CLIMATE RISK COUNTRY PROFILE

LIBYA

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LIBYA DEVELOPMENT TRUST FUND

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ACKNOWLEDGEMENTS

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). This Libya profile was authored by Anna Cabré Albós (Climate Change Consultant, CCKP, WBG). Guidance and inputs were received from Syed Adeel Abbas (Sr. Climate Change Specialist, WB MENA Planet Department), Matthew Ryan Brubacher (Consultant, WB MENA Planet Department) and other WB regional and country experts. The team is grateful for the financial support provided by the Libya Development Trust Fund (LDTF).

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

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
World Bank Group

KEY MESSAGES

Libya faces significant vulnerability to climate change, particularly in sectors such as agriculture and dam management and safety, with hydrological variability being a major driving factor. The country also has a low level of readiness to address these impacts effectively.

- **Observed Climate:** Libya is primarily a hot desert country in North Africa, with a hot Mediterranean climate only in some northern coastal regions. The Mediterranean climate features mild, relatively rainy winters and hot, dry summers. In contrast, the rest of the country experiences sparse and erratic rainfall.
- **Observed Temperature:** Between 1971 and 2020, Libya's mean temperature increased by 0.25°C per decade.
  - **Northwestern regions** observed the greatest changes over this period.
- **Projected Temperature:** Under the SSP3-7.0 ensemble, Libya's annual mean temperatures nationwide are projected to increase further, from 22.20°C during the historical reference period of 1995–2014 to 23.12°C (22.20°C, 10th percentile, 24.01°C, 90th percentile) for the period 2020–2039, and to 23.95°C (23.01°C, 25.06°C) for the period 2040–2059.
- **Extreme Heat Risk:** By midcentury, Libya will experience higher minimum and maximum temperatures. The following key temperature metrics illustrate these risks under the SSP3-7.0 scenario for 2040–2059, compared to the historical reference period of 1995–2014, and are further detailed in Table 5 and 6.
  - Libya will experience the most significant temperature increases during the summer months and the smallest increases during winter. On average, Libya is projected to see a warming of 2.38°C (1.76°C to 3.18°C) in August and 1.49°C (0.47°C to 2.36°C) in December.
  - Summers will become dangerously hot more frequently, with projected average single-day maximum temperatures reaching 46.62°C during summer (JJA) and 35.84°C during winter (DJF).
  - The number of tropical nights (>26°C) in August is expected to increase fivefold from 2.88 days to 14.39 days (9.73–19.42). Most August nights are predicted to exceed 23°C (28.62 days, 25.62–30.07) compared to 17.77 days historically.
  - The number of very hot days in June (maximum temperature >40°C) is expected to double from 5.66 to 11.46, and days with maximum temperatures exceeding 42°C will more than triple from 1.82 to 5.7.
  - The heat index, which combines temperature and humidity, indicates the biophysiological threshold at which the body can no longer cool itself naturally. Historically, there were 0.27 days per year with a heat index of 35°C or higher. This is projected to increase to 1.63 days per year for 2020–2039 and to 5.54 days per year for 2040–2059. From 2050 to 2100, the trend shows an increase of 9.13 days per decade.
- **Observed Precipitation:** Over the 50-year period of 1971–2020, most of the Mediterranean region, including northern Libya, is seeing a consistent decline in precipitation and a reduction in the number of consecutive wet days. In contrast, the interior of North African countries is seeing patchier trends, experiencing either a slight increase in precipitation or no change.
- **Projected Precipitation:** Climate change is expected to cause a long-term decrease in the average Libya's annual precipitation levels, but interannual variability remains remarkably high. The decreasing nationwide trend becomes significant around 2050 for SSP3-7.0, and a decade earlier for SSP5-8.5. Libya will experience more Mediterranean influences in the north (decrease in precipitation) and Sahel-type trends in the desertic south (slight increase in precipitation).

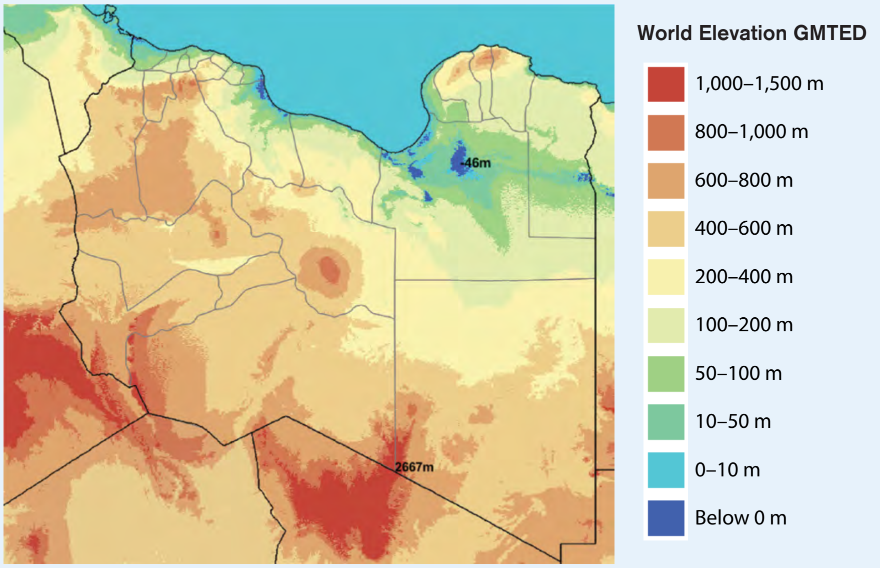
- **Precipitation Risk:** Intense precipitation events will likely recur more frequently (e.g., the return period will decrease), which can negatively affect the flooding risk, and be dangerous for infrastructure, safety, or agriculture.
- **Other climate change impacts:**
    - **Sea level rise** is projected to increase by 0.23 meters by 2050 and 0.68 m by 2100 under the scenario SSP3-7.0 with respect to the historical period (1995–2014). Even though the uncertainties are high, it is certain that sea-level rise will keep increasing in all scenarios for centuries, which require long-term planning for sandy beaches and low-lying populated coastal areas.
    - **Desertification:** As temperatures rise and precipitation patterns shift, only a small region of Libya is expected to retain its Mediterranean climate, where rainfall remains significant.
    - **Sand and dust storms:** Climate science indicates that future warming will lead to less frequent but more intense sand and dust events.
    - **Food security:** Climate change and desertification are increasingly impacting food and water security in Libya as temperatures rise and droughts intensify. Increased evaporation and warming will heighten irrigation demands in a country already facing severe water scarcity. Most irrigation water is sourced from non-renewable deep southern fossil aquifers, with renewable shallow aquifers in the Northern Mediterranean regions already facing salinization and warming. Additionally, Libya's sheep population will face increasing heat stress.

COUNTRY OVERVIEW

Libya, located in the north of Africa between 20°N–33°N latitude and 10°E–25°E longitude, lies within the Sahara Desert. Libya is bordered by the Mediterranean Sea to the north (across from Italy, Greece, and Malta), Egypt to the east, Sudan to the southeast, Niger and Chad to the south, and Tunisia and Algeria to the west. Covering almost 1.8 million km^2 of land (1,759,541 km^2) and 351,589 km^2 of sea exclusive economic zone, the country boasts a long coastline stretching 1,770 km.

The major physical features of Libya include the Nafusah Plateau and the Al-Jifarah (Gefara) Plain in the northwest, both at low sea levels, and the Akhar Mountains ("Green Mountains") in the northeast, rising to 900 meters (**Fig. 1**). The vast Saharan plateau covers much of the remaining territory. Libya experiences little and erratic rainfall, with significant precipitation occurring only along the Mediterranean coast, especially in the Akhar Mountains.

FIGURE 1. Topography of Libya (meters), with Labels for the Lowest (–46 m) and Highest (2267 m) Locations

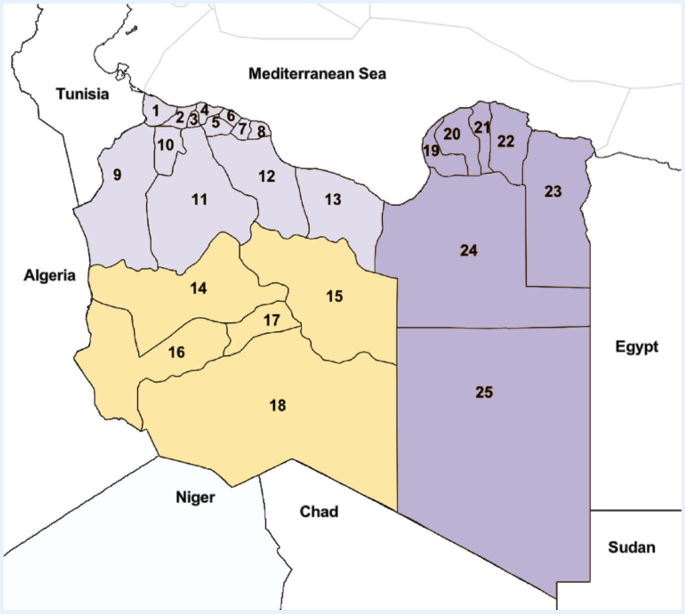


Data from the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010[1]). Figure done with ArcGIS online.

Historically, Libya was divided into three provinces: Tripolitania in the northwest, Cyrenaica in the east, and Fezzan in the southwest (**Fig. 2**). Today, the country is subdivided into 25 governorates. Libya has a low population of estimated 7 million people, concentrated along the coast and its immediate hinterland, where the cities of Tripoli and Benghazi are located, and in few oases more to the south (**Fig. 3**), with Sabha being the largest of these southern cities. The population growth rate is high, and 81.3% of the population lives in urban areas. **Table 1** shows additional development indicators, and how these compare to neighboring countries.

[1] GMTED2010 https://pubs.usgs.gov/of/2011/1073/

FIGURE 2. Libya's Subnational Governorates, Historical Provinces (Tripolitania, Fezzan, and Cyrenaica), Exclusive Economic Zone (gray line), and Neighboring Countries[2]



Tripolitania

1 Nuqat Al Khams
2 Az Zawia (azzawiya)
3 Al Aziziyah
4 Tripoli (tarabulus)
5 Tarhunah
6 Al Khoms
7 Zeleitin (zliten)
8 Misurata
9 Ghadamis
10 Yafran (yefren)
11 Gharyan
12 Sawfajjin (sofuljeen)
13 Surt (sirte)

Fezzan

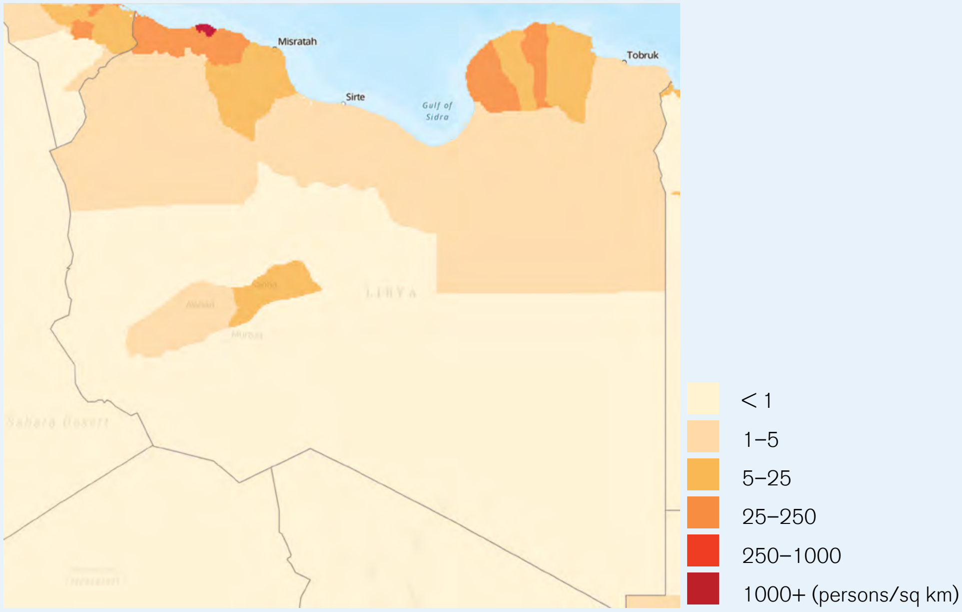
14 Ash Shati
15 Al Jufrah
16 Awbari (ubari)
17 Sabha
18 Murzuq

Cyrenaica

19 Banghazi
20 Al Fatah
21 Al Jabal Al Akhdar
22 Darnah
23 Tubruq (tobruk)
24 Ajdabiya (agedabia)
25 Al Kufrah

For each province, governorates are numbered from northwest to southeast. Figure done with ArcGIS online.

FIGURE 3. Population Density (people per square km)

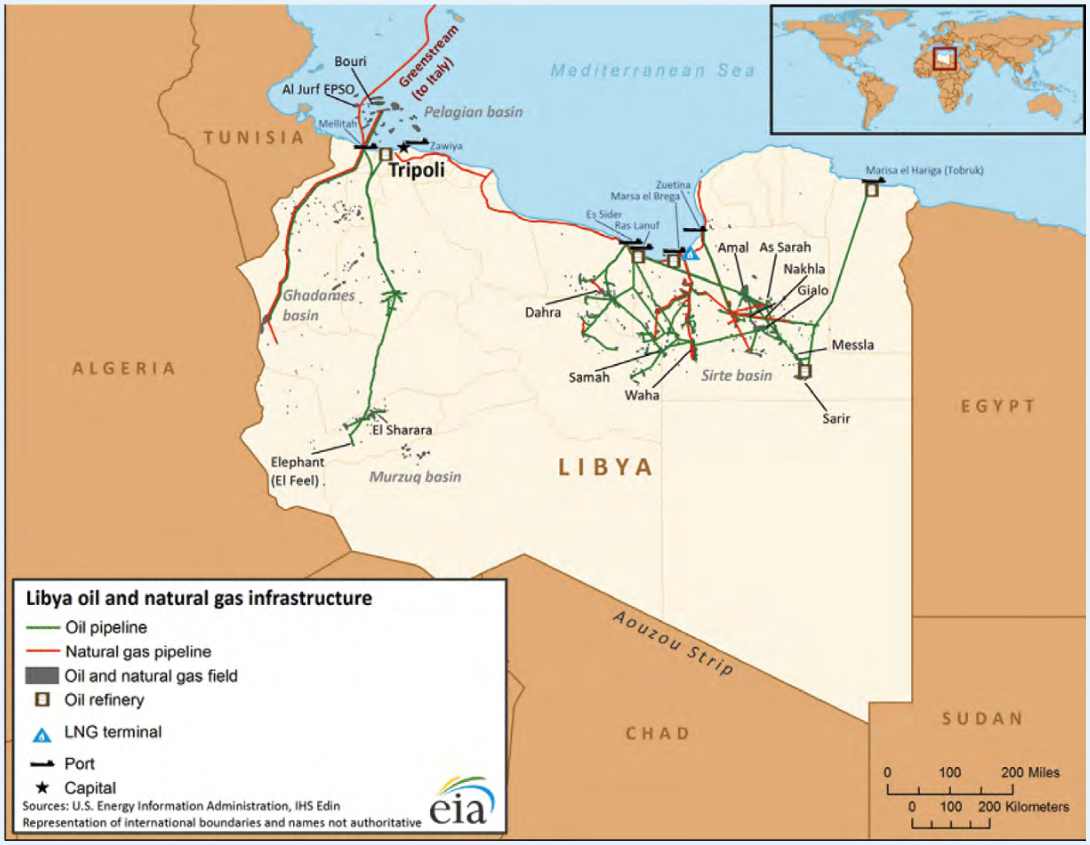


From the Center for International Earth Science Information Network (CIESIN), 2015[3]

[2] World Bank Cartography
[3] World Bank Interactive https://maps.worldbank.org/datasets/Population_Density?viewMore=Population

Since the discovery of oil in the late 1950s (**Fig. 4**), Libya's economy has depended primarily on revenues from the petroleum sector, which account for 98% of export earnings and 68% of GDP, in 2023[4]. These oil revenues, combined with a small population, have given Libya one of the highest GDPs per capita in Africa (**Table 1**). The country also has the highest CO_2 emissions in the region, with gas flaring being a major contributor to these emissions. Most of the workforce is employed in the services sector, followed by industry and agriculture (**Table 1**). Much of Libya's recent history is dominated by long-ruling leader Muammar al-Qaddafi, who governed from 1969 until his ousting in 2011. The most recent decade that followed has been marked by political instability.

FIGURE 4. Oil and Gas Infrastructure in Libya[5]



[4] African Economic Outlook 2024. African Development Bank Group. https://www.afdb.org/en/knowledge/publications/african-economic-outlook

[5] Wikipedia https://en.wikipedia.org/wiki/File:Libya_infrastructure_map.png

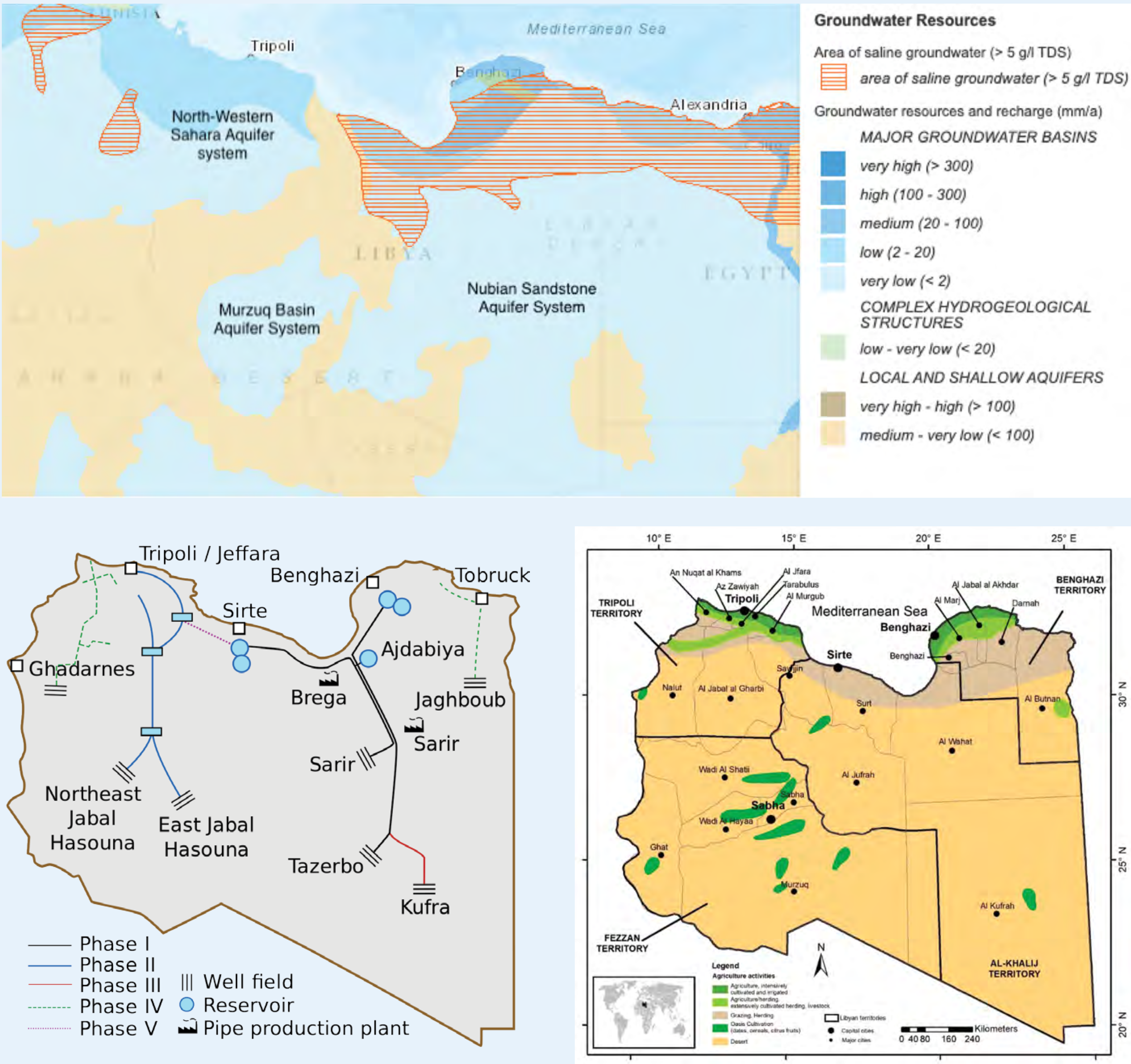
As a desert country, Libya faces significant water stress, utilizing 817% of its available renewable freshwater resources. The total renewable internal freshwater resources amount to 0.7 billion cubic meters, while the country withdraws 5.72 billion cubic meters annually[6]. Libya, with only 98 cubic meters per capita (annually) of renewable freshwater resources, falls below the water scarcity threshold established by the Food and Agriculture Organization of the United Nations (FAO), which is 500 cubic meters per capita. Libya has no permanent rivers, only flash floods that temporarily fill during the rains but quickly dry up. To meet most of its water needs, Libya relies on groundwater from fossil water stored in non-recharging aquifers such as the Nubian Sandstone Aquifer System (shared with Egypt, Chad, and Sudan), the North-Western Sahara Aquifer System (shared with Algeria and Tunisia), and the Murzuq Basin Aquifer System (shared with Niger) (**Fig. 5**). The exact amount of water in these aquifers is highly uncertain. Combined with unpredictable future usage, this makes it difficult to estimate how long they will last. In the northern region, groundwater can be extracted from shallow aquifers that are renewable, albeit at low rates, with many experiencing salinization (**Fig. 5**).

Thanks to its wealth, Libya has been able to undertake large projects, such as the Great Man-Made River[7], a network of pipes supplying more than half of the total freshwater withdrawals from the fossil aquifers beneath the southern desert to the northern regions, where most of the population lives (**Fig. 5**). The Great Man-Made River has facilitated irrigated agriculture, which is significant in coastal regions and oasis zones in Fezzan (**Fig. 5**), but limited renewable water resources, harsh climatic conditions, and poor soil severely constrain production. As a result, Libya must import about 75% of its food to meet local needs, making the country vulnerable to climate impacts on food production both domestically and globally. Animal husbandry also plays an important role in Cyrenaica, where herds graze on communal lands. Fisheries are not very significant in Libya's culture or economy.

[6] 2021, World Bank Dataset

[7] The Great Man-Made River https://www.britannica.com/topic/Great-Man-Made-River

FIGURE 5. Water Scarcity: a) Aquifers Systems[8], b) Great Man-made River[9], and c) Agricultural Areas[10]



[8] World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), https://www.whymap.org/whymap/EN/Home/whymap_node.html

[9] Great Man-made River https://en.wikipedia.org/wiki/Great_Man-Made_River

[10] Zurqani et al. (2019). A Review of Libyan Soil Databases for Use Within an Ecosystem Services Framework, Land 8, 82. DOI: https://doi.org/10.3390/land8050082

Climate change poses a significant threat to Libya's economic development and sustainability, by impacting urban centers, human and animal health, infrastructure, energy demand, and agriculture production. The country is particularly vulnerable to floods, extreme heat, water scarcity, sand and dust storms, desertification, and sea level rise. According to the ND-Gain Country Index[11], which assesses climate-change risks, Libya faces significant vulnerability to climate change, particularly in sectors such as agriculture and dam management and safety, with hydrological variability and extreme precipitation being major driving factors. The country also has a low level of readiness to address these impacts effectively. Libya ranks as the 91st most vulnerable country and the 167th most prepared country out of 185 nations. According to the Fragile States Index[12], Libya is now among the most fragile states as of 2023, ranking 17th out of 179 countries. This vulnerability is exacerbated by the country's weakened water and electrical infrastructure. Despite the wealth generated from oil, infrastructure has not been adequately maintained or upgraded due to conflict and abandonment. Increased vulnerability to climate change exacerbated extreme weather events was particularly evident on September 10, 2023, when the Mediterranean Storm Daniel hit Libya's coastline, triggering 52,000 internal displacements and at least 5,900 fatalities[13], after two aging dams breached resulting in widespread flooding and infrastructure damage[14]. According to the World Weather Attribution team[15], an event as extreme as the one observed over Libya, a one in 300 to 600 years event, "has become up to 50 times more likely and up to 50% more intense compared to a 1.2C cooler climate".

By analyzing temperature and precipitation changes over the past four decades, Jaber, Abu-Allaban, and Sengupta (2023)[16] identified 15 areas in the Arab world as the most vulnerable to climate impacts. Two of these areas are in Libya, specifically in northern central regions where significant human populations are not present.

Although Libya signed the United Nations Framework Convention on Climate Change in 2015 and ratified the Paris Climate Accord in 2021, it has not submitted the necessary policies, plans, or reports, including a Nationally Determined Contribution, National Adaptation Plans, or National Communications[17].

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11 ND-Gain Country Index https://gain.nd.edu/our-work/country-index/
12 Fragile States Index https://fragilestatesindex.org/global-data/
13 Reliefweb April 2024. https://reliefweb.int/report/libya/libya-assistance-overview-april-2024
14 Internal Displacement Monitoring Center https://www.internal-displacement.org/spotlights/Libya-Years-of-conflict-and-weakened-infrastructure-compound-Derna-flood-impact/
15 World Weather Attribution https://www.worldweatherattribution.org/interplay-of-climate-change-exacerbated-rainfall-exposure-and-vulnerability-led-to-widespread-impacts-in-the-mediterranean-region/
16 Jaber, Abu-Allaban, and Sengupta (2023). Spatial and temporal patterns of indicators of climate change and variability in the Arab world in the past four decades. Sci Rep 13, 15145. DOI: https://doi.org/10.1038/s41598-023-42499-y
17 UNDP https://www.undp.org/libya/environment-and-climate-change

TABLE 1. Key Development Indicators from the World Bank's Data Bank[18] (or otherwise indicated)

Key Demographic Indicators	Most Recent Value	Regional Comparisons
Total population (2022)	7,223,805	Much lower than surrounding countries
Population Density (people per sq km, 2021)	3.83	Lower density than surrounding countries
Population growth (annual %, 2022)	1.14%	Like surrounding countries
Population ages 65 and above (female/male/% of total, 2022)	182,774/148,643/4.86%	Like Egypt, lower than Algeria and Tunisia
Population ages 0 to 4 (female/male/% of total, 2022)	294,696/310,833/8.89%	Like Tunisia, lower than Egypt and Algeria
Urban population (% of total, 2022)	81.3	The highest in the region
Life Expectancy (for total population in years, 2022)	72.20	Like Egypt, lower than Tunisia and Algeria, higher than Chad, Niger and Sudan
Fertility Rate (total births per woman, 2022)	2.40	Like MENA countries. Much lower than Chad, Niger, and Sudan
Dependency Ratio (dependents per 100 working-age people, 2022)	49.61	Lower than bordering countries
Key Economic Indicators	**Most Recent Value**	**Regional Comparisons**
GDP per Capita (in current $US, 2022)	$6,716.10	Higher than bordering countries
CO2 emissions (metric tons per capita, 2020)	6.68	The highest in the region
% Employed in Agriculture (2022)	9.21%	Like Algeria. About half than Tunisia and Egypt
% Employed in Industry (2022)	22.77%	Less than Algeria, Tunisia, and Egypt. More than southern countries
% Employed in Services (2022)	68.02%	More than surrounding countries
Unemployment Rate (% of total labor force, 2023)	18.52%	Among the highest across region, together with Sudan
Electricity production from oil & gas sources (% of total, 2015)	100%	Like other MENA countries
% of agricultural land (2021)	8.72%	Above Egypt value (4.1%) and below Tunisia and Algeria
Key environmental indicators	**Most Recent Value**	**Regional Comparisons**
Level of water stress (freshwater withdrawal as a proportion of available freshwater resources, 2020)	817.14%	Much more than surrounding countries
Renewable internal freshwater resources per capita (cubic meters, 2020)	105.20	Only Egypt has a lower value
Annual freshwater withdrawals, agriculture (% of total freshwater withdrawal, 2020)	83.19%	Like surrounding countries, although Algeria is a 20% less
Forest area (sq. km/% of total area, 2021)	2170 sq. km/0.12%	Only higher than Egypt

[18] World Bank (2024). DataBank – World Development Indicators. URL: https://databank.worldbank.org/source/world-development-indicators

TABLE 1. Key Development Indicators from the World Bank's Data Bank (or otherwise indicated) *(Continued)*

Key Vulnerability Indicators	Most Recent Value	Regional Comparisons
% Population with Access to Electricity (urban) (2021)	70.21% (100%)	Lower than other MENA countries
Quality of electric supply (from 1 to 7, 2014)[19]	2.85	Worse than Algeria and Tunisia. Like Egypt in 2014. Egypt has recovered since. No data for Libya after 2014.
Prevalence of moderate or severe food insecurity in the population (% of total, 2021)	39.8%	Higher than surrounding MENA Mediterranean countries
Urban land area where elevation is below 5 meters (sq. km, 2022)	237.76 sq km	Like Algeria and Tunisia (higher than Algeria, lower than Tunisia), 20 times less than Egypt

Data for each indicator's most recently measured year is compared to surrounding countries in the far-right column.

OBSERVED AND CURRENT CLIMATE

Data Overview

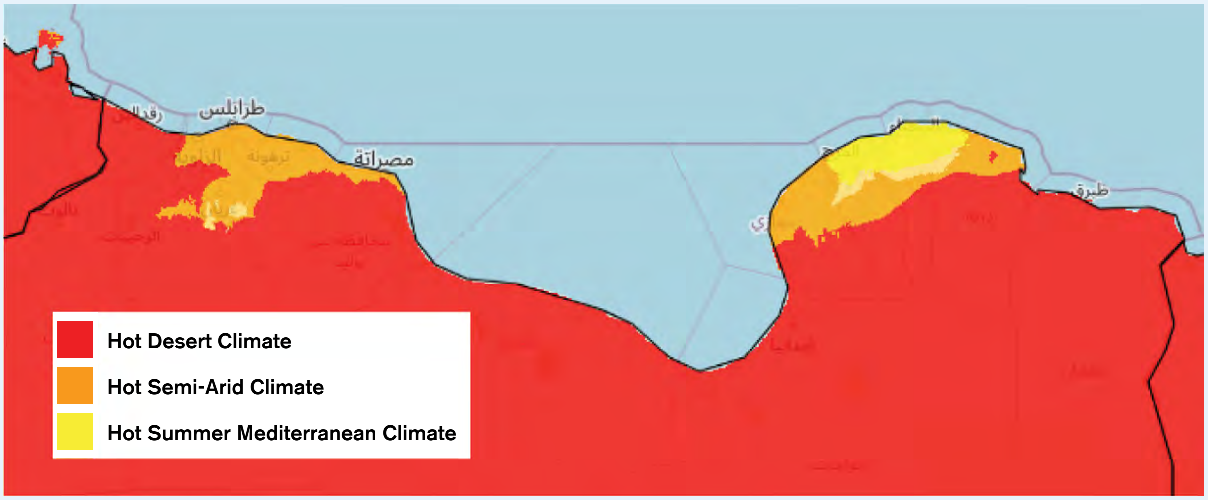
The data presented are from the World Bank Group's Climate Change Knowledge Portal (CCKP). Historical, observed data is derived from the Climatic Research Unit, University of East Anglia (CRU), CRU TS version 4.07 gridded dataset (data available 1901–2022) and ERA5 reanalysis collection from ECMWF (1950–2020).

Climate Overview

Libya is classified as a hot desert climate (red in **Fig. 6**) for approximately 95% of its area according to the Köppen-Geiger climate classification system. In the northern regions, adjacent to the Mediterranean Sea, there are small areas with a hot semi-arid climate (orange), characterized by hot summers and warm to cool winters with minimal precipitation, and few regions with a hot summer Mediterranean climate (yellow), featuring hot, dry summers and mild, relatively wet winters. Libya's climate is shaped by the contrasting influences of the Mediterranean Sea to the north and the Sahara Desert to the south, resulting in sudden and dramatic changes in weather conditions throughout the country.

[19] https://prosperitydata360.worldbank.org/, WEF Global Competitiveness Index

FIGURE 6. Köppen-Geiger Climate Classification System for the Historical Period 1991–2020[20]

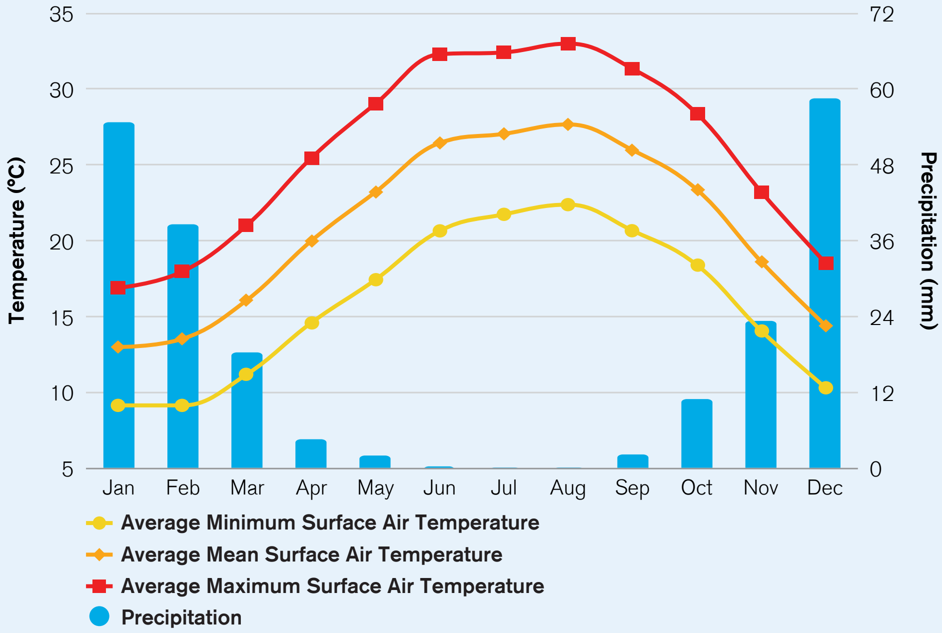


In Libya, temperatures peak in the boreal summer, around June for the desertic southern landlocked regions and towards August for the Mediterranean northern region due to the sea temperature inertia that delays peak temperatures. During the historical period (1991–2020), the average air surface temperature in summer (DJF) was 30.37°C, with a minimum of 23.56°C and a maximum of 37.23°C. In winter, the average air surface temperature was 13.60°C, ranging from a minimum of 7.18°C to a maximum of 20.06°C. The northern Mediterranean regions experience milder day-to-night temperature variations, whereas the southern desert regions endure pre-desert and desert conditions characterized by scorching temperatures and significant daily thermal fluctuations (**Fig. 7**, **Table 2**).

As a desert country, Libya has an average annual rainfall of only 38.10 mm (1991–2020 average), but there are considerable variations from place to place (**Fig. 7**) and from year to year. Approximately 93% of the land surface receives less than 100 mm of rain per year. Rainfall predominantly occurs during the winter months (DJF), totaling 20.54 mm on average. The northern highlands of Jabal Nafusah (west) and Jabal Akhar (east) feature a plateau climate characterized by higher rainfall and humidity. Consequently, governorates near Tripoli and Benghazi receive the highest average annual rainfall. Specifically, the northeast governorate of Al Jabal Al Akhar, home to the highest coastal mountains, receives the highest rainfall at 374 mm annually. In contrast, the southern desert regions experience rare and sporadic rainfall (**Table 2**). Libya is also affected by extreme precipitation events with potential for flooding and flash flooding, this is described below.

[20] https://koppen.earth/, Beck et al. (2023). High-resolution (1 km) Köppen-Geiger maps for 1901–2099 based on constrained CMIP6 projections, Sci Data 10, 724. DOI: https://doi.org/10.1038/s41597-023-02549-6

FIGURE 7. Monthly Climatology of Average Surface Air Temperature (minimum, mean, and maximum), and Annual Precipitation, for the Historical Period 1991–2020, for a) Banghazi (northeast, rainy-Mediterranean), and b) Sabha (central-south-west, desert)



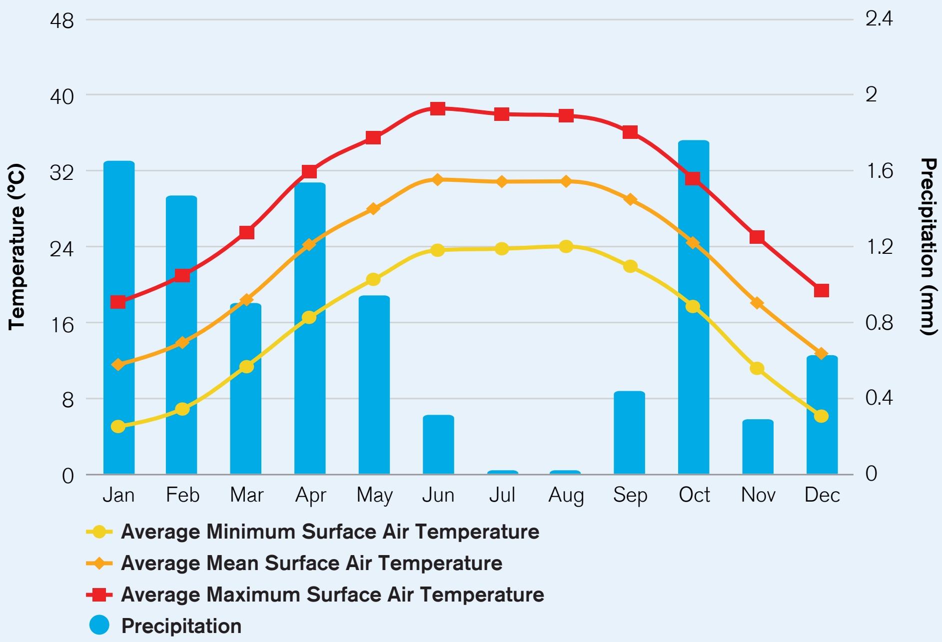


TABLE 2. Observed Temperature and Precipitation Seasonal Cycle for 1991–2020 and Observed Decadal Trends from 1971 to 2022 Across Libya's Regions (CRU TS4.07 dataset)

Regions	Temperature				Precipitation		
	Average Temp	Warmest Month	Coldest Month	Temp Trend Per Decade	Total Annual Precip	Wettest Month	Precip Trend Per Decade
Libya	22.77°C	**Aug: 30.53°C** (23.96°C–37.16°C)	**Jan: 12.52°C** (6.31°C–18.79°C)	**0.25°C**	**38.09 mm**	Jan: 7.51 mm	**−1.40 mm**
Nuqat Al Khams	21.77°C	**Aug: 29.97°C** (25.09°C–34.89°C)	**Jan: 13.27°C** (8.71°C–17.89°C)	**0.38°C**	**184.20 mm**	Dec: 33.85 mm	**−14.23 mm**
Az Zawia (azzawiya)	21.55°C	**Aug: 29.77°C** (24.3°C–35.3°C)	**Jan: 12.6°C** (7.84°C–17.42°C)	**0.38°C**	**221.67 mm**	Jan: 39.68 mm	**−16.69 mm**
Al Aziziyah	21.06°C	**Aug: 29.36°C** (23.56°C–35.21°C)	**Jan: 11.97°C** (7.16°C–16.82°C)	**0.38°C**	**251.24 mm**	Jan: 47.46 mm	**−17.99 mm**
Tripoli (tarabulus)	21.26°C	**Aug: 29.37°C** (23.59°C–35.2°C)	**Jan: 12.46°C** (7.7°C–17.27°C)	**0.37°C**	**259.68 mm**	Jan: 51.33 mm	**−17.38 mm**
Tarhunah	20.56°C	**Aug: 28.63°C** (22.97°C–34.32°C)	**Jan: 11.72°C** (7.12°C–16.36°C)	**0.36°C**	**234.71 mm**	Jan: 44.08 mm	**−15.07 mm**
Al Khoms	21.03°C	**Aug: 28.75°C** (23.55°C–34.01°C)	**Jan: 12.74°C** (8.34°C–17.19°C)	**0.35°C**	**242.47 mm**	Dec: 49.31 mm	**−15.01 mm**
Zeleitin (zliten)	21.09°C	**Aug: 28.6°C** (23.71°C–33.55°C)	**Jan: 12.99°C** (8.74°C–17.29°C)	**0.34°C**	**198.60 mm**	Dec: 43.7 mm	**−11.87 mm**
Misurata	21.14°C	**Aug: 28.33°C** (23.93°C–32.79°C)	**Jan: 13.55°C** (9.56°C–17.59°C)	**0.33°C**	**205.92 mm**	Dec: 50.07 mm	**−11.38 mm**
Ghadamis	21.94°C	**Aug: 31.28°C** (24.42°C–38.19°C)	**Jan: 10.74°C** (5.13°C–16.4°C)	**0.36°C**	**60.50 mm**	March: 12.38 mm	**−5.02 mm**
Yafran (yefren)	20.89°C	**Aug: 29.63°C** (23.83°C–35.47°C)	**Jan: 11.06°C** (6.31°C–15.85°C)	**0.38°C**	**162.02 mm**	March: 24.37 mm	**−13.24 mm**
Gharyan	21.33°C	**Aug: 29.92°C** (23.5°C–36.39°C)	**Jan: 10.86°C** (5.33°C–16.44°C)	**0.33°C**	**61.09 mm**	March: 10.33 mm	**−3.68 mm**
Sawfajjin (sofuljeen)	21.24°C	**Aug: 28.73°C** (23.2°C–34.3°C)	**Jan: 12.58°C** (7.61°C–17.61°C)	**0.31°C**	**94.75 mm**	Dec: 21.07 mm	**−4.85 mm**
Surt (sirte)	20.80°C	**Aug: 27.76°C** (22.2°C–33.38°C)	**Jan: 12.62°C** (7.66°C–17.62°C)	**0.25°C**	**118.54 mm**	Jan: 30.05 mm	−3.87 mm
Ash Shati	22.66°C	**July: 31.28°C** (24.03°C–38.59°C)	**Jan: 11.28°C** (4.72°C–17.9°C)	**0.25°C**	**16.78 mm**	Oct: 2.72 mm	−0.15 mm
Al Jufrah	21.35°C	**Aug: 29.09°C** (22.18°C–36.04°C)	**Jan: 11.2°C** (4.92°C–17.54°C)	**0.22°C**	**28.91 mm**	Jan: 5.72 mm	−0.45 mm
Awbari (ubari)	23.68°C	**June: 32.4°C** (25.16°C–39.7°C)	**Jan: 12.19°C** (5.25°C–19.18°C)	**0.19°C**	**8.76 mm**	Oct: 1.84 mm	−0.46 mm
Sabha	22.75°C	**June: 31.06°C** (23.61°C–38.56°C)	**Jan: 11.55°C** (5.02°C–18.13°C)	**0.18°C**	**9.97 mm**	Oct: 1.76 mm	0.08 mm
Murzuq	23.75°C	**June: 31.83°C** (24.25°C–39.46°C)	**Jan: 12.6°C** (5.65°C–19.6°C)	**0.18°C**	**6.43 mm**	Aug: 1.14 mm	0.04 mm

TABLE 2. Observed Temperature and Precipitation Seasonal Cycle for 1991–2020 and Observed Decadal Trends from 1971 to 2022 Across Libya's Regions (CRU TS4.07 dataset) (*Continued*)

Regions	Temperature				Precipitation		
	Average Temp	Warmest Month	Coldest Month	Temp Trend Per Decade	Total Annual Precip	Wettest Month	Precip Trend Per Decade
Banghazi	20.76°C	**Aug: 27.66°C** (22.37°C–32.99°C)	**Jan: 12.98°C** (9.13°C–16.88°C)	**0.25°C**	**213.34 mm**	Dec: 58.58 mm	–3.68 mm
Al Fatah	19.72°C	**Aug: 26.76°C** (21.87°C–31.69°C)	**Jan: 12.04°C** (8.64°C–15.5°C)	**0.25°C**	**312.25 mm**	Dec: 81.98 mm	0.47 mm
Al Jabal Al Akhdar	19.17°C	**Aug: 26.22°C** (21.59°C–30.91°C)	**Jan: 11.56°C** (8.35°C–14.84°C)	**0.25°C**	**374.45 mm**	Dec: 95.17 mm	4.10 mm
Darnah	19.84°C	**Aug: 26.88°C** (22.35°C–31.46°C)	**Jan: 12.29°C** (8.84°C–15.79°C)	**0.25°C**	**270.25 mm**	Dec: 67.4 mm	3.49 mm
Tubruq (tobruk)	21.40°C	**Aug: 28.95°C** (22.75°C–35.22°C)	**Jan: 12.66°C** (7.45°C–17.92°C)	**0.27°C**	**43.61 mm**	Jan: 11.13 mm	–1.35 mm
Ajdabiya (agedabia)	22.37°C	**Aug: 29.88°C** (23.29°C–36.51°C)	**Jan: 13.01°C** (7.41°C–18.65°C)	**0.25°C**	**33.29 mm**	Jan: 9.68 mm	**–2.94 mm**
Al Kufrah	24.10°C	**July: 31.58°C** (24.73°C–38.48°C)	**Jan: 13.6°C** (6.68°C–20.57°C)	**0.25°C**	**6.95 mm**	Aug: 3.01 mm	**–0.15 mm**

Rows are classified according to the historical regions Tripolitania, Fezzan, and Cyrenaica as in **Fig. 2** with governorates organized from northwest to southeast. For 1991–2020, averaged annual surface air temperature (shaded according to temperature), averaged surface air temperature during the hottest (coldest) month (in parenthesis the averaged minimum and maximum temperatures for those months), total annual precipitation average (shaded greener when wetter), and averaged precipitation during the wettest month. Trends per decade are calculated from 1971 to 2022 for average temperature and precipitation (shaded redder if warmer trend, and yellow-green if trend is drier or wetter). The trend is significant at 95% level when values are bolded, significant to the 68% level if not bold, and not significant if values are gray. Trend is calculated using linear regression statistics.

Seasonal and interannual climate variability is driven by the influence of subtropical high-pressure systems, Mediterranean Sea oscillations, the north Atlantic oscillation (NOA), the East Atlantic–West Russia Pattern, the Saharan air layer, jet streams, tropical and subtropical cyclones, and monsoonal flows. The Saharan influence intensifies during the summer months. From October to March, prevailing westerly winds deliver rainfall to northern Libya. The El Niño-Southern Oscillation (ENSO) is not the primary driver of natural climate variability in Libya, but it does exert some influence. During El Niño years, Libya typically experiences hotter-than-average summers and autumns, wetter autumns, drier winters, and colder springs[21].

Historical Temperature Changes (ERA5 dataset)

Between 1971 and 2020, Libya's air surface temperature increased 1.85°C (1.9°C–1.7°C for the average minimum and maximum air surface temperatures, ERA5 dataset), while the global temperature rose by 0.9°C. The IPCC AR6 reports on Africa[22] and the Mediterranean region[23] 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

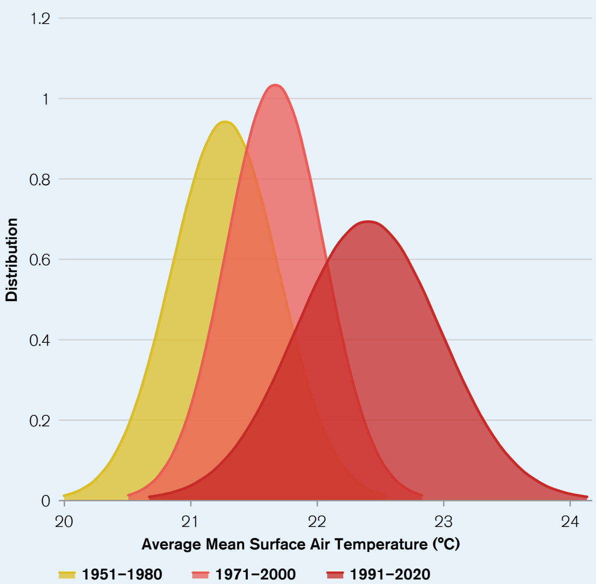
[21] This pattern is supported by the temporal correlation between the Niño 3.4 index and observed historical temperature and precipitation data from the CRU TS4.07 dataset
[22] IPCC AR6 Ch. 9 (Africa) https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-9/
[23] IPCC AR6 cross-chapter 4 (Mediterranean region) https://www.ipcc.ch/report/ar6/wg2/chapter/ccp4/

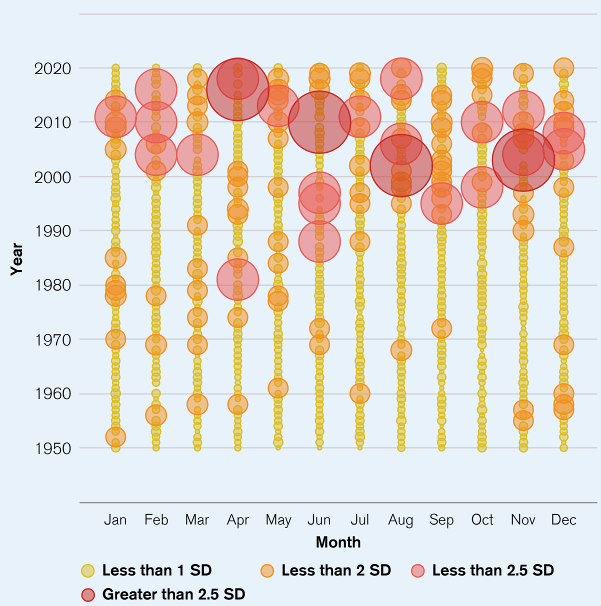
temperatures have increased at twice the global rate over most regions in north Africa due to human-induced climate change". The recent warming acceleration is largely due to the combined effect of declining aerosols and a negative trend in near-surface soil moisture.[24] The anthropogenic influence on temperature increase is significant in Libya, a result that is also reported by Callaghan et al. (2021).[25]

Across the nation, the average temperature increased by 0.29°C per decade between 1951 and 2020 and by 0.43°C per decade between 1991 and 2020, indicating an acceleration in warming. Additionally, between 1991 and 2020, the number of tropical nights (with minimum temperatures above 20°C) increased by 5.98 nights per decade. The maximum air surface temperature has increased most significantly in western Libya, driven primarily by temperature changes in spring (March–May) and autumn (September–November). The minimum air surface temperature has increased most in the northwestern part of Libya, mainly due to rising temperatures in autumn, but also in spring and summer.

The range of average mean surface air temperatures has widened recently (1991–2020) compared to previous 30-year periods (**Fig. 8a**). This increase in temperature variability is especially pronounced in the more desertic interior and southern regions, as well as in the eastern part of the country. The Mediterranean regions around Tripoli (northwest) experienced a similar widening of temperature distribution earlier, from 1971 to 2000, that has continued until now. As anticipated with climate change, the intensity of maximum daily high temperatures is increasing (**Fig. 8b**).

FIGURE 8. a) Distribution of Average Mean Surface Air Temperature for Three 30-year Historical Periods, 1951–1980, 1971–2000, and 1991–2000 for Libya b) Event Intensity of Maximum of Daily Max Temperatures, Between 1951 and 2020, Libya





[24] Urdiales-Flores, D., Zittis, G., Hadjinicolaou, P. et al. Drivers of accelerated warming in Mediterranean climate-type regions. npj Clim Atmos Sci 6, 97 (2023). https://doi.org/10.1038/s41612-023-00423-1

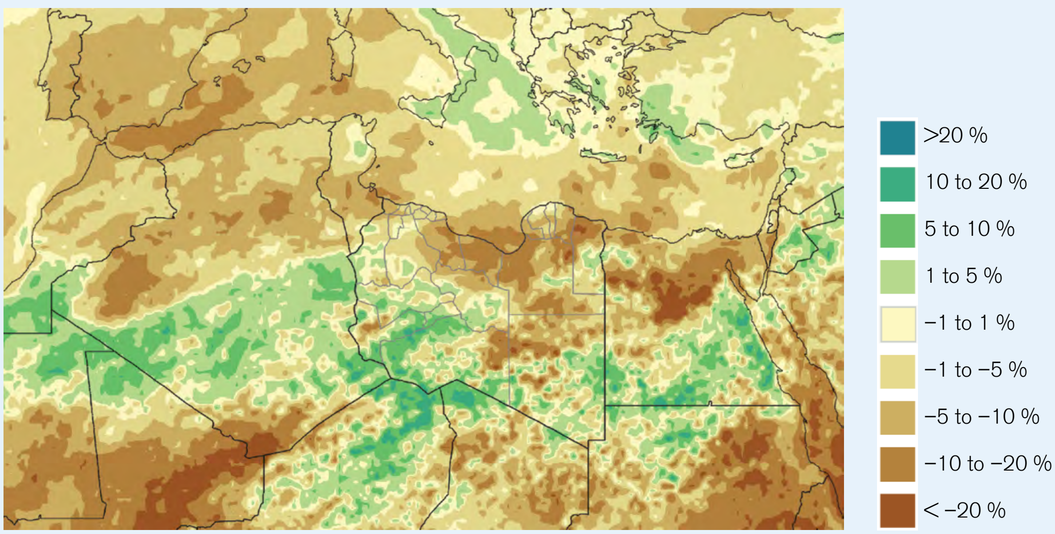
[25] Callaghan et al. (2021). Machine-learning-based evidence and attribution mapping of 100,000 climate impact studies. Nat. Clim. Chang. 11, 966–972, DOI: https://doi.org/10.1038/s41558-021-01168-6

Historical Precipitation Changes (ERA 5 dataset)

Most of the Mediterranean region, including northern Libya, is seeing a consistent decline in precipitation and a reduction in the number of consecutive wet days. In contrast, the interior of North African countries is seeing patchier trends, experiencing either a slight increase in precipitation or no change (**Fig. 9**).

Nationwide, precipitation has decreased by 1.6 mm per decade from 1971 to 2020, more so than the trend from 1950 to 2020 (–0.4 mm). Even though the precipitation decreasing trend has been getting larger in recent decades, it is not significant due to high interannual variability (**Fig. 10a**). Although precipitation interannual variability remains high (**Fig. 10b**), it has been slightly lower for the last 30 years as compared to the decades before 1990 (**Fig. 10c**). Accordingly, the intensity of precipitation events was slightly higher around 1950 than today (**Fig. 10d**).

FIGURE 9. Percent Change of Precipitation Per Decade Over the Period 1971–2020 Relative to the Reference Period of 1995–2014, for Libya and Surrounding Regions

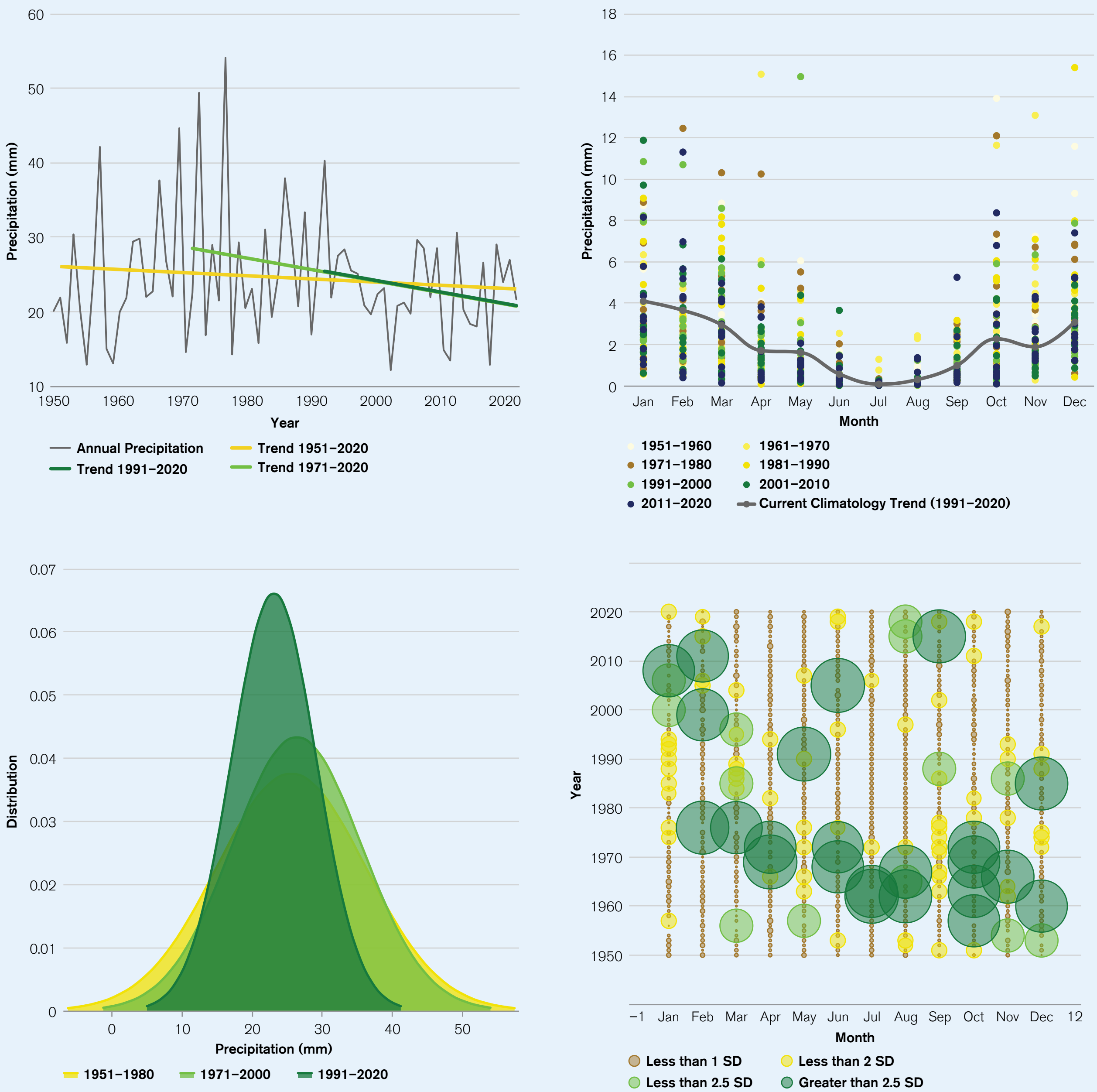


These precipitation trends are not significant in most of the region at the pixel level. The trend is only significant in the northern middle Mediterranean zone. ERA5 dataset. Figure done with ArcGIS online.

Historical Temperature and Precipitation Changes (CRU TS4.07 dataset)

In **Table 2**, we present a summary of historical climatological averages and trends from 1971 to 2022, derived from the CRU TS4.07 dataset. While the results show slight variations compared to the ERA5 dataset, the primary conclusions remain consistent. Air surface temperatures have risen across Libya at a rate faster than the global average, particularly in the Mediterranean and northwest regions. Additionally, averaged precipitation has decreased in these regions (significantly above the large interannual variability), with minimal to no significant changes in

FIGURE 10. Libya's a) Annual Precipitation Decadal Trends for Different Periods Between 1951 and 2020, b) Variability in Average Monthly Precipitation 1951–2020, c) Distribution of Annual Precipitation Three 30-year Historical Periods, d) Event Intensity of Annual Precipitation, 1951–2020



rainfall elsewhere. However, research shows that high precipitation variability, coupled with scarce and inconsistent datasets, particularly in MENA countries, makes trend detection challenging.[26] Attributing precipitation trends to anthropogenic forces has been particularly challenging in these regions (IPCC).

[26] Zittis, G. Observed rainfall trends and precipitation uncertainty in the vicinity of the Mediterranean, Middle East and North Africa. *Theor Appl Climatol* 134, 1207–1230 (2018). https://doi.org/10.1007/s00704-017-2333-0)

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 Intercomparison 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 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. Projections for extreme precipitation events use data presented at a 1.00° × 1.00° (100km × 100km) resolution. This risk profile focuses primarily on SSP3-7.0.[27] Other SSPs are highlighted where appropriate given different trends and outlooks that should be noted. The SSP3-7.0 scenario 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).

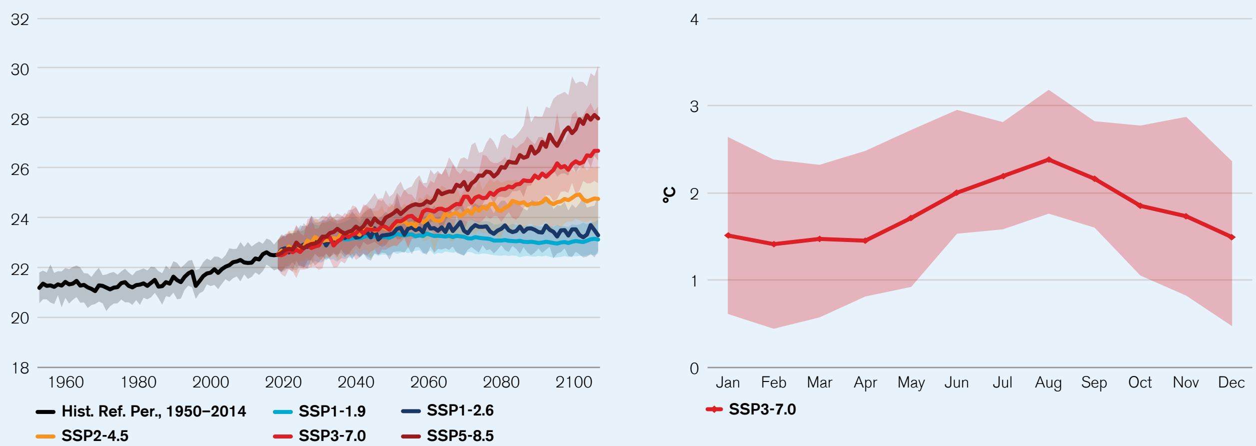
Temperature Projected Future Change (CMIP6)

Libya's temperatures are projected to increase further for all the scenarios. Under SSP3-7.0, the mean temperature nationwide increases from 22.20°C during the historical reference period of 1995–2014 to 23.12°C (22.20°C, 10th percentile, 24.01°C, 90th percentile) for the period 2020–2039, and to 23.95°C (23.01°C, 25.06°C) for the period 2040–2059. Minimum temperature nationwide increases from 15.64°C during the historical

[27] 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 infomration see: IPCC AR6 https://data.ceda.ac.uk/badc/ar6_wg1/data/spm/spm_08/v20210809/panel_a.

reference period to 16.59°C (15.71°C, 17.42°C) for the 2020–2039 period, and 17.44°C (16.58°C, 18.49°C) for 2040–2059. Maximum temperature increases from 28.75°C to 29.65°C (28.66°C, 30.64°C) for the 2020–2039 period, and 30.47°C (29.50°C, 31.66°C) for 2040–2059. Warming is projected to continue at an approximately steady rate after 2050 under the SSP3-7.0 scenario (**Fig. 11a**). Projected warming under SSP2-4.5 and SSP1-2.6 is lower, and under SSP5-8.5, higher (**Fig. 11a**).

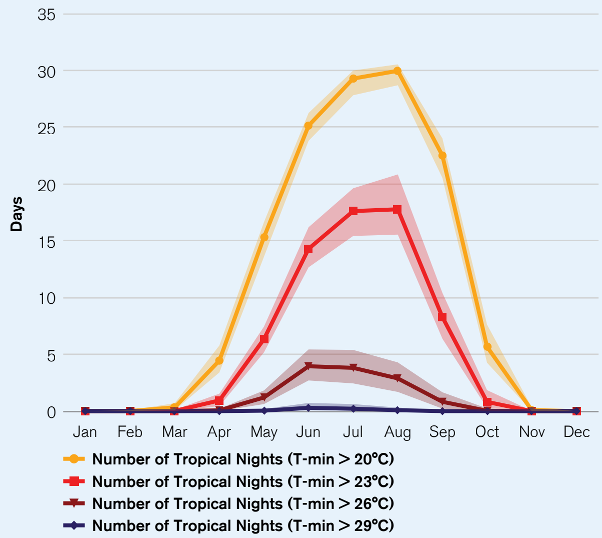
FIGURE 11. a) Historical and Projected Average Mean Surface Air Temperature for Different Climate Change Scenarios, b) Projected Seasonal Change in Average Mean Surface Air Temperature for 2040–2059 with Respect to the Historical Period (1995–2014) Under SSP3-7.0



Under SSP3-7.0, by mid-century (2040–2059) compared to the historical reference period (1995–2014), Libya will experience the most significant temperature increases during the summer months and the smallest increases during winter (**Fig. 11b**). On average, Libya is projected to see a warming of 2.38°C (1.76°C to 3.18°C) in August and 1.49°C (0.47°C to 2.36°C) in December. Summers will become dangerously hot more frequently, with projected average single-day maximum temperatures reaching 46.62°C during summer (JJA) and 35.84°C during winter (DJF). This will also result in more tropical (anomalously hot) nights. The number of tropical nights (>26°C) in August is expected to increase fivefold from 2.88 days to 14.39 days (9.73–19.42) (**Fig. 12**). Most August nights are predicted to exceed 23°C (28.62 days, 25.62–30.07) compared to 17.77 days historically. By 2035, 82% of Awbari's population is projected to experience dangerous levels of tropical nights (**Table 7**). Ghadamis, Sabha, and Murzuq will also face high exposure by then, with the percentage of affected populations increasing further by 2075, extending to regions like Nuqat al Khams. This poses significant risks not only to health but also to agriculture in Mediterranean areas. The number of very hot days in June (maximum temperature > 40°C) is expected to double from 5.66 to 11.46, and days with maximum temperatures exceeding 42°C will more than triple from 1.82 to 5.7. By 2075, most of the population in the northern lowland regions will be exposed to dangerous levels of extreme heat, a condition not experienced historically (**Table 7**). See **Table 4** and **5** for changes across regions., and **Table 7** for population exposure.

As temperatures rise, the heat risk factor for hot days and tropical nights will extend beyond summer, including spring and fall, and eventually affect winter (**Fig. 13**).

FIGURE 12. a) Historical (1995–2014) and b) Projected (2040–2059, SSP3-7.0) Number of Tropical Nights at Different Temperature Thresholds



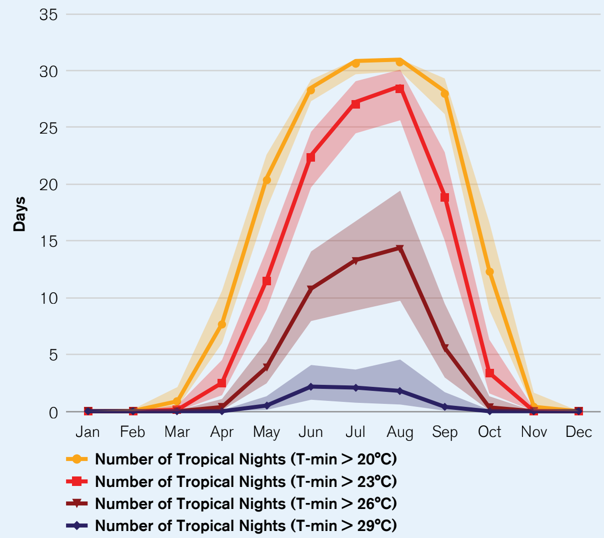
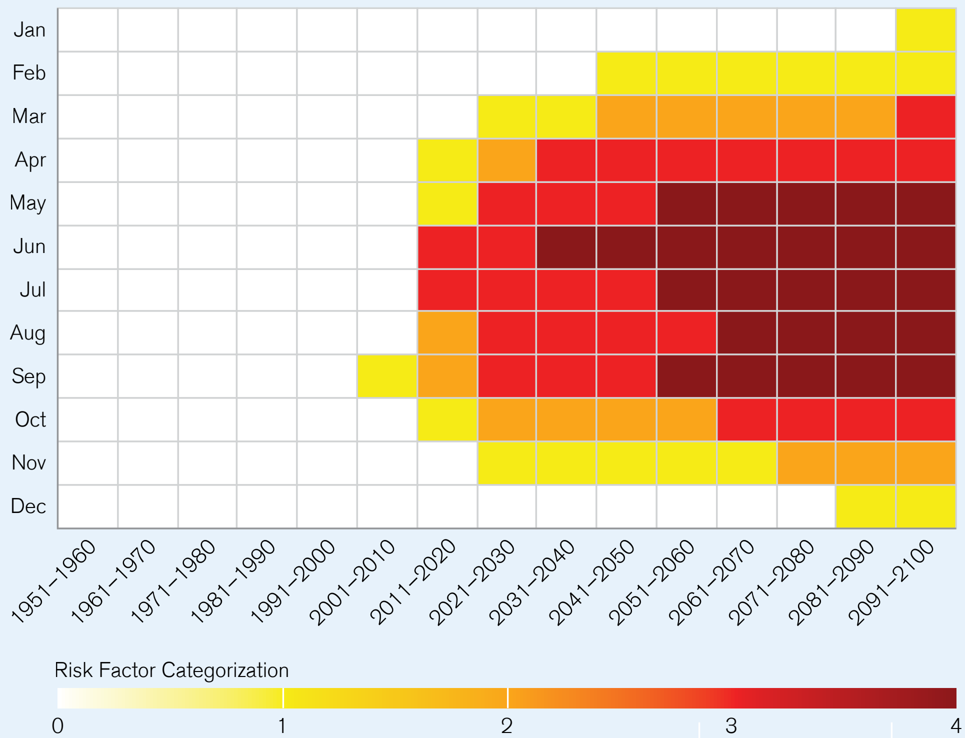


FIGURE 13. The Predicted Risk Heat Factor for Hot Days and Tropical Nights for the Scenario SSP3-7.0 (50th percentile)



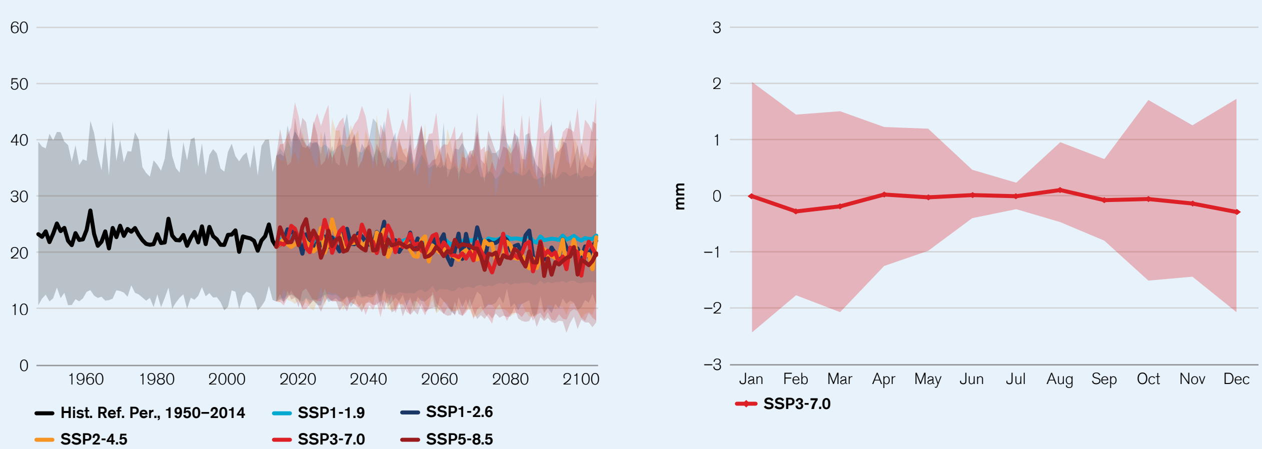
The heat index (hi), which measures apparent temperature by accounting for atmospheric moisture, indicates the biophysiological threshold at which the body can no longer cool itself naturally. Libya, being largely arid, has historically experienced minimal humidity, with only 0.27 days per year having a heat index of 35°C or higher. However, under SSP3-7.0, this is projected to increase to 1.63 days per year by 2020–2039 and to 5.54 days per year by 2040–2059. From 2050 to 2100, the trend shows an increase of 9.13 more days per decade, resulting in an average of 38.8 days per year with a heat index exceeding 35°C by 2080–2099. This poses a significant health risk, particularly for the northwestern regions, as there is no historical precedent for dealing with such humid heat in the country. **Table 6** shows the projected heat index (hi35) across regions and periods of time. Historically, only a negligible percentage of the population was exposed to humid heat. However, by 2075, exposure is projected to become widespread (see **Table 7**). Al Jabal Al Akhdar will remain an exception, with only 41% of the population exposed. Similarly, a growing share of the population will face dangerous wet bulb temperatures (another measure of humid heat) by 2075, particularly in regions like Nuqat al Khams (61%) and Misurata (76%).

Increased heat poses health hazards for both humans and livestock, highlighting the urgent need for adaptive responses especially given the growing and aging vulnerable population. It is important to note that mid-century population projections under the SSP3-7.0 scenario estimate a large (young and old) vulnerable population – 414,880 males and 439,780 females under 4 years old, and 1.15 million males and 955,290 females over 65 years old. This indicates a significantly larger number of vulnerable people compared to today (**Table 1**). Additionally, increased heat leads to higher energy demand for cooling and significantly impacts energy supply and transmission capabilities.

Precipitation Projected Future Change (CMIP6)

In Libya, climate change is expected to cause a long-term decrease in the average annual precipitation levels, mostly driven by changes in the rainy winter season, but interannual variability remains very high (**Fig. 14**). Under SSP3-7.0, Libya's average annual precipitation is predicted to change minimally nationwide the following decades: from 22.35 mm during the historical period (1995–2014) to 22.52 mm (10.98 mm, 10th percentile, 42.22 mm,

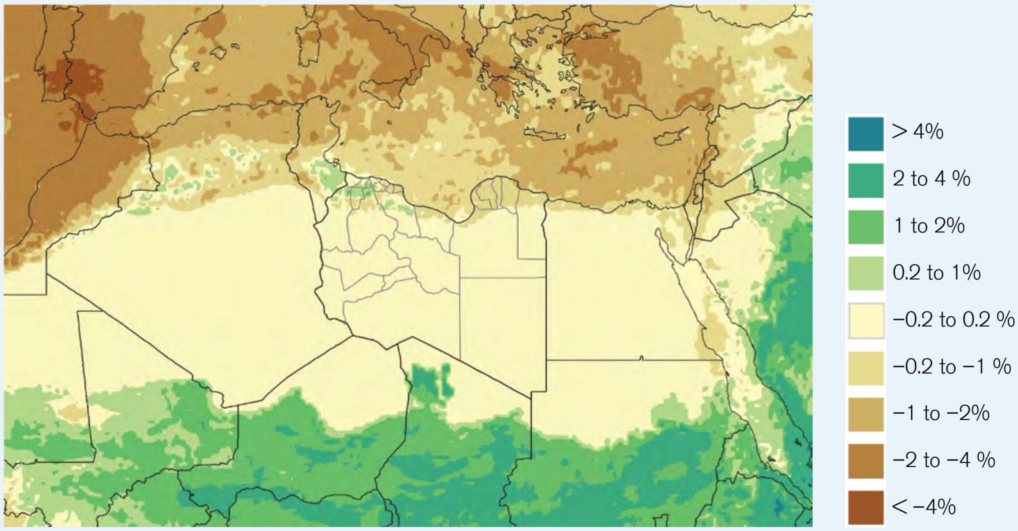
FIGURE 14. a) Historical and Projected Average Precipitation for Different Climate Change Scenarios, b) Projected Change in Average Precipitation for Each Month for 2040–2059 with Respect to the Historical Period (1995–2014)



90th percentile) for 2020–2039, and to 21.74 mm (10.42 mm, 41.10 mm) for 2040–2059. The decreasing trend becomes significant around 2050 for SSP3-7.0, and a decade earlier for SSP5-8.5.

Precipitation patterns around Libya are projected to change in latitudinal bands (**Fig. 15**). While rainfall in the northern Mediterranean region is expected to decrease, it is projected to increase in the southern Sahel African countries. Accordingly, rainfall is expected to decline in the northern districts, which are typically rainier like the Mediterranean, while there may be a slight increase in precipitation in the southern desert regions, following the trend observed historically.

FIGURE 15. Percent Change of precipitation Per Decade Over the Period 2000–2050 Relative to the Reference Period of 1995–2014 for Libya and Surrounding Regions



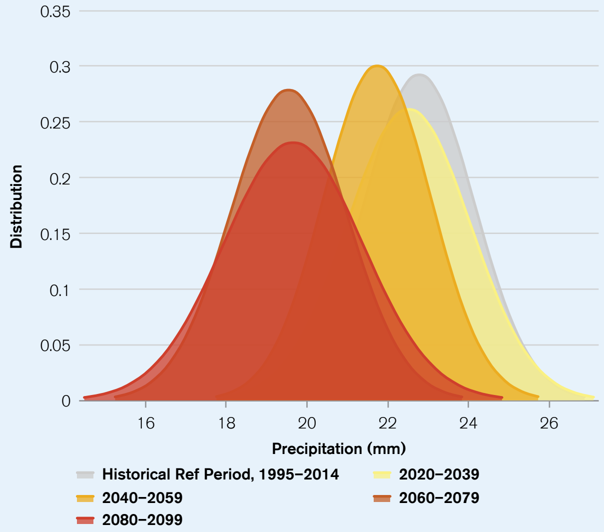
In Libya, the trend is not significant.

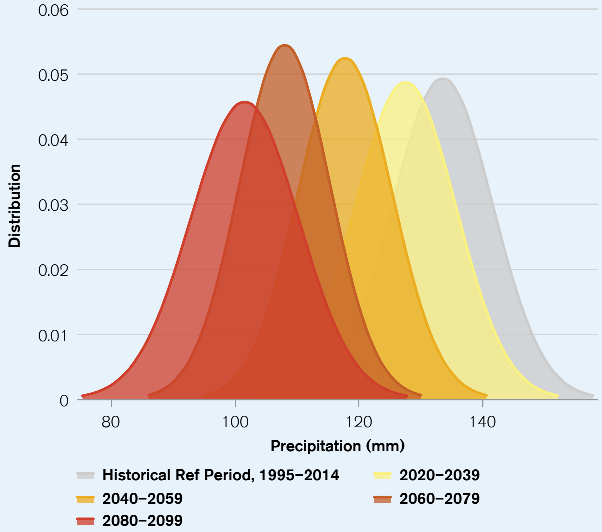
Figure 16 illustrates the projected decrease in Libya's precipitation by the end of the 21st century under the scenario SSP3-7.0, primarily affecting northern regions such as Al Fatah (northeast). In contrast, desertic southern regions like Al Kufrah (southeast) are expected to see a slight increase in precipitation, albeit with high variability.

It is worth noting that CMIP6 models tend to underestimate rainfall in Libya's northern regions, likely due to their lack of high resolution, which prevents them from accurately resolving the mountain ranges near the sea that are crucial for rain formation. While historical data from the CRU dataset indicates an average annual rainfall of 37.75 mm for the period 1995–2014, the historical CMIP6 multi-model average shows only 22.35 mm for the same period. Despite this discrepancy, the models correctly capture the overall patterns (**Fig. 17**) and represent the best available scientific data. It is then prudent to assume a decrease in average rainfall in the northern regions based on historical and projected trends.

In a warmer world, the potential of air to carry moisture goes up exponentially, and thus the potential for heavier precipitation goes up. As expected, the Future Return Period of Largest 1-Day Precipitation is decreasing almost everywhere in Libya (which means more frequent extreme rain), although the uncertainty in the prediction is large (**Table 3**). This means that intense precipitation events will likely recur more frequently (e.g. the return period will decrease), which can negatively affect the flooding risk, and be dangerous for infrastructure, human safety, or agriculture. Flash floods will become more frequent due to intense rain events combined with overall drier conditions.

FIGURE 16. Distribution of Average Precipitation for 20-year Historical (1995–2014) and Projected Periods for the Scenario SSP3-7.0 for Libya, and Districts Al Fatah (northeast relatively rainy region) and Al Kufrah (southeast desert region)





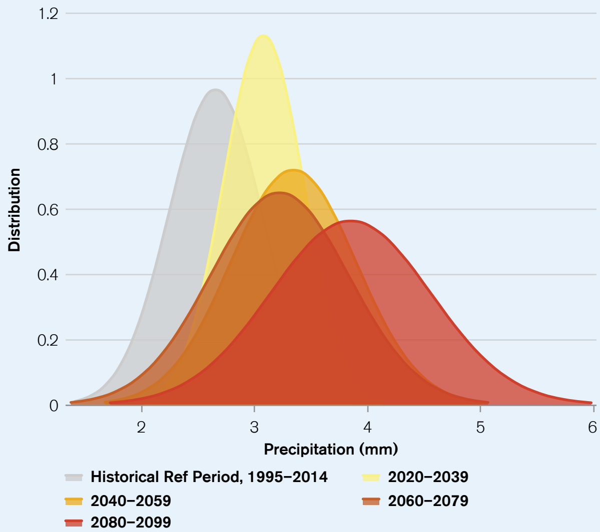


FIGURE 17. Annual Average Rain for the Historical Period 1995–2014 for Observations (CRU dataset), and the Multi-model CMIP6 Average Historical Scenario

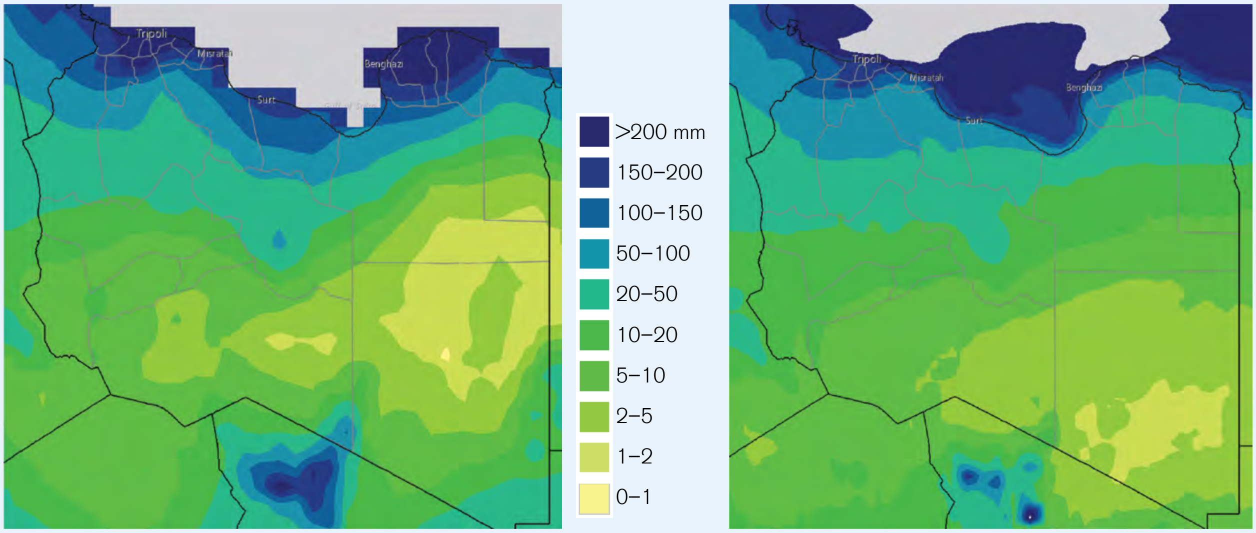


TABLE 3. Future Return Period (years) for Extreme Precipitation Events that Correspond to the Return Levels for the Largest Single-day Event during the Historical Period (1985–2014) for SSP3-7.0

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	4.36 (2.47–8.19)	8.68 (4.30–19.47)	17.58 (7.32–51.57)	22.16 (8.69–68.70)	44.51 (14.59–180.06)	89.90 (24.21–501.62)
2070–2099 center 2085	3.68 (2.12–.35)	7.11 (3.53–5.94)	13.87 (5.70–37.45)	17.35 (6.61–52.64)	32.74 (10.39–116.98)	63.38 (16.24–302.91)

Summary of Projected Temperature and Precipitation Changes (CMIP6)

Table 4 provides a summary of the projected decadal trends in Average Mean Surface Air Temperature for each season and the trends in total annual precipitation for each governorate from 2000 to 2050, compared to the historical period of 1995–2014, under the SSP3-7.0 scenario. As previously discussed, summer temperatures are expected to rise more rapidly than winter temperatures, leading to a broader temperature distribution. **Table 5** presents additional heat indices, all of which indicate a significantly higher risk of heat compared to historical levels. This increase in heat risk has important implications for public health, energy demand, and water demand for irrigation. **Table 6** illustrates the increasing number of hot and humid summer days, the most dangerous for human health, particularly after 2050.

TABLE 4. Projected Decadal Changes in Temperature Seasonal Cycle and Total Annual Precipitation from 2000 to 2050 Across Libya's Regions, Under the Climate Change Scenario SSP3-7.0

Regions	Average Mean Surface Air Temperature (trend/decade)				Precipitation (trend/decade)
	Winter–DJF	Sprint–MAM	Summer–JJA	Fall–SON	Total Annual
Libya	0.31°C	0.34°C	0.48°C	0.42°C	–0.02 mm
Nuqat Al Khams	0.32°C	0.31°C	0.43°C	0.36°C	–0.81 mm
Az Zawia (azzawiya)	0.32°C	0.31°C	0.43°C	0.35°C	–0.45 mm
Al Aziziyah	0.32°C	0.30°C	0.43°C	0.35°C	–0.17 mm
Tripoli (tarabulus)	0.31°C	0.29°C	0.42°C	0.34°C	–0.71 mm
Tarhunah	0.31°C	0.30°C	0.44°C	0.35°C	–0.48 mm
Al Khoms	0.30°C	0.28°C	0.41°C	0.34°C	–0.86 mm
Zeleitin (zliten)	0.30°C	0.29°C	0.42°C	0.35°C	–0.41 mm
Misurata	0.30°C	0.29°C	0.41°C	0.34°C	–0.42 mm
Ghadamis	0.32°C	0.38°C	0.50°C	0.40°C	–0.22 mm
Yafran (yefren)	0.33°C	0.35°C	0.46°C	0.38°C	–0.45 mm
Gharyan	0.33°C	0.36°C	0.48°C	0.40°C	–0.20 mm
Sawfajjin (sofuljeen)	0.33°C	0.32°C	0.45°C	0.37°C	0.12 mm
Surt (sirte)	0.32°C	0.29°C	0.41°C	0.37°C	–0.08 mm
Ash Shati	0.32°C	0.37°C	0.49°C	0.43°C	0.21 mm
Al Jufrah	0.30°C	0.32°C	0.47°C	0.41°C	0.08 mm
Awbari (ubari)	0.30°C	0.39°C	0.50°C	0.45°C	0.25 mm
Sabha	0.31°C	0.35°C	0.48°C	0.43°C	0.06 mm
Murzuq	0.30°C	0.36°C	0.48°C	0.45°C	0.25 mm
Banghazi	0.30°C	0.28°C	0.42°C	0.36°C	–1.77 mm
Al Fatah	0.29°C	0.29°C	0.42°C	0.36°C	–2.47 mm
Al Jabal Al Akhdar	0.28°C	0.30°C	0.43°C	0.37°C	–2.77 mm
Darnah	0.29°C	0.29°C	0.45°C	0.38°C	–1.51 mm
Tubruq (tobruk)	0.30°C	0.30°C	0.47°C	0.39°C	–0.37 mm
Ajdabiya (agedabia)	0.31°C	0.30°C	0.46°C	0.40°C	–0.06 mm
Al Kufrah	0.31°C	0.33°C	0.50°C	0.44°C	0.10 mm

Rows are classified according to the historical regions Tripolitania, Fezzan, and Cyrenaica as in **Fig. 2** with governorates organized from northwest to southeast. Columns show the decadal trend for the average mean surface temperature seasonal cycle and total annual precipitation.

TABLE 5. Historical and Projected Heat Indices Across Libya's Regions for CMIP6 Multi-model Means

Regions	Warm Spell Duration Index		Cooling Degree Days		Number Days with Daily Max Temp >=35°C		Number of Tropical Nights (T-min > 26°C)	
	Historical	Projected Decadal Trend	Historical	Projected Decadal Trend	Historical	Projected Decadal Trend	Historical	Projected Decadal Trend
Libya	6.71 days	7.20 days	3621.60 degF	185.38 degF	102.88 days	7.77 days	12.75 days	7.58 days
Nuqat Al Khams	4.43 days	3.67 days	3010.17 degF	154.35 degF	46.74 days	7.15 days	12.53 days	6.22 days
Az Zawia (azzawiya)	4.44 days	3.68 days	2943.34 degF	154.71 degF	46.26 days	7.76 days	7.02 days	4.96 days
Al Aziziyah	4.27 days	3.91 days	2803.68 degF	152.49 degF	42.41 days	7.90 days	4.34 days	3.57 days
Tripoli (tarabulus)	4.35 days	4.20 days	2637.27 degF	149.00 degF	25.43 days	6.60 days	3.36 days	3.65 days
Tarhunah	4.10 days	3.61 days	2455.01 degF	144.65 degF	33.72 days	7.00 days	1.40 days	1.46 days
Al Khoms	4.14 days	3.99 days	2361.29 degF	142.41 degF	13.30 days	4.06 days	5.17 days	3.57 days
Zeleitin (zliten)	3.83 days	3.52 days	2653.64 degF	146.63 degF	33.73 days	7.31 days	1.79 days	2.28 days
Misurata	3.78 days	4.29 days	2496.02 degF	147.99 degF	14.02 days	3.99 days	8.34 days	6.03 days
Ghadamis	6.23 days	6.19 days	3493.71 degF	182.37 degF	97.86 days	6.75 days	22.54 days	8.22 days
Yafran (yefren)	4.97 days	4.00 days	2648.18 degF	161.22 degF	54.22 days	7.70 days	4.67 days	3.32 days
Gharyan	5.29 days	4.79 days	2999.69 degF	171.68 degF	73.14 days	7.87 days	6.63 days	4.50 days
Sawfajjin (sofuljeen)	4.14 days	3.18 days	3025.44 degF	165.75 degF	59.85 days	8.49 days	6.18 days	3.55 days
Surt (sirte)	4.45 days	3.17 days	2774.80 degF	152.82 degF	42.85 days	7.43 days	3.71 days	2.00 days
Ash Shati	6.61 days	6.85 days	3826.28 degF	190.37 degF	118.74 days	6.71 days	18.42 days	8.95 days
Al Jufrah	5.86 days	4.84 days	3405.69 degF	178.81 degF	91.96 days	9.03 days	7.51 days	4.68 days
Awbari (ubari)	7.10 days	9.14 days	4353.30 degF	207.95 degF	144.04 days	5.88 days	31.42 days	11.97 days
Sabha	6.78 days	7.15 days	3922.71 degF	192.36 degF	120.21 days	7.17 days	20.41 days	9.61 days
Murzuq	7.76 days	8.77 days	4035.29 degF	200.71 degF	130.97 days	7.36 days	16.11 days	9.92 days
Banghazi	5.62 days	6.30 days	2734.97 degF	150.98 degF	36.13 days	7.16 days	2.09 days	2.44 days
Al Fatah	5.62 days	6.41 days	2320.32 degF	141.55 degF	26.79 days	6.08 days	0.81 days	0.89 days
Al Jabal Al Akhdar	5.30 days	5.69 days	2136.54 degF	138.85 degF	27.76 days	5.47 days	0.82 days	0.84 days
Darnah	5.09 days	5.74 days	2513.66 degF	149.10 degF	35.77 days	7.21 days	1.22 days	1.51 days
Tubruq (tobruk)	5.46 days	6.27 days	3063.03 degF	167.12 degF	63.35 days	8.58 days	4.44 days	4.39 days
Ajdabiya (agedabia)	5.78 days	4.82 days	3478.44 degF	171.83 degF	88.02 days	8.75 days	11.17 days	6.80 days
Al Kufrah	8.09 days	9.71 days	3894.42 degF	197.30 degF	120.88 days	8.03 days	12.34 days	9.15 days

The historical period considered is 1995–2014. Projections show multi-model averaged decadal trends for the period 2000–2050 under scenario SSP3-7.0. Rows are classified according to the historical regions Tripolitania, Fezzan, and Cyrenaica as in **Fig. 2** with governorates organized from northwest to southeast. Columns show warm spell duration index (The number of days in a sequence of at least six consecutive days during which the value of the daily maximum temperature is greater than the 90th percentile of daily maximum temperature), cooling degree days (The cumulative number of degrees that the daily average temperature over a given period is above 65°F, which is a measurement designed to quantify the demand for energy needed to cool a building), number of days with daily max temperature ≥35°C, and number of tropical nights (Tmin > 26°C)

TABLE 6. Historical and Projected Number of Days Where the Heat Index ≥ 35°C Heat Indices Across Libya's Regions for CMIP6 Multi-Model Averages

Regions	Number of Days Where the Heat Index ≥ 35°C			
	1995–2014 Average (center 2005)	2020–2039 Average (center 2030)	2040–2059 Average (center 2050)	Trend/Decade from 2050–2100
Libya	0.27 days	1.63 days	5.54 days	9.13 days
Nuqat Al Khams	3.92 days	13.68 days	29.20 days	12.03 days
Az Zawia (azzawiya)	1.42 days	7.18 days	18.84 days	12.45 days
Al Aziziyah	0.34 days	3.04 days	10.50 days	11.45 days
Tripoli (tarabulus)	0.35 days	3.58 days	12.75 days	12.32 days
Tarhunah	0.03 days	0.55 days	3.48 days	7.91 days
Al Khoms	0.32 days	2.65 days	9.69 days	11.38 days
Zeleitin (zliten)	0.44 days	3.07 days	12.63 days	12.98 days
Misurata	0.84 days	5.45 days	17.35 days	12.93 days
Ghadamis	0.64 days	3.36 days	10.13 days	10.23 days
Yafran (yefren)	0.28 days	1.26 days	4.48 days	6.38 days
Gharyan	0.10 days	0.98 days	4.05 days	6.95 days
Sawfajjin (sofuljeen)	0.94 days	4.36 days	12.82 days	11.56 days
Surt (sirte)	0.38 days	2.01 days	6.68 days	9.52 days
Ash Shati	0.18 days	1.92 days	7.14 days	10.41 days
Al Jufrah	0.14 days	1.12 days	4.38 days	7.31 days
Awbari (ubari)	0.33 days	2.64 days	8.88 days	12.90 days
Sabha	0.15 days	1.71 days	6.56 days	10.59 days
Murzuq	0.04 days	0.73 days	3.23 days	8.44 days
Banghazi	0.06 days	0.99 days	4.84 days	11.56 days
Al Fatah	0.03 days	0.23 days	1.25 days	4.81 days
Al Jabal Al Akhdar	0.03 days	0.24 days	1.02 days	3.11 days
Darnah	0.06 days	0.54 days	2.35 days	7.07 days
Tubruq (tobruk)	0.27 days	1.54 days	5.46 days	11.14 days
Ajdabiya (agedabia)	0.69 days	3.16 days	9.46 days	11.86 days
Al Kufrah	0.14 days	0.79 days	2.98 days	7.48 days

The historical period considered is 1995–2014. Projections show multi-model averaged measurements for 2030, 2050, and decadal trends for the period 2050–2100 under scenario SSP3-7.0. Rows are classified according to the historical regions Tripolitania, Fezzan, and Cyrenaica as in **Fig. 2**.

TABLE 7. Historical and Projected Population Exposure to Extreme Heat Conditions

Regions	Heat index > 35°C			Wet bulb temp > 27°C	Hot days (Temp max > 40°C)			Tropical nights (Tmin > 29°C)		
	2000	2035	2075	2075	2000	2035	2075	2000	2035	2075
Nuqat Al Khams	11.18	100	100	61.39	34.19	55	96.7	0	3.22	100
Az Zawia (azzawiya)	0	91.25	100	43.06	3.85	58.27	100	0	0	59.92
Al Aziziyah	0	51.54	100	11.32	0	39.57	100	0	0	3.61
Tripoli (tarabulus)	0	75.36	100	34.31	0	0	88.99	0	0	0.61
Tarhunah	0	0	100	0	0	1.39	93.38	0	0	0
Al Khoms	0	21.83	100	21.41	0	0	7.51	0	0	12.8
Zeleitin (zliten)	0	67.65	100	15.93	0	14.72	83.58	0	0	0
Misurata	0	100	100	76.18	0	0	32.13	0	0	20.22
Ghadamis	0	44.41	100	0	97.13	100	100	3.17	38.57	100
Yafran (yefren)	0	24.01	98.38	0	42.29	100	100	0	0	68.6
Gharyan	0	3.48	96.4	0	61.87	88.34	100	0	0.48	73.96
Sawfajjin (sofuljeen)	0	64.38	100	22.8	33.85	63.81	93.39	0	0	33.63
Surt (sirte)	0	11.84	100	9.87	34.16	71.23	92.94	0	0.24	7.91
Ash Shati	0	16.28	100	0	100	100	100	0	45.62	100
Al Jufrah	0	0	97.62	0	99.52	100	100	0	0	90.44
Awbari (ubari)	0	35.54	100	0	99.97	100	100	5.95	82.6	100
Sabha	0	6.72	100	0	100	100	100	0	51.99	100
Murzuq	0	2.97	92.9	0	94.64	99.38	99.82	0	34.63	97.36
Banghazi	0	4.96	100	10.71	0	46.02	56.6	0	0	2.14
Al Fatah	0	0	73.47	0.51	0	35.24	55.63	0	0	0.63
Al Jabal Al Akhdar	0	0	41.11	0.29	0	28.88	42.97	0	0	0.48
Darnah	0	0	76.71	0.08	0	39.3	67.32	0	0	2.21
Tubruq (tobruk)	0	0	100	0.72	17.33	73.34	84.79	0	0	59.02
Ajdabiya (agedabia)	0	27.61	100	2.16	58.03	93.17	99.49	0	9.76	66.14
Al Kufrah	0	2.81	85.24	0	79.87	99.08	99.68	0	16.24	99.01

For each admin1 district, percent of the population[28] 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 indicates that, on average once every 50 years, a year occurs with: a) more than 20 days when the heat index exceeds 35°C; b) more than 15 days with wet bulb temperatures[29] exceeding 27°C (note: in this case, population exposure is zero in 2000 and 2035, so results are only shown for 2075); c) more than 20 days with daytime temperatures exceeding 40°C; d) more than 20 nights with minimum temperatures exceeding 29°C.

[28] Population dataset: Gridded Population of the World, Version 4: GPWv4; Revision 11, Dec 2018.

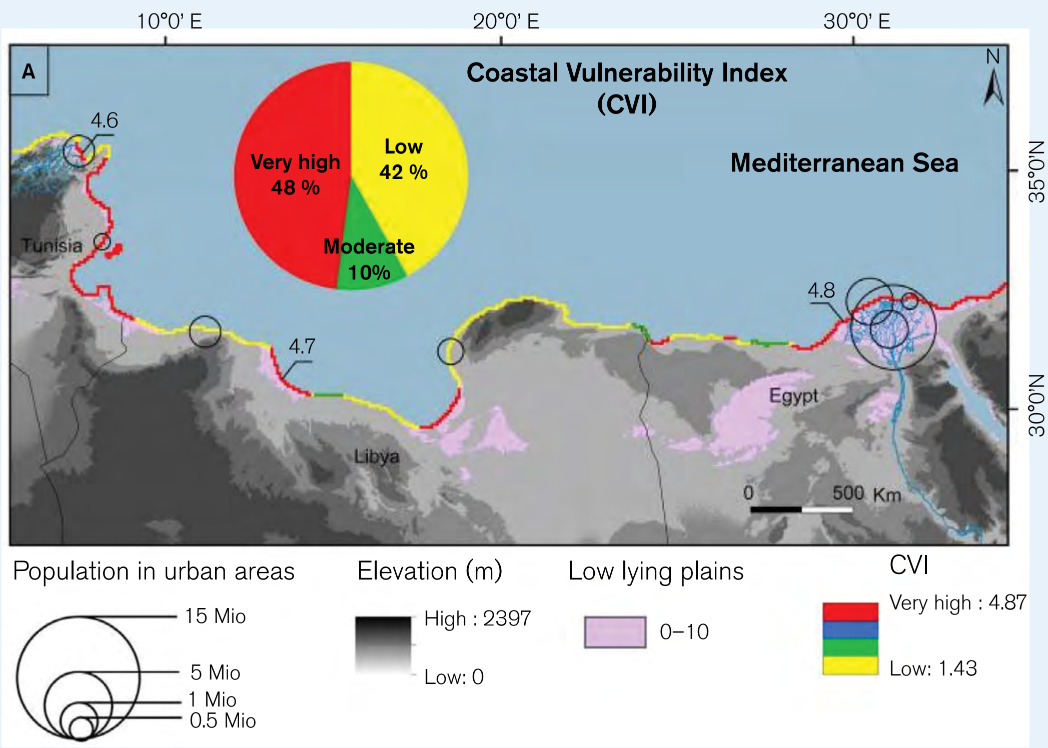
[29] Stull, R. (2011). *Wet-bulb temperature from relative humidity and air temperature.* Journal of Applied Meteorology and Climatology, 50(11), 2267–2269. https://doi.org/10.1175/JAMC-D-11-0143.1

Sea Level Rise and Sea Surface Temperature

The Mediterranean Sea maintains a relatively warm average sea surface temperature of 19.2°C[30]. 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. 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.

Sea level rise and coastal inundation will pose an increasing threat to Libya's coastal zones, particularly along stretches with sandy beaches. **Fig. 18** illustrates the coastal vulnerability index[31], which is particularly high along two sections of Libya's coast. This index was calculated considering factors such as geomorphology, coastal slope

FIGURE 18. Coastal Vulnerability Index Along Libya's Coast



Software: Esri. ArcGIS 10.2 (https://www.esri.com/software/arcgis)

The Highest risk is on stretches with sandy beaches. Figured copied from Hzami et al. 2021.

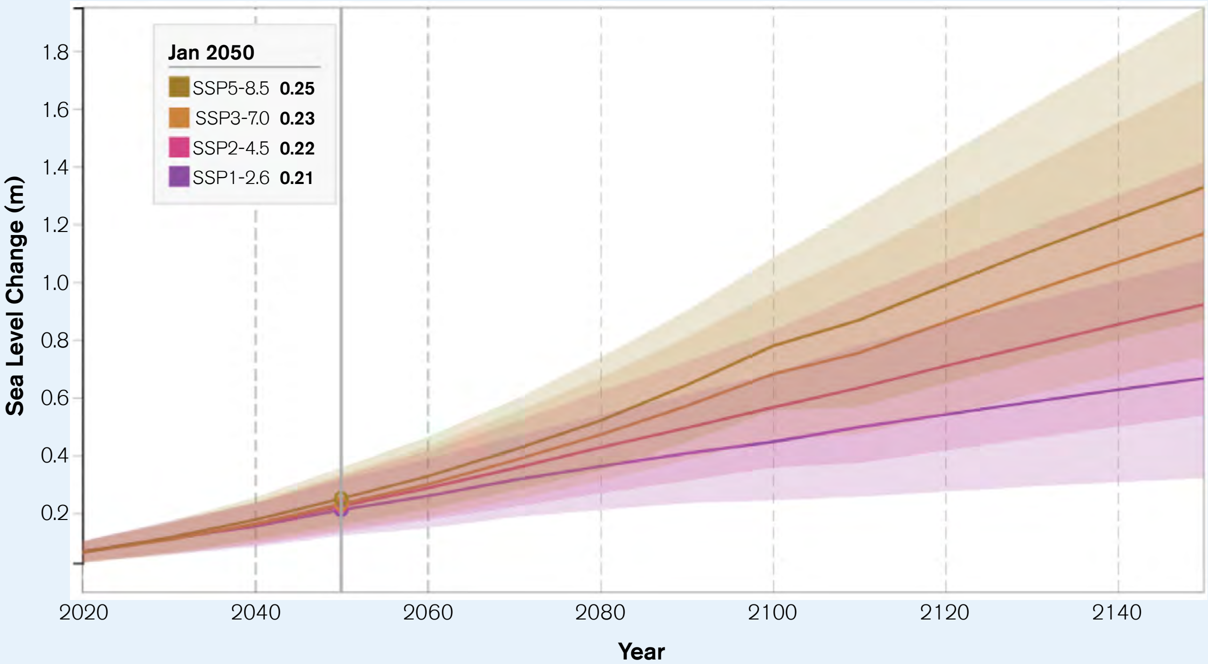
[30] Data from the IPCC WGI Interactive Atlas, for multi-model CMIP6 historical and projected sea surface temperatures, https://interactive-atlas.ipcc.ch/

[31] Hzami et al. (2021). Alarming coastal vulnerability of the deltaic and sandy beaches of North Africa, Sci Rep. 11(1):2320. DOI: https://doi.org/10.1038%2Fs41598-020-77926-x

and elevation, shoreline retreat rate, sea-level rise, mean wave height, and mean tide range. Coastal vulnerability is further amplified when combined with high population density or significant infrastructure.

Sea level rise is projected to increase by 0.23 meters by 2050 and 0.68 m by 2100 under the scenario SSP3-7.0 with respect to the historical period (1995–2014) (**Fig. 19**). Even though the uncertainties are high, it is certain that sea-level rise will keep increasing in all scenarios for centuries, which require long-term planning. Sea level rise could reach 0.3 m above historical conditions as early as 2050 in all scenarios.

FIGURE 19. Projected Total Sea Level Change Under Different SSP Scenarios Relative to the Historical Baseline (1994–2014)



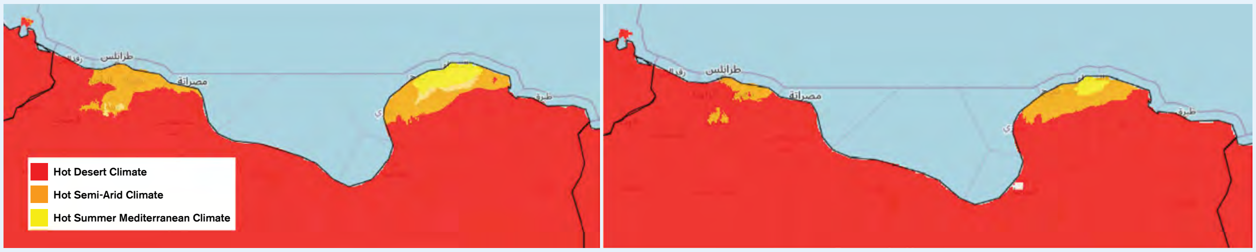
The shaded ranges show uncertainties at 17th–83rd percentile ranges. Data reflects the grid at 31°N, 19°E (Libya's coast). Data from NASA Sea Level Projection Tool[32].

Desertification

Desertification, typically driven by anthropogenic pressures such as urbanization and agriculture, poses one of the highest risks in Libya. The impact of human activities on the land has accelerated the degradation of arid and semi-arid areas, leading to a loss of productive soil and increased vulnerability to desert expansion. With climate change, warming is projected to further intensify desertification across the country, exacerbating the already critical situation. As temperatures rise and precipitation patterns shift, only a small region of Libya is expected to retain its Mediterranean climate, where rainfall remains significant (**Fig. 20**). This shrinking zone of Mediterranean climate will become increasingly crucial for sustaining agriculture and human habitation, highlighting the urgent need for sustainable land management practices and climate adaptation strategies to mitigate the impacts of both desertification and climate change.

[32] NASA Sea Level Projection Tool https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?lat=31&lon=+19&data_layer=scenario

FIGURE 20. Köppen-Geiger Climate Classification System for 30-year periods[33]: a) Historical 1991–2020 b) Projected 2071–2099 Under SSP3-7.0 Using CMIP6 Simulations



In red, desert climate. In orange, semi-arid climate. In yellow, hot summer Mediterranean climate.

Sand and Dust Storms

As a Sahara Desert country bound to become even more arid, Libya is a significant source of sand and dust storms[34]. While sandstorms have a limited reach, dust storms can reach thousands of kilometers. Saharan dust storms can affect Libya's cities, but also 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[35]. Sand and dust storms are particularly prominent from February to May[36]. Research suggests that the main driver for decadal variability in dust storms is the Atlantic Meridional Oscillation AMO[37].

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[38]. A net decrease of 30.1% in the frequency of Sand and Dust Storms was observed during the decade 2000–2009 compared to the average values for the reference period 1961–1990 (WMO report). However, the storms will be more intense due to greater dust availability resulting from increased drought occurrences.

With desertification and climate change intensifying, preparedness becomes crucial. Forecasting tools such as the CAMS forecast by Copernicus[39] and the daily dust forecasts by the WMO Barcelona Dust Regional Center[40] play an essential role in this effort.

[33] Data and Plots from https://koppen.earth/
[34] Sand and Dust Storms Source Base-map https://maps.unccd.int/sds/
[35] 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
[36] Dust/sand storms over Libya. Spatial distribution, frequency and seasonality, technical report by the World Meteorological Organization (2015), https://library.wmo.int/records/item/37483-dust-sand-storms-over-libya
[37] 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
[38] Evan et al. (2016). The past, present and future of African dust, Nature 531, 493–495, DOI: https://doi.org/10.1038/nature17149
[39] CAMS by Copernicus https://stories.ecmwf.int/forecasting-dust-storms/index.html
[40] WMO Barcelona Dust Regional Center https://dust.aemet.es/

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 Libya (Carrao et al. 2016[41]), and the number of moderate-to-severe drought days is projected to increase further especially in the Mediterranean region and North African countries (Pokhrel et al. 2021[42]).

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. Most of the irrigation water in Libya is sourced from aquifers, including non-renewable deep southern fossil aquifers. The renewable shallow aquifers in the Northern Mediterranean regions, already facing salinization, are projected to warm due to climate change (Benz et al., 2024[43]). This warming could lead to new challenges related to health and water quality.

Libya's predominant livestock species is sheep, totaling more than 5 million units. Due to climate change, sheep in Libya are projected to experience increasing heat stress. According to Thornton et al. (2021)[44], sheep will endure about four additional months of heat stress annually by the end of the 21st century compared to 2000. 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.

By the period 2090–2099, marine animal biomass along Libya's coast is expected to decline[45]. Under the low-emissions scenario RCP2.6 (+1.8°C), the decrease could be up to 20%, while under the high-emissions scenario RCP8.5 (+4.4°C), the decline may range from 20% to 40%, relative to levels observed during 1990–1999.

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[41] 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

[42] 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

[43] 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

[44] 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

[45] 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

CLIMATE RISK COUNTRY PROFILE

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