Drought and heat-stress mortality risks: Assessing the role of climate change, socioeconomic vulnerabilities, and population growth

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Motivation:

- To quantify the future changes of drought risk in Africa considering the main components of risk (i.e. hazard, vulnerability, and exposure).
- To develop a multi-dimensional framework for quantifying drought vulnerability through integrating various socioeconomic factor (i.e. economy, energy and infrastructure, health, land use, society, and water resources).
- To implement scenario analysis for probabilistic future projections and characterize the uncertainty of each component of risk.

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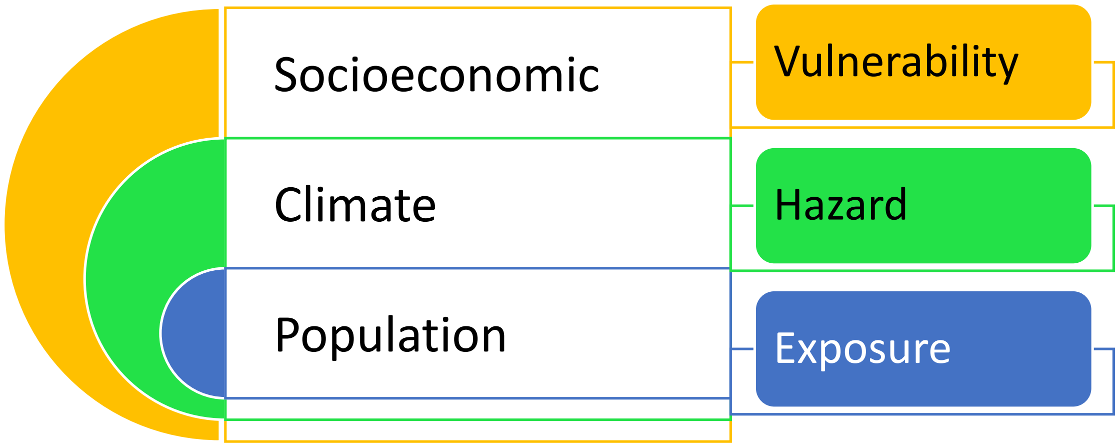
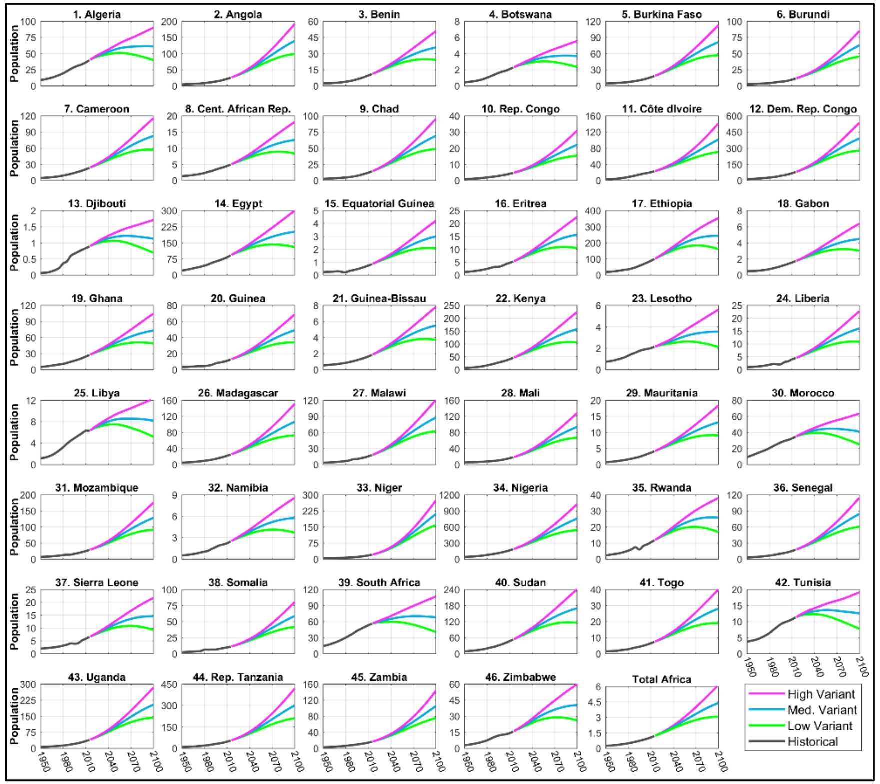
- **Drought risk:**
  - The potential losses from the hazard imposed by a drought event

- Definition of “risk” according to the United Nations International Strategy for Disaster Reduction (UNISDR) and Intergovernmental Panel on Climate Change (IPCC):
  - ➢ $Risk = Vulnerability \times Hazard \times Exposure$

- **Hazard:** The likelihood of an extreme event (natural and/or anthropogenic)
  - The Standardized Precipitation Evapotranspiration Index (SPEI) is utilized to quantify drought hazard

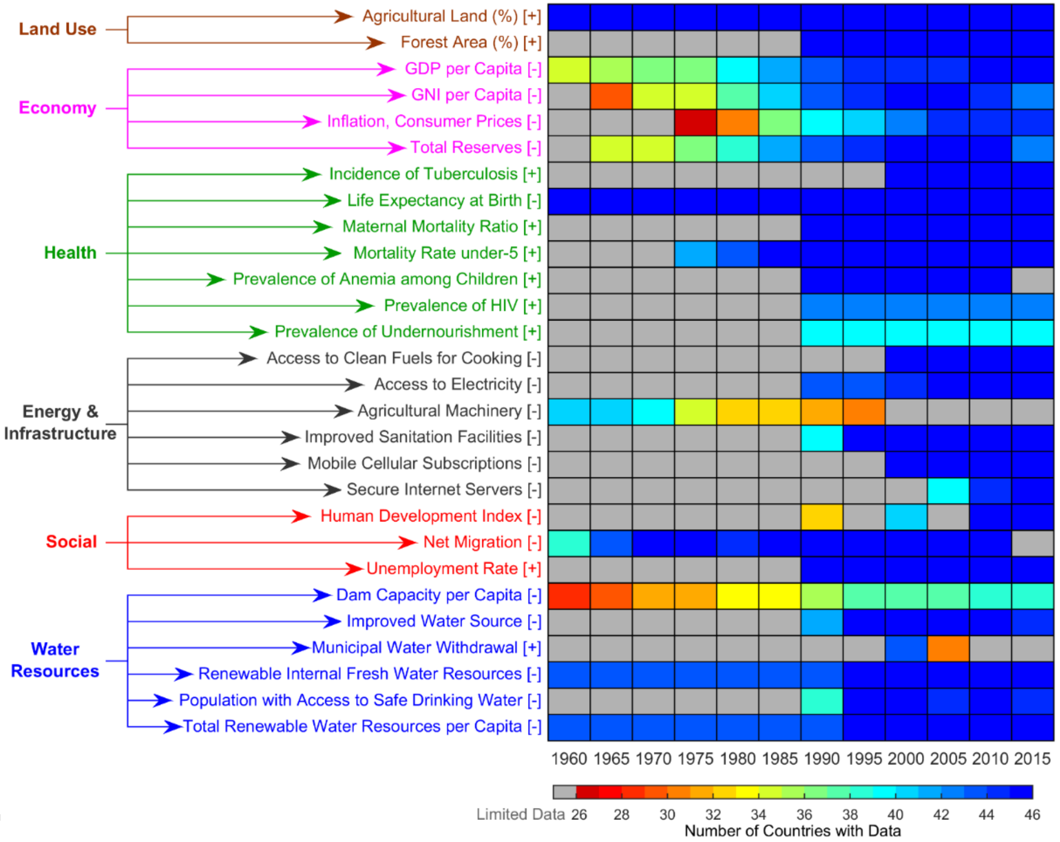
- Three types of data utilized in this project for quantifying drought risk:





Socioeconomic Data:

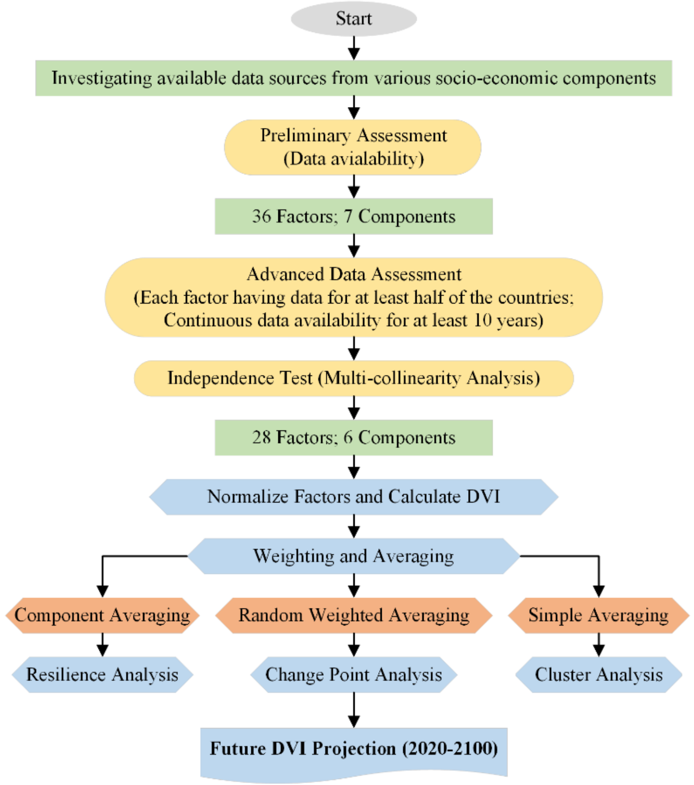
Population Data

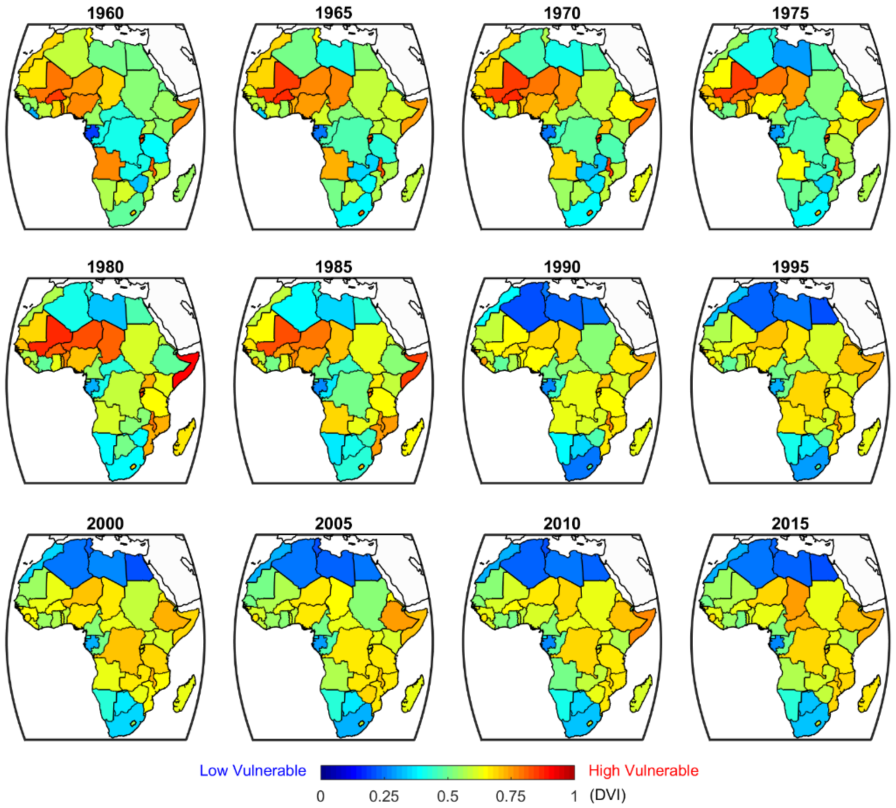


- **Climate Data:** CORDEX RCMs, daily, 0.44° spatial resolution, Prec and PET

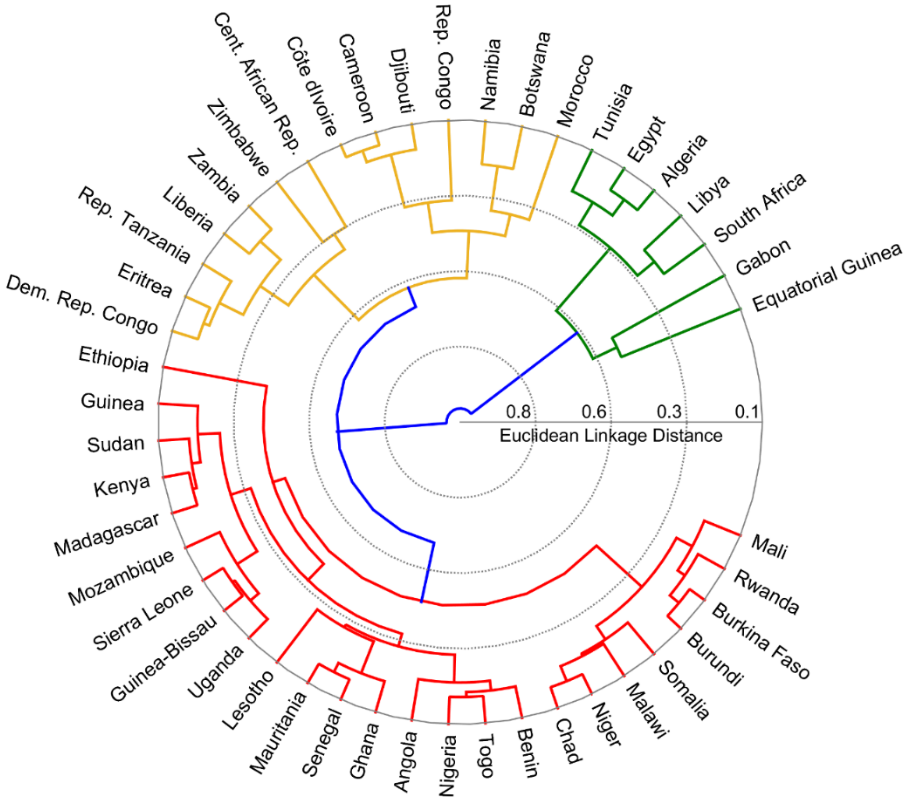
No	Deriving GCM	Original Modeling Institute	Original Resolution (lat × lon)	Ens. Member
1	CanESM2	Canadian Centre for Climate Modeling and Analysis	2.8° × 2.8°	r1i1p1
2	CNRM-CM5	National Centre of Meteorological Research, France	1.4° × 1.4°	r1i1p1
3	CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization, Australia	1.8° × 1.8°	r1i1p1
4	EC-EARTH	EC-EARTH consortium	1.0° × 1.0°	r12i1p1
5	GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory	2.5° × 2.0°	r1i1p1
6	HadGEM2-ES	Met. Office Hadley Centre	1.88° × 1.25°	r1i1p1
7	IPSL-CM5A-MR	Institut Pierre-Simon Laplace	2.5° × 1.25°	r1i1p1
8	MIROC5	Atmosphere & Ocean Research Institute, National Institute for Environmental Studies, and Japan Agency forMarine-Earth Science & Tech	1.4° × 1.4°	r1i1p1
9	MPI-ESM-LR	Max Planck Institute for Meteorology (MPI-M)	1.9° × 1.9°	r1i1p1
10	NorESM1-M	Norwegian Climate Centre	2.5° × 1.9°	r1i1p1

- **Drought Vulnerability:**

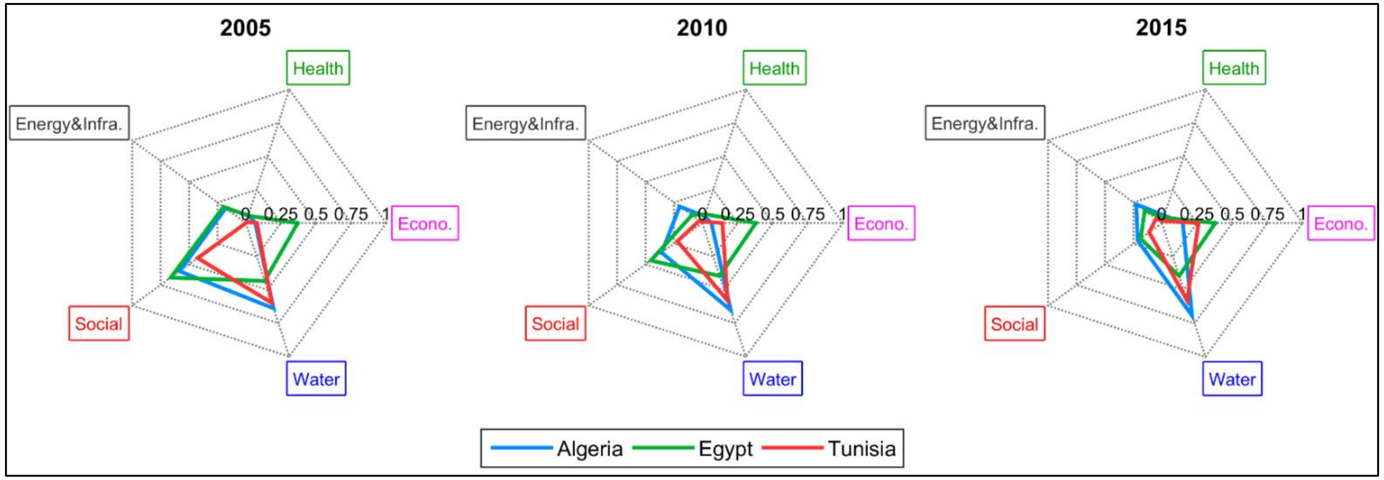




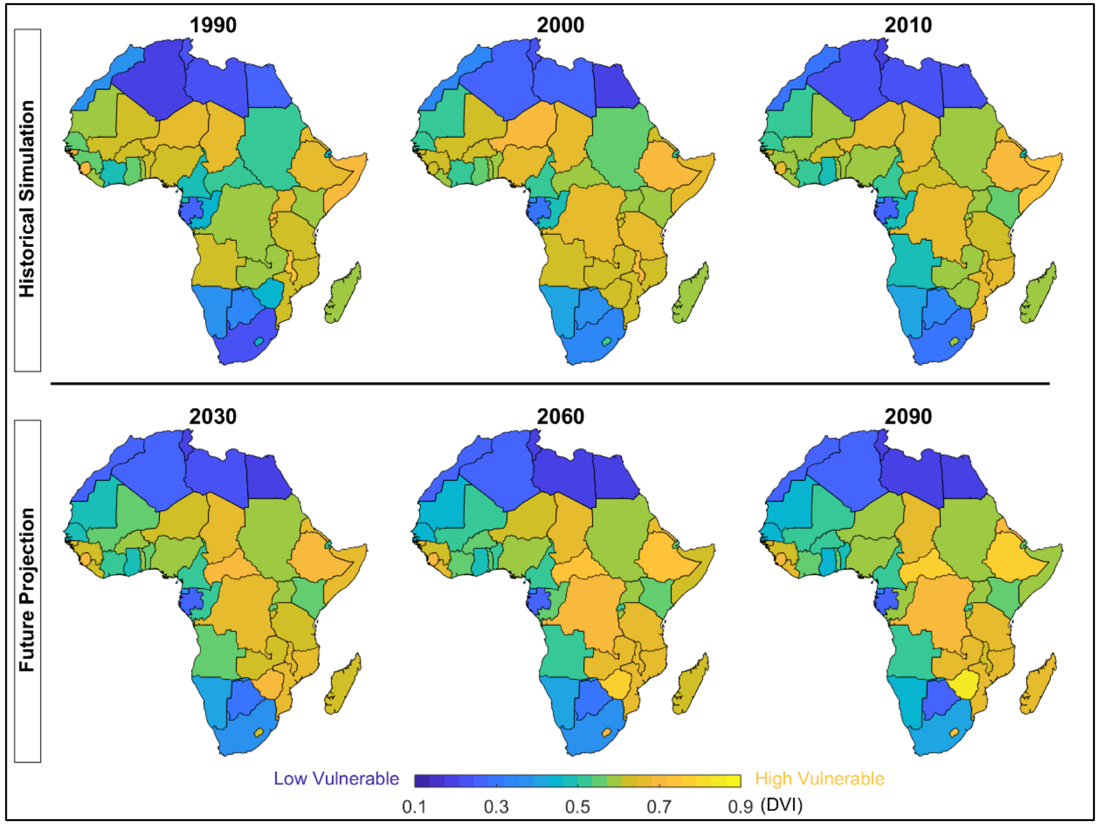
Drought Vulnerability Index

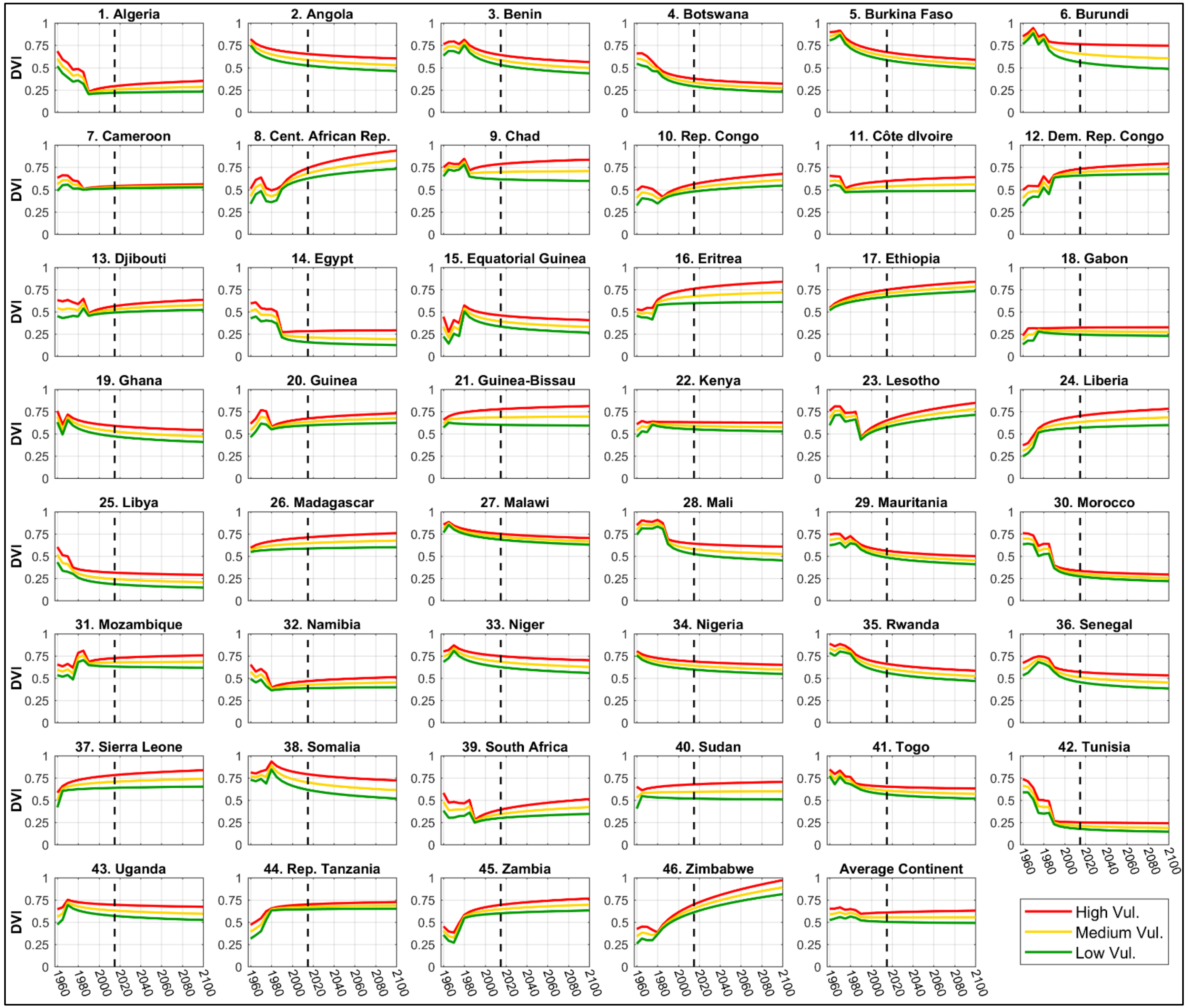


Least Drought Vulnerable Countries:

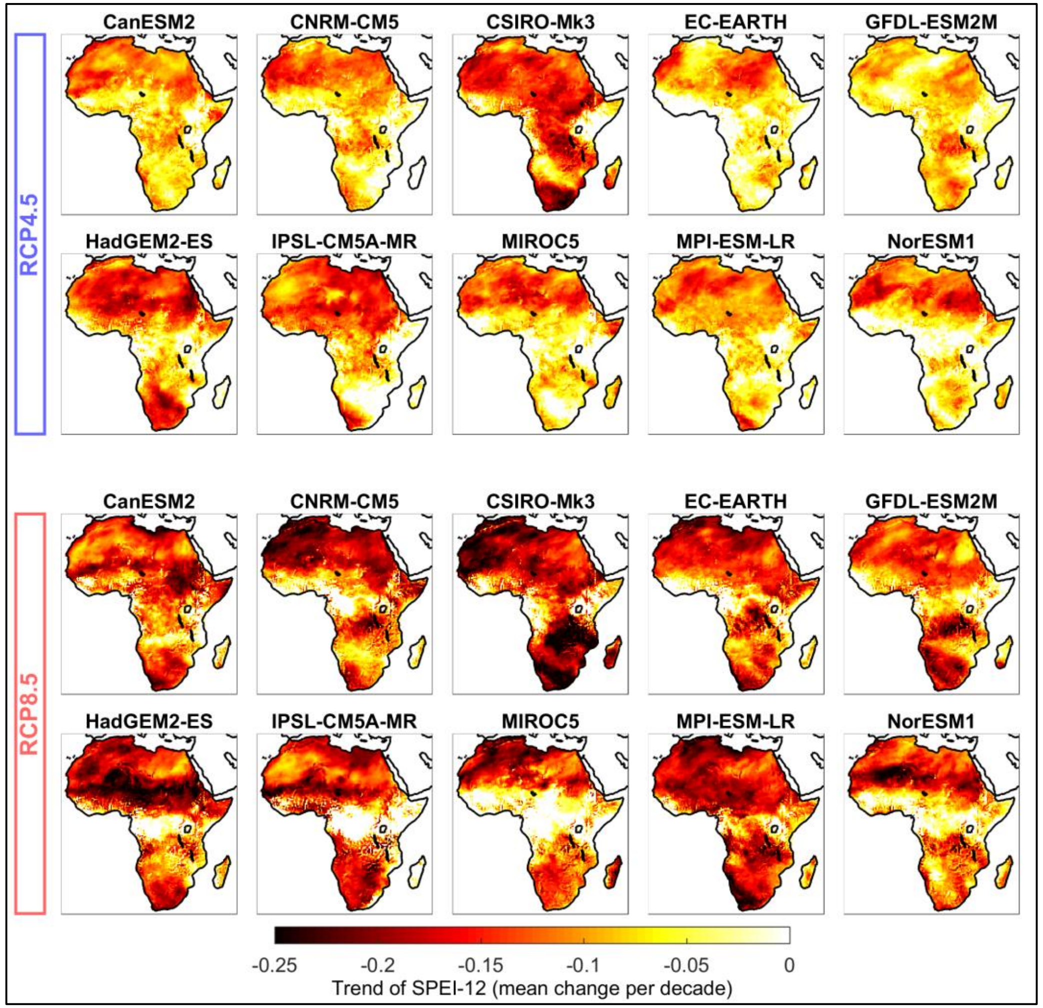


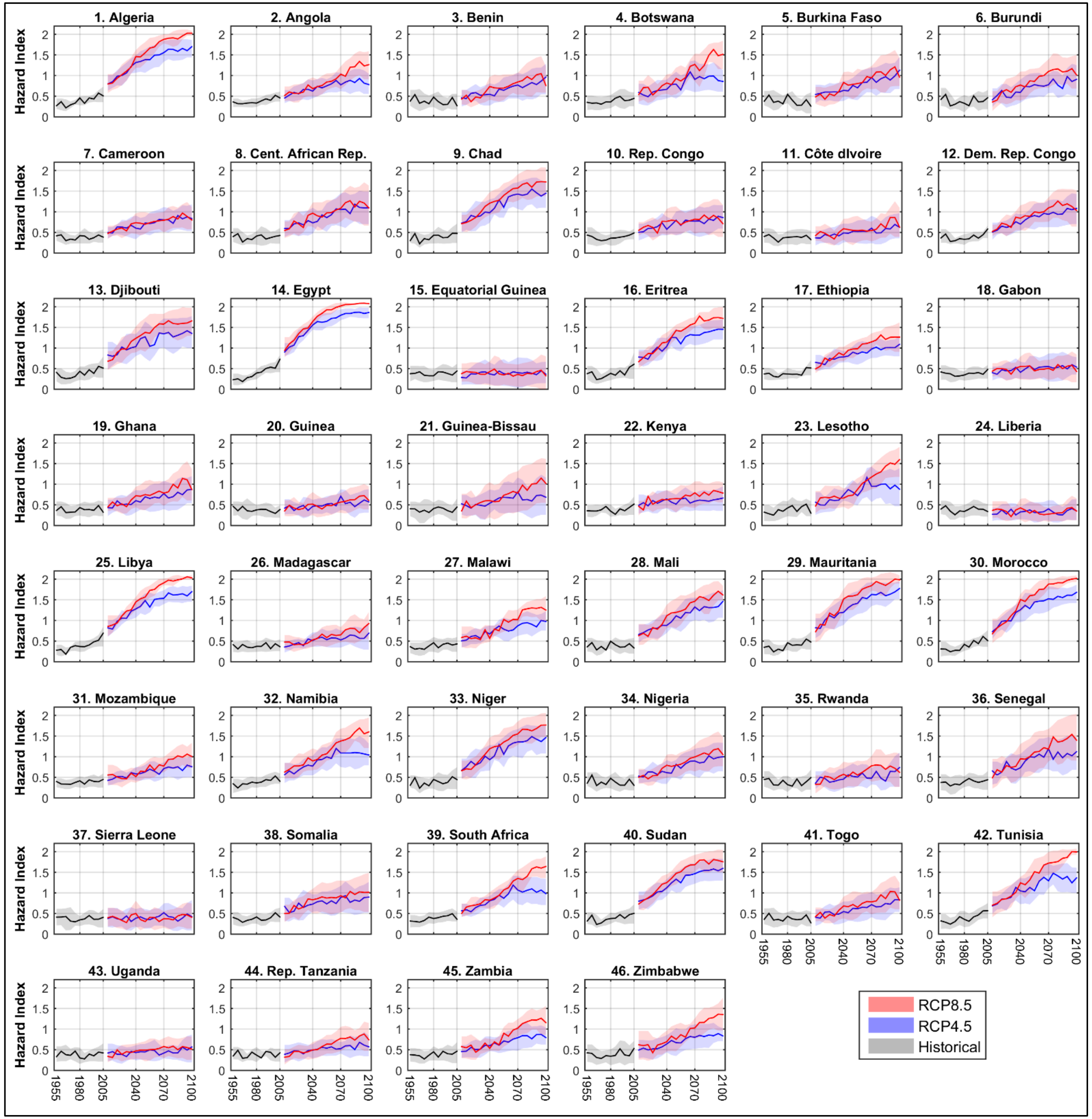
- **Drought Vulnerability Index (DVI):**





- **Drought Hazard:**

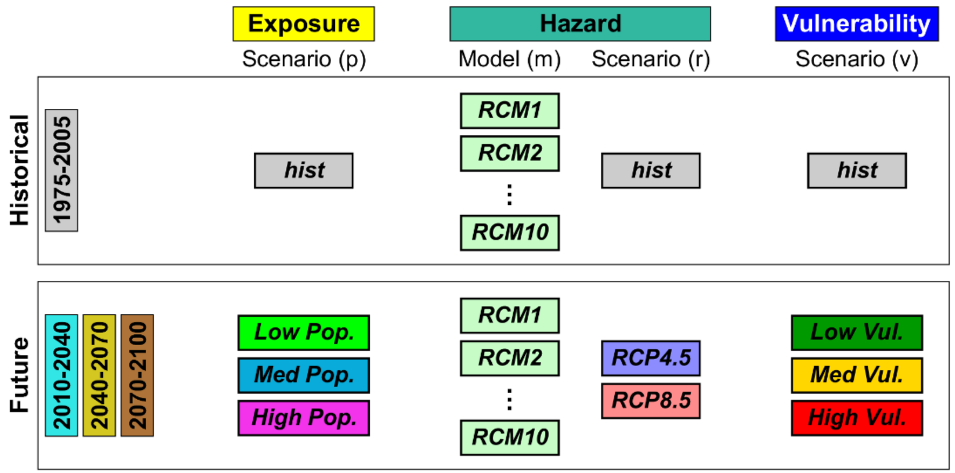




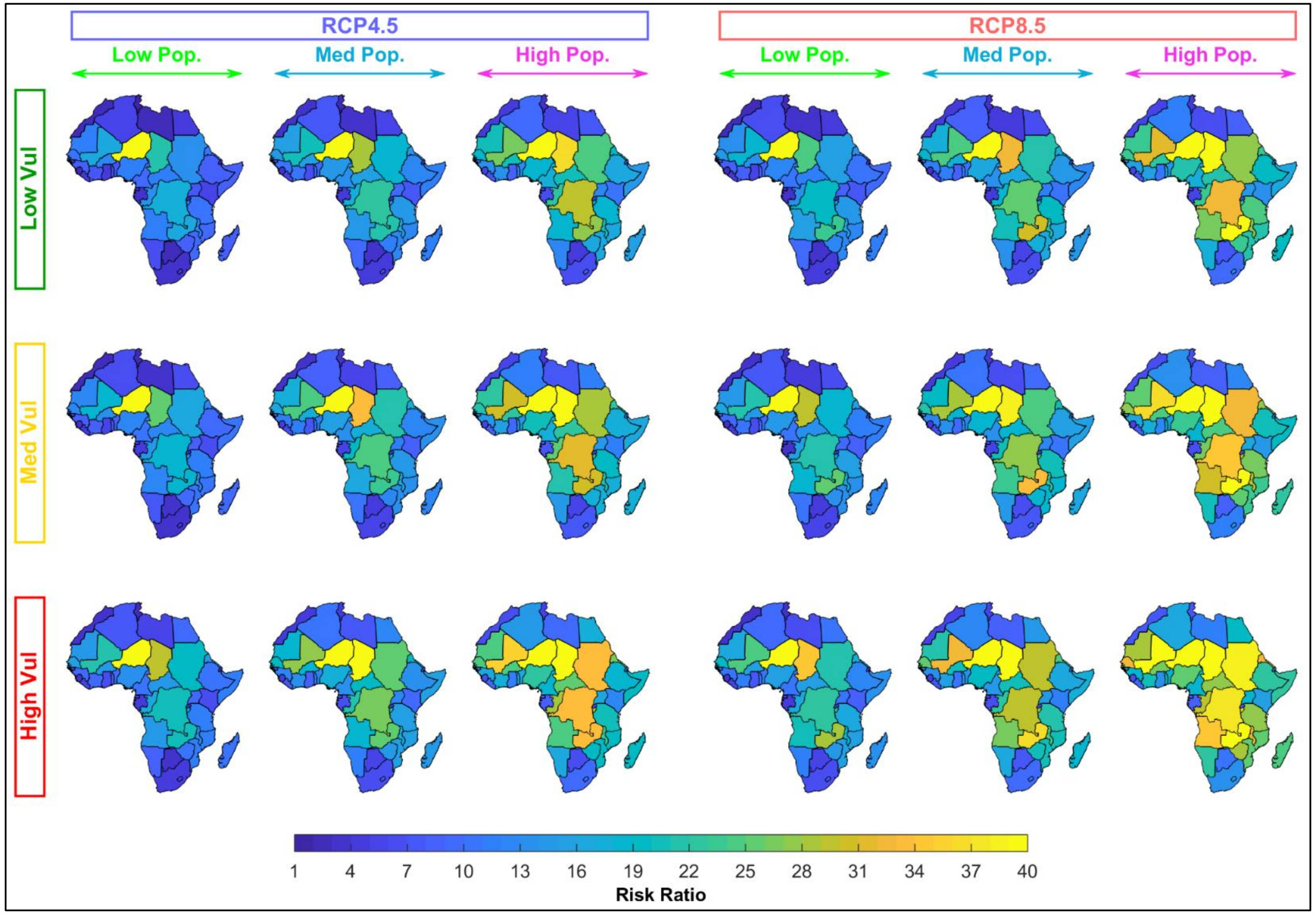
A trend value of -0.2 in SPEI means that in 25 years, the average value of SPEI will decrease by 0.5 (-0.2×2.5)

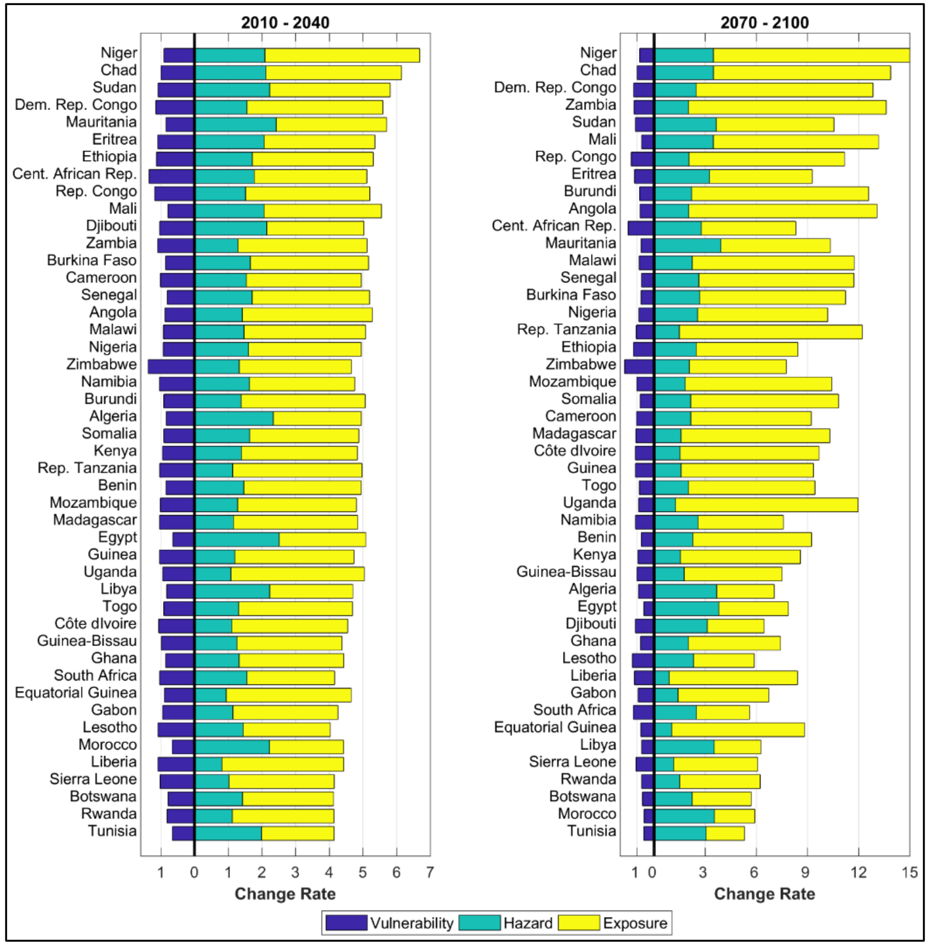
- **Drought Risk Ratio:**

$$Risk\ Ratio = \boxed{\frac{Vulnerability_{fut}}{Vulnerability_{hist}}} \times \boxed{\frac{Hazard_{fut}}{Hazard_{hist}}} \times \boxed{\frac{Exposure_{fut}}{Exposure_{hist}}}$$

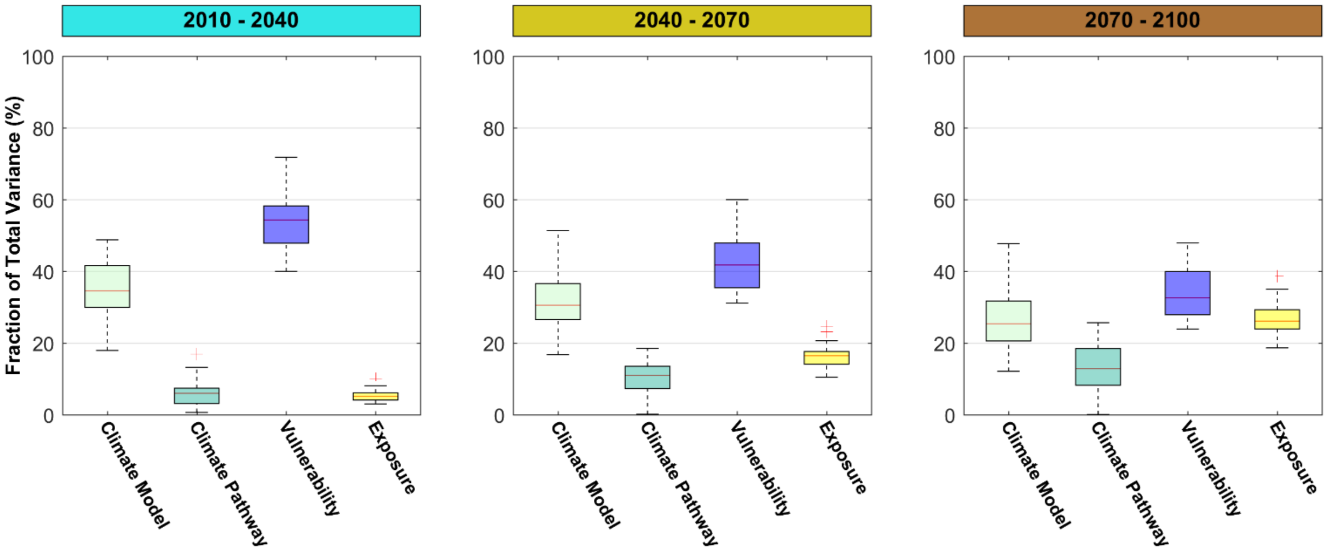


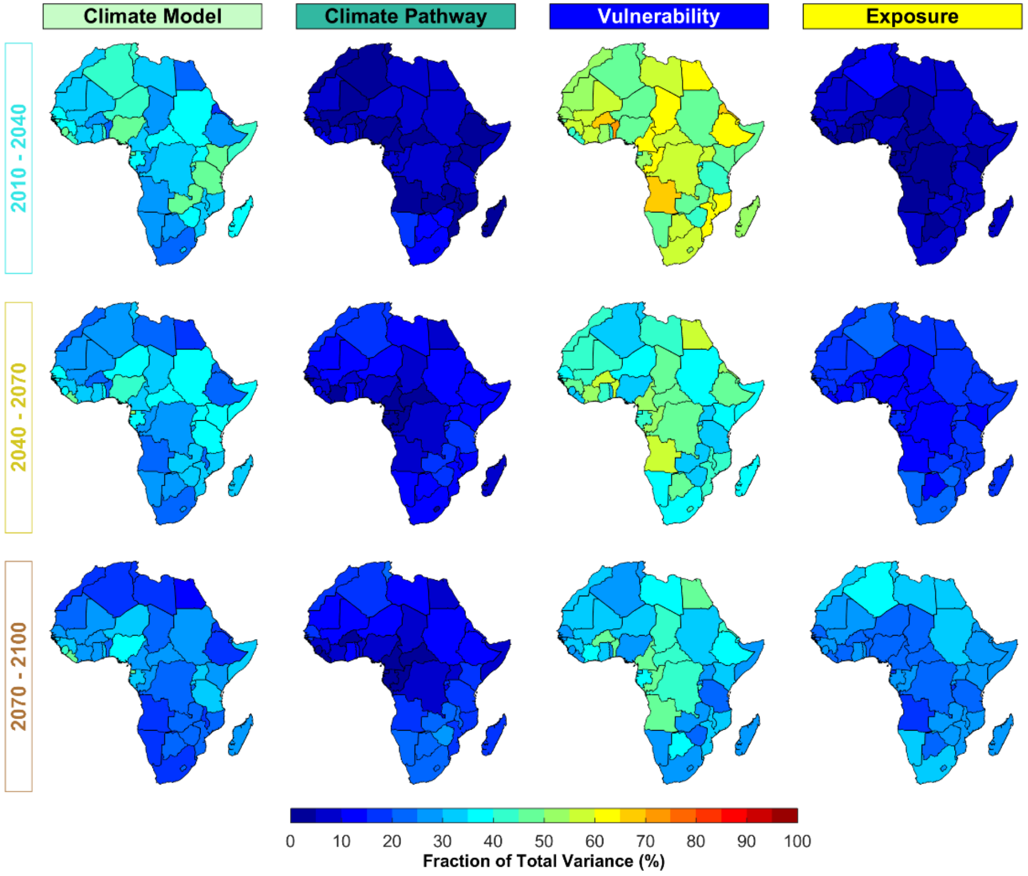
Drought Risk Ratio for 2070-2100 (compared with 1975-2005):





Characterizing Uncertainties:





Conclusions:

- Drought risk will increase in future for the entire African continent. The change rates are higher for the central African countries compared to the other regions.
- Different future scenarios indicate similar results in near future, whereas vast differences are found between the moderate and extreme scenarios in the distant future.
- Niger and Chad indicate the highest risk ratios due to population growth and increasing drought hazard.
- Tunisia and Morocco indicate the lowest risk ratio, albeit increasing drought hazard.

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Multi-dimensional assessment of drought vulnerability in Africa: 1960–2100

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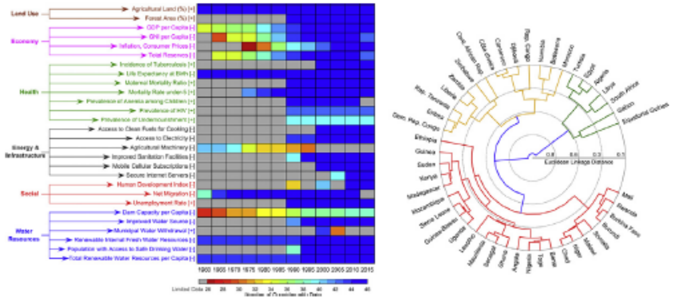
HIGHLIGHTS

- A comprehensive assessment is conducted to analyze drought vulnerability in Africa.
- Various socioeconomic datasets (28 factors from 6 major components) are utilized.
- Drought Vulnerability Index (DVI) is calculated at national scale during 1960–2015.
- The most and least vulnerable countries are identified over time.
- Following statistical analyses, DVI is projected for future period of 2020–2100.

GRAPHICAL ABSTRACT



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ABSTRACT

Drought vulnerability is a complex concept that identifies the capacity to cope with drought, and reveals the susceptibility of a system to the adverse impacts of drought. In this study, a multi-dimensional modeling framework is carried out to investigate drought vulnerability at a national level across the African continent. Data from 28 factors in six different components (i.e. economy, energy and infrastructure, health, land use, society, and water resources) are collected for 46 African countries during 1960–2015, and a composite Drought Vulnerability Index (DVI) is calculated for each country. Various analyses are conducted to assess the reliability and accuracy of the proposed DVI, and the index is evaluated against historical observed drought impacts. Then, regression models are fitted to the historical time-series of DVI for each country, and the models are extrapolated for the period of 2020–2100 to provide three future scenarios of DVI projection (low, medium, and high) based on historical variations and trends. Results show that Egypt, Tunisia, and Algeria are the least drought vulnerable countries, and Chad, Niger, and Malawi are the most drought vulnerable countries in Africa. Future DVI projections indicate that the difference between low- and high-vulnerable countries will increase in future, with most of the southern and northern African countries becoming less vulnerable to drought, whereas the majority of central African countries indicate increasing drought vulnerability. The projected DVIs can be utilized for long-term drought risk analysis as well as strategic adaptation planning purposes.

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Future drought risk in Africa: Integrating vulnerability, climate change, and population growth

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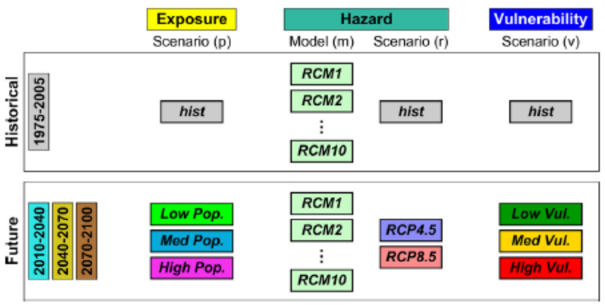
HIGHLIGHTS

- Drought risk is studied in Africa by integrating hazard, vulnerability and exposure.
- Multi-model and multi-scenarios are employed at a national level.
- Uncertainty of each risk component is characterized for each country.
- The role of climate change, population growth and vulnerability on risk is explored.
- The spatiotemporal patterns of drought risk and its uncertainties are identified.

GRAPHICAL ABSTRACT



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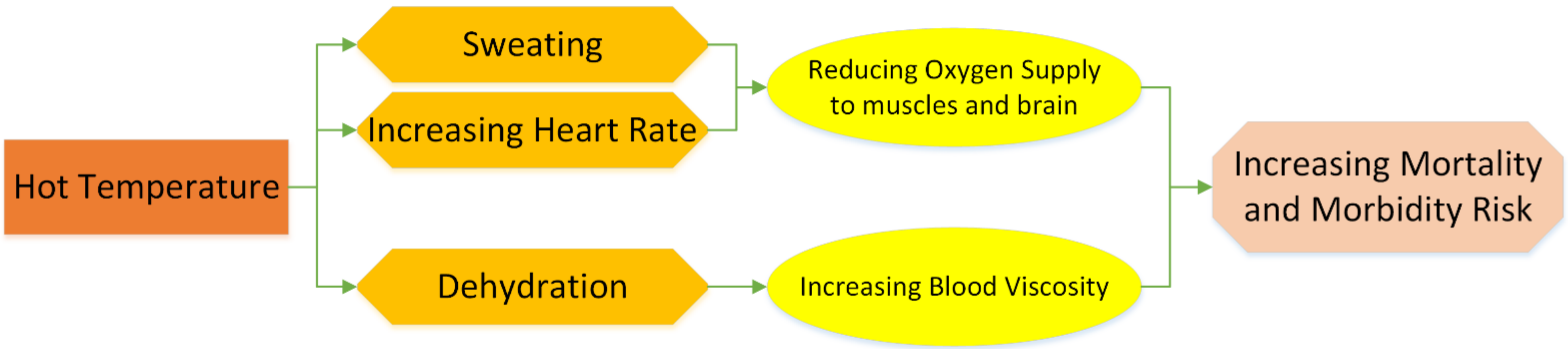
ABSTRACT

Drought risk refers to the potential losses from hazard imposed by a drought event, and it is generally characterized as a function of vulnerability, hazard, and exposure. In this study, drought risk is assessed at a national level across Africa, and the impacts of climate change, population growth, and socioeconomic vulnerabilities on drought risk are investigated. A rigorous framework is implemented to quantify drought vulnerability considering various sectors including economy, energy and infrastructure, health, land use, society, and water resources. Multi-model and multi-scenario analyses are employed to quantify drought hazard using an ensemble of 10 regional climate models and a multi-scalar drought index. Drought risk is then assessed in each country for 2 climate emission pathways (RCP4.5 and RCP8.5), 3 population scenarios, and 3 vulnerability scenarios during three future periods between 2010 and 2100. Drought risk ratio is quantified, and the role of each component (i.e. hazard, vulnerability, and exposure) is identified, and the associated uncertainties are also characterized. Results show that drought risk is expected to increase in future across Africa with varied rates for different models and scenarios. Although northern African countries indicate aggravating drought hazard, drought risk ratio is found to be highest in central African countries as a consequent of vulnerability and population rise in that region. Results indicate that if no climate change adaptation is implemented, unprecedented drought hazard and risk will occur decades earlier. In addition, controlling population growth is found to be imperative for mitigating drought risk in Africa (even more effective than climate change mitigation), as it improves socioeconomic vulnerability and reduces potential exposure to drought.

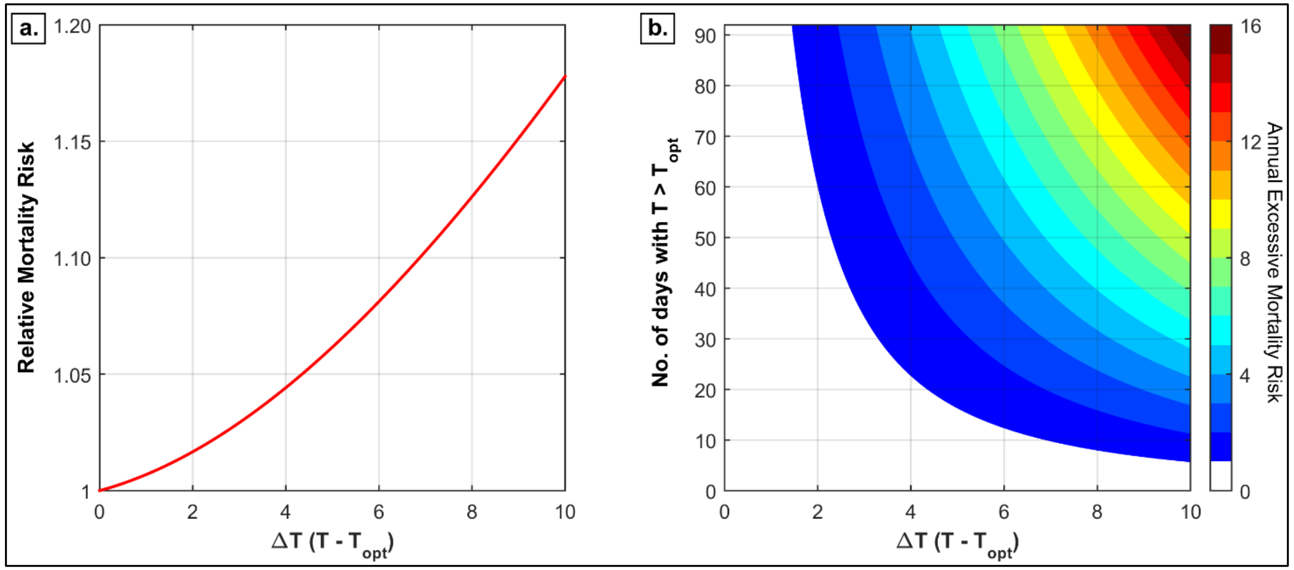
Heat-stress Mortality Risk

Motivation:

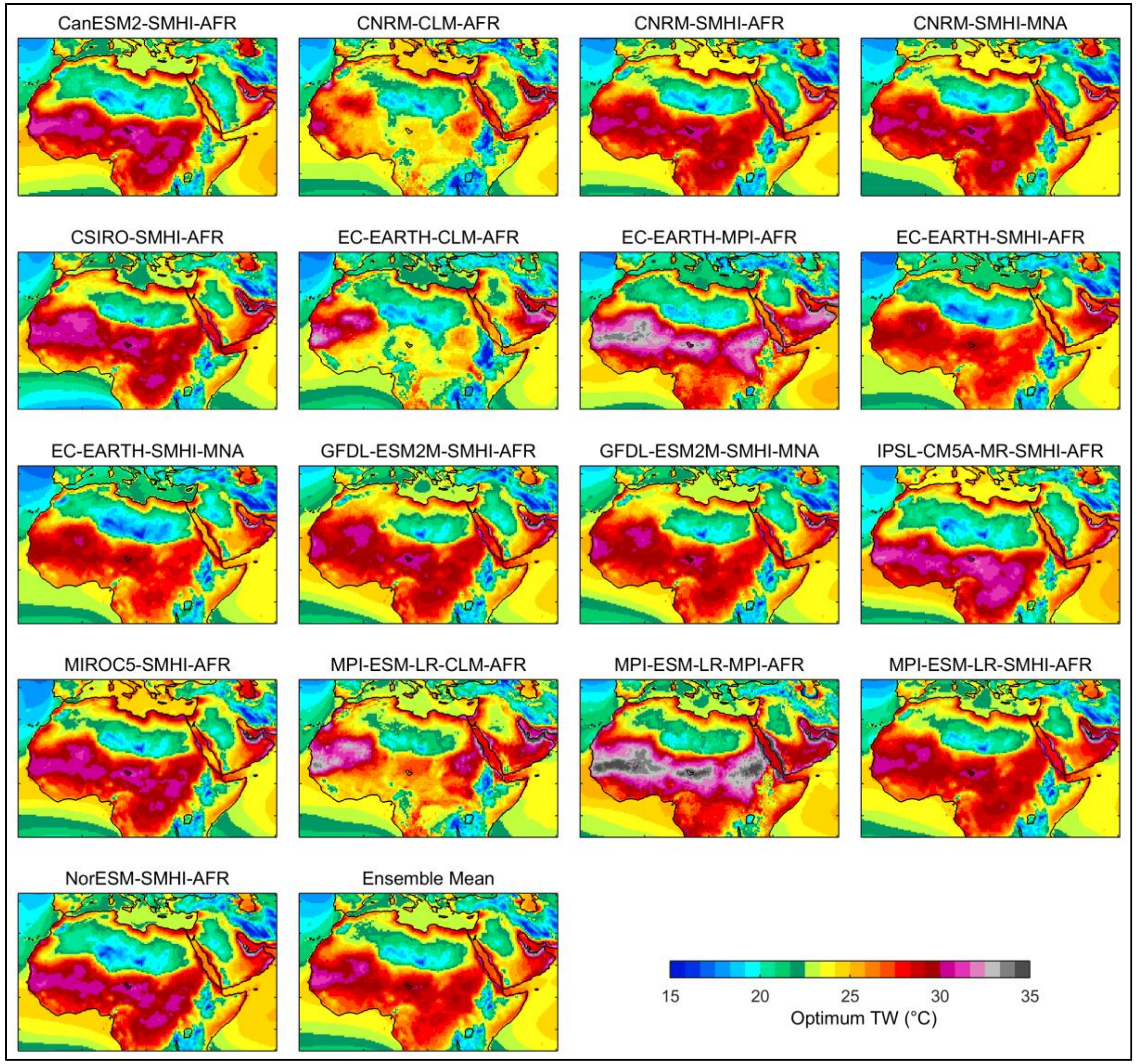
- To implement a spatially explicit health risk model and accounts for regional temperature thresholds for quantifying all cause mortality risk
- To assess the impact of climate change on heat-stress mortality risk across the Middle East and North Africa (MENA)
- To identify the spatiotemporal patterns of mortality risk and identify the underlying factors for such patterns
- To investigate any correspondence between future mortality risk and the economic status of the affected regions



- **Methodology:**

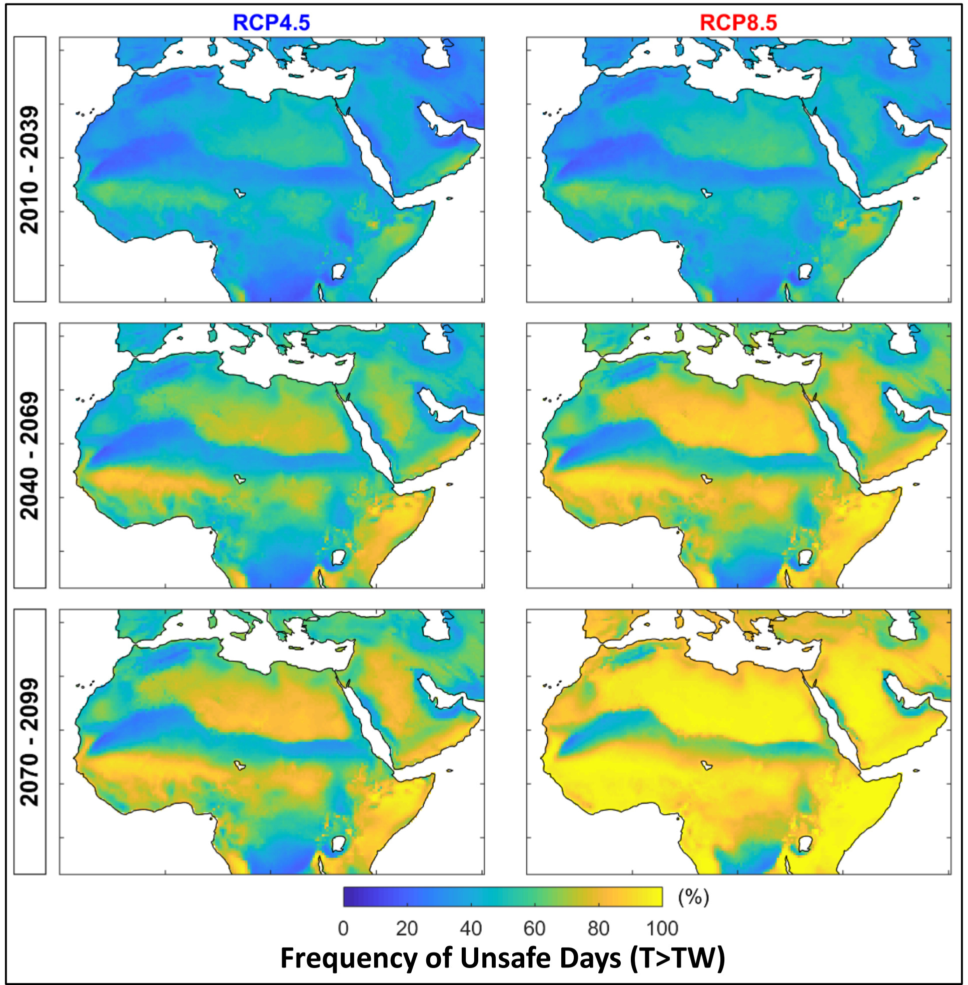


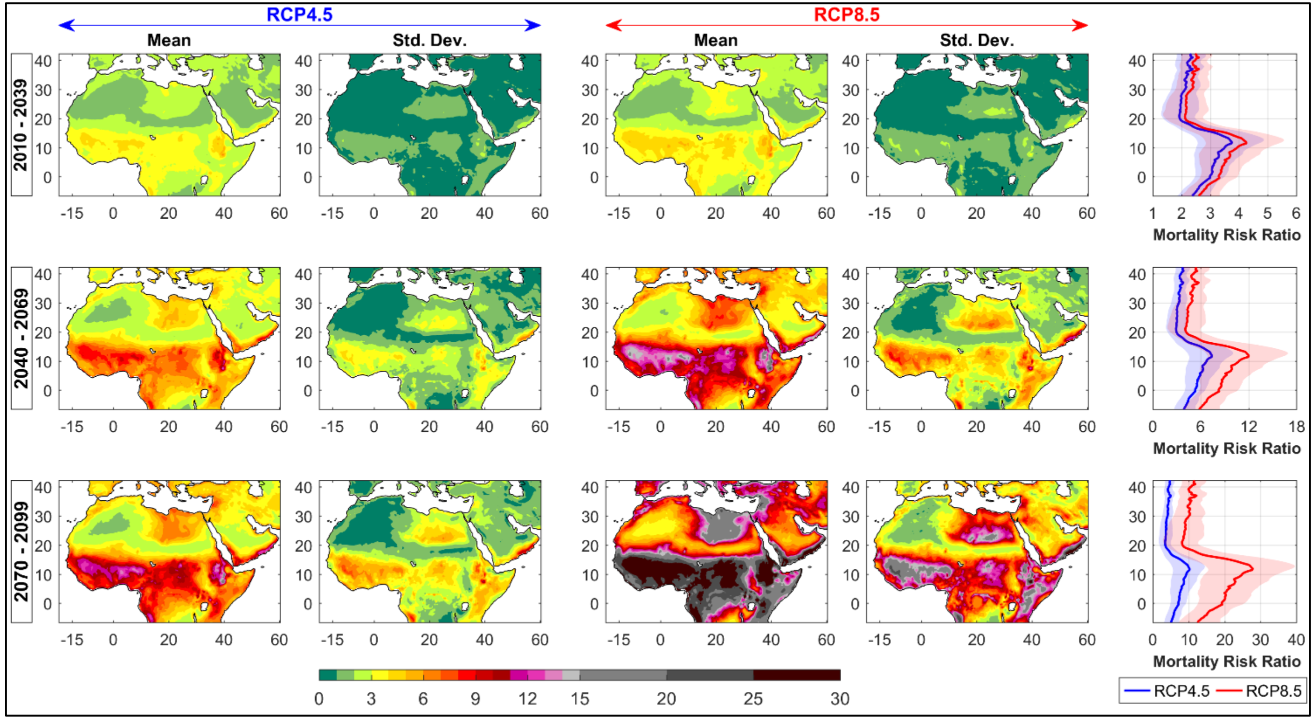
- Mortality risk is at its minimum in an optimal temperature (TW), and then increases as temperature rises.
- The optimum temperature is regionally explicit and depends on the adaptability of human body to heat and humidity. An empirical function suggested by World Health Organization (WHO) is utilized to calculate TW for each model.

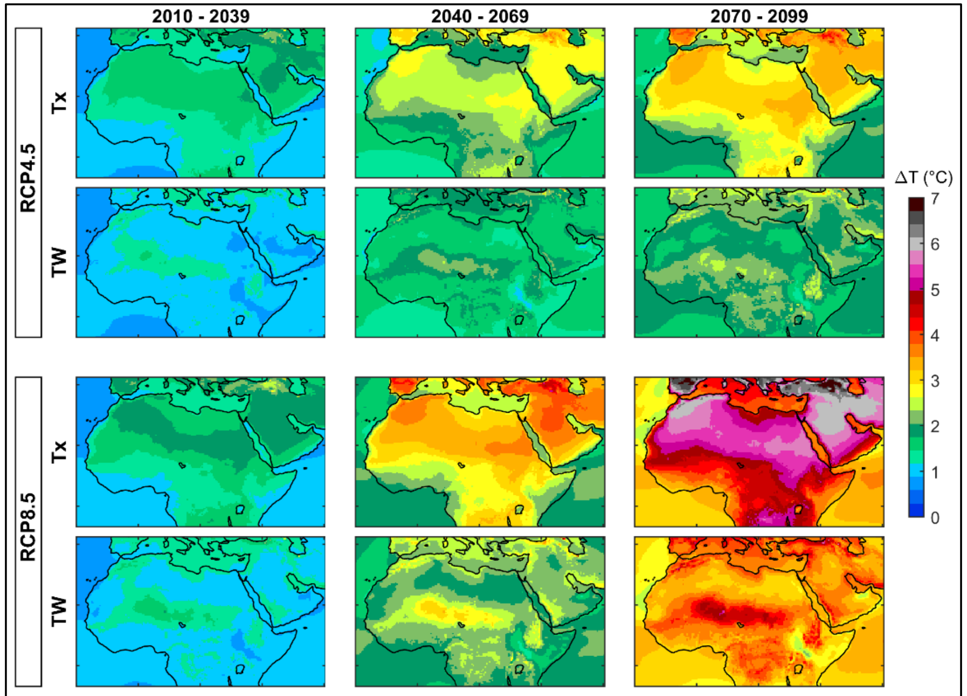


- **Mortality Risk Ratio:**

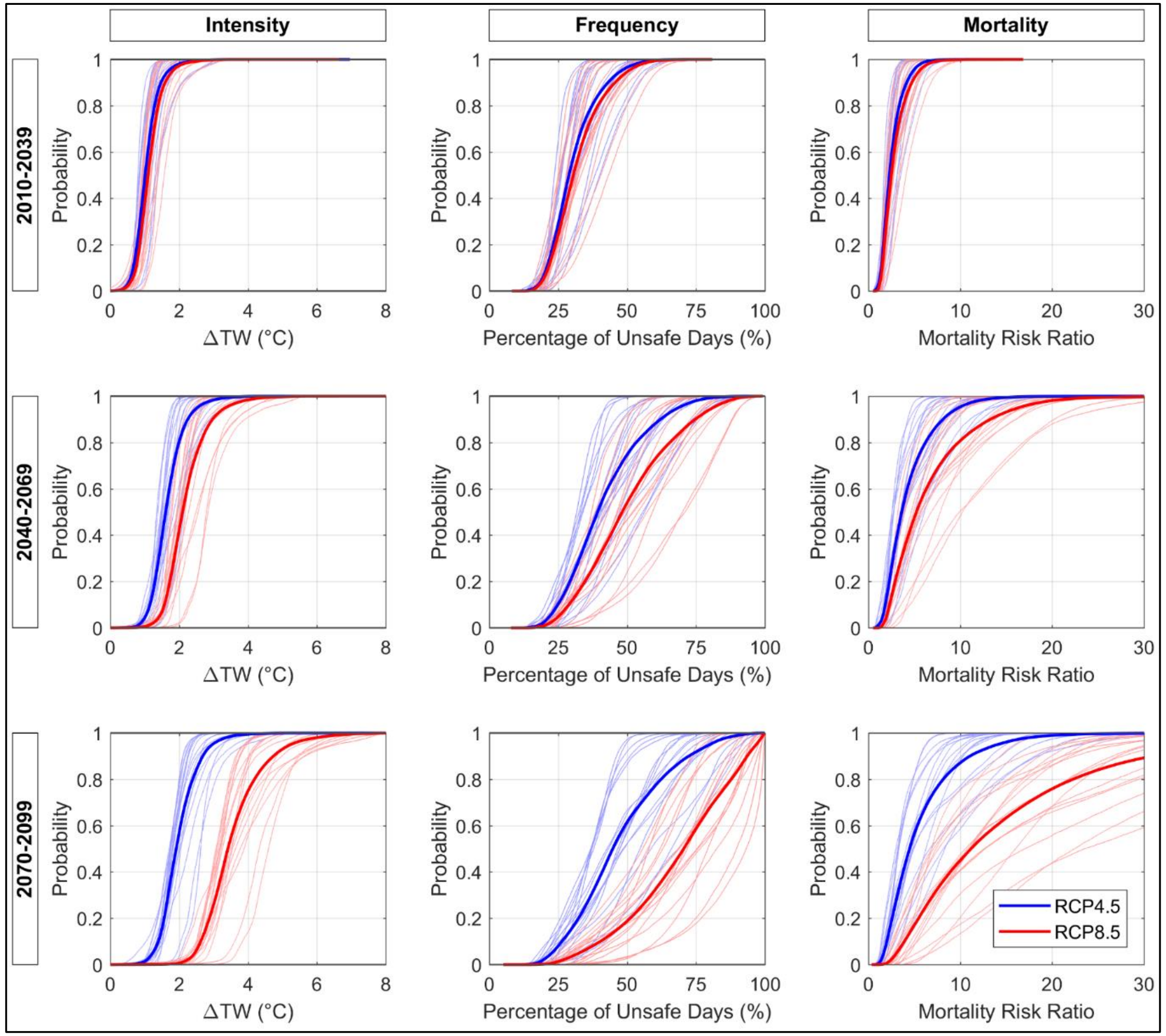
- Two factors impact mortality risk:
    - Intensity (ΔT)
    - Frequency of unsafe days

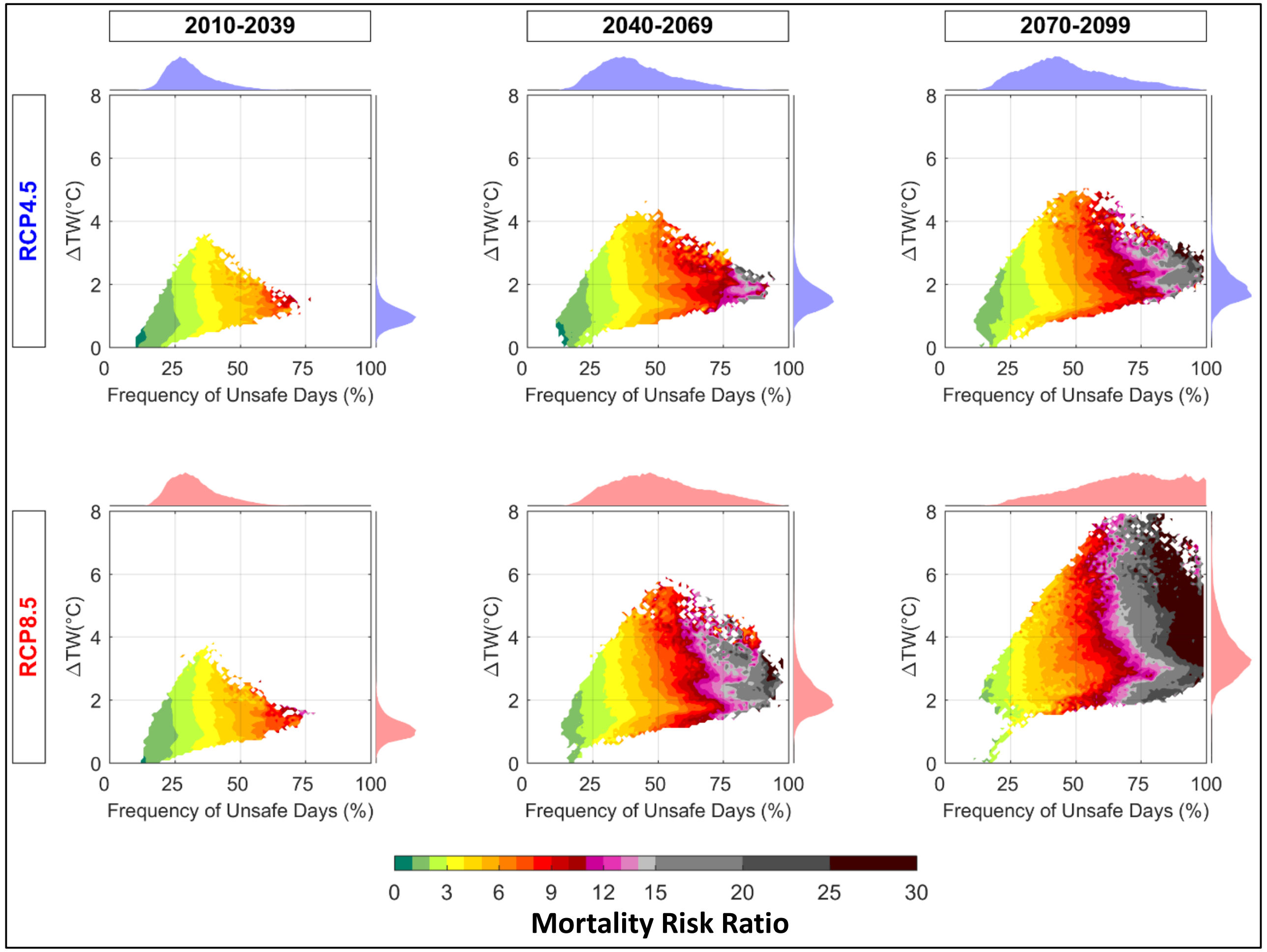




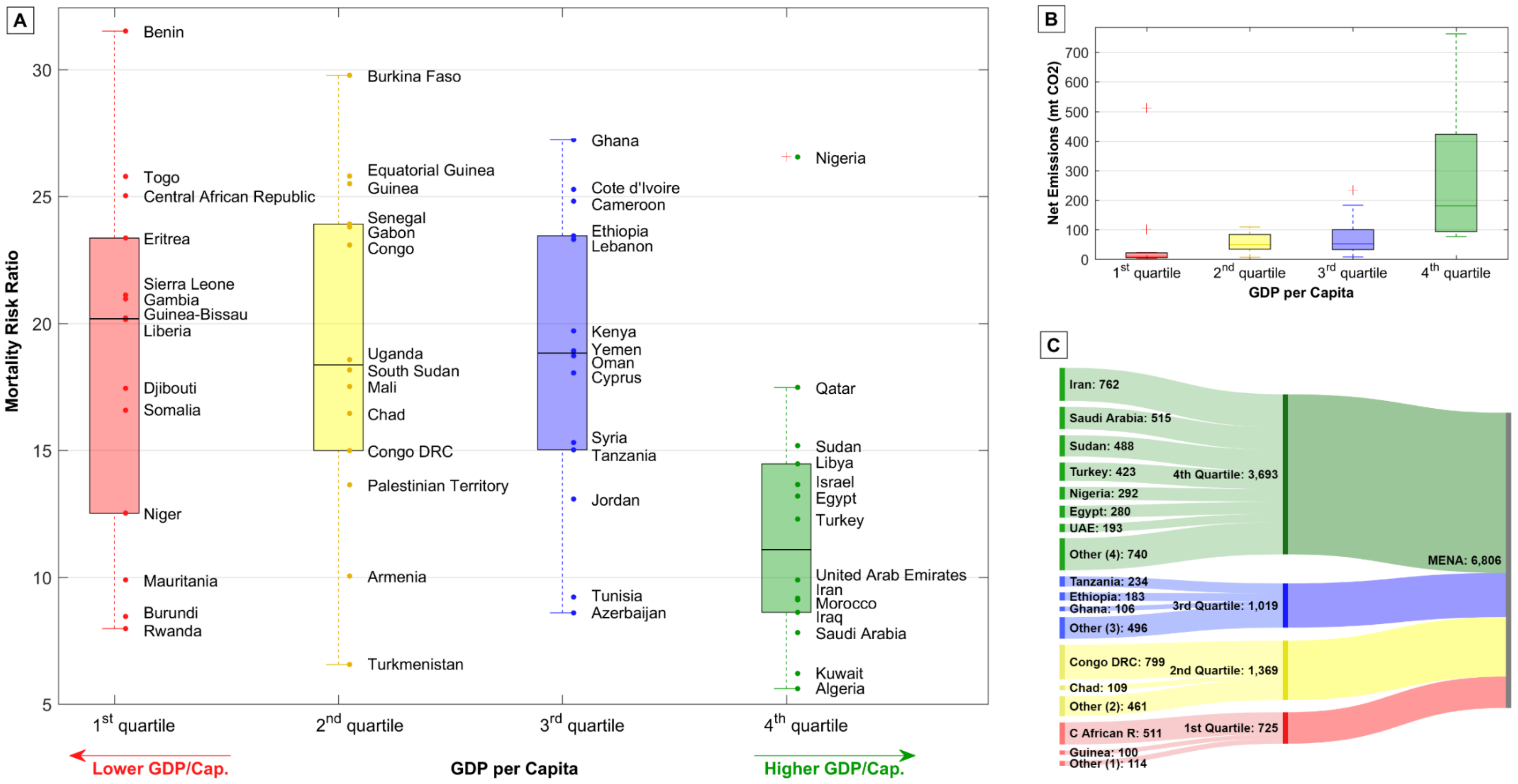


- A small raise in intensity of heat-stress caused by climate change (ΔT) leads to substantial increase in the frequency of unsafe days, which results in markedly high mortality risk ratio.





- **Mortality risk and the economic status:**



The poorest countries with least contribution to climate change are expected to be most impacted by it, as they will experience higher mortality risks compared to wealthier nations.

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Escalating heat-stress mortality risk due to global warming in the Middle East and North Africa (MENA)

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ABSTRACT

Climate change will substantially exacerbate extreme temperature and heatwaves. The impacts will be more intense across the Middle East and North Africa (MENA), a region mostly characterized by hot and arid climate, already intolerable for human beings in many parts. In this study, daily climate data from 17 fine-resolution Regional Climate Models (RCMs) are acquired to calculate wet-bulb temperature and investigate the mortality risk for people aged over 65 years caused by excessive heat stress across the MENA region. Spatially adaptive temperature thresholds are implemented for quantifying the mortality risk, and the analysis is conducted for the historical period of 1951–2005 and two future scenarios of RCP4.5 and RCP8.5 during the 2006–2100 period. Results show that the mortality risk will increase in distant future to 8–20 times higher than that of the historical period if no climate change mitigation is implemented. The coastal regions of the Red sea, Persian Gulf, and Mediterranean Sea indicate substantial increase in mortality risk. Nonetheless, the risk ratio will be limited to 3–7 times if global warming is limited to 2 °C. Climate change planning and adaptation is imperative for mitigating heat-related mortality risk across the region.

1. Introduction

Global warming will increase the frequency and intensity of heatwaves and extreme high temperatures (Fischer and Knutti, 2015; Mora et al., 2017; Pal and Eltahir, 2016). Even if the global mean temperature increase is limited to 2 °C, the warming over land will be far beyond 2 °C in many regions (Coffel et al., 2017; Fischer et al., 2013; King et al., 2017). The social impacts of climate change and extreme temperatures gamered more attention after the 2003 European heatwave which caused high mortality (Christidis et al., 2015; Li et al., 2016). The ongoing anthropogenic temperature rise has raised serious concerns regarding human health (Kingsley et al., 2016; Mitchell et al., 2016; Williams et al., 2012) and economy (Dunne et al., 2013; Underwood et al., 2017; Zander et al., 2015; Zhao et al., 2016). Climate change has already prolonged the heatwaves and increased their frequency in various locations of the world (Sun et al., 2014). The severe heatwaves of Texas in 2011 (Luo and Zhang, 2012), Australia in 2012 (Lewis and Karoly, 2013), China in 2015 (Miao et al., 2016), and Egypt in 2015 (Mitchell, 2016) were all experienced at large spatial extent and prolonged duration.

The anthropogenic warming in MENA is strongest in summer, whereas elsewhere it is usually stronger in winter (Lelieveld et al., 2016; Waha et al., 2017). Considering the hot arid climate of the majority of MENA region, the morbidity and mortality risk of extreme high temperatures is one of the grand challenges facing human health and society (Russo et al., 2016). Studies have demonstrated that climate change will increase air temperature across the Middle East to thresholds not tolerable for human body, especially around the Persian Gulf (Im et al., 2017; Pal and Eltahir, 2016). Schär (2016) discussed that the air temperature has already exceeded the postulated tolerance threshold in some humid areas around the Persian Gulf (e.g. Bandar Mahshahr, Iran).

When exposed to hot temperatures, human body dissipates heat by sweating and increasing heart rate in order to increase blood flow to the body surface, which in turn reduces the oxygen supply to muscles and brain. In addition, dehydration increases the blood viscosity and makes it harder for the heart to circulate it. The physiological processes caused by increased core body temperature result in mental and physical fatigue, and augment the likelihood of exhaustion, heart attack, and mortality (Kjellstrom et al., 2016; Loughnan et al., 2010; Ross et al., 2018). Accordingly, multitude of studies have projected significant increase in heat-related morbidity and mortality by the end of 21st century due to exposure to higher ambient temperatures (Chen et al., 2017; Ostro et al., 2012; Peng et al., 2011; Weinberger et al., 2017).

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Mortality risk from heat stress expected to hit poorest nations the hardest

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Abstract

Anthropogenic climate warming has increased the likelihood of extreme hot summers. To facilitate mitigation and adaptation planning, it is essential to quantify and synthesize climate change impacts and characterize the associated uncertainties. By synergistically using projections of climate scenarios from an ensemble of regional climate models and a spatially explicit version of an empirical health risk model, here we quantify the mortality risk associated with excessive heat stress for people aged over 65 years old across the Middle East and North Africa (MENA). Our results show that mortality risk is expected to intensify by a factor of 8–20 in the last 30 years of the twenty-first century with respect to the historical period (1951–2005) if no climate change mitigation planning is undertaken. If global warming is limited to 2 °C, the mortality risk is expected to rise by a factor of 3–7 for the same period. Further analyses reveal that much of the increase in mortality risk is due to the increase in frequency of warm days rather than their intensity. Unfortunately, the poorest countries with least contribution to climate change are expected to be most impacted by it, as they will experience higher mortality risks compared to wealthier nations.

Key points

• A spatially explicit health risk model that accounts for regional temperature thresholds is utilized to quantify mortality risk in MENA.
• Substantial increase in mortality risk is expected, which is due to the increase in frequency of warm days rather than their intensity.
• Mortality risk ratio is found highest in poor nations with least contribution to anthropogenic climate change.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10584-018-2348-2) contains supplementary material, which is available to authorized users.