CLIMATE RISK COUNTRY PROFILE

YEMEN

WORLD BANK GROUP

Cover Photos: © Bill Lyons/World Bank, "Centuries old cistern in town of Hababa. Yemen." August 21, 2007 via Flickr, Creative Commons CC BY-NC-ND 2.0. © Curt Carnemark/World Bank "Women travel hours every day for water." August 13, 2007 via Flickr, Creative Commons CC BY-NC-ND 2.0.

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This profile is part of a series of Climate Risk Country Profiles developed by Climate Change Group of the World Bank Group (WBG). The country profiles aim to present a high-level assessment of the climate risks faced by countries, including rapid-onset events and slow-onset changes in climate conditions, many of which are already underway, as well as summarize relevant information on policy and planning efforts at the country level.

The country profile series are designed to be a reference source for development practitioners to better integrate detailed climate data, physical climate risks and need for resilience in development planning and policy making.

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Unless otherwise noted, data is sourced from the WBG's Climate Change Knowledge Portal (CCKP), the WBG's designated platform for climate data. Climate, climate change and climate-related data and information on CCKP represents the latest available 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 climate and development specialists, as well as climate research scientists and institutions for their advice and guidance on the use of climate related datasets.

CONTENTS

FOREWORD 1

KEY MESSAGES 2

COUNTRY OVERVIEW 4

OBSERVED AND CURRENT CLIMATE 8

Data Overview 8

Climate Overview. 8

Temperature 15

Precipitation 15

PROJECTED CLIMATE 17

Data Overview 17

Temperature 18

Precipitation 22

Extreme Precipitation Events 25

CLIMATE-RELATED NATURAL HAZARDS 26

Sea Level Rise and Sea Surface Temperature 27

Flood and Drought Risk 28

Earthquake, Volcano, and Landslide Hazards 29

KEY NATIONAL DOCUMENTS 30

ANNEX OF PROJECTED CLIMATE SCENARIOS 31

FOREWORD

Climate change is a major risk to good development outcomes and presents an existential threat to the World Bank Group's (WBG) twin goals of ending extreme poverty and promoting shared prosperity in a sustainable way. The WBG is thus committed to supporting client countries to invest in a low-carbon and climate-resilient future.

Our approach is outlined in the *WBG Climate Change Action Plan (CCAP) 2021–2025*, which focuses on helping countries integrate climate into their development agendas, with the goal to combine mitigation and adaptation with economic growth and poverty reduction. Guided by the *CCAP*, the WBG prioritizes climate action across five key systems: energy; agriculture, food, water, and land; cities; transport; and manufacturing. Only through transforming these systems can we begin to address climate change, achieve a resilient and low-carbon future, and support natural capital and biodiversity, while achieving development goals.

A key element of this strategy relies on the capacity to systematically incorporate and manage climate risks in development operations. We are thus investing in processes and tools that allow us to inform lending with climate data.

The Climate Change Knowledge Portal (CCKP) is an online 'one-stop-shop' for foundational climate data at the global, regional, and country levels. CCKP provides inputs to the WBG's Climate and Disaster Risk Screening Tool, which contributes to assessing short- and long-term climate and disaster risks in operations as well as national or sectoral planning processes.

Supplementing this effort, the *Climate Risk Country Profile* you are about to read is a signature product of CCKP which supports a better understanding of the impacts of physical climate risks. Guided by the Climate Risk Country Profile, WBG, key external partners, and development practitioners may conduct initial assessments of climate risks and opportunities that will eventually inform upstream country diagnostics, policy dialogue, and strategic planning for developing countries.

It is my hope that these efforts will spur the prioritization of long-term risk management and deepen the WBG's commitment to integrate adaptation planning into strategic country engagements and lending operations.

Jennifer J. Sara
Global Director
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KEY MESSAGES

- **<u>Observed Climate:</u>** Yemen has a tropical arid and semiarid climate along its coast and inland desert, and a subtropical and temperate climate in its highlands, with generally wide temperature ranges (average mean temperature of 25.54°C) and two monsoonal rainy and dry seasons annually (189.81 mm year-round).
- **<u>Observed Temperature:</u>** Between 1971 and 2020, Yemen's mean annual temperature increased by 0.42°C per decade, with large regional and seasonal differences accompanying a significantly increasing number of hot and humid days and nights.
  - **Northern interior regions** observed the greatest temperature changes over this period during summer and fall months.
- **<u>Projected Temperature:</u>** Under SSP3-7.0, Yemen's temperatures are projected to increase 0.76°C (0.35°C, 1.34°C) from an annual mean of 25.40°C during the historical reference period to 26.16°C (25.51°C, 26.92°C) for the period 2020–2039 and 1.64°C (1.00°C, 2.42°C) to 27.02°C (26.16°C, 28.00°C) for the period 2040–2059. Midcentury anomalies of 1.45°C (0.93°C, 2.19°C) above the reference period under SSP2-4.5 and 1.19°C (0.69°C, 1.81°C) under SSP1-2.6 are notably lower than under SSP3-7.0.
  - By midcentury under SSP3-7.0, **coastal governorates** are projected to experience greater mean temperature increases during winter and spring months, **highland governorates** during spring months, and **eastern interior governorates** during summer and fall.
  - Several **highland governorates** are expected to endure conditions characteristic of different climatic zones by midcentury under SSP3-7.0.
- **<u>Extreme Heat Risk:</u>** Yemen is projected to experience spatially and seasonally heterogeneous shifts in extreme heat conditions by midcentury. The following key metrics for temperature illustrate these risks under the SSP3-7.0 scenario for the period of 2040–2059, compared to the historical reference period of 1995–2014.
  - <u>Number of High Heat Index Days, Days Surpassing Heat Index of 35°C:</u> Yemen's high atmospheric moisture content over certain seasons makes the number of days surpassing the Heat Index >35°C annually increase 14.06 (4.62, 26.89) nationwide from the reference period by midcentury, but by higher anomalies subnationally along the coasts. This not only exacerbates human health concerns, but also presents risks to water and food security.
    - **Coastal regions** experienced the greatest projected increase in number of high Heat Index days annually by midcentury, with the largest increase of 51.40 (12.16, 79.05) days annually above the reference period in Hajjah, primarily during spring and fall months.
  - <u>Summer Days, T-max>25°C:</u> The annual number of days with a maximum temperature >25°C, increase 21.23 (13.52, 29.61) nationwide from the reference period by midcentury, concentrated in governorates with high elevations. An increase in the number of summer days with high maximum temperature thresholds coupled with tropical nights with high minimum temperature thresholds present elevated risks of prolonged heat exposure.
    - **The highlands** are projected to experience the greatest year-round increases in summer days by midcentury, with the largest anomalies during winter months. Ibb in the southern highlands is projected to experience the highest increase of 68.43 (31.59, 100.97) days annually above the reference period by midcentury.
  - <u>Number of Tropical Nights, T-min >20°C</u>: The number of tropical nights with a minimum temperature >20°C is projected to increase 36.45 (21.50, 51.49) from the reference period annually by midcentury. An increase in number of hot days, coupled with the rise in the number of tropical nights with high minimum temperature thresholds, magnify human health risks.

        - **The northern highlands** are projected to experience the greatest increases during summer months by midcentury. Raymah is projected to experience the highest increase of 64.90 (40.33, 86.00) nights annually above the reference period by midcentury.
    - Number of Tropical Nights, T-min>26°C: The number of tropical nights with a minimum temperature >26°C, an even higher minimum threshold, is projected to increase 34.99 (19.23, 51.51) annually nationwide above the reference period by midcentury, particularly along all coastal regions and parts of the eastern interior. The combination of increased hot days and tropical nights disproportionately concern: the elderly, pregnant women, children and newborns, people with chronic illnesses and disabilities, outdoor workers, low-wage earners, and people living in areas with poorly equipped and ill-prepared health services.
        - **Governorates along the coast and inland desert** are projected to experience the greatest increases during summer months by midcentury. Socotra is projected to experience the largest annual increase of 64.39 (43.17, 105.98) nights above the reference period by 2040–2059.
- **Observed Precipitation:** Over the 50-year period of 1971–2020, Yemen experienced a decrease in annual precipitation (–6.25 mm) per decade, though not significantly at a national level, and precipitation trends varied regionally and interannually.
    - **Western and southwestern coastal regions** observed significant decreases in precipitation over this time period, mostly during summer and fall months.
- **Projected Precipitation:** Projected precipitation volumes under SSP3-7.0 nationally signal increases by midcentury with seasonally and regionally distinct shifts outlined below, but with significant uncertainty.
    - **All regions** are expected to experience an annual increase in precipitation by 2040–2059 under SSP3-7.0, especially during summer months.
        - By midcentury, governorates (especially in the **northern highlands**) tend to experience the largest seasonal percent increases above the reference period typically during the wettest months of the year at median rates higher than 10%.
        - By midcentury, governorates (especially in the **central and southern highlands**) tend to experience median annual increases in intensity (according to average largest 5-day precipitation amounts) greater than 10 mm above the reference period.
- **Precipitation Risk:** By midcentury, Yemen is likely to experience more extreme precipitation intensities, though the timing and severity of extreme anomalies vary by region. The following key metrics for precipitation illustrate these shifts for the period of 2040–2059 under SSP3-7.0, compared to the historical reference period of 1995–2014.
    - Percent Change in Precipitation: Large percent changes in Yemen's total precipitation amounts, which are relatively low, can pose interannual and long-term challenges in water resources management. At the national level, precipitation totals increase by a median of 2.76% (–3.73%, 18.85%) annually from the 1995–2014 reference period under SSP3-7.0. However, they increase by greater anomalies subnationally and seasonally.
        - **Governorates in the Tihama and parts of the highlands** are projected to experience the greatest percent increases by midcentury, mostly during summer months. Annual precipitation totals increase the highest in Aden, 9.70% (–10.16%, 48.28%) above the historical reference period by midcentury.
    - Average Largest 5-Day Precipitation: Annual increases in the average largest precipitation amount over a 5-day period, which rise by an anomaly of 4.43 mm (–26.89 mm, 38.88 mm) nationally above the reference period by midcentury, pose risks for flood management and do not always coincide with months experiencing the largest anomalies in total projected precipitation volumes.
        - **The central and southern highlands** are expected to experience the biggest changes in average largest 5-day precipitation by midcentury, with locally varying seasonal patterns. Al Mahwit is expected to experience the largest increase annually above the reference period of 24.00 mm (–126.46 mm, 221.57 mm) by midcentury.

- **<u>Extreme Precipitation Occurrence:</u>** By midcentury, Yemen is likely to more frequently experience extreme precipitation event occurrence. These conditions pose risks for flood-related safety, health, and critical infrastructure.
    - **All governorates except the easternmost** are projected to be at least twice as likely to experience extreme events with 5-day cumulative precipitation amounts and 100-year historical return periods by midcentury under SSP3-7.0.
- **<u>Climate-Related Hazards:</u>**
    - Sea level rise, inundation, and erosion will increasingly threaten Yemen's coastline (**Tihama and Socotra**) by the end of the century.
    - Flooding across **all of Yemen's main regions** has recently increased and will likely continue occurring with greater intensity and frequency. However, drought and related water scarcity still pose major ongoing risks.
    - Climate variability can exacerbate Yemen's moderately high seismic risk conditions. Earthquake hazards pose the greatest threat **along the coast and parts of the highlands**. The **western coast** has the highest volcanic hazard risks, while steep terrain poses landslide hazard risks in **all governorates**.

For National Policies, see key documents linked at the end of this profile.

COUNTRY OVERVIEW

The Republic of Yemen, located on the southern edge of the Arabian Peninsula between 12–19°N latitude, is a topographically diverse country subdivided into 21 governorates or *muhafazat* and one municipal capital or *amanah* (**see Figure 1)**. The country covers 527,970 km^2 of land south of Saudi Arabia and west of Oman and features five major topo-geographic regions.[1] (1) The Tihama region is a hot and humid coastal plain that receives little precipitation. It extends 2,200 kilometers (30–60 km wide) along the shores of the Red Sea to the west and the Gulf of Aden and Arabian Sea to the south. The important port cities of Aden on the Gulf of Aden and Al Hudaydah on the Red Sea are both located in this zone. (2) The Sarawat Mountains, which comprise western and central highlands, rise abruptly from the coast along Yemen's entire western perimeter and continue northward into Saudi Arabia. The western highlands range from 1,000 to over 3,000 meters (m) and contain the highest point on the Arabian Peninsula, Jabal Al-Nabi Shu'ayb at 3,665 meters above sea level.[2] These highlands, which include the cities of Taizz and Ibb, receive the most precipitation on the entire Arabian Peninsula. The temperate central highlands, where the capital Sana'a resides, meanwhile comprise most of the elevated expanse above 2,000 meters shaded purple in **Figure 1** and are drier compared to the western highlands. (3) The sparsely populated eastern highlands, stretching across Hadramawt and Al Mahrah, have lower elevations up to approximately 1,000 meters and experience a climate similar to the southern coast. Since Yemen has no permanent waterways, seasonal wadis flow down from the highlands toward the coast or inland regions.[3] (4) The hot and sandy Rub al-Khali Desert or "Empty Quarter" occupies the north and northeastern interior. More than half

[1] Environmental Protection Authority (2018). Third National Communication to the UNFCCC. URL: https://unfccc.int/sites/default/files/resource/3490581_Yemen-NC3-2-Yemen_TNC_2018_Final.pdf
[2] Wenner, M. W., and Burrowes, R. (2023). Yemen. Encyclopedia Britannica. URL: https://www.britannica.com/place/Yemen
[3] Wenner, M. W., and Burrowes, R. (2023). Yemen. Encyclopedia Britannica. URL: https://www.britannica.com/place/Yemen

of Yemen's territory is classified as desert and is largely devoid of settlements.[4] (5) Yemen additionally claims more than 112 islands in the Red Sea, such as the Kamaran and Hanish Islands and Perim along the Bab el Mandab, the strategic shipping strait at the entrance of the Red Sea. The islands are a rich source of mangroves, coral reefs, and fisheries. Socotra, an ecologically distinct four-island archipelago in the Arabian Sea located 240 km from Somalia with an area of 3,900 km^2, became a separate governorate in 2013.[5]

According to the World Bank's DataBank,[6] the Republic of Yemen is the most populous country on the Arabian Peninsula after Iraq and Saudi Arabia, with an estimated 33.7 million people as of 2022. Most of the country's population is concentrated along its western and southwestern coasts and highlands, with a majority (60.8% of the 2022 population) living in rural areas despite a growing trend toward urbanization. Compared to its global peers, Yemen has a high annual population growth rate of 2.1% (2022), high fertility rate, and high youth dependency ratio (**see Table 1**). It is classified as a low-income country that also ranks low on the Human Development index (183 out of 191) for 2021, considering factors such as life expectancy, education, and income per capita.[7] The country had a 2022 GDP (Gross Domestic Product in current $US) of $22.7 billion – roughly half of its GDP before intense conflict began in 2015 – and a declining annual GDP growth rate of 1.5%.[8] Since 2015, conflict disrupted the oil sector (which used to account for 75% of public revenue) and destroyed critical infrastructure sustaining the dominant informal economy, now split between areas controlled by the internationally recognized government and de facto authorities.[9] Many Yemenis depend on small-scale subsistence agriculture, employment in public administration (classified under the service sector in **Table 1**), and remittances and foreign aid in the midst of its ongoing humanitarian crisis.[10] The U.N. estimates that 24.1 million people, a majority of its population, are at risk of hunger and disease, including outbreaks of cholera, diphtheria, measles, and dengue fever.[11] Meanwhile, more than half of the population lacks basic water and sanitation services. Yemen has the lowest GDP per capita ($677 in $US) in the Middle East and North Africa, except for Syria, and roughly half of its population now lives below the national poverty line, making it among the highest globally (**see Table 1**).[12] In 2022, the Kingdom of Saudi Arabia and the United Arab Emirates provided US$3.3 billion in economic and humanitarian aid to Yemen, after President Abdrabbuh Mansur Hadi transferred executive authority to a designated leadership council.[13] However, longer-term improvements in socioeconomic conditions hinge on competing factions resolving the ongoing conflict.

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[4] Environmental Protection Authority (2018). Third National Communication to the UNFCCC. URL: https://unfccc.int/sites/default/files/resource/3490581_Yemen-NC3-2-Yemen_TNC_2018_Final.pdf

[5] Current CCKP data considers the island of Socotra as part of the governorate of Hadramawt when reporting historical observations and extremes, but as its own separate governorate for future projections. This profile notes trends specific to the Socotra Governorate, as data permits, where pertinent.

[6] World Bank (2023). DataBank – World Development Indicators. URL: https://databank.worldbank.org/source/world-development-indicators

[7] UNDP (2022). Human Development Report 2021/2022. URL: https://hdr.undp.org/system/files/documents/global-report-document/hdr2021-22pdf_1.pdf

[8] World Bank (2023). Macro Poverty Outlook for Yemen: April 2023. URL: https://documents1.worldbank.org/curated/en/099031204122368119/pdf/IDU09aa75c18095aa04de20855a063af647280db.pdf; World Bank (2022). Yemen Economic Monitor: Clearing Skies Over Yemen? URL: https://documents1.worldbank.org/curated/en/099445406102232164/pdf/IDU02c5915390fb9604bd10ae55053ca415f59f9.pdf

[9] World Bank (2022). Yemen Economic Monitor: Clearing Skies Over Yemen? URL: https://documents1.worldbank.org/curated/en/099445406102232164/pdf/IDU02c5915390fb9604bd10ae55053ca415f59f9.pdf

[10] World Bank (2023). Macro Poverty Outlook for Yemen: April 2023. URL: https://documents1.worldbank.org/curated/en/099031204122368119/pdf/IDU09aa75c18095aa04de20855a063af647280db.pdf; World Bank (2022). Yemen Economic Monitor: Clearing Skies Over Yemen? URL: https://documents1.worldbank.org/curated/en/099445406102232164/pdf/IDU02c5915390fb9604bd10ae55053ca415f59f9.pdf

[11] World Bank (2023). "Yemen Overview." URL: https://www.worldbank.org/en/country/yemen/overview#1

[12] UNDP (2022). Global Multidimensional Poverty Index 2022. URL: https://hdr.undp.org/system/files/documents/hdp-document/2022mpireportenpdf.pdf

[13] World Bank (2023). "Yemen Overview." URL: https://www.worldbank.org/en/country/yemen/overview#1

FIGURE 1. Relief Map of Yemen's Governorates[14]

[14] UN OCHA (2010). Yemen: Reference Map. URL: https://reliefweb.int/map/yemen/yemen-reference-map-2010

TABLE 1. Key Development Indicators[16]

Key Demographic Indicators	Most Recent Value	Global Rank
Population Density (people per sq km, 2020)	61.15	140 (out of 215)
Life Expectancy (for total population in years, 2021)	63.75	170 (out of 209)
Fertility Rate (total births per woman, 2021)	3.80	40 (out of 210)
Dependency Ratio (dependents per 100 working-age people, 2022)	72.89	41 (out of 217)
Key Economic and Social Development Indicators	**Most Recent Value**	**Global Rank**
GDP per Capita (in current $US, 2022)	$676.93	177 (out of 186)
% Population Below National Poverty Line (2020)[15]	48.60%	16 (tied, out of 100)
Unemployment Rate (% of total labor force, 2022)	13.59%	23 (out of 183)
% Employed in Agriculture (2021)	28.09%	67 (out of 185)
% Employed in Industry (2021)	11.67%	155 (out of 185)
% Employed in Services (2021)	60.24%	93 (out of 185)
% Population with Access to Electricity (2021)	74.88%	170 (out of 215)
% Population Using at Least Basic Sanitation Services (2020)	54.12%	145 (out of 188)

Data for each indicator's most recently measured year is ranked compared to all countries and entities globally in the far-right column, as tracked by the World Bank's DataBank. Global ranking for the population experiencing multidimensional poverty only includes countries classified as developing by UNDP.

Yemen submitted its Intended Nationally Determined Contribution (INDC) to the UNFCCC in 2015, First Biennial Update Report in 2017, and Third National Communication (TNC) in 2018. The INDC established a target for reducing greenhouse gas emissions 14% by 2030, in addition to outlining proposed adaptation measures organized under sector-specific national frameworks.[17] The TNC updated the Second National Communication's (2013) greenhouse gas mitigation scenario and identified strategies for a 26% reduction of 2010 emissions by 2040, focusing primarily on energy production and the transportation sector. The latest communication also expands the three critical adaptation sectors identified by the 2009 draft National Adaptation Programme of Action or NAPA (water resources, agriculture, coastal zones) to include public health and biodiversity. Since 2021, the internationally recognized government's Ministry of Water and the Environment tasked its Climate Change Unit to draft an action plan for an updated national adaptation program, which it expects to release in 2023 according to local journalists.[18]

[15] UNDP (2022). Global Multidimensional Poverty Index 2022. URL: https://hdr.undp.org/system/files/documents/hdp-document/2022mpireportenpdf.pdf

[16] World Bank (2023). DataBank – World Development Indicators. URL: https://databank.worldbank.org/source/world-development-indicators

[17] Yemen has signed but not ratified the Paris Agreement as of August 2023.

[18] Al-Sarari, L. (2023). Yemen's Climate: From Tree Day to the Race of the Tortoise and the Hare. Assafir Al-Arabi. URL: https://assafirarabi.com/en/50353/2023/01/31/yemens-climate-from-tree-day-to-the-race-of-the-tortoise-and-the-hare/

Data Overview

The data presented are from the World Bank Group's Climate Change Knowledge Portal (CCKP).[19] Historical, observed data is derived from the Climatic Research Unit, University of East Anglia (CRU), CRU TS version 4.07 gridded dataset (data available 1901–2022) and ERA5 reanalysis collection from ECMWF (1950–2020).

Climate Overview

Yemen has a tropical arid and semiarid climate along its coast and inland desert, and a subtropical and temperate climate in its highlands, with generally wide temperature ranges and two monsoonal rainy and dry seasons annually. Over the current climatology (1991–2020), Yemen observed a mean annual temperature of 25.54°C. Average seasonal temperatures nationally during this 30-year period's warm season (May – September) ranged from a minimum of 22.45°C in September to a maximum of 36.50°C in June. Whereas, in the coolest months (November – February), average seasonal temperatures during the same period ranged from a minimum of 12.93°C in January to a maximum of 28.90°C in November. Mean annual precipitation at the national level from 1991–2020 totaled 189.81 mm, however there are a variety of regionally and seasonally distinct precipitation regimes discussed further below (**see Figures 2a-c**). During the course of a typical year, a cooler and drier winter monsoon characterized by northeasterly trade winds across the Arabian Peninsula occurs in all regions from October to March, with the lowest precipitation nationally during the month of December (3.55 mm). The Red Sea Convergence Zone (RSCZ) plays a dominant role in northern governorates' variable winter and early spring precipitation. This rainfall pattern is driven by the confluence of northwesterly winds from the Mediterranean meeting southeasterly winds from the Gulf of Aden.[20] During spring months (March – May), the first wet season or *saif* delivers roughly one-third of annual precipitation on average nationally.[21] The Intertropical Convergence Zone (ITCZ) travels quickly across Yemen during May,[22] the spring rainy season's peak month with national mean precipitation of 28.15 mm. When the ITCZ passes northward in June, the entire country endures a noticeable dip in mean precipitation (17.28 mm nationally). *Kharif* rains transported by the southwesterly summer wet monsoon occur from July to September and account for another third of annual rainfall, peaking in August in most regions (27.95 mm monthly mean nationally), after which the ITCZ moves southward beyond the Gulf of Aden.

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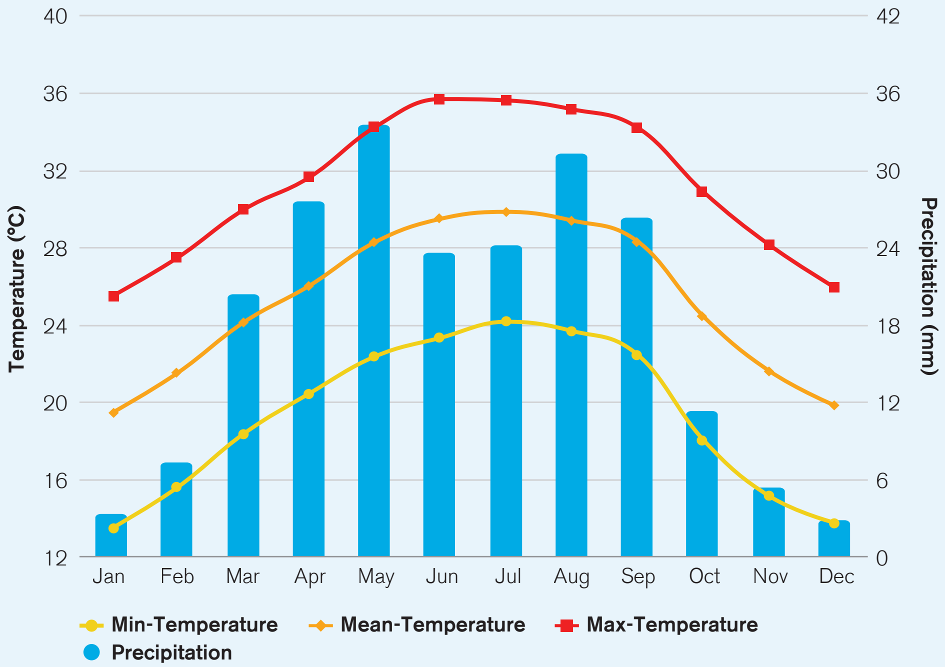
19 World Bank Climate Change Knowledge Portal (2023). Yemen, Rep. Climatology. URL: https://climateknowledgeportal.worldbank.org/country/yemen-rep/climate-data-historical

20 Dasari, H. P., Langodan, S., Viswanadhapalli, Y., Vadlamudi, B. R., Papadopoulos, V. P., and Hoteit, I. (2018). ENSO influence on the interannual variability of the Red Sea convergence zone and associated rainfall. International Journal of Climatology, 38(2), 761–775. DOI: https://doi.org/10.1002/joc.5208

21 GFDRR (2011). Yemen Climate Risk and Adaptation Country Profile. URL: https://climateknowledgeportal.worldbank.org/sites/default/files/2018-10/wb_gfdrr_climate_change_country_profile_for_YEM.pdf

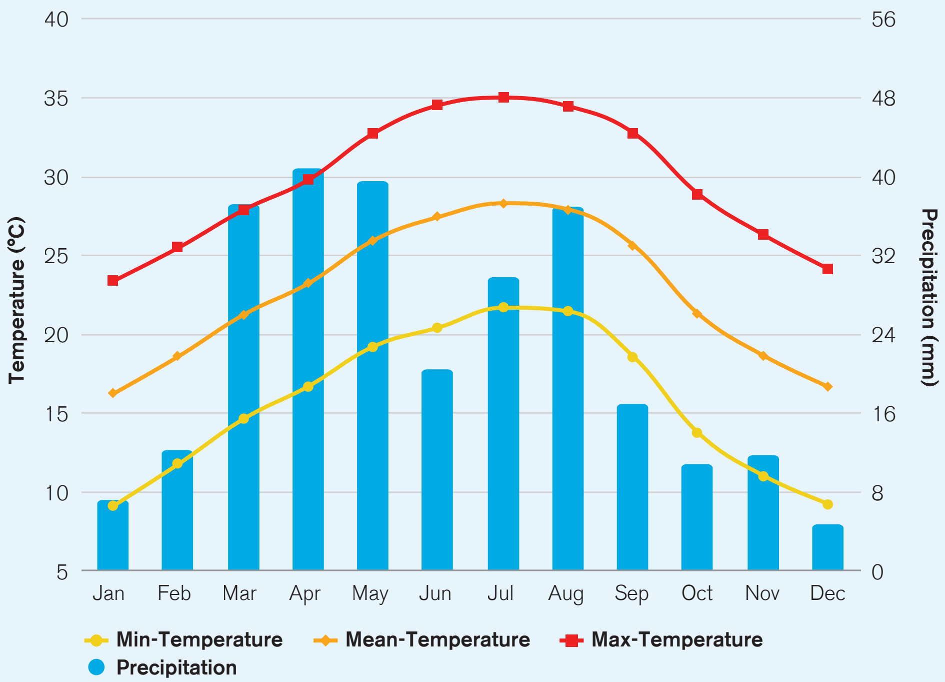
22 Lashkari, H., Mohammadi, Z., and Keikhosravi, G. (2017). Annual fluctuations and displacements of inter tropical convergence zone (ITCZ) within the range of Atlantic Ocean-India. Open Journal of Ecology, 7(1), 12–33. DOI: 10.4236/oje.2017.71002

FIGURE 2A. Observed Monthly Climatology of Shabwah's Temperature and Precipitation, 1991–2020



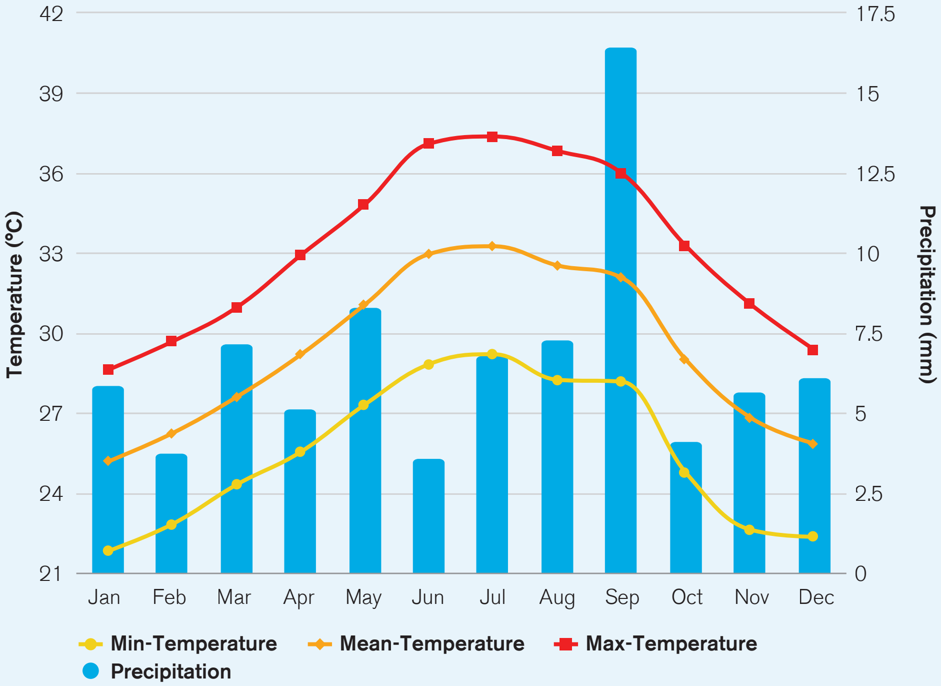
This distribution – encompassing coastal, highland, and interior topographical regions – reflects diverse seasonal temperatures and a nearly unimodal precipitation regime with one wet season and one dry season, which closely mirror Yemen's national average climatology.

FIGURE 2B. Observed Monthly Climatology of Sa'ada's Temperature and Precipitation, 1991–2020



This is a bimodal precipitation regime in the northernmost highlands with two wet seasons and two dry seasons, representative of what most governorates trend toward. Note the earlier onset of the first wet season (early spring) and second dry season (early fall). The scale on the y-axis reflects wetter precipitation peaks and lower temperature minimums.

FIGURE 2C. Observed Monthly Climatology of Aden's Temperature and Precipitation, 1991–2020



This is a largely aseasonal precipitation regime on the southern coast, with no defined pattern other than a monthly peak in September. The scale on the y-axis reflects warmer than average temperatures and lower than average total precipitation values.

Table 2 details Yemen's seasonal temperature and precipitation trends observed over the period 1991–2020 for each subnational unit across the country's three climatic-topographic regions – the Tihama, highlands, and eastern interior (shaded light yellow, purple, and dark yellow, respectively). Since many governorates encompass more than one climatic zone within their boundaries, they tend to reflect a blend of different climatic characteristics. The Tihama coastal region is the hottest and driest, while the eastern and interior regions observe similar precipitation extremes and high rates of evaporation but have lower monthly and annual mean temperatures. The highlands have the lowest mean and annual temperatures of the three regions, but the highest monthly and annual precipitation means. These patterns underscore how temperatures generally decrease and rainfall generally increases as one moves east to west across the country and toward higher elevations.

Temperature extremes bolded in **Table 2** illustrate these patterns. In the Tihama region, Al Hudaydah on the Red Sea observed the hottest annual and monthly mean temperatures between 1991 and 2020 (29.68°C and 33.93°C in July, respectively), while Abyan on the Gulf of Aden observed the coolest monthly mean of 21.49°C in January. In the eastern interior region, Hadramawt observed the hottest monthly mean during a different peak month than in other regions (31.64°C in June, not July) and Al Jawf in the west observed the coolest monthly mean of 17.88°C in January. In the highland region, Amanat al Asimah, home to the capital Sana'a, not only had the coolest monthly and annual mean temperature nationally (13.07°C and 18.04°C, respectively), but also featured the largest seasonal ranges between minimum and maximum temperatures. Sa'ada in the north observed the warmest mean July temperature in the highlands at 28.30°C.

As **Table 2** details, most governorates across the three main climatic-topographic regions have two wet seasons with roughly equivalent precipitation peaks and two dry seasons with the longest and driest occurring over winter months. The governorates further north of and including Sana'a have the most clearly bimodal precipitation distributions, with spring wet seasons and fall dry seasons that start earlier than other regions (March and September or October, respectively). Sa'ada has the driest monthly and annual mean precipitation in the highlands (4.69 mm and 268.42 mm, respectively), encompassing much of the Sarawat Mountains' eastern rain shadow. Only Sa'ada, Hadramawt, and Al Mahrah have earlier spring rainfall peaks during the month of April instead of May. As opposed to the Tihama and eastern interior, the highlands experience a wetter second rainy season than in spring, especially moving southward. Ibb in the southwest observed the wettest monthly and annual totals in the highlands (88.10 mm and 518.75 mm, respectively). Taizz, the southwestern governorate with the wettest monthly and annual totals on the coast (48.56 mm and 299.77 mm, respectively), also similarly encompasses higher-altitude topography. Marib has the highest monthly and annual mean precipitation totals in the eastern interior (45.48 mm and 290.91 mm, respectively), partly because of its proximity to the central highlands. By comparison, Al Mahrah in the far eastern interior observed the driest monthly and annual means nationally (1.46 mm and 79.87 mm, respectively), reflecting its large expanse of the Rub al-Khali Desert. Overall, the variations across each region reflect the ITCZ's greater influence as a percentage of annual precipitation in the south and the RSCZ's greater influence as a percentage of annual precipitation in the north and east.[23]

Among the areas that exhibit more localized precipitation patterns, the southern coast receives low and irregular rainfall and approaches a unimodal distribution in some governorates (**see Figures 2a-c**). Aden, located on the southern coast and entirely within the Tihama, lacked seasonality and only received notable precipitation during the month of September at the end of the summer monsoon. Meanwhile, the subnational units with the most unimodal precipitation distributions (one wet season and one dry season), Abyan and Shabwah, possessed a mix of coastal and highland topography in Yemen's south.

Yemen's interannual seasonal fluctuations in precipitation are influenced by El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) events. During winter months of El Niño years, the RSCZ shifts northward and precipitation tends to increase over the northeastern Red Sea. However, during winter months of La Niña years is when the RSCZ shifts southward closer to Yemen and has greater potential to influence its precipitation.[24] Warm-phase IODs in the western Indian Ocean are strongly correlated with higher rainfall anomalies in East Africa, equatorial regions, as well as the Red Sea, including parts of Yemen.[25] However, it does not strongly correlate with summer monsoon rainfall over eastern Yemen.[26] Water access, health and sanitation, rural agricultural livelihoods, and disruptions to infrastructure and economic activities are critical concerns stemming from conditions that coincide with ENSO and IOD, especially given Yemen's ongoing humanitarian crisis.

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[24] Dasari, H. P., Langodan, S., Viswanadhapalli, Y., Vadlamudi, B. R., Papadopoulos, V. P., and Hoteit, I. (2018). ENSO influence on the interannual variability of the Red Sea convergence zone and associated rainfall. International Journal of Climatology, 38(2), 761–775. DOI: https://doi.org/10.1002/joc.5208

[25] Chakraborty, A., Behera, S. K., Mujumdar, M., Ohba, R., and Yamagata, T. (2006). Diagnosis of tropospheric moisture over Saudi Arabia and influences of IOD and ENSO. Monthly Weather Review, 134(2), 598–617. DOI: https://doi.org/10.1175/MWR3085.1

[26] Charabi, Y. (2009). Arabian summer monsoon variability: teleconexion to ENSO and IOD. Atmospheric Research, 91(1), 105–117. DOI: https://doi.org/10.1016/j.atmosres.2008.07.006

TABLE 2. Observed Temperature and Precipitation Trends for 1991–2020 Climatology Across Yemen's Three Main Regions

Climatic-Topographic Region and Governorate	Observed Warmest (Top) and Coolest (Bottom) Months by Mean Temp.	Duration of Wet and Dry Seasons	Observed Wettest and Driest Months per Season	Observed Annual Precip.
Tihama (Tropical Desert and Tropical Dry)				
Al Hudaydah (Red Sea, central)	**July: 33.93°C** (29.04°C, 38.87°C)	W1: May W2: July-Aug	W1: May (17.07 mm) W2: Aug (15.70 mm)	128.00 mm
	Jan: 25.03°C (19.89°C, 30.21°C)	D1: June D2: Oct-Feb	D1: June (9.38 mm) D2: Jan (6.79 mm)	
Aden (Gulf of Aden, south)	July: 33.25°C (29.20°C, 37.37°C)	Aseasonal	W: Sept (16.46 mm)	**80.30 mm**
	Jan: 25.18°C (21.82°C, 28.62°C)		D: June (3.59 mm)	
Tihama and Western Highlands (Tropical Desert, Tropical and Subtropical Dry)				
Hajjah (Red Sea, north)	July: 32.09°C (26.77°C, 37.45°C)	W1: Mar-May W2: July-Aug	W1: May (22.98 mm) W2: Aug (21.45 mm)	169.40 mm
	Jan: 22.65°C (16.94°C, 28.41°C)	D1: June D2: Sept-Feb	D1: June (11.79 mm) D2: Dec (7.59 mm)	
Taizz (Red Sea, south)	July: 30.78°C (25.88°C, 35.72°C)	W1: May W2: Aug-Sept	W1: May (46.27 mm) **W2: Aug (48.56 mm)**	**299.77 mm**
	Jan: 22.19°C (17.05°C, 27.40°C)	D1: June D2: Nov-Feb	D1: June (24.04 mm) D2: Jan (5.95 mm)	
Tihama and Central Highlands (Tropical Desert, Tropical and Subtropical Dry)				
Lahij (Gulf of Aden, south)	July: 31.01°C (26.38°C, 35.70°C)	W1: May W2: Aug-Sept	W1: May (35.98 mm) W2: Sept (39.27 mm)	236.97 mm
	Jan: 22.60°C (18.13°C, 27.15°C)	D1: June D2: Nov-Feb	D1: June (19.62 mm) D2: Jan (5.70 mm)	
Abyan (Gulf of Aden, south)	July: 30.23°C (25.30°C, 35.24°C)	W: Apr-Sept	W1: May (30.34 mm) W2: Aug, Sept (28.38 mm)	197.59 mm
	Jan: 21.49°C (16.52°C, 26.53°C)	D: Nov-Feb	**D: Dec (3.40 mm)**	
Western Highlands (Tropical, Subtropical, Warm Temperate Dry)				
Al Mahwit (north)	July: 29.07°C (23.39°C, 34.80°C)	W: Mar-Sept	W1: May (42.29 mm) W2: Aug (45.07 mm)	293.35 mm
	Jan: 20.23°C (13.80°C, 26.69°C)	D: Oct-Feb	D: Jan (7.39 mm)	
Raymah (central)	July: 27.94°C (22.39°C, 33.58°C)	W: Apr-Sept	W1: May (57.89 mm) W2: Aug (62.32 mm)	379.30 mm
	Jan: 19.46°C (13.01°C, 25.92°C)	D: Nov-Feb	D: Jan (6.28 mm)	

(*continues*)

TABLE 2. Observed Temperature and Precipitation Trends for 1991–2020 Climatology Across Yemen's Three Main Regions (*Continued*)

Climatic-Topographic Region and Governorate	Observed Warmest (Top) and Coolest (Bottom) Months by Mean Temp.	Duration of Wet and Dry Seasons	Observed Wettest and Driest Months per Season	Observed Annual Precip.
Western and Central Highlands (Tropical, Subtropical, Warm Temperate Dry)				
Amran (north)	July: 26.65°C (20.18°C, 33.16°C)	W: Mar-Sept	W1: May (50.68 mm) W2: Aug (52.66 mm)	347.47 mm
	Dec: 16.41°C (8.74°C, 24.08°C)	D: Oct-Feb	D: Dec (6.27 mm)	
Al Dhale'e (south)	July: 25.32°C (19.75°C, 30.89°C)	W: Apr-Sept	W1: May (77.27 mm) W2: Aug (82.30 mm)	497.54 mm
	Dec: 16.83°C (10.48°C, 23.25°C)	D: Nov-Feb	D: Jan (6.09 mm)	
Central Highlands (Subtropical Dry)				
Amanat al Asimah (north)	July: 22.63°C (15.85°C, 29.47°C)	W: Mar-Sept	W1: May (73.02 mm) W2: Aug (83.67 mm)	515.46 mm
	Dec: 13.07°C (4.72°C, 21.47°C)	D: Oct-Feb	D: Dec (8.92 mm)	
Western and Central Highlands (Subtropical and Warm Temperate Dry)				
Sana'a (north)	July: 24.51°C (18.02°C, 31.05°C)	W: Mar-Sept	W1: May (66.65 mm) W2: Aug (73.79 mm)	459.23 mm
	Dec: 14.92°C (7.06°C, 22.83°C)	D: Oct-Feb	D: Dec (7.57 mm)	
Dhamar (south)	July: 24.77°C (18.79°C, 30.81°C)	W: Apr-Sept	W1: May (73.60 mm) W2: Aug (82.33 mm)	494.55 mm
	Dec: 16.04°C (8.87°C, 23.25°C)	D: Nov-Feb	D: Jan (7.38 mm)	
Ibb (south)	July: 25.17°C (19.50°C, 30.87°C)	W: Apr-Sept	W1: May (79.40 mm) **W2: Aug (88.10 mm)**	**518.75 mm**
	Dec: 16.81°C (10.14°C, 23.50°C)	D: Nov-Feb	D: Jan (6.95 mm)	
Central Highlands (Subtropical and Warm Temperate Dry)				
Al Bayda (south)	July: 24.83°C (18.94°C, 30.76°C)	W: Apr-Sept	W1: May (69.34 mm) W2: Aug (73.82 mm)	462.79 mm
	Dec: 15.73°C (8.96°C, 22.53°C)	D: Nov-Feb	D: Dec (6.33 mm)	
Central Highlands and Eastern Interior (Tropical Dry and Tropical Desert, Subtropical and Warm Temperate Dry)				
Sa'ada (north)	**July: 28.30°C** (21.66°C, 35.01°C)	W1: Mar-May W2: July-Aug	W1: Apr (40.95 mm) W2: Aug (37.00 mm)	**268.42 mm**
	Jan: 16.21°C (9.08°C, 23.37°C)	D1: June D2: Sept-Feb	D1: June (20.43 mm) **D2: Dec (4.69 mm)**	

(*continues*)

TABLE 2. Observed Temperature and Precipitation Trends for 1991–2020 Climatology Across Yemen's Three Main Regions (*Continued*)

Climatic-Topographic Region and Governorate	Observed Warmest (Top) and Coolest (Bottom) Months by Mean Temp.	Duration of Wet and Dry Seasons	Observed Wettest and Driest Months per Season	Observed Annual Precip.
Central Highlands and Eastern Interior (Tropical Desert, Tropical and Subtropical Dry)				
Al Jawf (north)	July: 31.31°C (24.55°C, 38.09°C)	W: Mar-Sept	W1: May (34.53 mm) W2: Aug (28.91 mm)	215.60 mm
	Jan: 17.88°C (10.77°C, 25.04°C)	D: Oct-Feb	D: Dec (3.09 mm)	
Marib (north)	July: 29.27°C (23.06°C, 35.50°C)	W: Mar-Sept	**W1: May (45.48 mm)** W2: Aug (43.08 mm)	**290.91 mm**
	Jan: 18.29°C (11.55°C, 25.10°C)	D: Oct-Feb	D: Dec (3.78 mm)	
Tihama, Eastern Highlands, and Eastern Interior (Tropical Desert, Tropical and Subtropical Dry)				
Shabwah (east)	July: 29.85°C (24.15°C, 35.63°C)	W: Mar-Sept	W1: May (33.60 mm) W2: Aug (31.37 mm)	217.40 mm
	Jan: 19.43°C (13.45°C, 25.48°C)	D: Oct-Feb	D: Dec (2.80 mm)	
Hadramawt (east)	**June: 31.64°C** (24.92°C, 38.41°C)	W1: Mar-May W2: Aug	W1: Apr (20.47 mm) W2: Aug (16.40 mm)	122.17 mm
	Jan: 19.11°C (12.76°C, 25.51°C)	D1: June-July D2: Oct-Feb	D1: June (10.37 mm) D2: Dec (2.49 mm)	
Al Mahrah (east)	June: 30.81°C (25.20°C, 36.48°C)	W1: Mar-May W2: July-Aug	W1: Apr (14.06 mm) W2: Aug (13.56 mm)	**79.87 mm**
	Jan: 19.62°C (13.74°C, 25.54°C)	D1: June D2: Sept-Feb	D1: June (6.04 mm) **D2: Jan (1.46 mm)**	

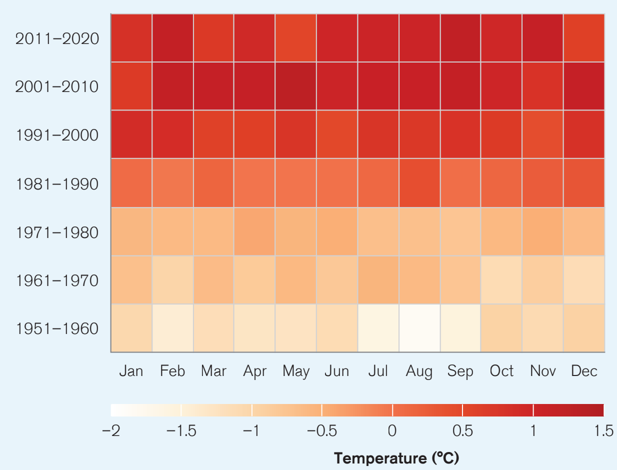
Climatic zones are classified according to characteristics in Sayre et al. and grouped by primary topo-geographic region (Tihama shaded light yellow, highlands shaded purple, and eastern interior shaded dark yellow).[27] Governorates that possess highlands have cooler monthly temperatures and greater annual temperatures ranges. The highest and lowest monthly and annual values for each region are bolded. For the column listing mean monthly temperatures, the minimum (left) and maximum (right) temperatures are shown in parentheses. Precipitation regimes indicate wettest (W) and driest (D) months by first (W1, D1) and second (W2, D2) season if relevant, and are further interpreted in the text.

[27] Sayre, R., Karagulle, D., Frye, C., Boucher, T., Wolff, N. H., Breyer, S., et al. (2020). An assessment of the representation of ecosystems in global protected areas using new maps of World Climate Regions and World Ecosystems. Global Ecology and Conservation, 21, e00860. DOI: https://doi.org/10.1016/j.gecco.2019.e00860

Temperature

Between 1971 and 2020, Yemen's mean annual temperature increased by 0.42°C per decade, with large regional and seasonal differences accompanying a significantly increasing number of hot and humid days and nights. Nationwide, average minimum temperatures increased 0.46°C per decade between 1971–2020, while average maximum temperatures increased 0.38°C per decade over the same period. Al Jawf in the eastern interior recorded the highest annual average mean temperature increase (0.58°C per decade), minimum temperature increase (0.65°C per decade), and maximum temperature increase (0.51°C per decade). By comparison, coastal Aden observed the lowest average temperature increases (mean and minimum of 0.16°C per decade, maximum of 0.17°C per decade). Assessing observed changes seasonally, the greatest temperature increases occurred during summer and fall months, centered around Yemen's northern interior. Al Jawf observed large increases during these seasons – a 0.85°C and 0.74°C minimum increase per decade over summer and fall months, respectively, and a 0.65°C mean increase per decade during both seasons. Mean and minimum increases above 0.50°C per decade also extended into the highlands and eastern interior during summer and fall months. Likewise, these seasons observed the greatest differences compared to governorates with the lowest temperature increases along the coasts. The lowest seasonal mean, minimum, and maximum increases (0.14°C, 0.14°C, and 0.15°C per decade, respectively) occurred in Aden during spring months, as no significant increases occurred during winter months along Yemen's southern coast and the island of Socotra. Notably, over the 1971–2020 historical period, the maximum of daily maximum temperature significantly increased 0.43°C per decade (**see Figure 3**). Over the same time period, the number of tropical nights with a minimum temperature >20°C significantly increased 9.97 nights per decade, while days per decade with a Heat Index >35°C significantly increased by 2.82 days per decade. This latter measure accounts for both temperature and atmospheric moisture content. The implications of these trends are discussed further below under projected temperature conditions.

FIGURE 3. Heatplot of Historically Observed Maximum of Daily Maximum Temperature Trend per Month Nationally (1951–2020)

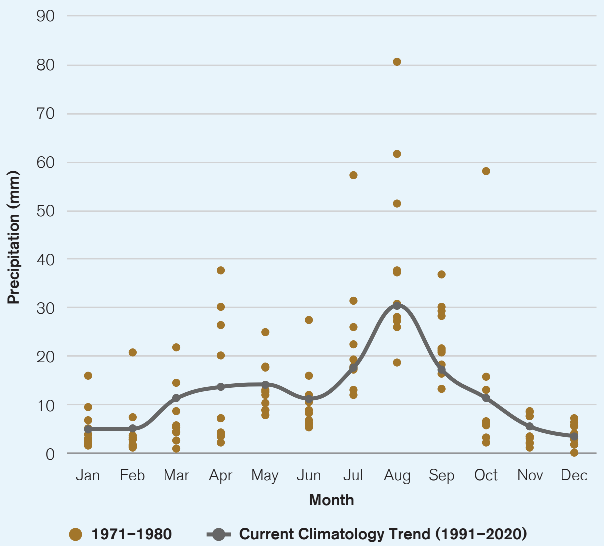


While one must consider gaps in Yemen's observational record, note the drastic increase in temperature year-round since the 1980s.

Precipitation

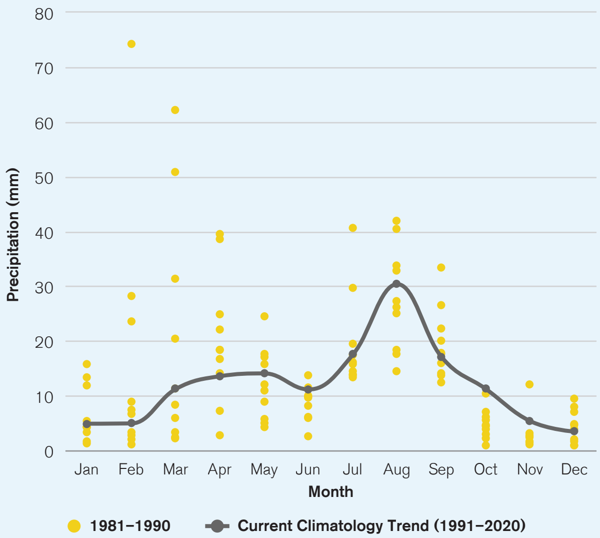
Over the 50-year period of 1971–2020, Yemen experienced significant decreases in annual precipitation per decade along the western and southwestern coast, though precipitation trends varied regionally and interannually. For the period of 1971–2020, Yemen's mean annual precipitation decreased (–6.25 mm per decade), but not significantly. During the 1971–2020 climatology, Al Hudaydah on the Red Sea observed the largest total decreases in precipitation per decade (–38.25 mm) with significant decreases during summer (–15.34 mm per decade) and fall months (–12.46 mm per decade). However, governorates outside the coastal

FIGURE 4A. Historical Precipitation Variability in Yemen (1971–1980)



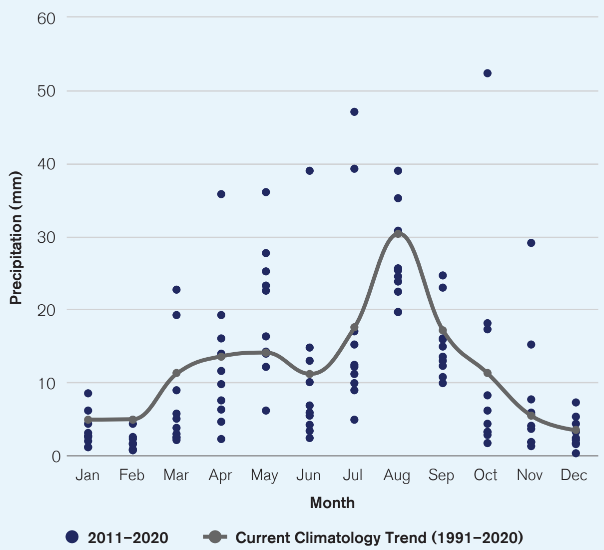
Note the higher variability from July to September compared to 1991–2020.

FIGURE 4B. Historical Precipitation Variability in Yemen (1981–1990)



Note the anomalously high variability during February and March compared to 1991–2020, Figure 4a, and Figure 4c. Also, note Figure 4b has a smaller vertical axis scale.

FIGURE 4C. Historical Precipitation Variability in Yemen (2011–2020)



Note the wider range of variability from May to June and October to November compared to 1971–1980 and 1981–1990. Figure 4c has the smallest vertical axis scale.

Tihama zone and east of Abyan did not exhibit any significant annual or seasonal precipitation trend. The same spatial and seasonal pattern applied to the average 5-day cumulative precipitation between 1971 and 2020, of which Al Hudaydah significantly decreased the most per decade annually by –6.05 mm compared to the national average of –0.31 mm per decade. The lack of significant change in observed precipitation across much of the country underscores the role of high annual and interannual variability, as well as the historical influence of ENSO and IOD.

Figures 4a–c provide an illustration of Yemen's interannual precipitation variability. From 1971–1980 (**Figure 4a**), the nation observed particularly high precipitation variability during the peak of the summer monsoon season (July to September) compared to both 1981–1990 and the current climatology trend (1991–2020). By contrast, from 1981–1990 (**Figure 4b**) Yemen observed less variable summer monsoon seasons (which several El Niño events may have influenced), but a very wide range of monthly precipitation totals during the onsets of the spring rainy season (February and March). Over the most recent decade (2011–2020, **Figure 4c**), the transitional month of October recorded a much wider range of precipitation than it did over 1981–1990, as did the months of May and June, which indicate that the spring rainy season exhibited a shift in its cessation. These examples demonstrate the complexity of identifying conclusive interannual precipitation trends and contributors, as well as predicting future patterns, given the gaps in Yemen's observational record.

PROJECTED CLIMATE

Data Overview

Modeled climate data is derived from CMIP6, the Coupled Model Intercomparison Project, Phase 6. The CMIP efforts are overseen by the World Climate Research Program, which supports the coordination for the production of global and regional climate model compilations that advance scientific understanding of the multi-scale dynamic interactions between the natural and social systems affecting climate. CMIP6 is the foundational data used to present global climate change projections presented in the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC). CMIP6 relies on the Shared Socioeconomic Pathways (SSPs), which represent possible societal development and policy scenarios for meeting designated radiative forcing (W/m^2) by the end of the century. Scenarios are used to represent the climate response to different plausible future societal development storylines and associated contrasting emission pathways to outline how future emissions and land use changes translate into responses in the climate system. Model-based, climate projection data is derived from the Coupled Model Inter-comparison Project-Phase 6 (CMIP6). CMIP is a standard framework for the analysis of coupled atmosphere-ocean general circulation models (GCMs) providing projections of future temperature and precipitation according to designated scenarios. CMIP6 projections are shown through five shared socio-economic pathway (SSP) scenarios defined by their total radiative forcing (a cumulative measure of GHG emissions from all sources) pathway and level by 2100. These represent possible future greenhouse gas concentration trajectories adopted by the IPCC.

The following assessment explores projected climate conditions and changes under multiple scenarios[28] for the near (the 2030s; 2020–2039) and medium term (2050s; 2040–2059) using data presented at a 0.25° × 0.25° (25km × 25km) resolution.[29] This risk profile focuses primarily on SSP3-7.0. Other SSPs are highlighted where appropriate given different trends and outlooks that should be noted. Projections for extreme precipitation events use data presented at a 1.00° × 1.00° (100km × 100km) resolution.[30]

Temperature

Under SSP3-7.0, Yemen's temperatures are projected to further increase but vary regionally (see Figure 5). The national-level mean annual temperature increases from 25.40°C during the historical reference period of 1995–2014 to 26.16°C (25.51°C, 10th percentile, 26.92°C, 90th percentile) for the period 2020–2039, and to 27.02°C (26.16°C, 28.00°C) for the period 2040–2059. Minimum temperature increases nationwide from 19.26°C during the historical reference period to 20.08°C (19.40°C, 20.86°C) for the 2020–2039 period, and to 20.97°C (20.09°C, 21.97°C) for the 2040–2059 period. Maximum temperature increases from 31.54°C to 32.24°C (31.52°C, 33.07°C) for the 2020–2039 period, and to 33.04°C (32.15°C, 34.15°C) for the 2040–2059 period. However, projected temperature changes under SSP2-4.5 and SSP1-2.6 scenarios are relatively lower.[31] Under SSP3-7.0, coastal governorates are projected to experience greater mean temperature increases during winter and spring months, highland governorates during spring months, and eastern interior governorates during summer and fall. Compared to the historical reference, Socotra has an annual minimum temperature anomaly of 1.20°C, a mean anomaly of 1.18°C, and a maximum anomaly of 1.17°C for 2040–2059. On the mainland, Aden has an annual minimum anomaly of 1.43°C, a mean anomaly of 1.39°C, and a maximum anomaly of 1.33°C from the reference period for 2040–2059. Al Jawf has the highest projected increases of all governorates, with an annual minimum anomaly of 1.87°C, a mean anomaly of 1.82°C, and a maximum anomaly of 1.70°C from the reference period for 2040–2059. High minimum temperature anomalies above 1.80°C are most extensive across the highlands and interior during fall months.

Projected mean temperatures under SSP3-7.0 underscore how several governorates with high elevations are expected to endure conditions characteristic of different climatic zones by midcentury (**see Table 3**). Sana'a is expected to observe a future mean temperature above 20°C annually, outside characteristic temperate ranges. However, this does not include the capital, Amanat al Asimah. Al Mahwit and Raymah, both located at lower elevations, are meanwhile expected to observe midcentury mean temperatures above 25°C, the approximate annual mean temperature of Marib (desert interior) over the historical reference period. Other governorates possessing low-elevation terrain with annual means above 25°C for their reference period – but populations mainly concentrated in upper elevations (e.g., Ibb and Taizz) – may also experience less temperate local conditions by midcentury.

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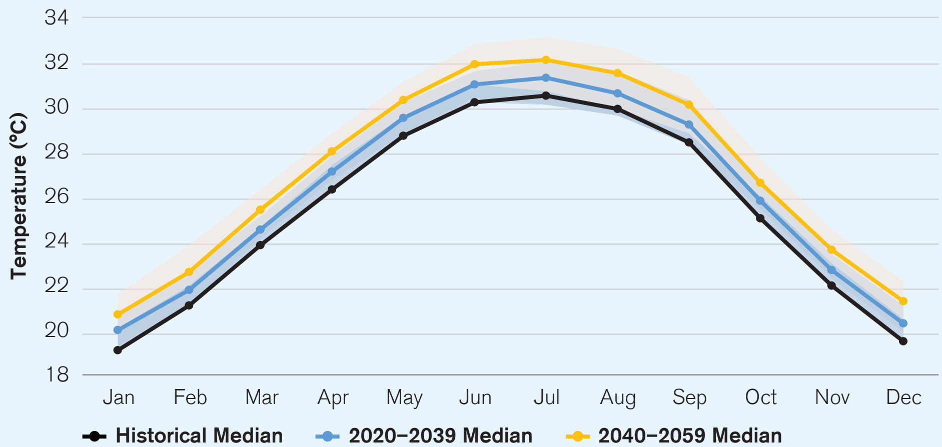
28 SSP3-7.0 represents a higher emissions scenario and is considered a more realistic worst-case scenario in which warming reaches ~3.5–4°C by 2100. When considering 'risk' it is most prudent to use higher scenarios in order to not dangerously under-estimate potential changes and risk conditions.

29 World Bank Climate Change Knowledge Portal (2023). Yemen, Rep. Climate Projections. URL: https://climateknowledgeportal.worldbank.org/country/yemen-rep/climate-data-projections

30 World Bank Climate Change Knowledge Portal (2023). Yemen, Rep. Extreme Events. URL: https://climateknowledgeportal.worldbank.org/country/yemen-rep/extremes

31 Under SSP1-2.6, the minimum temperature nationwide only increases to 20.49°C (19.73°C, 21.45°C) and under SSP2-4.5, increases to 20.76°C (20.05°C, 21.73°C) by 2040–2059. Under SSP1-2.6, the maximum temperature increases nationwide to 32.67°C (31.92°C, 33.51°C), and under SSP2-4.5, increases to 32.90°C (32.09°C, 33.83°C) by 2040–2059.

FIGURE 5. Projected Climatology of Mean Temperature Countrywide for 2020–2039 and 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0



Areas shaded blue indicate 10th and 90th percentiles for 2020–2039, while areas shaded orange indicate 10th and 90th percentiles for 2040–2059. Note that for most months, the 2040–2059 projected climatology of mean temperature countrywide increased more than one time above the 2020–2039 projected climatology from the reference period.

TABLE 3. Projected Annual Mean Temperatures in High-Elevation Governorates for 2020–2039 and 2040–2059 (from Ref. Period 1995–2014) Under SSP3-7.0

Governorate (Region)	Mean Annual Temperature		
	1995–2014	2020–2039	2040–2059
Yemen	25.40°C	26.16°C (25.51°C, 26.92°C)	27.02°C (26.16°C, 28.00°C)
Al Mahwit (north)	23.63°C	24.36°C (23.58°C, 25.04°C)	**25.17°C** (24.18°C, 26.02°C)
Raymah (central)	24.09°C	24.81°C (24.13°C, 25.47°C)	**25.60°C** (24.66°C, 26.45°C)
Amran (north)	20.95°C	21.70°C (20.86°C, 22.44°C)	22.56°C (21.46°C, 23.47°C)
Al Dhale'e (south)	21.24°C	21.95°C (21.32°C, 22.54°C)	22.73°C (21.94°C, 23.59°C)
Amanat al Asimah (north)	17.51°C	18.29°C (17.45°C, 19.00°C)	19.13°C (18.07°C, 20.04°C)
Sana'a (north)	19.97°C	20.74°C (19.90°C, 21.45°C)	**21.59°C** (20.54°C, 22.50°C)
Dhamar (south)	20.03°C	20.76°C (20.05°C, 21.44°C)	21.58°C (20.63°C, 22.45°C)
Ibb (south)	20.26°C	20.97°C (20.33°C, 21.56°C)	21.77°C (20.86°C, 22.58°C)
Al Bayda (south)	20.68°C	21.43°C (20.73°C, 22.11°C)	22.25°C (21.38°C, 23.14°C)
Sa'ada (north)	21.72°C	22.51°C (21.68°C, 23.26°C)	23.42°C (22.36°C, 24.32°C)

10th percentile and 90th percentile values shown in parentheses. Median temperatures projected to increase above 20°C for the highest elevation temperate zones and above 25°C for the rest of the highland region from the reference period are shaded orange and bolded. Other governorates with elevations above 1,000 meters not listed here already experience annual means of at least 25°C. Note the governorates reaching thresholds for different climatic zones include Sana'a, Al Mahwit, and Raymah.

Yemen is projected to experience spatially and seasonally heterogeneous shifts in extreme heat conditions by midcentury according to a host of metrics (see Table 4). The number of hot days above 35°C will increase in coastal and interior regions by the 2040–2059 period under SSP3-7.0, particularly during spring and fall months. Al Hudaydah is projected to experience the greatest increase of 46.29 (16.24, 71.89) hot days by midcentury. In the highlands, summer days with a maximum temperature >25°C increase most during the winter months, extending into fall in Ibb and spring in Amanat al Asimah. Ibb in the southern highlands is projected to experience the highest increase of 68.43 (31.59, 100.97) summer days by 2040–2059 under SSP3-7.0, followed by Dhamar and Amanat al Asimah. Single-day maximum of daily maximum temperatures, meanwhile, increase the most annually under SSP3-7.0 in the northern interior near the border with Saudi Arabia, especially during summer months. Al Jawf's maximum of daily maximum increases the most dramatically from the reference period by an anomaly of 2.20°C (0.64°C, 3.47°C) for 2040–2059. Furthermore, Amanat al Asimah, Sa'ada, Marib, Amran, and Sana'a are all projected to experience maximum of daily maximum anomalies greater than 2°C by this time period. However, the SSP1-2.6 scenario forecasts a more modest annual increase in the maximum of daily maximum by midcentury.

Heat-related risks can be compounded when considering both daytime temperature conditions and nighttime temperature conditions. On nights temperatures do not go below 20°C, the human body reaches a biophysiological threshold where it cannot adequately cool down to achieve restorative sleep. The number of tropical nights with a minimum temperature >20°C (**see Table 4**) rises most in the northern highlands. Such tropical nights increase by more than 50 days annually in Raymah by 2040–2059 under SSP3-7.0, especially during spring and fall months. For most other governorates, the largest seasonal increase in number of tropical nights occurs during summer months. However, the capital city Sana'a in Amanat al Asimah Governorate does not experience a significant change by midcentury according to newly downscaled data. In governorates along the coast and inland desert, the number of tropical nights with a minimum temperature >26°C, an even higher threshold, increases the most during summer months by midcentury (2040–2059) compared to the historical reference period.[32] However, Al Hudaydah and Aden increase the most during spring months. Socotra is projected to experience the largest annual increase of 64.39 (43.17, 105.98) nights by 2040–2059, followed by Al Hudaydah with an increase of 51.13 (32.67, 69.45) nights by midcentury. But Al Jawf experiences the largest seasonal increase of 30.33 (10.43, 41.30) nights during summer months. The largest increase in number of Heat Index days surpassing 35°C by midcentury occurs in Hajjah, which rises annually by 51.40 (12.16, 79.05) days primarily during spring and fall months, and Lahij, which rises annually by 50.37 (10.71, 79.97) days primarily during summer months.[33] The combination of hot days, tropical nights, and high atmospheric moisture content along the coast during the winter dry monsoon raises extreme heat risk particularly in Aden and Al Hudaydah in the spring and fall months. For further detail on how Yemen's projected temperature changes under SSP3-7.0 compare to other scenarios, see the profile's Annex.

[32] The SSP3-7.0 scenario forecasts for tropical nights (T-min > 20°C and T-min > 26°C) do not differ significantly from the SSP2-4.5 and SSP1-2.6 scenarios by midcentury.

[33] Projected Heat Index days >35°C and extreme heat risk under the SSP3-7.0 scenario use 1.00° × 1.00° (100km × 100km) data resolution.

TABLE 4. Key Governorate-Level Projected Anomalies for 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0

Projected Anomalies for 2040–2059 Under SSP3-7.0 (Ref. Period 1995–2014)						
Governorate	Hot Days (No. Days T-max >35°C) Annually	Max. of Daily Max. Temp. Anomaly Annually	Summer Days (No. Days T-max >25 °C) Annually	Tropical Nights (No. Nights T-min >20°C) Annually	Tropical Nights (No. Nights T-min >26°C) Annually	High Heat Index Days (No. Days T-max >35°C) Annually
Yemen	28.40 (14.09, 46.61)	1.87°C (0.85°C, 3.19°C)	21.23 (13.52, 29.61)	36.45 (21.50, 51.49)	34.99 (19.23, 51.51)	14.06 (4.62, 26.89)
Tihama						
Al Hudaydah	**46.29** (16.24, 71.89)	1.67°C (0.57°C, 2.51°C)	0.96 (0.51, 1.65)	14.58 (9.87, 19.53)	**51.13** (32.67, 69.45)	38.70 (–17.74, 60.77)
Aden	27.54 (15.66, 41.94)	1.30°C (0.41°C, 2.88°C)	5.99 (3.38, 8.21)	3.23 (1.47, 5.65)	42.84 (30.72, 63.13)	33.59 (–20.63, 56.85)
Hajjah	34.45 (12.37, 52.55)	**1.84°C** (0.88°C, 2.80°C)	11.93 (7.58, 16.05)	34.99 (17.40, 45.72)	36.67 (15.74, 54.66)	**51.40** (12.16, 79.05)
Taizz	41.32 (14.74, 65.40)	1.53°C (0.66°C, 2.73°C)	14.88 (9.73, 18.14)	38.10 (24.34, 48.58)	33.34 (16.87, 50.44)	45.10 (–13.43, 72.69)
Lahij	32.85 (13.93, 51.24)	1.46°C (0.46°C, 2.80°C)	14.23 (9.99, 18.14)	40.34 (26.66, 50.79)	33.50 (19.48, 48.97)	50.37 (10.71, 79.97)
Abyan	31.87 (16.10, 54.95)	1.64°C (0.87°C, 2.81°C)	**21.66** (15.78, 27.09)	**42.71** (27.64, 58.25)	35.01 (20.58, 52.78)	29.88 (16.36, 55.65)
Highlands						
Al Mahwit	14.04 (4.04, 25.44)	1.82°C (0.49°C, 2.75°C)	42.45 (19.17, 59.35)	45.78 (25.38, 66.96)	18.01 (7.06, 30.80)	47.25 (–0.80, 63.75)
Raymah	16.88 (2.77, 27.49)	1.78°C (0.46°C, 2.61°C)	31.41 (21.09, 39.99)	**64.90** (40.33, 86.00)	**31.90** (9.33, 43.83)	33.10 (–30.60, 58.10)
Amran	6.49 (1.78, 18.24)	2.01°C (1.17°C, 2.92°C)	52.12 (22.55, 72.81)	59.55 (9.00, 86.05)	1.47 (0.02, 3.44)	38.89 (20.62, 59.30)
Al Dhale'e	3.35 (0.75, 7.88)	1.61°C (0.68°C, 2.73°C)	55.64 (34.85, 77.72)	46.66 (18.63, 63.36)	1.48 (0.37, 2.62)	**47.49** (19.12, 70.75)
Amanat al Asimah	0.00 (0.00, 0.00)	**2.09°C** (0.65°C, 2.91°C)	62.50 (16.06, 100.08)	0.31 (0.00, 3.41)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)
Sana'a	8.25 (0.72, 15.10)	2.01°C (0.63°C, 2.79°C)	54.71 (23.00, 84.55)	33.06 (10.57, 51.58)	1.11 (0.35, 2.48)	9.25 (–1.48, 13.07)
Dhamar	3.93 (0.52, 8.11)	1.82°C (0.86°C, 2.64°C)	63.08 (24.43, 94.30)	20.33 (8.64, 33.83)	4.12 (1.47, 6.90)	9.97 (–9.22, 17.51)
Ibb	0.97 (0.21, 3.42)	1.65°C (0.76°C, 2.68°C)	**68.43** (31.59, 100.97)	34.41 (11.68, 48.43)	1.57 (0.01, 3.41)	26.12 (–0.87, 40.72)
Al Bayda	9.89 (1.51, 21.55)	1.73°C (0.92°C, 2.81°C)	49.87 (30.83, 70.76)	38.06 (11.78, 63.45)	0.02 (0.00, 0.30)	2.77 (1.16, 4.83)
Sa'ada	**20.84** (3.49, 35.91)	2.07°C (0.81°C, 3.09°C)	42.10 (23.18, 58.01)	50.06 (12.82, 79.82)	6.21 (0.50, 12.15)	17.42 (12.28, 29.89)

(*continues*)

TABLE 4. Key Governorate-Level Projected Anomalies for 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0 (*Continued*)

Projected Anomalies for 2040–2059 Under SSP3-7.0 (Ref. Period 1995–2014)						
Governorate	Hot Days (No. Days T-max >35°C) Annually	Max. of Daily Max. Temp. Anomaly Annually	Summer Days (No. Days T-max >25 °C) Annually	Tropical Nights (No. Nights T-min >20°C) Annually	Tropical Nights (No. Nights T-min >26°C) Annually	High Heat Index Days (No. Days T-max >35°C) Annually
Eastern Interior						
Al Jawf	33.02 (14.16, 52.05)	**2.20°C** (0.64°C, 3.47°C)	**21.08** (14.17, 28.44)	38.27 (18.77, 51.48)	39.03 (13.27, 55.56)	0.01 (0.00, 0.36)
Marib	34.01 (13.19, 52.70)	2.04°C (0.61°C, 3.27°C)	20.31 (13.61, 27.22)	**40.19** (18.11, 56.01)	30.96 (7.78, 46.48)	0.00 (0.00, 0.00)
Shabwah	**38.39** (19.46, 60.46)	1.82°C (0.90°C, 3.27°C)	17.13 (12.83, 22.31)	38.51 (22.85, 55.48)	27.05 (10.59, 46.71)	7.53 (2.98, 19.26)
Hadramawt	27.97 (15.84, 46.75)	1.98°C (1.08°C, 3.57°C)	16.00 (11.44, 22.38)	33.84 (23.43, 47.40)	45.51 (28.51, 60.95)	12.10 (4.99, 26.31)
Al Mahrah	30.48 (18.51, 49.57)	1.61°C (0.66°C, 2.82°C)	15.36 (11.63, 22.03)	38.27 (27.15, 54.95)	37.32 (21.78, 65.47)	**23.14** (9.01, 39.90)
Socotra	5.42 (2.86, 21.36)	1.36°C (0.71°C, 2.27°C)	11.29 (7.83, 13.47)	22.80 (18.19, 29.36)	**64.39** (43.17, 105.98)	NA

10th percentile and 90th percentile values are shown in parentheses. Largest anomalies (>50 days or >1.80°C) are shaded orange and smallest relative anomalies from the reference period are shaded gray. The largest anomaly in each region is bolded. Note that the maximum of daily maximum anomalies apply least to the Tihama, hot day and tropical night (T-min>26°C) anomalies apply least to the highlands, and summer day anomalies apply most to the highlands. High Heat Index day anomalies use 1.00° × 1.00° (100km × 100km) data resolution and consider Socotra as part of Hadramawt. See text for interpretation.

Precipitation

Projected precipitation patterns under SSP3-7.0 nationally signal increases by midcentury with seasonally and regionally distinct shifts, but a wide range of uncertainty. Since Yemen receives relatively low precipitation annually, assessing its projected percent change in precipitation is particularly revealing (**see Table 5**). At the national level, precipitation totals increase by a median of 2.76% (–3.73%, 18.85%) annually from the 1995–2014 reference period under SSP3-7.0. However, governorates in the Tihama and parts of the highlands are projected to experience precipitation increases between 5–10% annually by midcentury, with the highest being Aden at a median of 9.70% (–10.16%, 48.28%) above the historical reference period. Critically, as **Table 5** details, many seasonal shifts already occur during 2020–2039 for these governorates. Governorates tend to experience their greatest seasonal precipitation percent increases around their wettest months at median rates higher than 10%, except in Al Jawf, Marib, Hadramawt, and Al Mahrah. Hajjah in the Tihama is projected to experience the largest median increase by midcentury of 26.30% (3.93%, 52.79%) during summer months. However, some regions such as Amanat al Asimah and Al Dhale'e are projected to observe substantial seasonal increases over the 2020–2039 period. These patterns reflect spatially and temporally uneven changes, which are slightly lower annually under SSP2-4.5 and slightly higher annually under SSP1-2.6.

TABLE 5. Projected Median Percent Change in Total Precipitation for 2020–2039 and 2040–2059 from Ref. Period 1995–2014 Under SSP3-7.0

Governorate	Annual Anomaly		Largest Seasonal Anomaly		Season
	2020–2039	2040-2059	2020–2039	2040-2059	
Yemen	1.60% (–3.79%, 16.30%)	2.76% (–3.73%, 18.85%)	5.07% (0.00%, 20.54%)	6.82% (–0.20%, 23.93%)	Summer
Al Hudaydah	1.50% (–8.55%, 31.02%)	6.00% (–10.22%, 41.80%)	15.52% (6.03%, 62.25%)	20.66% (2.18%, 64.02%)	Summer
Aden	2.69% (–10.29%, 50.28%)	**9.70%** (–10.16%, 48.28%)	4.18% (–9.55%, 46.80%)	17.96% (–14.71%, 62.95%)	Fall
Hajjah	3.91% (–8.66%, 33.37%)	6.72% (–11.00%, 41.49%)	17.62% (6.64%, 62.64%)	**26.30%** (3.93%, 52.79%)	Summer
Taizz	2.30% (–7.94%, 31.60%)	6.61% (–9.08%, 39.31%)	12.68% (4.53%, 53.32%)	16.98% (5.31%, 57.79%)	Summer
Lahij	3.43% (–9.60%, 35.35%)	7.89% (–8.80%, 40.00%)	5.43% (–8.64%, 31.31%)	17.80% (–14.64%, 50.26%)	Fall
Abyan	5.24% (–9.09%, 40.36%)	8.57% (–8.41%, 42.60%)	13.05% (0.15%, 45.29%)	16.38% (0.47%, 59.18%)	Summer
Al Mahwit	2.14% (–7.27%, 22.65%)	5.95% (–8.17%, 32.49%)	13.27% (5.65%, 43.82%)	20.41% (4.36%, 44.31%)	Summer
Raymah	–0.67% (–6.53%, 18.95%)	3.54% (–8.41%, 27.53%)	10.76% (3.60%, 34.11%)	13.42% (3.24%, 38.10%)	Summer
Amran	4.48% (–5.60%, 25.80%)	**6.65%** (–6.94%, 32.57%)	14.59% (8.65%, 44.26%)	**21.25%** (6.76%, 41.49%)	Summer
Al Dhale'e	1.40% (–8.70%, 23.40%)	4.93% (–8.05%, 25.92%)	10.67% (2.18%, 25.30%)	11.83% (–0.92%, 34.57%)	Summer
Amanat al Asimah	4.07% (–6.39%, 23.59%)	5.30% (–6.54%, 32.98%)	19.54% (4.72%, 49.44%)	20.31% (4.20%, 51.11%)	Summer
Sana'a	2.57% (–6.06%, 18.76%)	4.99% (–5.36%, 24.57%)	13.18% (5.60%, 33.58%)	16.73% (6.54%, 34.14%)	Summer
Dhamar	0.31% (–8.08%, 19.15%)	2.12% (–7.76%, 24.68%)	10.60% (2.75%, 25.84%)	12.57% (3.10%, 31.63%)	Summer
Ibb	–0.76% (–8.61%, 22.86%)	2.08% (–10.20%, 26.25%)	9.65% (2.74%, 26.63%)	11.87% (0.48%, 32.15%)	Summer
Al Bayda	2.95% (–7.91%, 23.56%)	5.14% (–6.01%, 28.37%)	10.83% (1.87%, 27.67%)	12.08% (1.50%, 37.92%)	Summer
Sa'ada	4.17% (–6.67%, 23.81%)	3.61% (–8.33%, 25.34%)	11.14% (5.15%, 32.50%)	13.61% (4.99%, 32.21%)	Summer

(*continues*)

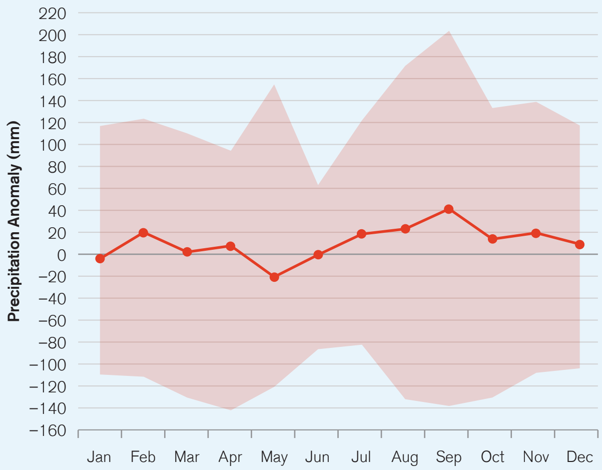
TABLE 5. Projected Median Percent Change in Total Precipitation for 2020–2039 and 2040–2059 from Ref. Period 1995–2014 Under SSP3-7.0 (*Continued*)

Governorate	Annual Anomaly		Largest Seasonal Anomaly		Season
	2020–2039	2040-2059	2020–2039	2040-2059	
Al Jawf	1.13% (–2.41%, 6.86%)	1.00% (–2.92%, 8.80%)	2.92% (1.53%, 8.02%)	3.47% (0.74%, 7.06%)	Summer
Marib	0.38% (–3.65%, 11.60%)	1.58% (–2.56%, 13.43%)	3.18% (1.89%, 7.97%)	4.11% (2.12%, 8.67%)	Summer
Shabwah	3.71% (–4.02%, 24.29%)	4.36% (–3.52%, 22.78%)	8.15% (0.17%, 29.98%)	11.11% (0.50%, 37.22%)	Summer
Hadramawt	1.01% (–1.83%, 9.71%)	1.39% (–1.73%, 10.72%)	1.97% (–1.13%, 7.93%)	3.99% (–0.85%, 11.15%)	Fall
Al Mahrah	0.09% (–1.13%, 11.49%)	0.68% (–0.73%, 14.58%)	0.42% (–0.13%, 6.30%)	3.84% (–0.29%, 12.10%)	Fall
Socotra	–0.25% (–10.43%, 20.64%)	**4.85%** (–7.97%, 34.94%)	1.68% (–16.19%, 29.40%)	**12.00%** (–8.95%, 44.75%)	Spring

10th percentile and 90th percentile values are shown in parentheses. Anomalies bolded in black for 2040–2059 indicate the greatest increases from the historical reference period in each region. Median percentages shaded orange indicate largest anomalies (>10%) from the reference period. Median percentages shaded gray indicate smallest relative anomalies (<2.5%) from the reference period. See text for interpretation.

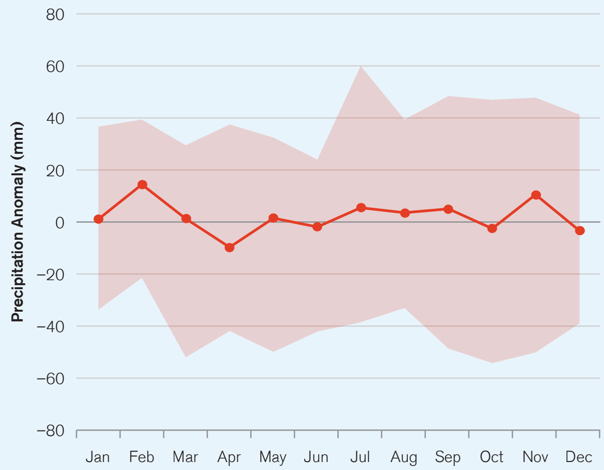
Projected changes for the average largest 5-day precipitation totals, which increase the most in the central and southern highlands, suggest locally specific seasonal shifts in timing and intensity. For example, **Figures 6a–b** depict 5-day precipitation anomalies for each month over the 2040–2059 period compared to the historical reference period (1995–2014) in two governorates – the one with the largest projected change (Al Mahwit) and the one that encompasses the populous capital region (Amanat al Asimah). By midcentury, Al Mahwit's 5-day precipitation totals increase more than 20 mm in August and September, the end of the summer rainy season, but also decrease more than 20 mm in May, the peak of the spring rainy season. This could indicate a shift towards a more pronounced bimodal precipitation distribution and greater percentage of annual precipitation over the summer months. However, a wide range of uncertainty exists. For example, the projection for September is a median increase of 40.04 mm, but a decrease of –137.21 mm (10th percentile) or increase of 201.92 mm (90th percentile) is also possible. Amanat al Asimah has a seasonal precipitation distribution similar to Al Mahwit, but alternatively, its 5-day totals increase more than 10 mm in the months of February and November by midcentury. This may indicate an earlier shift to the start of the rainy season, as well as the potential effects of the Red Sea Convergence Zone during the typical dry season. Such diverging seasonal precipitation trends will require further monitoring. Projected annual increases in precipitation at the national level do not preclude more frequent or severe dry periods from also occurring (see subsection on climate-related hazards). More extreme wet and dry events will impact food security, water access, health and sanitation, and public safety. For further detail on how Yemen's projected precipitation changes under SSP3-7.0 compare to other scenarios, see the profile's Annex.

FIGURE 6A. Al Mahwit's Projected Average Largest 5-Day Cumulative Precipitation Anomaly for 2040–2059 Under SSP3-7.0 (Ref. Period 1995–2014)



Area shaded red indicates 10th–90th percentiles. Note the largest projected 5-day precipitation anomalies (>20 mm) are positive at the end of the wet summer monsoon (August and September) and negative at the end of the spring rainy season (May), though with a wide potential distribution range.

FIGURE 6B. Amanat al Asimah's Projected Average Largest 5-Day Cumulative Precipitation Anomaly for 2040–2059 Under SSP3-7.0 (Ref. Period 1995–2014)



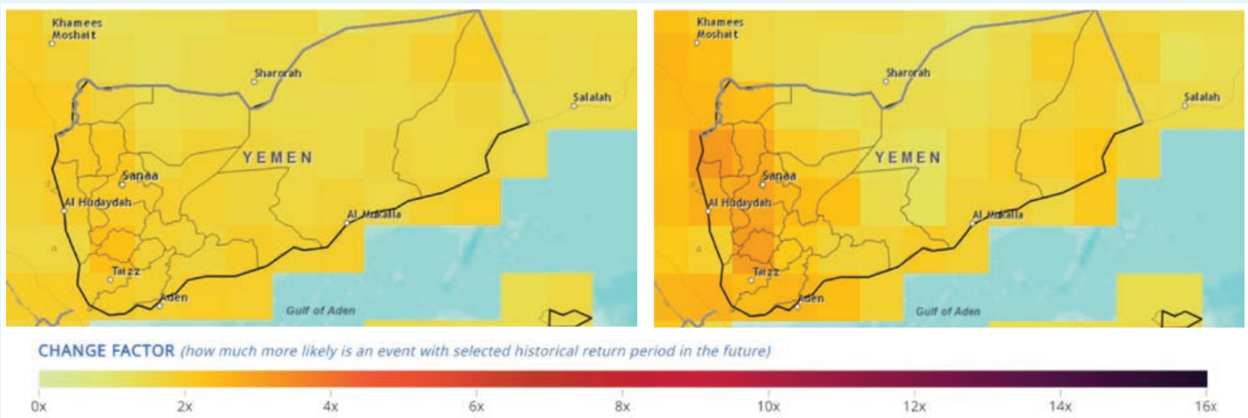
The largest projected 5-day precipitation anomalies (>10 mm) are positive at the beginning and end of the dry winter monsoon (November and February, respectively). Note the y-axis for Al Mahwit is more than twice that of Amanat al Asimah's.

Extreme Precipitation Events

By midcentury, Yemen is likely to more frequently experience extreme precipitation event occurrence. For the projected period of 2035–2064 under SSP3-7.0, the largest 5-day precipitation amounts associated with 25-year, 50-year, and 100-year historical return periods will be two times more likely or more to occur throughout the country except in Aden and the three easternmost governorates. The rate of change is lowest for 10-year events (**see Figures 7a–b**), though still two times more likely or more to occur in parts of the southern highlands (Ibb, Dhamar, and Al Dhale'e). By comparison, precipitation amounts for 50-year events will be two times more likely or more to occur throughout the country, though highest in the northern highlands (Amanat al Asimah, Amran, Hajjah, and Sana'a). The greatest changes are projected in these governorates for 100-year historical return periods, which are expected to be three times more likely or more to occur. SSP1-2.6 and SSP2-4.5 forecast extreme event frequencies at similar rates as SSP3-7.0 for 2035–2064, though with fewer governorates experiencing rates of change above three and two times in frequency for their respective intervals. More frequently occurring extreme precipitation events underscore future health risks related to flood impacts, agricultural yields, disease ranges, and critical infrastructure, including for water, sanitation, and hygiene.

FIGURE 7A. Change in Annual Exceedance Probability of Largest 5-Day Cumulative Precipitation, 10-Year Event (SSP3-7.0, 2035–2064, Center 2050)

FIGURE 7B. Change in Annual Exceedance Probability of Largest 5-Day Cumulative Precipitation, 50-Year Event (SSP3-7.0, 2035–2064, Center 2050)



In other words, the largest 5-day precipitation amounts associated with an event of a 10-year historical return period would be 2 times more likely to occur by midcentury if it had a change factor of 2. The largest change factors (>2) for 10-year events are projected for the southern highlands.

Change factors increase with higher (50-year) return periods. The largest change factors (>2) for 50-year events are projected for the northern highlands.

CLIMATE-RELATED NATURAL HAZARDS

Yemen faces a relatively high risk of extreme heat, flooding, drought, sea level rise, and seismic activity, all of which climate change will likely exacerbate. Temperature increases and extreme heat not only pose direct human health risks (e.g., heatstroke, malaria, cholera, diarrheal diseases), but also affect economic activities, energy demand, and water security. Flash floods threaten critical infrastructure, water quality, economic activities, and human health and mortality. Any future seasonal increases in precipitation also do not eliminate Yemen's high extant drought risk, which threatens food and water security. Coastal areas are subject to localized flooding, inundation, and salinization worsened by sea level rise. Impacts associated with sea level rise affect the country's critical infrastructure and port activities, as well as the essential ecosystem services from mangroves and coral reefs. Coastal and highland areas additionally assume potential asset losses and casualty risks from frequent seismic activity. These hazard risks are discussed below.

Sea Level Rise and Sea Surface Temperature

According to recent literature, historically observed sea surface temperatures (1985–2009) in the Red Sea and Gulf of Aden reflect different seasonal patterns and rates of warming.[34] Mean sea surface temperatures in the Red Sea during this period fluctuated between one seasonal peak in August (approximately 31°C) near the end of the summer monsoon, and one seasonal minimum in February (approximately 26°C) near the end of the winter monsoon. However, mean temperatures in the Gulf of Aden during this period exhibited two seasonal maxima and minima. In addition to a roughly equivalent maximum and minimum in September and January, respectively, the basin also featured an earlier maximum in June (approximately 31°C) and relative minimum in July (approximately 29°C) due to seasonal upwelling of colder, deeper water. Annual sea surface temperature anomalies displayed an increasing trend in both basins across all seasons since 1993, with the highest increase of 0.64°C per decade in the Red Sea (1993–2009) and <0.40°C per decade in the Gulf of Aden over the same time period. Sea surface temperature anomalies are important contributors to interannual and decadal climate variability in Yemen. On average, El Niño and positive IOD phases are correlated with warmer sea surface temperatures and La Niña and negative IOD phases are correlated with cooler sea surface temperatures. However, their correlation and severity vary by event. Warmer sea surface temperatures have increasingly contributed to coral bleaching events in Yemen's coastal zones.[35]

Sea level rise, inundation, and erosion will increasingly threaten Yemen's coastline by the end of the century. Under SSP3-7.0 with a historical baseline of 1995–2014, sea level rise is projected to increase 0.22 m (0.17 m, 0.28 m) by 2050 and 0.67 m (0.51 m, 0.91 m) by 2100 in the largest coastal city Aden.[36] Aden's built environment is particularly vulnerable, as 0.60 m of sea level rise above 2008 levels by the end of the century would result in an estimated $2 billion in property damage and potential storm surge affecting half of the governorate's population.[37] Critically, half of Aden's water supply also originates from local aquifers vulnerable to saltwater intrusion. The port of Mukalla in the eastern governorate of Hadramawt, the second largest in southern Yemen, would likewise lose nearly 10% of its urban area in addition to wetland habitat due to coastal erosion associated with sea level rise of 0.50 m by 2035.[38] Under SSP3-7.0 (1995–2014 baseline), Socotra has the highest projected sea level rise along Yemen's coastline, increasing 0.25 m (0.17 m, 0.35 m) by 2050 and 0.77 m (0.53 m, 1.06 m) by 2100.[39] Managing the impacts of sea level rise and warming in coastal ecosystems will be a key concern in Socotra.

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[36] NASA (2023). Sea Level Projection Tool. URL: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool; note the figures inside parentheses represent 17th and 83rd percentiles, respectively.

[37] Environmental Protection Authority (2013) Second National Communication to the UNFCCC. URL: https://unfccc.int/resource/docs/natc/yemnc2.pdf

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[39] NASA (2023). Sea Level Projection Tool. URL: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool; median values based on projections for geographic coordinates closest to Yemen's shoreline.

Flood and Drought Risk

Incidents of flooding in Yemen have increased and will likely occur with greater intensity and frequency in the future alongside continued drought and water scarcity risks. For example, in 2020, flash floods amid ongoing conflict killed nearly 150 people and left 300,000 without their homes according to UNHCR.[40] More recently, the summer rainy season in 2022 was 300% above average annual intensity, contaminating water resources and leading to the displacement of over 100,000 people primarily on the frontlines of conflict in Hajjah, Al Hudaydah, and Marib.[41] GFDRR identifies Marib and surrounding regions with the highest risk of river (wadi) flood hazard, Dhamar and the eastern interior with the highest risk of urban flood hazard, and all coastal governorates with coastal flooding.[42] Flood hazard risks especially threaten sanitation, hygiene, safety, and critical infrastructure access.

Tropical cyclones affecting eastern Yemen represent another dimension of the trend toward more frequent and intense flooding and are a key factor influencing coastal precipitation variability. The Arabian Sea typically generates approximately two tropical cyclones a year before and after the summer monsoon season (April – June, October – December, respectively).[43] However from 1982–2000 to 2001–2019, cyclones in the Arabian Sea increased 52% in frequency, 80% in duration, and grew in their intensity, measured according to accumulated cyclone energy.[44] Increasing sea surface temperatures, also associated interannually with a positive phase Indian Ocean Dipole, play a major role in this trend.[45] Over the last two decades, Yemen faced a series of unprecedented cyclones including a 2008 cyclone that killed 73 people and cost $1.6 billion in damages.[46] In 2015, Cyclone Chapala made landfall along the coast of Hadramawt and Shabwah after passing north of Socotra, causing 10 m of storm surge and dropping many times the average yearly rainfall in a couple days.[47] Tropical cyclones pose the greatest risk to governorates in the eastern interior and Socotra.

Despite projected increases in overall precipitation and intensity, drought episodes continue to pose a threat due to multi-model uncertainty, Yemen's high precipitation variability, and longstanding water scarcity. Yemen is among the most water-stressed countries in the world, experiencing high rates of groundwater extraction further exacerbated by agricultural demands and ongoing conflict.[48] Yemen is also highly susceptible to drought-related health impacts such as malnutrition, vector-borne, and water-borne diseases.[49] Four major droughts affected Yemen over the last 30 years, with the most recent between 2007–2009.[50] However, sparse data records prevent complete identification of drought drivers and characteristics of variability, which require further study.

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Earthquake, Volcano, and Landslide Hazards

Yemen is located on the Arabian Plate near two tectonically active rifting regions, with moderately high seismic risk conditions that climate variability can exacerbate. Off the west coast is the Red Sea Rift, an extension of the East African Rift zone that borders the Afar Triangle triple-plate-junction. Off the south coast is the Aden Ridge, the more seismically active divergent spreading zone bordering the Somali Plate (**see Figure 8**). Small and moderate earthquakes also periodically occur onshore in western Yemen 200–300 km from the Red Sea's rifting axis.[51] Smaller fault systems detected in the western and central highlands are the results of historical uplift and division that either run parallel to the Red Sea or the Gulf of Aden (between Taizz and Ibb). The ancient Marib-Shabwah rift system, pictured, bisects central Yemen but is less associated with modern-day seismic activity.[52]

The greatest potential for peak ground movement (with 10% exceedance over a 50-year period) is forecasted for Yemen's coasts, particularly Aden and Al Hudaydah, followed by earthquake hotspots in and near the western and central highlands, including Sana'a, Dhamar, and Marib (**see Table 6**). Seismic activity along Yemen's divergent rift systems is characterized by earthquake swarms – series of earthquakes that display a similar magnitude (usually magnitude 3 to 5 on the Richter Scale) and recur every few decades, rather than one large event followed by smaller aftershocks.[53] However, sometimes events of magnitude 6 or higher occur. The deadliest earthquake in recent history was centered near Dhamar in 1982 (magnitude 6.3), resulting in approximately 2,800 casualties and structural damage to tens of thousands of buildings that affected more than half a million people. Earthquakes of moderate magnitude, such as the 1991 Al-Udayn earthquake near Ibb (magnitude 4.7), are still capable of causing widespread structural damage due to substandard construction and steep terrain.[54]

Yemen's offshore islands occasionally experience volcanic activity.[55] Earthquake swarms in the Zubair Archipelago of the southern Red Sea culminated in a volcanic eruption at Jebel at Tair in 2007 and formed the new islands of Sholan in 2011–2012 and Jadid in 2015. Further south, the Hanish Islands have been associated with earthquake swarms. Submarine eruptions also recently occurred along the Aden Ridge.

The Global Facility for Disaster Risk Reduction (GFDRR) classifies Al Hudaydah and governorates along the southwest coast with medium volcanic hazard risk.[56] Most of Yemen's governorates also have a high risk of landslide hazards according to GFDRR, partly due to their steeper terrain. More intense precipitation and tropical cyclones in the future are likely to increase incidents of landslides in Yemen, especially along slopes with little vegetation.[57]

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[54] Alrubaidi, M., Alhaddad, M. S., Al-Safi, S. I., Alhammadi, S. A., Yahya, A. S., and Abadel, A. A. (2021). Assessment of seismic hazards in Yemen. Heliyon, 7(12). DOI: https://doi.org/10.1016/j.heliyon.2021.e08520

[55] Ruch, J., Keir, D., Passarelli, L., Di Giacomo, D., Ogubazghi, G., and Jonsson, S. (2021). Revealing 60 years of earthquake swarms in the southern red sea, Afar and the Gulf of Aden. Frontiers in Earth Science, 9, 664673. DOI: https://doi.org/10.3389/feart.2021.664673

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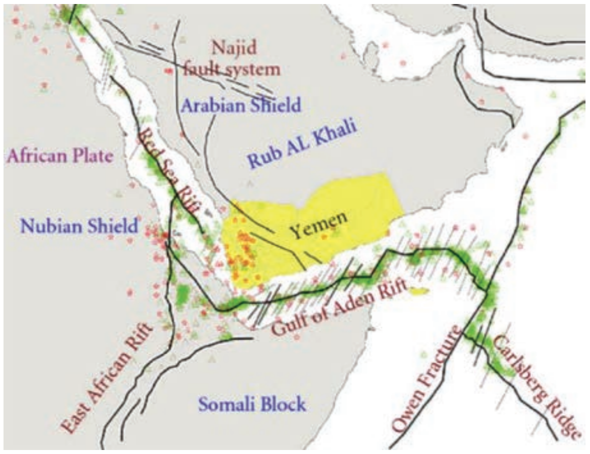
FIGURE 8. Map of Yemen's Historical Seismic Activity[58]



Black lines denote major faults, red stars denote earthquake epicenters observed 1962 and earlier, and green triangles denote earthquake epicenters observed after 1962. The map depicts where the East African Rift joins the Red Sea Rift to the northwest of Yemen, separating the African Plate from the Arabian Plate. It also delineates the Aden Ridge, which extends from Djibouti's Gulf of Tadjoura to the Owen Fracture in the Arabian Sea (east of the island of Socotra) and separates the Arabian Plate from the Somali Plate.

TABLE 6. Seismic Hazard Risk for Key Yemeni Cities According to Two Study Methods, Measured in Peak Ground Acceleration (PGA) with 10% Probability of Exceedance in 50 Years

City (Governorate)	2012 PGA (cm/sec^2)	2021 PGA (cm/sec^2)
Aden (Aden)	29	23
Dhamar (Dhamar)	19	29
Al Hudaydah (Al Hudaydah)	24	22
Marib (Marib)	20	26
Sana'a (Amanat al Asimah)	24	21
Ibb (Ibb)	15	24
Al Mukalla (Hadramawt)	14	18
Sa'ada (Sa'ada)	13	18
Al Bayda (Al Bayda)	5	18
Al Mahrah (Al Mahrah)	10	4

Alrubaidi et al. (2021) attempt to correct modeling biases in an initial assessment by Mohindra et al. (2012).[59] Major cities shaded red attained the highest seismic risk averaged between the two studies, measured in peak ground acceleration with 10% probability of exceedance in 50 years.

KEY NATIONAL DOCUMENTS

- Third National Communication to the UNFCCC (2018)
- First Biennial Update Report to the UNFCCC (2017)
- Intended Nationally Determined Contribution (2015)
- Second National Communication to the UNFCCC (2013)
- National Adaptation Programme of Action (2009)
- Initial National Communication to the UNFCCC (2001)

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ANNEX OF PROJECTED CLIMATE SCENARIOS

Compared to the most likely scenario SSP3-7.0, which results in the greatest temperature and precipitation shifts nationally across all key metrics by the end of the century (see Table 7), SSP1-2.6 and SSP2-4.5 demonstrate Yemen's lower overall rates of change and severity of climate impacts as a result of carbon emission reductions. The differences between projected temperatures under the three scenarios are particularly pronounced (**see Figure 9a**). SSP1-2.6 has the lowest annual mean temperature increase – an anomaly greater than 1°C by 2080–2099. Mean temperature rises by an anomaly greater than 2°C by end-of-century under SSP2-4.5 and greater than 3°C by end-of-century under SSP3-7.0. For SSP1-2.6, the median number of high Heat Index days nationwide during the reference period (14.51 days) rises minimally by the end of the century and only slightly more under SSP2-4.5, whereas the number increases more than 40 days by end-of-century under SSP3-7.0. The anomalous number of tropical nights (T-min >20°C) experienced nationally by the end of the century is among the most notable metrics. Under SSP2-4.5, the number of tropical nights projected above the reference period by the end of the century roughly doubles compared to under SSP1-2.6 and increases by another month under SSP3-7.0 by the end of the century (for a total approaching three months longer than during the reference period). Tropical nights with a higher temperature threshold (T-min >26°C) predict estimates nearly equivalent to those of the lower temperature threshold across all timescales and scenarios, reflecting how temperature shifts across different regions (the highlands, Tihama, and eastern interior) ultimately equate to similar nationwide averages when aggregated. The number of summer days (T-max >25°C) increase the most above the reference period under SSP3-7.0 by the end of the century compared to the other scenarios. However, only SSP1-2.6 does not approach an anomaly of one month projected by 2080–2099, which SSP2-4.5 and SSP3-7.0 both reach.

TABLE 7. Key National-Level Projected Anomalies Through End-of-Century (Ref. Period 1995-2014) Under SSP1-2.6, SSP2-4.5, and SSP3-7.0 Scenarios

	SSP1-2.6 Projection		
Metric	**2020–2039**	**2040–2059**	**2080–2099**
Annual Mean Temperature	0.76°C (0.39°C, 1.27°C)	1.19°C (0.69°C, 1.81°C)	1.20°C (0.60°C, 2.11°C)
High Heat Index Days (No. Days T-max >35°C) Annually	6.34 (–0.61, 11.35)	9.73 (0.91, 16.72)	11.03 (1.58, 20.06)
Tropical Nights (No. Nights T-min >20°C) Annually	16.60 (8.22, 28.23)	26.00 (13.29, 41.50)	25.90 (12.02, 46.94)
Summer Days (No. Days T-max >25°C) Annually	11.21 (3.87, 19.03)	17.05 (9.08, 24.68)	16.53 (8.33, 26.65)
Percent Change in Annual Total Precipitation	4.20% (–2.61%, 13.10%)	6.10% (–1.80%, 18.22%)	5.02% (–2.74%, 19.91%)
Average Largest 5-Day Cumulative Precipitation (mm) Annually	3.76 (–23.46, 33.95)	6.73 (–20.21, 40.65)	3.46 (–21.30, 32.84)
	SSP2-4.5 Projection		
Metric	**2020–2039**	**2040–2059**	**2080–2099**
Annual Mean Temperature	0.78°C (0.43°C, 1.26°C)	1.45°C (0.93°C, 2.19°C)	**2.33°C** (1.57°C, 3.40°C)
High Heat Index Days (No. Days T-max >35°C) Annually	6.72 (–0.75, 12.40)	12.78 (2.76, 22.42)	24.37 (11.47, 44.44)

(*continues*)

TABLE 7. Key National-Level Projected Anomalies Through End-of-Century (Ref. Period 1995–2014) Under SSP1-2.6, SSP2-4.5, and SSP3-7.0 Scenarios (*Continued*)

Metric	SSP2-4.5 Projection		
	2020–2039	2040–2059	2080–2099
Tropical Nights (No. Nights T-min >20°C) Annually	17.51 (8.93, 28.11)	31.60 (20.48, 48.33)	**51.15 (33.66, 76.70)**
Summer Days (No. Days T-max >25°C) Annually	11.60 (4.53, 18.93)	18.87 (11.68, 27.46)	27.59 (20.53, 34.52)
Percent Change in Annual Total Precipitation	3.13% (–3.29%, 12.60%)	4.54% (–3.46%, 14.48%)	6.70% (–2.55%, 21.96%)
Average Largest 5-Day Cumulative Precipitation (mm) Annually	7.97 (–18.20, 40.74)	5.90 (–18.79, 36.21)	8.43 (–18.58, 39.68)
Metric	**SSP3-7.0 Projection**		
	2020–2039	**2040–2059**	**2080–2099**
Annual Mean Temperature	0.76°C (0.35°C, 1.34°C)	1.64°C (1.00°C, 2.42°C)	**3.42°C (2.40°C, 5.08°C)**
High Heat Index Days (No. Days T-max >35°C) Annually	6.36 (–0.69, 12.24)	14.06 (4.62, 26.89)	**45.81 (26.45, 79.48)**
Tropical Nights (No. Nights T-min >20°C) Annually	17.37 (7.82, 30.06)	**36.45 (21.50, 51.49)**	**82.19 (56.45, 118.16)**
Summer Days (No. Days T-max >25°C) Annually	11.07 (2.47, 20.01)	21.23 (13.52, 29.61)	**35.18 (27.83, 41.93)**
Percent Change in Annual Total Precipitation	1.60% (–3.79%, 16.30%)	2.76% (–3.73%, 18.85%)	**10.13% (–2.50%, 34.06%)**
Average Largest 5-Day Cumulative Precipitation (mm) Annually	3.76 (–25.67, 38.31)	4.43 (–26.89, 38.88)	**13.73 (–21.10, 59.30)**

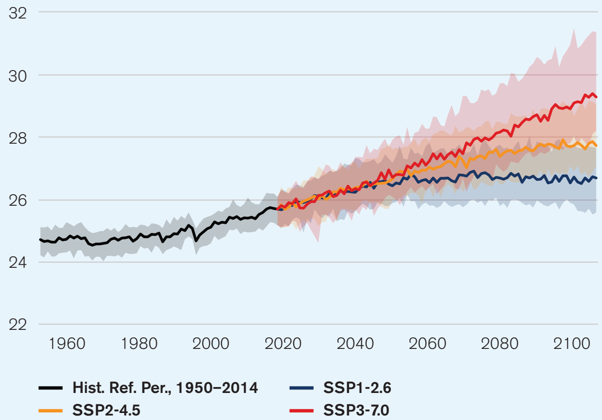
10th percentile and 90th percentile values are shown in parentheses. Key values or shifts over time are shaded orange and bolded. Projected high Heat Index days use 1.00° × 1.00° (100km × 100km) data resolution. See text for interpretation.

Projected precipitation patterns countrywide under the three scenarios produce certain differences by the end of the century but are not as clear as mean temperature trends under higher emission trajectories (**see Figure 9b**). By the period 2080–2099, Yemen is expected to experience a roughly similar positive change in precipitation from the reference period under SSP1-2.6 and SSP2-4.5. Under SSP3-7.0, the positive anomaly is greater than 10%, approximately double that of the other two scenarios for the same time period. The average largest 5-day cumulative precipitation expected by the end of the century remains relatively unchanged from the reference period under SSP1-2.6. However, under SSP3-7.0, the nationwide metric noticeably increases (>10 mm) above the reference period by the end of the century, much higher than the anomaly projected by midcentury.

Sea level rise under SSP2-4.5 is projected to increase 0.50 meters from the historical reference period on Aden's coast by 2090.[60] By comparison, under SSP3-7.0 sea level rise exceeds this threshold earlier and under SSP1-2.6 sea level rise exceeds this threshold after 2100 (**see Figure 10**). SSP1-2.6 and SSP2-4.5 also have much wider ranges of uncertainty represented by the 83rd percentile in **Figure 10**. Compared to SSP3-7.0 which rises 0.22 m (0.17 m, 0.28 m) by 2050, SSP1-2.6 rises 0.18 m (0.14 m, 0.24 m) and SSP2-4.5 rises 0.20 m (0.16 m, 0.27 m).

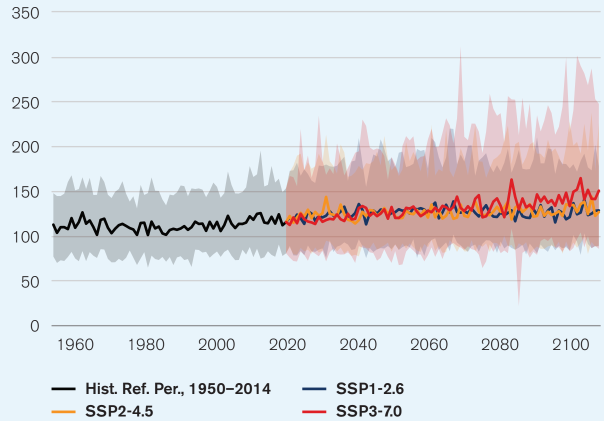
60 NASA (2023). Sea Level Projection Tool. URL: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool; note the figures inside parentheses represent 17th and 83rd percentiles, respectively.

FIGURE 9A. Projected Average Mean Temperature in Degrees Celsius Nationwide (Ref. Period 1995–2014) Under Various Scenarios



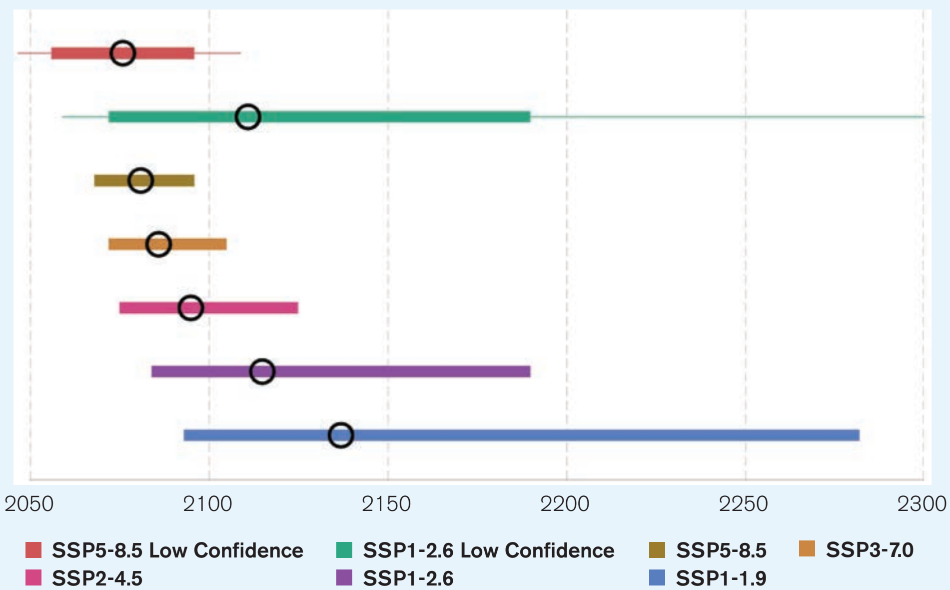
Shaded areas indicate ranges of 10th–90th percentiles. Note clearly higher increase of SSP3-7.0 starting midcentury.

FIGURE 9B. Projected Precipitation in Millimeters Nationwide (Ref. Period 1995–2014) Under Various Scenarios



Shaded areas indicate ranges of 10th–90th percentiles. Note relatively higher increase under SSP3-7.0 by the end of the century, but probability ranges also extend below the historical reference period (decreasing for all scenarios), indicating a potential likelihood for precipitation decreases rather than increases.

FIGURE 10. Projected Timing of 0.5-Meter Sea Level Rise Along Aden's (Yemen's) Coast Under Various Scenarios (Ref. Period 1995-2014)[61]



Thick bars show 17th–83rd percentile ranges, and black circles show median value. Thin bars also show 5th–95th percentile ranges for SSP1-2.6 Low Confidence and SSP5-8.5 Low Confidence scenarios.

[61] NASA (2023). Sea Level Projection Tool. URL: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool

CLIMATE RISK COUNTRY PROFILE

YEMEN

WORLD BANK GROUP