfccc.int/sites/default/files/resource/Pngnc2.pdf

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

[51] Pacific Climate Change Portal (2018). Reported at UN Climate Change Conference COP23. URL: https://cop23.com.fj/papuanewguinea/

[52] Papua New Guinea (2014). Second National Communication. URL: https://unfccc.int/sites/default/files/resource/Pngnc2.pdf

[53] Lovelock, C. E., Cahoon, D. R., Friess, D. A., Guntenspergen, G. R., Krauss, K. W., Reef, R., . . . Triet, T. (2015). The vulnerability of Indo-Pacific mangrove forests to sea-level rise. Nature, 526, 559. URL: https://pubmed.ncbi.nlm.nih.gov/26466567/

TABLE 6. 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)[54].

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

TABLE 7. 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 PNG (UK Met Office, 2014)[55]

Scenario	Without Adaptation	With Adaptation
RCP2.6	34,310	130
RCP8.5	44,260	270

Fisheries and Coral Reefs

Coral reefs around PNG already face growing pressures from human development in upstream river basins and in the vicinity of the coast.[56] As outlined in the IPCC's 5th Assessment Report, Pacific coral reefs face a negative outlook under all climate change scenarios.[57] 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.[18] 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.[18] 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.

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

[55] UK Met Office (2014). Human dynamics of climate change: Technical Report. Met Office, UK Government. URL: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/climate/human-dynamics-of-climate-change/hdcc_alternative_version.compressed.pdf

[56] Tulloch, V.J., Brown, C.J., Possingham, H.P., Jupiter, S.D., Maina, J.M. and Klein, C., 2016. Improving conservation outcomes for coral reefs affected by future oil palm development in Papua New Guinea. Biological Conservation, 203, pp. 43–54. URL: https://www.sciencedirect.com/science/article/abs/pii/S0006320716303160

[57] Nurse, L., McLean, R., Agard, J., Briguglio, L., Duvat-Magnan, V., Pelesikoti, N., Tompkins, E. and Webb, A. (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. URL: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap29_FINAL.pdf

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 18.2–24.9kg/year.[58] Further research is also required to better understand the climate change impact on ocean fisheries. One study suggested PNG may experience a 30% decline in Skipjack Tuna catch by the end of the century under a high emissions scenario.[59]

Forests

PNG 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.[60] Forest products represent a major source of both household and export income. Over recent decades PNG has experienced major challenges in the forestry sector. Illegal and unsustainable logging, facilitated by poor governance, have led to rapid deforestation, and the benefits of forest exports have accrued disproportionately to the wealthiest groups in society.[61] 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.[62] 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. Study has been very 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.[63] These findings are supported by research from similar environments in other regions.[64]

Economic Sectors

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. On an international level, these impacts are expected to damage key staple crop yields, even on

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58 Gillett, R. (2009). Fisheries in the Economies of the Pacific Island Countries and Territories. Asian Development Bank. Manila. URL: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap29_FINAL.pdf

59 ADB (2013). The Economics of Climate Change in the Pacific. Full Report. Asian Development Bank. URL: https://www.adb.org/publications/economics-of-climate-change-in-the-pacific

60 Venter, M., Dwyer, J., Dieleman, W., Ramachandra, A., Gillieson, D., Laurance, S., Cernusak, L.A., Beehler, B., Jensen, R. and Bird, M.I. (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. URL: https://pubmed.ncbi.nlm.nih.gov/28560838/

61 Laurance, W. F., Kakul, T., Keenan, R. J., Sayer, J., Passingan, S., Clements, G. R., . . . Sodhi, N. S. (2011). Predatory corporations, failing governance, and the fate of forests in Papua New Guinea. Conservation Letters, 4(2), 95–100. URL: https://www.cabdirect.org/cabdirect/abstract/20113150298

62 Shearman, P. L., Ash, J., Mackey, B., Bryan, J. E., & Lokes, B. (2009). Forest Conversion and Degradation in Papua New Guinea 1972–2002. Biotropica, 41(3), 379–390. URL: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1744-7429.2009.00495.x

63 Maiguo, E., Keenan, R., & Nitschke, C. (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). URL: https://onlinelibrary.wiley.com/doi/full/10.1002/wcc.314

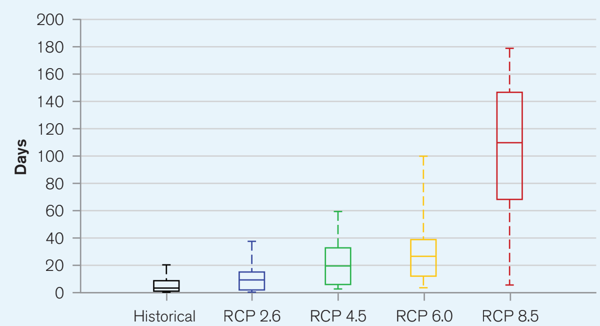
64 Struebig, M. J., Wilting, A., Gaveau, D. L. A., Meijaard, E., Smith, R. J., Abdullah, T., . . . Kramer-Schadt, S. (2015). Targeted Conservation to Safeguard a Biodiversity Hotspot from Climate and Land-Cover Change. Current Biology, 25(3), 372–378. URL: https://www.sciencedirect.com/science/article/pii/S0960982214015656

lower emissions pathways. Tebaldi and Lobell (2018)[65] 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°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.

The UNDP (2018) estimates that 70% of households in PNG remain dependent on subsistence agriculture.[35] These communities are highly vulnerable to climate-related hazards. A major drought associated with ENSO in 1997 highlighted the nation's food insecurity, with over a million people (around 20% of the population) facing food shortages. 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. It is significant then that a review of multiple studies suggested that sweet potato yields in PNG may decline by as much as 10% by 2050 as a result of changing climate conditions. Indeed, all the crops assessed, including cassava, maize, rice, sugarcane and taro, showed negative yield trends of a similar magnitude.[58] The rise in night-time minimum temperatures is believed to be a particularly important driver of these losses, with staple crops such as rice reported to have vulnerability in this regard.[66] In addition to losses due to changes in the suitability of the climate conditions, production losses are already being experienced in coastal areas due to saltwater contamination of soils and groundwater, and across the country due to flood and drought. Further areas of concern include the potential for greater incidences of pest and disease in a warmer world.[67] Across all of these areas there is a significant lack of high-quality research.

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. Work by Dunne et al. (2013) 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).[68] This phenomenon demands further investigation in the PNG context, given the expected increase in maximum temperatures towards dangerous levels (**Figure 11**). 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 11. Ensemble estimate of the annual number of very hot (Tmax >35°C) days in 2080–2099 under four emissions pathways in PNG[26]



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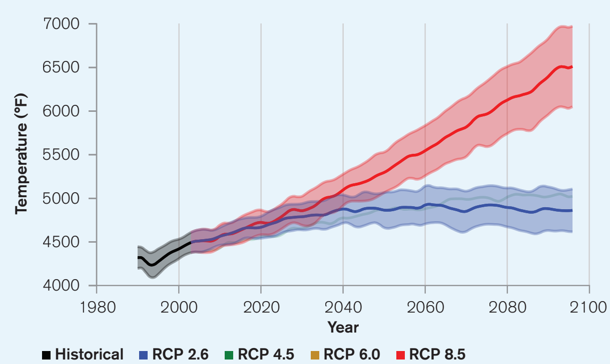
Urban and Energy

PNG's urbanized areas are dominated by informal settlements, making up about half of Port Moresby's residences.[69] These areas often lack basic infrastructure and due to low enforcement of spatial planning often develop 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.

As well as 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).[70] Generally the impact of an increase in temperature on these indicators depends on whether the temperature rise moves the ambient temperature closer to, or further away from, the optimum temperature range. The optimum range varies depending on local conditions and adaptations. In PNG, an increase in temperatures will almost certainly reduce productivity and hence living standards. As well as impacting on rural laborers there could be implications for urban dwellers and the service sector economy. In PNG, this is largely centered around Port Moresby, a city which is expected to surpass a population of one million before 2050.[68] The effects of heat stress in PNG's urban centers may amplify if the phenomenon of Urban Heat Island (UHI) develops with growth of built-up areas. If effective mitigation measures are not put in place dark surfaces, residential and industrial sources of heat, an absence of vegetation, and air pollution[71] could push temperatures higher than those of the rural surroundings, typically anywhere in the range of 0.1–3°C in global mega-cities.[72]

A very large increase in the amount of indoor cooling required in PNG is projected, particularly under higher emissions pathways (**Figure 12**). Research suggests that on average a one degree increase in ambient temperature can result in a 0.5–8.5% increase in electricity demand.[73] Notably this serves business and residential air conditioning systems. This increase in demand places strain on energy

FIGURE 12. Historic and projected annual cooling degree days in PNG (cumulative degrees above 65°F) under RCP2.6 (blue) and RCP8.5 (red). The values shown represent the median of the multi-model ensemble with the shaded areas showing the 10–90th percentiles.[26]



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[73] Santamouris, M., Cartalis, C., Synnefa, A., & Kolokotsa, D. (2015). 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. URL: https://www.sciencedirect.com/science/article/pii/S0378778814007907

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 efficiency.[74] Many of these issues, while understood on a theoretical level, are under-studied in PNG and there is an urgent needed for further work.

Transportation

Poor inter-regional and international transport connectivity have been identified as key factors hindering PNG's development progress, including ability to address poverty, malnourishment, 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 Medium Term Development Plan III (MTDP III) 2018–2022. This region also represents a hotspot of landslide risk.[40] 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 climate change. Mining relies on plentiful water supplies,[75] and like the transport network is susceptible to landslide impacts.[76]

Communities

Poverty, Inequality, and Disaster Vulnerability

Understanding vulnerability and deprivation in PNG can be challenging due to the very low availability of reliable data. As shown in **Table 1**, many headline metrics are unavailable. The UNDP report poverty rates of between 30–40% and an adult literacy rate of around 50%[77] and PNG has consistently ranked among the lowest 30 countries

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

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[77] UNDP (2019). About Papua New Guinea. URL: http://www.pg.undp.org/content/papua_new_guinea/en/home/countryinfo.html [accessed 14/02/2019]

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.[78]

UNISDR places the average annual economic losses to disaster at around 1% of GDP,[37] 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.[79] That same study estimates the number of people affected by natural hazards at 7 million between 1990–2012. Given inequalities within PNG, neither of these estimates capture 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.[80] 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 hazard 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.[81] A very significant adaptation and resilience building challenge is faced by PNG as it aims to protect its poorest communities from climate-related disasters.

Gender

An increasing body of research has shown that climate-related disasters have impacted human populations in many areas including agricultural production, food security, water management and public health. The level of impacts and coping strategies of populations depends heavily on their socio-economic status, socio-cultural norms, access to resources, poverty as well as gender. Research has also provided more evidence that the effects are not gender neutral, as women and children are among the highest risk groups. Key factors that account for the differences

[78] Tselios, V., & Tompkins, E. L. (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. URL: https://eprints.soton.ac.uk/425762/

[79] Noy, I. (2016). Natural disasters in the Pacific Island Countries: new measurements of impacts. Natural Hazards, 84(1), 7–18. URL: https://ideas.repec.org/a/spr/nathaz/v84y2016i1d10.1007_s11069-015-1957-6.html

[80] Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O. (2016) Heat, human performance, and occupational health: A key issue for the assessment of global climate change impacts. Annual Review of Public Health: 37: 97–112. URL: https://pubmed.ncbi.nlm.nih.gov/26989826/

[81] Harley, P., & Samanta, S. (2018). Modeling of inland flood vulnerability zones through remote sensing and GIS techniques in the highland region of Papua New Guinea. Applied Geomatics, 10(2), 159–171. URL: https://link.springer.com/article/10.1007/s12518-018-0220-8?shared-article-renderer

between women's and men's vulnerability to climate change risks include: gender-based differences in time use; access to assets and credit, treatment by formal institutions, which can constrain women's opportunities, limited access to policy discussions and decision making, and a lack of sex-disaggregated data for policy change.[82]

Human Health

Nutrition

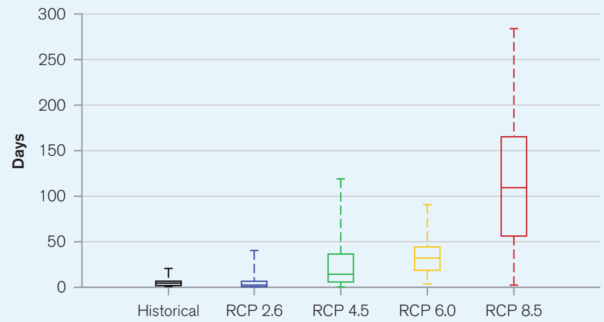
The World Food Program estimate that without adaptation the risk of hunger and child malnutrition on a global scale could increase by 20% respectively by 2050.[83] Work by Springmann et al. has assessed the potential for excess, climate-related deaths associated with malnutrition.[84] The authors identify two key risk factors that 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. Projections suggest there could be approximately 28.3 annual climate-related deaths per million population linked to lack of food availability in PNG by the year 2050 under RCP8.5.

Heat-Related Mortality

Research has placed a threshold of 35°C (wet bulb ambient air temperature) on the human body's ability to regulate temperature, beyond which even a very short period of exposure can present risk of serious ill-health and death.[85] 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. As shown in **Figure 13** days surpassing the 35°C threshold (Heat Index) are likely to become more frequent under all emissions pathways except RCP2.6 in PNG.

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.[86] The potential reduction in heat-related deaths achievable by pursuing lower emissions pathways is significant, as demonstrated by Mitchell et al.[87]

FIGURE 13. Historical (1986–2005) and projected (2080–2099) annual count of days with Heat Index >35°C under four emissions pathways in PNG[26]



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

[83] WFP (2015). Two minutes on climate change and hunger: A zero hunger world needs climate resilience. The World Food Programme. URL: https://docs.wfp.org/api/documents/WFP-0000009143/download/

[84] Springmann, M., Mason-D'Croz, D., Robinson, S., Garnett, T., Godfray, H. C. J., Gollin, D., . . . Scarborough, P. (2016). Global and regional health effects of future food production under climate change: a modelling study. The Lancet: 387: 1937–1946. URL: https://pubmed.ncbi.nlm.nih.gov/26947322/

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Disease

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,[88] and it is the cause of around 5% of hospital admissions.[89] 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.[90] Further research is required to understand potential future trends in climate-linked disease in PNG.

POLICIES AND PROGRAMS

National Adaptation Policies and Strategies

- Enhanced Nationally Determined Contribution (2020)
- Intended Nationally Determined Contribution (INDC) (2016)
- PNG Vision 2050 (2015)
- Second National Communication (2014)
- Adapting to Climate Change and Sustainable Energy Program (2014)
- National Climate Compatible Development Management Policy (2014)
- Initial National Communication (2000)

Climate Change Priorities of the WBG

WBG — Country Partnership Framework

The WBG and PNG have a Country Partnership Framework (CPF) for the period 2019–2023. The agreement lays out necessary engagement for climate change and disaster risk management took place under the first pillar of the agreement. Efforts are focused on the promotion of sound economic and natural resource management. as well as disaster risk management and climate change adaptation in agriculture and transport sectors; a climate change strategic framework; climate change stocktaking; and reducing the risks of disaster and climate variability.[91]

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88 UNICEF (2019). Data: Diarrhoeal Disease. URL: https://data.unicef.org/topic/child-health/diarrhoeal-disease/ [accessed 29/01/2019]

89 Toliman, P., Guwada, C., & Soli, K. (2013). A review of diarrhea aetiology in Papua New Guinea, 1995–2012. Papua New Guinea Medical Journal, 56(145–155). URL: https://pubmed.ncbi.nlm.nih.gov/26288933/

90 Wu, X., Lu, Y., Zhou, S., Chen, L., & Xu, B. (2016). Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. Environment International, 86, 14–23. URL: https://www.sciencedirect.com/science/article/pii/S0160412015300489

91 WBG (2019). Papua New Guinea — Country Partnership Framework, 2019–2023. URL: http://documents1.worldbank.org/curated/en/986831558749746464/pdf/Papua-New-Guinea-Country-Partnership-Framework-for-the-Period-FY19-FY23.pdf

CLIMATE RISK COUNTRY PROFILE

PAPUA NEW GUINEA

WORLD BANK GROUP