CLIMATE RISK COUNTRY PROFILE

MOROCCO

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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.

This effort is managed and led by MacKenzie Dove (Technical Lead, CCKP, WBG) and Pascal Saura (Task Team Lead, CCKP, WBG).

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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.

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FOREWORD

Development progress has stalled in many countries amid low growth, increased fragility and conflict, pandemic-related setbacks, and the impacts of climate change. Droughts, extreme heat, flooding and storms push millions into poverty annually, causing unemployment and risking unplanned internal and cross-border migration. Every year, an estimated 26 million people fall behind due to extreme weather events and natural disasters. These shocks have the potential to push a total of 130 million into poverty by 2030.

The World Bank Group (WBG) is supporting countries to meet these challenges. As part of our vision to end poverty on a livable planet, we are investing in development projects that improve quality of life while creating local jobs, strengthening education, and promoting economic stability. We are also helping people and communities adapt and prepare for the unpredictable and life-changing weather patterns they are experiencing, ensuring that limited development resources are used wisely and that the investments made today will be sustainable over time.

Having access to data that is accurate and easily understandable is of course critical to making informed decisions. This is where the report you are about to read comes in.

Climate Risk Country Profiles offer country-level overviews of physical climate risks across multiple spatiotemporal scales. Each profile feeds into the economy-wide Country Climate and Development Reports and draws its insights from the Climate Change Knowledge Portal, the WBG's 'one-stop-shop' for foundational climate data.

Guided by World Bank Group data and analytics, developing countries can conduct initial assessments of climate risks and opportunities that will inform upstream diagnostics, policy dialogue, and strategic planning. It is my sincere hope that this country profile will be used to inform adaptation and resilience efforts that create opportunities for people and communities around the world.

Valerie Hickey, PhD
Global Director
Climate Change Group
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KEY MESSAGES

The main climate change physical risks for Morocco are increased temperatures, decreased total rain, increased extreme weather events, desertification, and sea level rise.

In Morocco, temperatures are rising and are projected to increase at a rate exceeding the global average. Key temperature-related concerns include a growing number of hot days, which heighten health and fire risks, and tropical nights, posing threats to health and agriculture. These impacts will become significant by mid-century. By the end of the century, hot, humid days, detrimental to health, are also expected to occur more frequently.

Precipitation has been decreasing and is projected to continue declining across the country, with marked changes beyond natural variability anticipated in all regions before 2050. Longer drought seasons and the expansion of desertification northward are expected. At the same time, extreme precipitation events are likely to occur more frequently, increasing the risks of floods and landslides especially when combined with overall drier conditions.

Finally, rising sea levels and storm surges pose an escalating threat to densely populated coastal cities.

COUNTRY OVERVIEW

Morocco is located in the northwest corner of Africa, with the Atlantic Ocean to the west, the Alboran Sea (Mediterranean) to the north, and the Sahara Desert to the south and southeast. Its climate varies with the landscape, which includes the Rif Mountains in the north, the Atlas Mountains in the center, plateaus in the east, coastal plains in the west, and desert in the south. The Atlas Mountains create a natural divide between the coastal zones and the southern regions bordering the Sahara Desert.

Morocco is a lower middle-income country and has a population of almost 38 million people (2023[1]). Most of Morocco's population resides in the northern and coastal areas of the country, which mostly experience a typical Mediterranean climate, with mild, wet winters and hot, dry summers.

Morocco is highly vulnerable to climate variability and change. The main climate change physical risks for Morocco are increased temperatures, decreased total rain, increased extreme weather events, desertification, and sea level rise. Expectations of increasing frequency and intensity of droughts for the country are particularly alarming for the agricultural sector and forestry and will affect both rural livelihoods and the national economy as a whole. Increased temperatures and changing rainfall patterns will create additional risks for water resource availability, agriculture and livestock productivity. Climate and socio-economic environments in semi-arid areas in Morocco makes communities vulnerable to food insecurity and livelihoods as well as leads to unsustainable agroecological systems, crop failure, and unproductive rangelands.

Morocco is working to improve its resilience to climate change and make progress towards a green economy. Key priority is paid to the country's water resources, agriculture and forestry, energy and health sectors. Morocco submitted its Third National Communication in 2016[2], its Second Biennial Update Report in 2019[3], and its Updated Nationally Determined Contributions to the UNFCCC in 2021[4]. These documents, in conjunction with Morocco's 2030 National Climate Plan (2019), the 2030 National Sustainable Development Strategy (NSDD) (2017)[5], and the Morocco National Adaptation Plan 2022–2030[6] provide the guidance and platform to integrate responsible environmental management with climate change adaptation strategies, in line with the country's social and economic development targets. Morocco implements a sectoral approach, adapted to the circumstances and specific features of the territorial entities: mountain regions, the coast, oases, agricultural areas and urban areas when adapting to climate change to protect populations, natural heritage and climate-sensitive production systems.

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1 World Development Indicators, World Bank
2 Morocco. National Communication (NC 3). https://unfccc.int/documents/128109
3 Morocco. Biennial update report 2. https://unfccc.int/documents/208394
4 Morocco First NDC (Updated submission). https://unfccc.int/documents/497685
5 Morocco's 2030 National Climate Plan and 2030 National Sustainable Development Strategy https://www.4c.ma/documents?lang=en
6 Morocco National Adaptation Plan 2022–2030. https://unfccc.int/documents/636730

CLIMATE OVERVIEW

Data overview: Historical observed data is derived from the Climatic Research Unit, University of East Anglia (CRU), CRU TS version 4.08 gridded dataset (data available 1901–2023).

Morocco's climate varies significantly from north to south, shaped by the Atlantic Ocean to the west, the Mediterranean Sea to the north, and the Sahara Desert to the south and southeast. Winter brings colder air and cloudiness due to extratropical weather systems originating from Europe and the Atlantic Ocean. Most of Morocco's rainfall occurs between October and April, following a gradient that decreases from north to south, further influenced by the presence of the Atlas Mountains.

According to the Köppen-Geiger Climate Classification (1991–2020)[7], Morocco features diverse climate zones. The northwest, including much of the Mediterranean coastline, the northern Atlantic coast, and interior regions northwest of the Atlas Mountains, experiences a hot summer Mediterranean climate. The western areas, including cities like Essaouira and Agadir, are characterized by a hot semi-arid climate. The eastern regions near the border with Algeria exhibit a cold desert climate, while the southeastern and southern parts of the country are dominated by a hot desert climate.

Morocco's mean annual air temperature is 18.14°C (1991–2020, CRU data), with monthly averages ranging from 10°C in the peak of winter (December or January) to 27°C in the peak of summer (July or August) (**Fig. 1).** The maximum yearly temperature is 24.2°C, while the minimum is 12.13°C. In summer, coastal temperatures average around 25°C, ranging from 18°C to 28°C, while inland areas can reach up to 35°C. In winter, coastal temperatures range from 8°C to 17°C, while interior mountain regions can experience temperatures below 0°C (**Table A1**). The average difference between day and night temperatures is 12°C, with smaller variations near the coast and larger day-to-night variations inland and in mountainous areas.

Morocco receives an average of 316 mm of total annual rainfall (1991–2020). In the northern region Tanger-Tétouan-Al Hoceima, over 600 mm of rain falls each year, mostly during the colder months. Fès-Meknès, Rabat-Salé-Kénitra, and Béni Mellal-Khénifra, located just to the south of Tétouan-Al Hoceima, also experience significant rainfall, exceeding 500 mm annually. Coastal Casablanca-Settat and Marrakesh-Safi, along with the northeastern region Oriental, receive over 300 mm, while the southern Drâa-Tafilalet and Souss-Massa are much drier. Throughout the country, precipitation is minimal during the summer season (**Table A2**).

Morocco's weather patterns and drought conditions are heavily influenced by natural climate variability, particularly the North Atlantic Oscillation (NAO) and the El Niño-Southern Oscillation (ENSO). The NAO, a dominant atmospheric pressure pattern over the North Atlantic Ocean, alternates between positive and negative phases. During a positive NAO phase, Morocco experiences drier-than-average conditions. Similarly, ENSO events, particularly El Niño phases, are linked to warmer and drier conditions in Morocco, heightening the risk of drought[8]. Understanding and monitoring the NAO and ENSO are therefore critical for anticipating droughts and managing water resources effectively.

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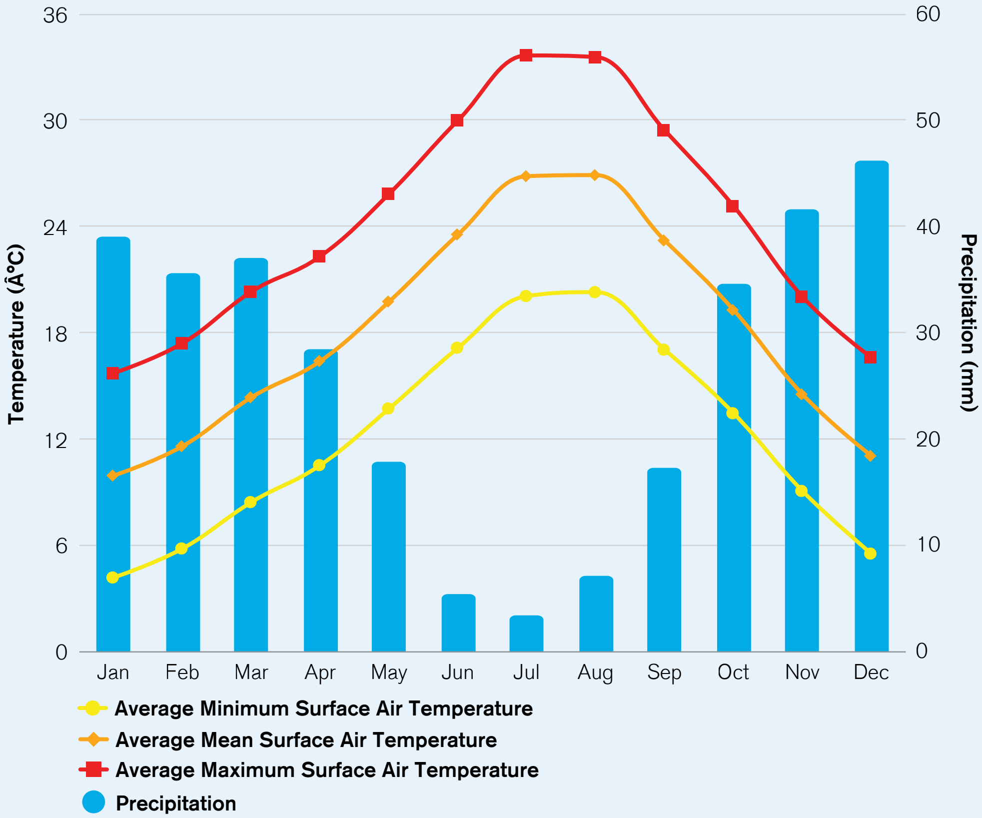
7 Köppen-Geiger Climate Classification (1991–2020) from https://koppen.earth/

8 e.g. Driouech F, Stafi H, Khouakhi A, et al. Recent observed country-wide climate trends in Morocco. Int J Climatol. 2021; 41 (Suppl. 1): E855–E874. https://doi.org/10.1002/joc.6734

FIGURE 1. Monthly Historical Climatology of Average Temperature (minimum, average, and maximum) and Total Precipitation (1991–2023) for Morocco (CRU dataset)



TEMPERATURE AND PRECIPITATION HISTORICAL AND PROJECTED TRENDS

Data overview: Historical observed data is derived from the ERA5 reanalysis collection from ECMWF (1950–2023). Modeled climate data is derived from CMIP6, the Coupled Model Intercomparison Project, Phase 6. This risk profile focuses primarily on SSP3-7.0[9], which projects a doubling of CO_2 emissions by 2100, a global temperature change of approximately 2.1°C by mid-century (2040–2059) and 2.7°C (likely 2.1°C to 3.5°C) by the end of the century (2080–2099), with respect to pre-industrial conditions (1850–1900).

[9] Climate scientists may prioritize SSP4.5 and SSP8.5 to cover a range of potential futures, but SSP8.5 is frequently avoided in policy discussions due to its extreme nature. SSP3-7.0 is understood as a balanced compromise—sufficiently pessimistic yet in line with current policies. Note that patterns of change are generally consistent across scenarios, differing only in timing and impact intensity. For example, impacts projected under SSP3-7.0 by 2070 (2.8°C warming) are projected to occur by 2060 under SSP5-8.5, given the same level of warming. This approach allows scenarios to be translated by focusing on the warming signal rather than specific timelines. Please see the attached tables, which illustrate the relationship between warming levels and future periods for different scenarios. For more information see: IPCC AR6 https://data.ceda.ac.uk/badc/ar6_wg1/data/spm/spm_08/v20210809/panel_a

Historical Temperature Changes

Between 1971 and 2020, Morocco's surface air temperature rose by 0.43°C per decade, exceeding the global trend. The IPCC AR6 reports on Africa[10] and the Mediterranean region[11] support these findings, noting that the Mediterranean region is a climate change hotspot, as it is warming faster than the global average, and noting that the "mean and seasonal temperatures have increased at twice the global rate over most regions in north Africa due to human-induced climate change". Minimum night temperatures increased by 0.39°C per decade, while maximum day temperatures rose more rapidly, at 0.52°C per decade. The largest increases in Tmin (>0.4°C per decade) occurred in Béni Mellal-Khénifra, Marrakesh-Safi, Drâa-Tafilalet, and Souss-Massa, which border the High Atlas Mountains. Maximum temperatures saw the highest rise (around 0.6°C per decade) in Oriental, Fès-Meknès, and Béni Mellal-Khénifra, which include the northern Atlas and the northeastern dry plateau. See **Table A1** for historical changes in temperature across regions.

Projected Temperature Changes

Morocco's temperatures are projected to increase further into the future for all the scenarios. Under SSP3-7.0, the mean temperature nationwide increases from 18.46°C during the historical reference period of 1995–2014 to 20.21°C (19.5°C, 10th percentile, 21.24°C, 90th percentile) for the period 2040–2059. The temperature trend from 2000 to 2050 is 0.38°C /decade (a bit lower on average than the historical trend). The trend is higher for summer (0.45°C /decade) than for winter (0.29°C /decade), and it is especially high in the eastern interior regions (>0.40°C /decade).

The minimum temperature nationwide increases from 12.81°C (1995–2014) to 14.45°C (13.74°C, 15.44°C) for the period 2040–2059. The 2000–2050 projected trend is 0.35°C per decade. The maximum temperature increases from 24.13°C to 25.97°C (25.16°C, 27.17°C) for the same periods, and the projected trend is high, 0.43°C per decade (0.48°C during the spring and summer seasons).

In summary, Morocco is projected to keep warming faster than the global average, and the warming rate is highest for day temperatures during spring and summer, and for the interior regions. See **Table A3** for projected changes in temperature across regions. Projected warming under SSP2-4.5 and SSP1-2.6 is lower, and under SSP5-8.5, higher (**Fig. 2**).

Historical Precipitation Changes

From 1970 to 2020, precipitation in Morocco declined by 13 mm per decade, equivalent to a 4.2% decrease per decade relative to the historical period (1995–2014) (**Fig. 3**). In the northern and central regions, significant reductions in rainfall (with 90% confidence) have been observed despite the high interannual variability, with most regions experiencing a precipitation decrease of 4–6% per decade (except for Oriental). Notably, precipitation in Casablanca-Settat has declined at a higher rate of 6.5% per decade. In the southern regions, while precipitation trends indicate a decline, these changes are not statistically significant. The overall reduction is largely attributed to decreasing rainfall during winter and spring, as well as summer in the northern and central regions. Conversely, a slight, though not significant, increase in rainfall has been observed during the fall across all regions. See **Table A2** for historical changes in precipitation across regions.

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10 IPCC AR6 Ch. 9 (Africa) https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-9/
11 IPCC AR6 cross-chapter 4 (Mediterranean region) https://www.ipcc.ch/report/ar6/wg2/chapter/ccp4/

FIGURE 2A. Projected Average Mean Surface Air Temperature for Different Climate Change Scenarios as Labeled

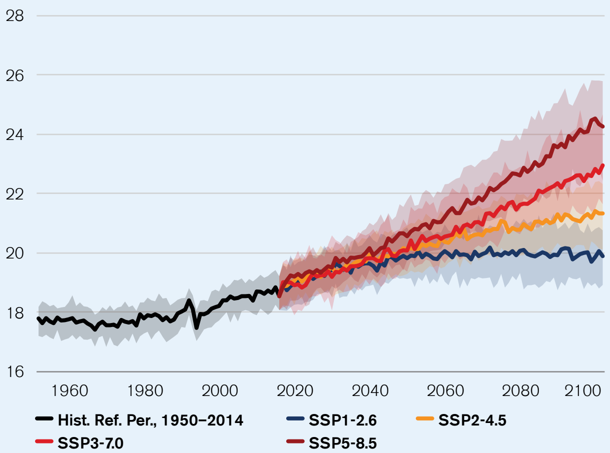


FIGURE 2B. The Projected Monthly Anomaly of the Average Mean Surface Air Temperature for 2040–2059 (relative to the reference period 1995–2014) Under SSP3-7.0, Along with the 10th–90th Percentile Dispersion Across Models

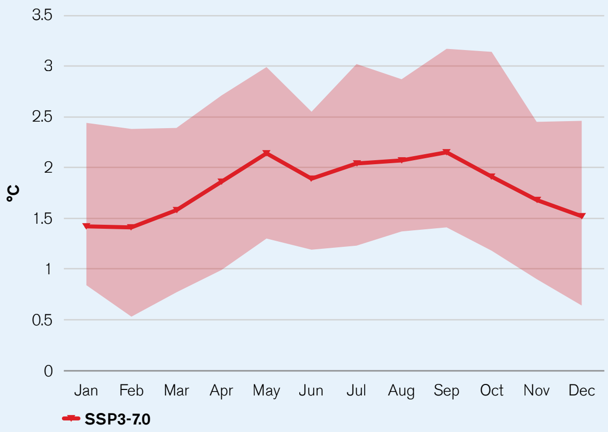


FIGURE 3A. Morocco's Annual Precipitation Between 1951 and 2023 and Decadal Trends for Different Periods as Indicated. Note the High Interannual Variability but Consistent Observed Decrease in Precipitation.

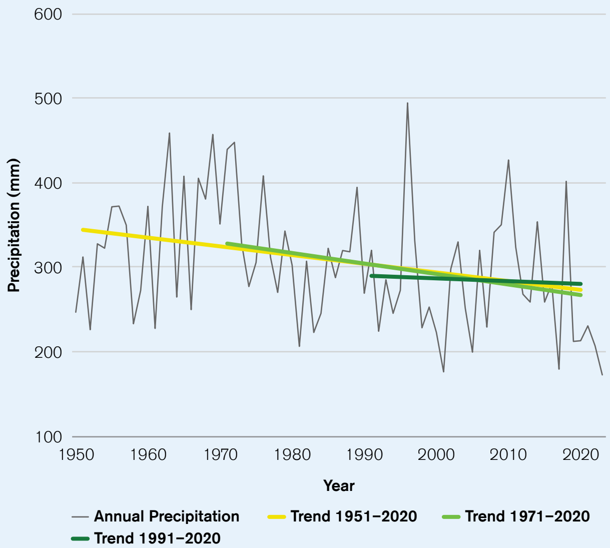
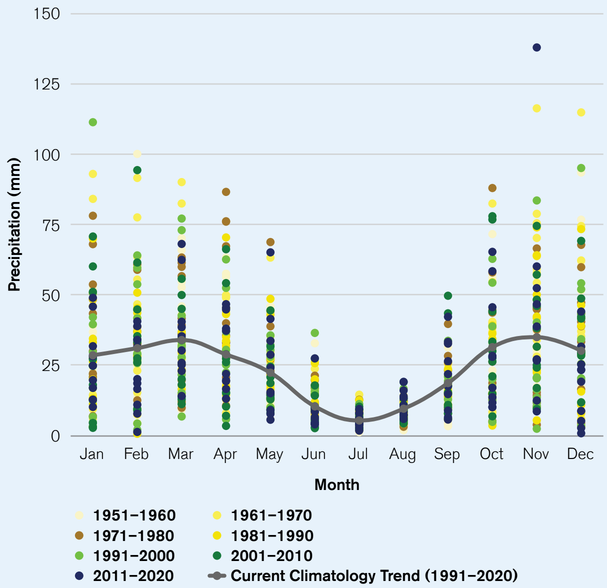


FIGURE 3B. Variability in Average Monthly Precipitation (1951–2020).



Projected Precipitation Changes

Under SSP3-7.0, Morocco's average annual precipitation is predicted to decrease significantly: from 298.29 mm (243.36 mm, 10th percentile, 352.62 mm, 90th percentile) during the historical period (1995–2014, historical scenario) to 255.22 mm (174.64 mm, 342.93 mm) for 2040–2059, a 14% total decrease most pronounced during the rainy winter (**Fig. 4**). The precipitation trend is highest - and robust across CMIP6 models - in the western side of the country, west to the Atlas Mountains. Precipitation in Morocco is projected to decrease significantly beyond natural variability by 2033 at the national level. The timing of this shift varies across regions, with emergence occurring between now and mid-century for all the regions, depending on local trends and variability. The rate of emergence is influenced by both the overall trend and natural variability—regions with higher variability and weaker trends will see delays in the emergence.

Tanger-Tétouan-Al Hoceima, which receives the highest precipitation, is projected to experience the largest absolute decline, with a reduction of 31 mm per decade from 2000 to 2050, with the year of emergence being 2043. Neighboring regions Fès-Meknès, Rabat-Salé-Kénitra, and Béni Mellal-Khénifra are also expected to see significant decreases of approximately 20 mm per decade.

Casablanca-Settat, Marrakesh-Safi, and Souss-Massa are anticipated to experience the most substantial percentage declines, with precipitation decreasing by more than 18% by mid-century (2040–2059) compared to the historical period (1995–2014). Most other regions are expected to see a 3–5% decline in precipitation per decade, like historical trends, except for Oriental, where the projected decline is only 2.3%, and Drâa-Tafilalet (where the decline is 2.4%).

See **Table A4** for projected changes in precipitation across regions.

FIGURE 4A. Projected Annual Precipitation for Different Climate Change Scenarios as Labeled

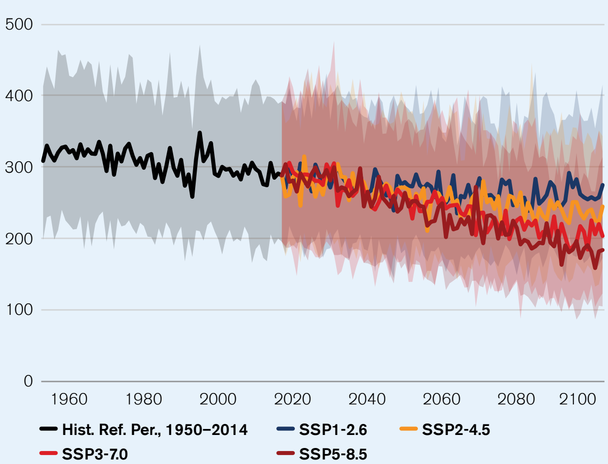
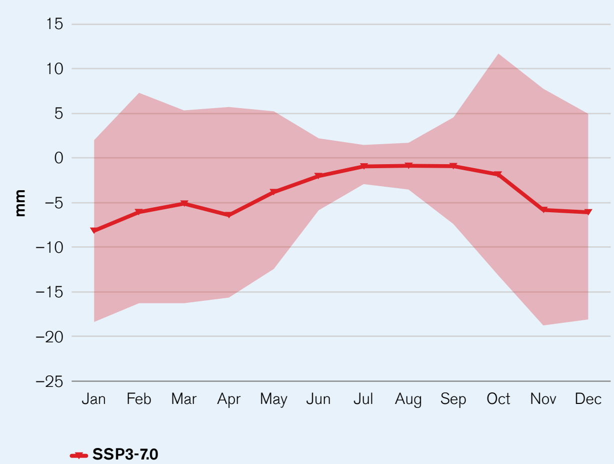


FIGURE 4B. The Projected Monthly Anomaly of Precipitation for 2040–2059 (relative to the reference period 1995–2014) Under SSP3-7.0, Along with the 10th–90th Percentile Dispersion Across Models



Hot Days

Hot days pose significant risks to human health, increasing the likelihood of heat-related illnesses, while also heightening the threat of wildfires, damaging crops, straining water supplies, increasing irrigation needs, and driving up energy demand, all of which can disrupt infrastructure, ecosystems and livelihoods. The annual number of hot days (Tmax > 35°C) across the country, historically averaging just over one month per year (1995–2014), is projected to increase by 4.41 days per decade (2000–2050 under the SSP3-7.0 scenario). By 2040–2059, this number is expected to nearly double, reaching approximately two months per year. This trend is largely driven by significant increases in the eastern desert regions of Drâa-Tafilalet and Souss-Massa, where the number of hot days is projected to rise from two months to almost three months annually (**Table A3**).

Next, we examine the percentage of the population at high health risk due to hot temperatures. High-risk areas are locations where the 50-year return level[12] of the annual number of days with maximum temperatures exceeding 35°C is greater than 30[13]. At the national level, population exposure to dangerous levels of hot temperatures increases significantly, rising from 38% during 1975–2025 to 67% in 2050–2099 (centered at 2075). By the end of the century, certain regions, such as Oriental and Fès-Meknès, see population exposure exceed 90% (**Table A5**), posing heightened risks to agriculture, health, and fire hazards.

Hot Nights – Tropical Nights

Hot nights pose risks to sleep quality, human health, and agricultural crops, as the lack of cooling during the night can exacerbate heat stress on plants, hindering growth and reducing yields, while also increasing the risk of heat-related illnesses, higher energy consumption, and greater strain on power grids. The number of hot nights, or tropical nights, is projected to rise rapidly. During the historical period, nighttime temperatures in July and August exceeded 20°C on half or more of the nights, with about a third surpassing 23°C and fewer than five nights exceeding 26°C. By mid-century (2040–2059) under SSP3-7.0, almost every night in July and August is projected to exceed 20°C, half month will surpass 23°C, a week will exceed 26°C, and about three nights will reach temperatures above 29°C (**Fig. 5**).

Tropical nights (minimum temperature > 23°C) are projected to increase at an average rate of 3.97 nights per decade between 2000 and 2050 under SSP3-7.0. Eastern desert regions such as Oriental, Drâa-Tafilalet, and Souss-Massa are expected to experience an even greater increase, exceeding 5 additional yearly nights per decade (**Table A3**).

Next, we examine the percentage of the population at high health risk due to hot nights. High-risk areas are locations where the 50-year return level of the annual number of days with night temperatures exceeding 26°C

[12] A 50-year return level refers to an event that is expected to occur, on average, once every 50 years.

[13] Population dataset: Gridded Population of the World, Version 4: GPWv4; Revision 11, Dec 2018. For each pixel (at approximately 25 km resolution), the return level for a given return period is calculated by fitting a Generalized Extreme Value (GEV) distribution. A pixel is classified as "too risky" (1) if the return level exceeds the specified threshold, and "not too risky" (0) otherwise. The reported population exposure represents the percentage of the total population in each region that is exposed to risk (1).

FIGURE 5A. Historical (1995–2014) Monthly Number of Tropical Nights at Different Temperature Thresholds

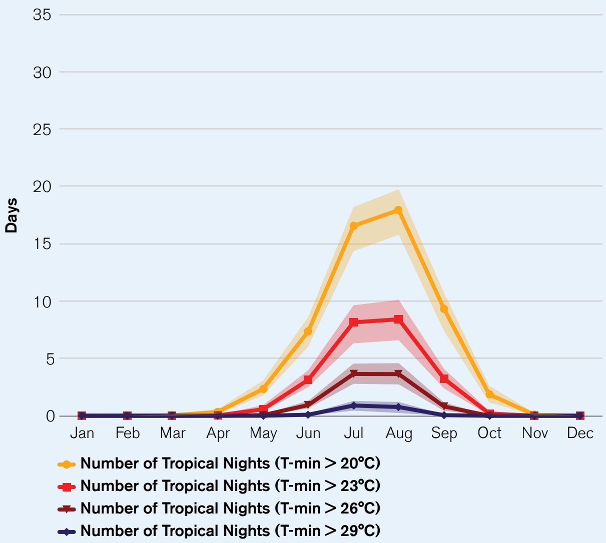
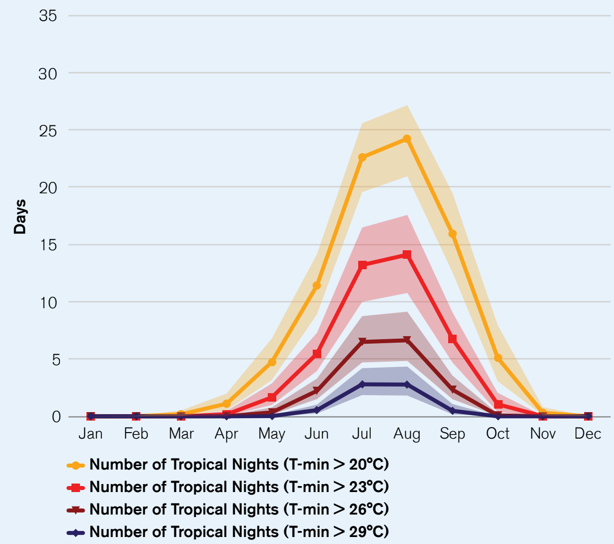


FIGURE 5B. Projected (2040–2059, SSP3-7.0) Monthly Number of Tropical Nights at Different Temperature Thresholds



is greater than 30. At the national level, population exposure to dangerous levels of tropical nights (T > 26°C at night) is projected to rise dramatically from 2% during the historical period to 22% by 2075. By the end of the 21st century, approximately half of the population in Fès-Meknès, Drâa-Tafilalet, and Souss-Massa is expected to be exposed (**Table A5**), posing heightened risk to health and agriculture.

Humid Heat

The Heat Index is a measure of perceived temperature that combines both air temperature and humidity[14]. When both are high, the Heat Index rises, significantly increasing the risk to human health. In such conditions, the body's ability to cool itself through sweating is impaired, which can lead to heat-related illnesses or even fatalities. The Dangerous Heat Index emerges as a major concern by the end of the 21st century. On average, Morocco is projected to experience 16.68 days annually with dangerous heat and humidity levels (heat index > 35°C) by 2080–2099. Drâa-Tafilalet and Souss-Massa are expected to face at least one month per year under such conditions. The remaining regions will experience a minimum of 3 days per year with similar conditions (**Table A3**).

Next, we examine the percentage of the population at high health risk due to increased humid heat. High-risk areas are locations where the 50-year return level of the annual number of days with heat index exceeding 35°C is greater than 20—a threshold considered particularly dangerous for health. Historically, no population was

[14] Heat Index as defined by US-National Weather Service - Steadman R.G., 1979: The assessment of sultriness, Part I: A temperature-humidity index based on human physiology and clothing science. J. Appl. Meteorol., 18, 861–873, doi: http://dx.doi.org/10.1175/1520-0450

exposed to a high heat index. However, by 2035, humid heat is expected to affect a few regions, with population exposure reaching up to 10% in Drâa-Tafilalet. During the latter half of the 21st century (2050–2099, with 2075 as the central year), the proportion of exposed populations rises sharply and affects all the regions, reaching two-thirds in Fès-Meknès and one-third in most other regions (**Table A5**). However, throughout the 21st century, Morocco's population is not expected to be exposed to dangerous wet-bulb temperatures. Wet-bulb temperature is an alternative measure of heat and humidity[15]. High-risk areas are locations where the 50-year return level of the annual number of days with wet bulb temperatures exceeding 27°C is greater than 15.

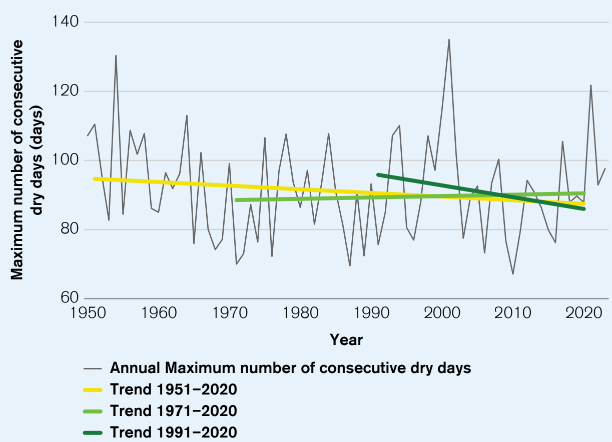
Drought

In Morocco, the average number of consecutive dry days[16] spans approximately three months during the historical period (**Fig. 6**), though this varies significantly from year to year and across regions. Typically, it ranges from just over a month in Béni Mellal-Khénifra (mountain region) to over two months in the northern regions to more than four months in the southern Souss-Massa. This pattern has remained relatively stable during the historical period (**Table A2**). In contrast, as Morocco is overall a dry country, the yearly maximum number of consecutive wet days (>1 mm) is considerably shorter, rarely exceeding 10 days in most areas.

In the future, the maximum number of consecutive dry days in Morocco, primarily occurring during the summer months, is projected to increase by an average of 1.29 days per decade between 2000 and 2050. This trend is particularly pronounced in the coastal regions of Tanger-Tétouan-Al Hoceima, Rabat-Salé-Kénitra, and Casablanca-Settat, where drought durations are expected to increase by nearly 2 days per decade over the same period, resulting in an additional 10 dry days over 50 years (**Table A4**).

This means that drought periods during the summer are lengthening and increasingly encroaching into spring and fall, leading to a projected rise in the percentage of the population exposed to drought throughout the 21st century. High-risk areas are locations where the 50-year return level of consecutive dry days in a year exceeds 90. Currently, over 80% of Morocco's population is already exposed to such prolonged

FIGURE 6. Morocco's Maximum Annual Number of Consecutive Dry Days Between 1951 and 2020 (ERA5 data). Note the High Interannual Variability at the Country Level.



[15] Wet Bulb Temperature formulation by Stull (2011) - Stull R., 2011: Wet-bulb temperature from relative humidity and air temperature. J. Appl. Meteorol. Climatol., 50(11), 2267–2269, doi: 10.1175/JAMC-D-11-0143-1

[16] The largest number of consecutive dry days (<1 mm) each year.

drought conditions, and this trend is expected to persist in the future. In Béni Mellal-Khénifra, which is predominantly mountainous, population exposure stands at 56% during the historical period but is projected to increase to 73% by 2075 (**Table A6**).

Extreme Precipitation

In a warmer world, the potential for air to carry moisture goes up, and thus the potential for heavier precipitation goes up. Intense precipitation events, characterized by the largest single-day event during the historical period, will likely recur more frequently (e.g. the return period will decrease, **Table 1**), which can negatively affect the flooding risk, and be dangerous for infrastructure, human safety, or agriculture. In Morocco, flash floods will become more frequent due to intense rain events combined with overall drier conditions. The largest fractional change is projected for rare 100-yr return periods events, which will be 31% more frequent by 2050 under the SSP3-7.0 scenario (1.31 in **Table 1**) and 85% more likely by 2080. However, the uncertainty in the prediction is large (**Table 1**). In Morocco, the historical 100-year return level for the largest 1-day precipitation is 48 mm, equivalent to the amount of rainfall that would typically accumulate over 1.5 months during winter, condensed into a single day.

TABLE 1. Future (2035–2064) and (2070–2099) Return Period (years) for Extreme Precipitation Events that Correspond to the Return Levels for the Largest Single-Day Event During the Historical Period (1985–2014) for SSP3-7.0. Change in Future Exceedance Probability Expressed as Change Factor for Extreme Precipitation Events that Correspond to the Return Levels for the Largest Single-Day Event During the Historical Period (1985–2014) for Future (2035–2064) and (2070–2099) SSP3-7.0.

Time Period	Historical Return Period (1985–2014, center 2000)					
1985–2014 center 2000	5-yr	10-yr	20-yr	25-yr	50-yr	100-yr
	Future Return Period (years) - Median (10th, 90th)					
2035–2064 center 2050	4.92 (3.16–7.71)	9.41 (5.41–16.15)	17.93 (9.30–35.14)	21.97 (10.98–45.57)	42.10 (18.07–103.98)	79.39 (29.28–246.04)
2070–2099 center 2085	5.27 (3.01–9.58)	9.52 (4.98–20.81)	16.91 (7.84–46.34)	20.33 (9.01–60.53)	35.88 (13.57–140.31)	62.61 (19.86–331.12)
	Change in Future Annual Exceedance Probability (change factor) - Median (10th, 90th)					
2035–2064 center 2050	1.04 (0.62–1.51)	1.09 (0.57–1.79)	1.14 (0.52–2.13)	1.17 (0.50–2.27)	1.23 (0.45–2.79)	1.31 (0.39–3.52)
2070–2099 center 2085	1.00 (0.5–1.61)	1.12 (0.45–1.98)	1.29 (0.40–2.45)	1.35 (0.38–2.65)	1.58 (0.33–3.47)	1.85 (0.30–4.69)

Fractional change above 1 indicates increased probability and decreased return period. For example, a fractional change of 1.31 indicates a 31% increase in the probability of suffering 100-year extreme precipitation events in the future, or 1.31 more likely.

High-risk areas are locations where the 25-year return level of the annual largest 5-day precipitation exceeds 130 mm. The population exposed to large rain events stays stable through the 21st century. The region most affected, now and in the future, is Tanger-Tétouan-Al Hoceima, at more than 70% of population exposed (**Table A6**).

Desertification, Sand and Dust Storms

Morocco is projected to experience increasing desertification as greenhouse gas emissions continue to rise. The Köppen-Geiger Climate Classification, comparing the historical period (1991–2020) with projections for 2071–2099 under SSP3-7.0[17], shows that in the future, the hot desert climate will expand northeastward, including inland from coastal Essaouira, which was previously hot semi-arid. The hot summer Mediterranean climate will also retreat, with only the areas near the Mediterranean Sea, north of the Atlantic Ocean, and northwest of the Atlas Mountains maintaining this classification.

Sand and dust storms originating from the Sahara Desert can affect Moroccan cities and agriculture. While sandstorms have a limited reach, dust storms can reach thousands of kilometers. Saharan dust storms can affect Moroccan's cities, European countries and even cross the Atlantic Ocean, affecting air quality, and hence human's health, agriculture and infrastructure. Historically, significant dust events in Northern Africa have been associated with drought conditions and increased wind speeds caused by changes in the pressure-temperature gradient[18]. Research suggests that the main driver for decadal variability in dust storms is the Atlantic Meridional Oscillation AMO[19]. Climate science indicates that future warming will lead to less frequent but more intense dust events. The decreased frequency is attributed to the expected weakening of winds, possibly linked to a slowdown in tropical circulation[20]. However, the storms will be more intense due to greater dust availability resulting from increased drought occurrences.

Sea Surface Temperatures

The Mediterranean Sea maintains a relatively warm average sea surface temperature of 19.2°C[21]. Sea surface temperatures typically range from around 15°C in late winter (Feb–March) to approximately 26°C in late summer (August) (historical, 1995–2014, multi-model CMIP6 average). These high temperatures in late summer are known to trigger sudden large, localized storms around late summer and early fall that might affect the northern region of Morocco. With climate change, the Mediterranean basin is already suffering more marine heatwaves. Under the scenario SSP3-7.0, sea surface temperatures are projected to increase 0.7°C (0.5°C, 10th percentile, 1.1°C, 90th percentile) near-term (2021–2040), 1.3°C (1°C, 1.8°C) by mid-century (2041–2060), and 2.8°C (2°C, 3.6°C) long term (2081–2100). The increase in temperatures is slightly higher during summer than winter.

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17 https://koppen.earth/ derived from Beck, H.E., McVicar, T.R., Vergopolan, N. *et al.* High-resolution (1 km) Köppen-Geiger maps for 1901–2099 based on constrained CMIP6 projections. *Sci Data* 10, 724 (2023). https://doi.org/10.1038/s41597-023-02549-6

18 Clifford et al. (2019). A 2000 Year Saharan Dust Event Proxy Record from an Ice Core in the European Alps, JGR Atmospheres, 124, 23, DOI: https://doi.org/10.1029/2019JD030725

19 Shao, Klose, and Wyrwoll (2013). Recent global dust trend and connections to climate forcing, JGR Atmospheres, 118, 19, DOI: https://doi.org/10.1002/jgrd.50836

20 Evan et al. (2016). The past, present and future of African dust, Nature 531, 493–495, DOI: https://doi.org/10.1038/nature17149

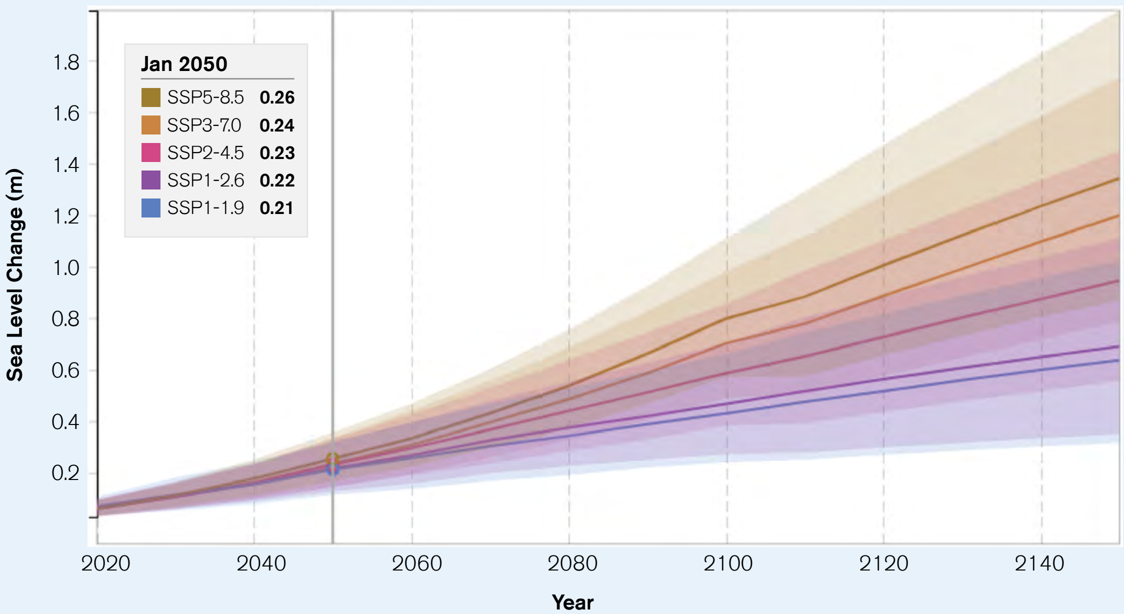
21 IPCC AR6 WGI Interactive Atlas https://interactive-atlas.ipcc.ch/. Note that the box used for Mediterranean Sea also includes most of the northern Atlantic Morocco

Sea Level Rise

Tide gauge measurements indicate an historical increase of 1.75 ± 0.79 mm per year in the Gibraltar Strait from 1993 to 2019[22]. According to altimetry (satellite) data, sea level rose 10 centimeters total from 1993 to present on average in Morocco[23].

Under the SSP3-7.0 scenario, sea level is expected to rise 18 centimeters from 2020 to 2050, with a likely range from 12 to 25 centimeters. This means that sea level rise is projected to increase by 0.21 meters by 2050 and 0.68 meters by 2100 under the SSP3-7.0 scenario, relative to the historical period (1995–2014)[24] (**Fig. 7**).

FIGURE 7. Projected Total Sea Level Change Under Different SSP Scenarios Relative to the Historical Baseline (1994–2014). The Shaded Ranges Show Uncertainties at 17th–83rd Percentile Ranges. Data Reflects the Grid at 33°N, 9°W (along Morocco's Atlantic coast). Data from NASA Sea Level Projection Tool.[25]



Over the next two decades, sea level rise is expected to occur at a similar rate regardless of emissions, scenarios, or warming levels. However, beyond this period, high-emission scenarios project significantly greater increases in sea level. Despite uncertainties, it is certain that sea levels will continue to rise across all scenarios for centuries, underscoring the need for long-term planning. Sea level rise could reach 0.3 m above historical conditions before

[22] NASA https://sealevel.nasa.gov/sea-level-evaluation-tool
[23] NASA https://earth.gov/sealevel/sea-level-explorer/
[24] NASA https://earth.gov/sealevel/sea-level-explorer/
[25] NASA https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?lat=33&lon=%20-9&data_layer=scenario

2050 in all scenarios, and 0.5 m during the second half of the 21st century[26]. "Under the SSP3-7.0 scenario, there is a 92% chance of exceeding half meter of global sea level rise 9% chance of exceeding 1 meter of global sea level rise by 2100"[27].

"On average across the coastlines of Morocco there were 417 days total exceeding the minor high water level between 1980 and 1990, and 549 between 2005 and 2015"[28]. The minor high-water level is defined as 40 cm above the average high tide (mean higher high water, MHHW) and serves as an indicator of potential flooding impacts.

Food Security

Food security, and hence water security, is increasingly affected by climate change and desertification as temperatures rise and droughts intensify. Drought hazard is already high in Morocco (Carrao et al., 2016[29]), and the number of moderate-to-severe drought days is projected to increase further especially in the Mediterranean region and North African countries, including Morocco (Pokhrel et al. 2021[30]).

These factors are projected to alter agricultural productivity and disrupt the seasonal cycle of crops. Furthermore, increased evaporation rates and warming will heighten the demand for irrigation, posing challenges in a country already facing severe water scarcity. The renewable shallow aquifers in the Northern Mediterranean regions, already facing salinization, are projected to warm due to climate change (Benz et al., 2024[31]). This warming could lead to new challenges related to health and water quality.

Due to climate change, sheep in Morocco are projected to experience increasing heat stress. According to Thornton et al. (2021)[32], sheep will endure one to four additional months of heat stress annually by the end of the 21st century compared to 2000 depending on the region. This projection is under the extreme SSP5-8.5 scenario, with an estimated warming of approximately 4.5°C by the end of the century (compared to the pre-industrial period).

By 2090–2099, marine animal biomass along Morocco's coast is projected to decline by up to 50% along the Mediterranean coast under the high-emissions scenario RCP8.5 (compared to 1990–1999 levels) (Tittensor et al., 2021[33]). In contrast, biomass is expected to increase along the Atlantic coast. These projections reflect the impact of climate change alone.

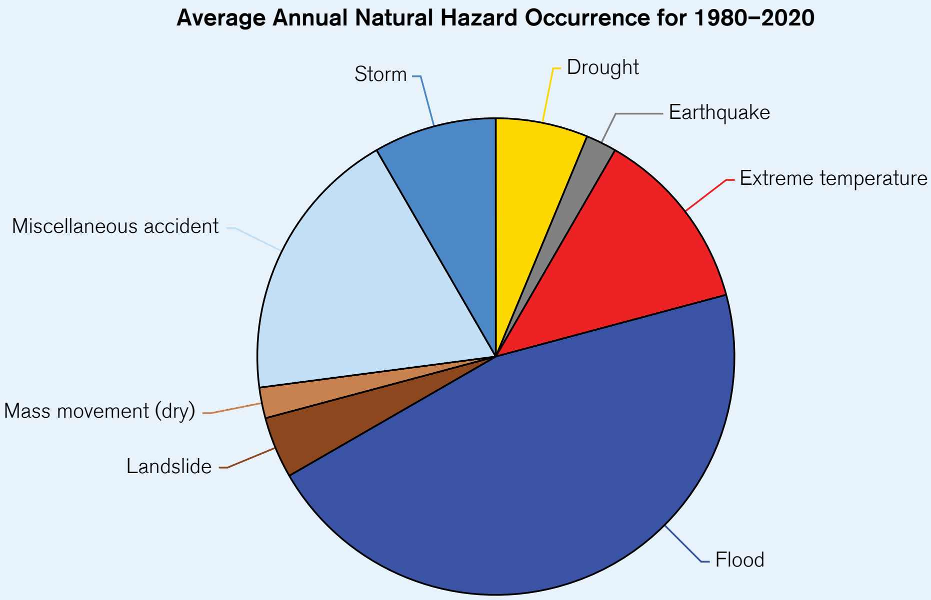
Note that this summary provides a broad overview and is not an exhaustive list.

26 NASA Sea Level Projection tool at 338N, 98W https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?lat=33&lon=%20-9&data_layer=scenario
27 NASA https://earth.gov/sealevel
28 NASA https://earth.gov/sealevel
29 Carrao, Naumann, Barbosa (2016). Mapping global patterns of drought risk: An empirical framework based on sub-national estimates of hazard, exposure and vulnerability. Global Env. Change, Volume 39, Pages 108–124, DOI: https://doi.org/10.1016/j.gloenvcha.2016.04.012
30 Pokhrel et al. (2021). Global terrestrial water storage and drought severity under climate change. Nat. Clim. Chang. 11, 226–233, DOI: https://doi.org/10.1038/s41558-020-00972-w
31 Benz et al. (2024). Global groundwater warming due to climate change. Nat. Geosci. 17, 545–551, DOI: https://doi.org/10.1038/s41561-024-01453-x
32 Thornton et al. (2021). Increases in extreme heat stress in domesticated livestock species during the twenty-first century. Global Change Biology, Volume 27, 22, Volume27, Issue22, 5762–5772, DOI: https://doi.org/10.1111/gcb.15825
33 Tittensor et al. (2021). Next-generation ensemble projections reveal higher climate risks for marine ecosystems. Nat. Clim. Chang. 11, 973–981, DOI: https://doi.org/10.1038/s41558-021-01173-9

Natural Hazards

Climate change is now recognized to have a significant impact on disaster management efforts and pose a significant threat to the efforts to meet the growing needs of the most vulnerable populations. EM-DAT[34] shows flood as the most relevant natural hazard, followed by extreme temperature, drought, storm, and landslide (**Fig. 8**). Think Hazard[35] identifies river floods, coastal floods, landslides, extreme heat, and wildfires as the highest natural risks, followed by urban floods, earthquakes, tsunamis, and water scarcity, categorized as medium risk—most of which are closely linked to the climate crisis. The GDIS disaster database indicates that most recorded disasters between 1960 and 2018 in Morocco are floods, storms, and extreme temperature events[36].

FIGURE 8. Natural Disaster Classification in Morocco (1980–2020) based on EM-DAT Data



[34] The International Disaster Database https://www.emdat.be/

[35] Think Hazard, GFDRR, https://thinkhazard.org/en/report/169-morocco

[36] Rosvold, E.L., Buhaug, H. GDIS, a global dataset of geocoded disaster locations. *Sci Data* 8, 61 (2021). https://doi.org/10.1038/s41597-021-00846-6

ANNEX – TABLES: HISTORICAL AND PROJECTED CHANGES ACROSS REGIONS

Historical Climate and Changes Across Regions

Table A1 and A2 show the variations in historical temperature and precipitation across Morocco's districts.

TABLE A1. Historical a) Air Surface Temperature Averages (1991–2020), CRU, and b) Trends per decade (1971–2020), ERA5, for temperatures (in deg C), colored according to intensity. The Decadal Trend is Bolded Whenever Significant at a 90% Level.

	Historical Air Surface Temperature Averages (1991–2020) (degrees C)					Trend per Decade (1971–2020) (degrees C/decade)		
Region	Temp	Min Temp (night temp)	Max Temp (day temp)	Coldest Month (January) temp	Warmest Month (July or August) temp	Temp	Min Temp	Max Temp
Morocco	18.14	12.12	24.2	9.84	26.86	**0.43**	**0.39**	**0.52**
Tanger-Tétouan-Al Hoceima	16.8	12.08	21.56	10.44	24.17	**0.33**	**0.27**	**0.46**
Oriental	17.19	11.12	23.32	7.96	27.51	**0.45**	**0.37**	**0.59**
Fès-Meknès	15.8	9.69	21.96	7.56	25.45	**0.46**	**0.35**	**0.62**
Rabat-Salé-Kénitra	17.99	12.49	23.54	11.5	24.94	**0.37**	**0.27**	**0.53**
Béni Mellal-Khénifra	16.23	9.29	23.22	7.54	26.08	**0.53**	**0.44**	**0.62**
Casablanca-Settat	18.39	12.7	24.14	11.87	25.26	**0.38**	**0.33**	**0.48**
Marrakesh-Safi	18.05	12.23	23.92	11.15	25.28	**0.45**	**0.41**	**0.51**
Drâa-Tafilalet	18.68	11.7	25.71	7.98	29.98	**0.48**	**0.46**	**0.54**
Souss-Massa	18.88	12.86	24.94	10.84	26.71	**0.44**	**0.44**	**0.46**

TABLE A2. a) Historical Data (1991–2020), CRU and b) Decadal Trend (1971–2020), ERA5, for Annual Precipitation (in mm), c) Historical Annual Maximum Number of Consecutive Dry Days (daily accumulated precipitation < 1 mm), ERA5, and d) Historical Annual Number of Consecutive Wet Days (daily accumulated precipitation ≥ 1 mm), ERA5, Color-Coded by Intensity. Interannual Variability (ERA5) is Expressed as the Standard Deviation of Annual Total Values from 1990 to 2020. Significant Decadal Trends, at the 90% Confidence Level, are Highlighted in Bold.

	Historical Precipitation Yearly Averages (1991–2020)				Precipitation Trend per Decade (1971–2020)		Hist Drought Days	Hist Wet Days
Regions	**Total PR (mm)**	**Interannual Variability (mm)**	**Max (mm) (December of January)**	**Min (mm) (Usually July)**	**Trend (mm)**	**Trend (% respect hist)**	**CDD (days)**	**CWD (days)**
Morocco	315.89	38.17	47.61	3.57	–13.19	–4.18	90.91	5.39
Tanger-Tétouan-Al Hoceima	634.1	122.91	96.55	3.16	**–27.15**	–4.28	68.12	9.43
Oriental	319.49	29.83	39.14	4.48	–10.96	–3.43	63.54	5.08
Fès-Meknès	502.29	60.94	72.7	4.97	**–21.72**	–4.32	47.2	7.44
Rabat-Salé-Kénitra	553.03	84.22	91.21	1.34	**–31.11**	–5.63	80.43	8.09
Béni Mellal-Khénifra	511.26	70.08	79.16	7.44	**–28.52**	–5.58	37.56	7.66
Casablanca-Settat	373.71	60.87	66.99	1.17	**–24.5**	–6.56	89.75	6.92
Marrakesh-Safi	323.14	51.28	53.71	2.66	**–16.59**	–5.13	72.07	6.23
Drâa-Tafilalet	233.73	25.3	31.27	4.73	**–9.06**	–3.88	104.41	4.02
Souss-Massa	205.15	35.01	35.46	2.58	–5.11	–2.49	127.76	4.15

Projected Climate and Changes Across Regions

Table A3 and A4 show the variations in CMIP6 historical and projected temperature and precipitation related variables across Morocco's districts.

TABLE A3. CMIP6 Simulated Historical Averages (1994–2015), Mid-Century SSP3-7.0 Projections (2040–2059), and Decadal Trends (2000–2050) for a) Average Surface Air Temperature, b) Number of Tropical Nights per Year with Tmin > 23°C, c) Number of Hot Days per Year with Tmax > 35°C, and d) Number of Days with Heat Index > 35°C - Hi35[37] (only for 2080–2099, as values are projected to be zero before this period).

	Average Surface Air Temperature (degrees C)			Number of Tropical Nights per Year with Tmin > 23°C (days)			Number of Hot Days per Year with Tmax > 35°C (days)			Hi35 (days)
Regions	**1994–2015**	**2040–2059**	**Trend**	**1994–2015**	**2040–2059**	**Trend**	**1994–2015**	**2040–2059**	**Trend**	**2080–2099**
Morocco	18.46	20.21	0.38	23.69	42.41	3.97	37.73	57.08	4.41	16.68
Tanger-Tétouan-Al Hoceima	16.94	18.41	0.34	1.93	10.35	1.76	3.39	9.54	1.42	3.85
Oriental	17.43	19.3	0.4	15.42	44.21	6.25	34.82	63.79	6.65	9.14
Fès-Meknès	16.32	18.2	0.41	5.22	20.86	3.33	19.24	40.43	4.79	8.31
Rabat-Salé-Kénitra	18.36	19.93	0.34	3.95	14.49	2.19	10.51	22.45	2.73	10.75
Béni Mellal-Khénifra	15.73	17.61	0.42	6.93	17.36	2.26	21.39	37.46	3.78	9.9
Casablanca-Settat	18.62	20.09	0.33	4.8	14.46	1.91	8.55	16.23	1.8	6.5
Marrakesh-Safi	18.16	19.77	0.36	6.17	16.33	1.96	17.25	30.51	3.06	7.71
Drâa-Tafilalet	18.86	20.83	0.43	52.36	76.44	5.21	63.17	86.83	5.35	30.09
Souss-Massa	20.4	22.19	0.39	44.97	68.57	4.95	61.98	83.41	4.84	28.24

[37] Steadman R.G., 1979: The assessment of sultriness, Part I: A temperature-humidity index based on human physiology and clothing science. J. Appl. Meteorol., 18, 861–873, doi: http://dx.doi.org/10.1175/1520-0450

TABLE A4. CMIP6 Simulated Historical Averages (1994–2015), Mid-Century SSP3-7.0 Averages (2040–2059), and Trends per Decade (2000–2050) for a) Precipitation, b) Maximum Number of Consecutive Dry Days (CDD), and c) Maximum Number of Consecutive Wet Days (CWD). The Table also Indicates the Year of Emergence for the Precipitation Trend (the year when precipitation change arises significantly above natural variability). For CWD, We Only Show the Historical Value as the Trend is Insignificant. Trend is Reported by Decade or Percentage (with respect to the historical period).

Regions	Precipitation (mm)						Consecutive Dry Days (days)			CWD (days)
	1994–2015	2040–2059	% Change (hist to 2050)	Trend	Trend (%)	Year of Emergence	1994–2015	2040–2059	Trend	1994–2015
Morocco	298.29	255.22	–14.4	–10.69	–3.58	2033	104.43	109.34	1.29	6.91
Tanger-Tétouan-Al Hoceima	759.91	648.21	–14.7	–31.37	–4.13	2043	62.5	68.78	1.76	11.8
Oriental	260.66	237.66	–8.8	–6.05	–2.32	2048	72.76	78.77	1.32	6.6
Fès-Meknès	512.55	444.65	–13.2	–18.14	–3.54	2041	56.28	61.86	1.31	10.12
Rabat-Salé-Kénitra	540.34	455.28	–15.7	–23.82	–4.41	2041	80.66	87.24	1.78	10.29
Béni Mellal-Khénifra	568.83	479.49	–15.7	–22.16	–3.90	2037	47.93	53.41	1.12	10.87
Casablanca-Settat	364.22	298.12	–18.1	–16.94	–4.65	2038	102.07	110.87	1.93	8.54
Marrakesh-Safi	342.89	279.05	–18.6	–14.63	–4.27	2033	90.72	97.22	1.29	8.06
Drâa-Tafilalet	167.25	149.48	–10.6	–4.1	–2.45	2012	119.21	121.45	0.82	5.11
Souss-Massa	180.16	145.83	–19.1	–7.48	–4.15	2019	144.91	148.74	1.02	4.98

Population Exposure Across Regions

Table A5 and A6 show the variations in CMIP6 historical and projected population exposure to temperature and precipitation related variables across Morocco's districts. Note that the time periods used for population exposure are longer than those in the previous tables, which focus on climatologies. As a result, these periods are not directly comparable. The longer time frames are necessary because a minimum of 50 years of data is required to fit extreme events using Generalized Extreme Value (GEV) distributions.

TABLE A5. For Each Admin1 District, Percent of the Population[38] at High Health Risk for Three Periods: Retrospective (1975–2024, centered on 2000), Future (2010–2059, centered on 2035), and Distant future (2050–2099, centered on 2075), Under SSP3-7.0. High-Risk Areas are defined as locations where the 50-year return level of the number of days in a year with a) maximum temperatures surpassing 35°C exceeds 30 days, b) night temperatures surpassing 26°C exceeds 30 days, c) a heat index surpassing 35°C exceeds 20 days (not showing retrospective period as data is everywhere zero then).

	Hot Days (Tmax > 35°C)			Tropical Nights (Tmin > 26°C)			Heat Index > 35°C	
Regions	**2000**	**2035**	**2075**	**2000**	**2035**	**2075**	**2035**	**2075**
Morocco	37.57	51.62	67.43	2.12	3.7	22.12	1.29	29.25
Tanger-Tétouan-Al Hoceima	6.91	17.38	42.52	0	0	2.22	0	9.37
Oriental	45.4	75.55	93.03	0.35	1.9	29.76	0	34.03
Fès-Meknès	70.44	85.83	98.65	0	0	47.68	0	66.55
Rabat-Salé-Kénitra	22.53	40.55	60.21	0	0	4.96	0	30.55
Béni Mellal-Khénifra	53.68	74.73	86.36	0	0	39.84	4.47	39.84
Casablanca-Settat	5.75	9.83	24.19	0	0	3.79	0	4.89
Marrakesh-Safi	51.34	69.7	87.95	0	0	12.16	0	33.04
Drâa-Tafilalet	56.24	68.97	86.06	28.01	38.62	57.4	10.5	32.36
Souss-Massa	51.97	71.25	75.4	4.15	16.22	45.77	3.79	28.74

[38] Population dataset: Gridded Population of the World, Version 4: GPWv4; Revision 11, Dec 2018. For each pixel (at approximately 25 km resolution), the return level for a given return period is calculated by fitting a Generalized Extreme Value (GEV) distribution. A pixel is classified as "too risky" (1) if the return level exceeds the specified threshold, and "not too risky" (0) otherwise. The reported population exposure represents the percentage of the total population in each region that is exposed to risk.

TABLE A6. For Each Admin1 District, Percent of the Population at High Health Risk for Three Periods: Retrospective (1975–2024, centered on 2000), Future (2010–2059, centered on 2035), and Distant Future (2050–2099, centered on 2075), Under SSP3-7.0. High-Risk Areas are Defined as Locations where: a) The 50-year return level of consecutive days of drought exceeds 90 days in a year, b) The 25-year return level of 5-day cumulative precipitation exceeds 130 mm in a year.

	Maximum Number of Consecutive Dry Days			Average Largest 5-Day Cumulative Precipitation		
Regions	**2000**	**2035**	**2075**	**2000**	**2035**	**2075**
Morocco	88.96	91.94	94.29	15.84	14.11	12.73
Tanger-Tétouan-Al Hoceima	86.77	100	100	81.83	82.56	74.11
Oriental	90.67	92.86	96.01	2.16	1.88	1.83
Fès-Meknès	80.68	83.75	88.83	13.77	11.7	11.25
Rabat-Salé-Kénitra	99.29	99.37	100	16.99	16.23	12.57
Béni Mellal-Khénifra	56.38	61.32	73.44	5.93	2.72	3.36
Casablanca-Settat	100	100	100	0	0	0
Marrakesh-Safi	91.71	93.1	93.99	7.22	3.27	3.38
Drâa-Tafilalet	73.33	75.7	81.11	0.33	0.25	0.61
Souss-Massa	98.21	98.71	99.06	28.56	27.57	26.12

CLIMATE RISK COUNTRY PROFILE

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