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REVIEW ARTICLE

Global Warming Status in the African Continent: Sources, Challenges, Policies, and Future Direction

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Abstract

Africa is the second largest continent after Asia, having a larger than 30 million km^2 area. Doubtlessly, one of the biggest ecological and societal problems of the twenty-first century is climate change. Since the early 1970s, it has been clear that Africa is already experiencing the effects of climate change, and it has given rise to a wide range of new and unusual phenomena, such as rising temperatures, poor agricultural output, extreme different weather scenarios, and the spread of disease, among other things. Therefore, the current review aims at screening the impact of climate change on agricultural sector, human health and food security in Africa compared to the other continents, evaluating the change projections in future and highlighting the role of African leaders in mitigating and adapting to these effects. Artificial intelligence, remote sensing, and high-tech algorithms were applied to analyze these effects. Historical data were downloaded in near real-time from January 2009 to the present from the FAO Water Productivity Open-access portal WaPOR and Terra Climate datasets on Earth Engine platform. Assessment process was performed using Google Earth Engine, whereas future data were downloaded from WorldClim 2.1. We used 2021–2040 timelines and two scenarios: SSP245 and SSP585. For the SSP and timeline, we downloaded four versions, based on four different global circulation models (GCMs): IPSL-CM6A-LR (France), MRI-ESM2-0 (Japan), CanESM5 (Canadian), and BCC-CSM2-MR (China), to reflect the uncertainty among GCMs. We averaged future projection of each variable and SSP across four GCMs to decrease the uncertainty connected with a particular GCM. We presented the averaged results as maps. Annual precipitation totals were significantly above average in Central and East Africa, while under SSP 245 scenario, Madagascar would experience high rainfall. The highest temperature anomalies were seen in parts of the Greater Horn of Africa, western equatorial regions, and the north-western part of the continent. Minimum and Maximum temperature predictions showed that Africa would experience harsh temperatures than previously recorded in the historical years. A high average maximum temperature is predicted across the sub-Sahara Africa, South Africa, Somalia, and Madagascar under SSP 245 and SSP 585. The MCD64A1 dataset tagged in Earth Engine was used to classify forest fire risk in Africa. Analysis revealed that the highest fire risk was recorded in Savannah in tropical and subtropical Africa. Further, changes in rainfall and increased temperature leading to increased evaporation would directly reduce runoff levels and recharge groundwater which in turn will have negative effects on biodiversity, agriculture, and food security. Notably, African leaders have played positive role in the recent climate negotiations and bright climate initiatives have been emerged. Hopefully they will solve the climate crisis across the continent.

Article Highlights

- **Africa contributes by two and three percent of global emissions.**
- **Over 1 °C of warming has already occurred across parts of Africa. Sahara desert has been expanding at a rate of more than 11,000 Km^2/year between 1950 and 2022.**
- **Less precipitation is predicted to occur over North Africa and the south-western regions of South Africa by 2040.**
- **COP27 has been a great turning point for the developing African countries.**

Extended author information available on the last page of the article

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Introduction

A major threat to natural diversity and ecosystems has arisen from climate change (Bedair et al. 2020). Notably, the average temperature has risen by 0.7 °C worldwide over the past century and is likely to continue to do so. According to the Intergovernmental Panel on Climate Change (IPCC), the temperatures are predicted to increase by 1.1–6.4 °C by the end of the twenty-first century in comparison to 1980–1999 baselines (Change 2014). Notably, the average global precipitation has risen by 2% in the last 100 years and is predicted to continue rising in future (Change 2014). On the other hand, Africa is a highly susceptible continent from the climate change perspective that directly confront the African people, their government, and African Union (AU), affecting various aspects of people's everyday lives (Tadesse 2010). For instance, 0.7 °C warming has been observed over the twentieth century with an expectation to increase by 0.2 °C–0.5 °C each decade (Change 2014; Hulme et al. 2001). Similarly, the precipitation pattern of Africa is also quite variable as the historical record reveals that in East and Central Africa, rainfall has increased over the past century (Change 2014; Hulme et al. 2001). In addition to the climate change in Africa, it has been observed to be linked with the changes in the frequency and intensity of extreme events such as episodes of El Nino-Southern Oscillation (ENSO) (Midgley and Bond 2015). Most importantly, with the increase in the climate change in the next decades, it is expected that this will majorly affect the biodiversity of Africa_ENREF_4 (Midgley and Bond 2015) and agricultural production (Coulibaly et al. 2020) immensely.

According to several studies, Africa has a rich biodiversity that is estimated to include one-fifth of all known mammal species, plants, and birds, as well as one-sixth of all known species of herbs. It also has a variety of ecosystems, including savannahs, tropical forests, coral reefs, marine, and freshwater ecosystems (Bedair 2020; Millennium ecosystem assessment 2005). These diverse ecosystems provide huge benefits to many of the African communities as ecosystem serves by providing sustainable livelihoods with feed/fuel-wood/food/timber, supporting soil establishment, nutrient accumulation, and cultural services/recreation/eco-tourism (Bedair 2020; Millennium ecosystem assessment 2005). However, the climate change along with the anthropogenic stressors largely threatened these biodiversity, ecosystem, and ecosystem services since it disrupts energy and material circulation dynamics (Zhong and Wang 2017). Notably, the climate change is also highly dependent on the conversion of biological resources to the useful goods and services. For instance, the process by which grasslands and forests are turned into agricultural land leads to the emission of various greenhouse gasses (GHGs) (Burnham and Ma 2016). Therefore, mitigation of climate change could be possible by successful management of the GHG emissions and carbon sequestration (Araos et al. 2016). Similarly, the climate change poses main risks to the African agriculture production that accounts for the Africa's major socio-economic development, leading to economic crisis, largely in the poor African countries in particular where temperature plays a pivotal role affecting the agricultural production. Also, the drought negatively impacts the African agrarian production largely, irrespective of the countries' economical and developmental states (Coulibaly et al. 2020). Therefore, it is crucial that African researchers and farmers implement cutting-edge techniques like synthetic biology, genomic selection, and CRISPR–CRISPR-associated protein 9 (Cas9) in agriculture that provide robust solutions for the environment affected by climate change (Francisco Ribeiro and Camargo Rodriguez 2020).

The current review, therefore, based on the literature and the available climate datasets, has aimed to analyze, summarize, and identify the effect of the climate change on Africa especially with the loss of biodiversity and the agricultural system. Current effects and future projections on precipitation, temperature, and water resources have been assessed as well. The forest fire risk along the continent in the recent 20 years has been also estimated. Additionally, the emerging technologies, initiatives, and policies that possibly could minimize the effects of climate change on Africa also been talked about. Also, investigation of the knowledge gaps and gray areas that could serve as a groundwork for subsequent studies by researchers and envisage prospects in the research were also explored.

African Climate Changes Over the Last Ten Years and Future Projections

Africa covers more than 30 million km^2 of land, making it the second largest continent after Asia (11 million mi^2). The waters of the Atlantic and Indian oceans border the continent on the west, the Red Sea, and the Indian Ocean on the east, the Mediterranean Sea on the north, and the Atlantic Ocean on the south. In fact, its climatic zonation reflects the fact that of all the continents, it is the most evenly spaced with respect to the equator (https://unstats.un.org/unsd/methodology/m49/). The Köppen–Geiger climate classification for Africa shows that only three of the major climatic types (Zone A: tropical or equatorial zone, Zone B: arid or dry zone, Zone C: warm/mild temperate zone) are present in Africa (Bedair et al. 2023a; Kottek et al. 2006).

The weather and the climate are becoming more unpredictable in Africa, which causes calamities and disrupts the economic, ecological, and social systems (https://library.wmo.int/doc_num.php?explnum_id=10421). According to a brand new report focused solely on the continent of Africa, the rise in sea levels, irregular rainfall patterns, rising temperatures, and more extreme weather are all blatant signs of climate change that endanger availability of food and water, human health and safety, and socioeconomic development (https://unfccc.int/news/climate-change-is-an-increasing-threat-to-africa). At roughly 3.6 mm/yr and 4.1 mm/yr, respectively, the sea-level rise rates along the tropical, South Atlantic, and Indian Ocean coasts are faster than the world mean rate. The pace of sea-level rise in the Mediterranean coasts is about 2.9 mm/year slower than the average rate worldwide (Bedair et al. 2022b) (https://library.wmo.int/doc_num.php?explnum_id=10421). Sea-level trends around Africa exhibit substantial geographical variation. From Madagascar eastward toward and beyond Mauritius, the south-western Indian Ocean experienced a sea-level rise of more than 5 mm each year. In several maritime regions encircling the continent, it reached 5 mm annually. This exceeds the typical annual worldwide sea-level rise of 3 to 4 mm (https://unfccc.int/news/climate-change-is-an-increasing-threat-to-africa). The coastlines of Benin, Côte d'Ivoire, Senegal, and Togo are eroding at a rate of about 56%, and this is predicted to get worse in future.

Precipitation

The precipitation data source in this study is Climate Hazards center InfraRed Precipitation with Station data (CHIRPS) (Table 1, Fig. 1). In east of the Gulf of Guinea, along West Africa's south coast, to the northwest of the High Atlas Mountains, in the Madeira and Canary Islands, and elsewhere in Southern Africa, and in some areas of Madagascar, the annual precipitation totals in 2019 were below the long-term means. By the end of the century, the Intergovernmental Panel on Climate Change (IPCC) predicts less precipitation will fall over the south-western parts of South Africa and North Africa (https://unfccc.int/news/climate-change-is-an-increasing-threat-to-africa). In Central and East Africa, annual precipitation totals that were significantly above average (above the 90th percentile) were noted. All of southern Africa's major regions, including the Canary Islands, northwest of the High Atlas Mountains, and east of the Gulf of Guinea, experienced extremely little yearly precipitation amounts (below the 10th percentile) (https://library.wmo.int/doc_num.php?explnum_id=10421).

For future projections, we downloaded a dataset of future precipitation from the WorldClim 2.1 database (Fick and Hijmans 2017). We used the dates 2021–2040 and the scenarios SSP245 (a moderate, middle-of-the-road scenario representing RCP4.5 from the fifth report) and SSP585 (fossil-fuel-based development or business-as-usual, reflecting RCP8.5) (Anibaba et al. 2022). Forecasting future precipitation is a bit difficult. In fact, our finding revealed future precipitation prediction for Africa is not uniform across the continent. Under SSP 245 scenario, Madagascar would experience high rainfall specifically the north-western part of country. However, western, northern, and some part of southern part of the continent would record low precipitation pattern within 2021–2040 timeline. Similar pattern was observed in SSP 585 for the studied timeline (Fig. 2). While declining in some areas of southern, western, and northern Africa, annual precipitation will increase across much of eastern and central Africa. Some areas have seen annual increases of more than 200 mm and more than 25%, while others have seen decreases of more than 100 mm and more than 20%. There is disagreement among climate models regarding the speed or even the direction of change. However, there are some areas where climate models agree strongly: for various regions of northern and southern Africa, less precipitation is predicted by more than 80% of climate models (Porter et al. 2014).

Temperature

In mainland Africa, the average temperature for 2019 ranged from 0.56 °C to 0.63 °C higher than the long-term mean of 1981–2010, making it the third warmest year on record behind 2010 and 2016. The average rate of temperature increase in Africa is 1 °C per year. South Africa, Namibia, and certain areas of Angola had temperatures that were more than 2 °C above the 1981–2010 normal. Large regions of the continent, spanning from the north to the south, were more than 1 °C above average. Only a small portion of the north-west, including Mauritania, and nearby ocean regions saw temperatures slightly below average between 1981 and 2010 (https://library.wmo.int/doc_num.php?explnum_id=10421). In all African sub-regions, the warming trend from 1991 to 2020 was higher than from 1961 to 1990 and noticeably

Table 1 Overview of annual precipitation data components (Nations 2020)

Data component	Unit	Range	Use	Temporal extent
PPT	mm/year	0 to 3000	Measures annual precipitation	Year (2009–2021)

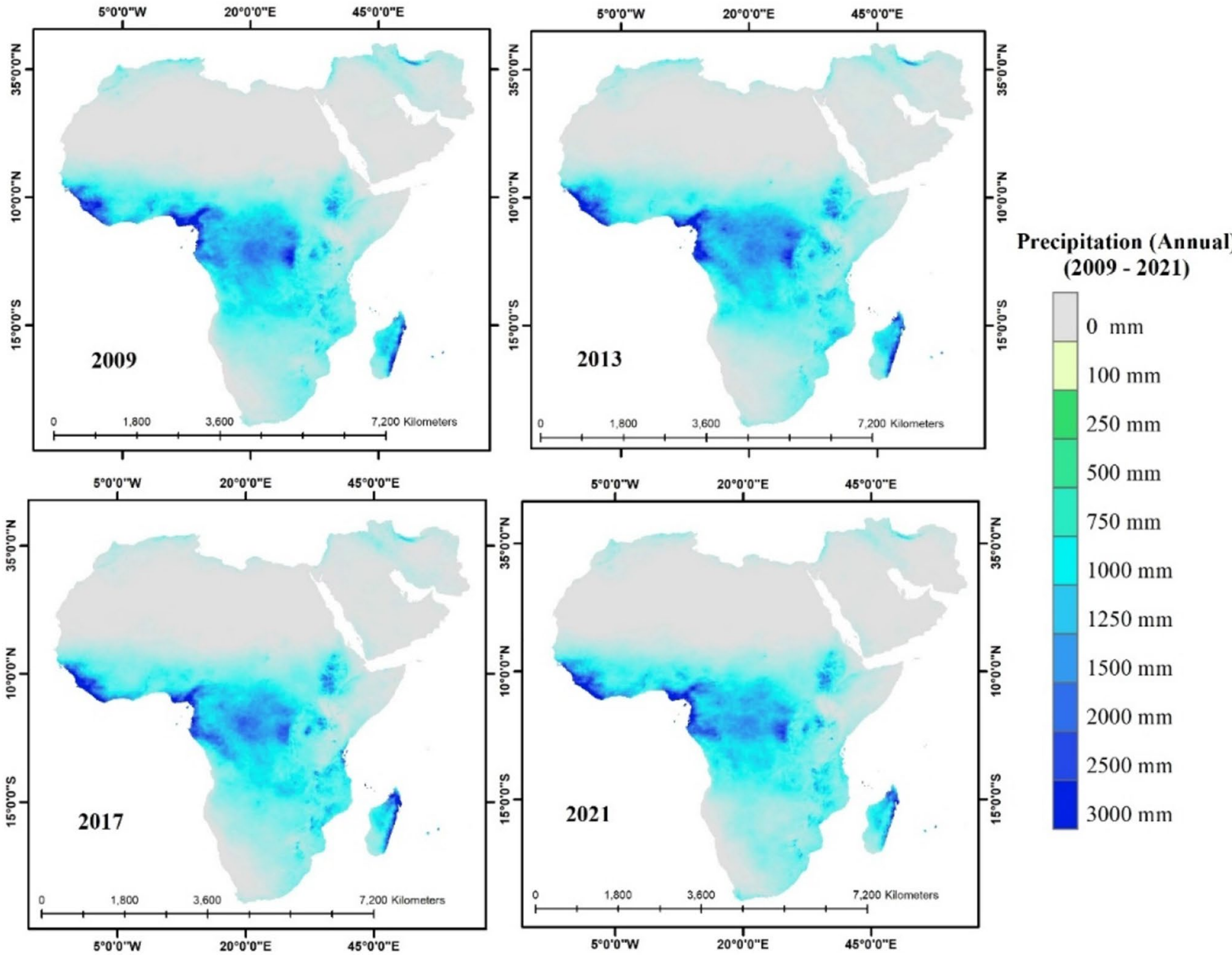

Fig. 1 Annual variability of precipitation of Africa (2009–2021). Source: WaPOR, remote sensing for water productivity Datasets tagged WaPOR in Earth Engine

higher than from 1931 to 1960 (Fig. 3). The highest temperature anomalies were seen in parts of the Greater Horn of Africa, western equatorial regions, and the north-western part of the continent (Blunden and Boyer 2021). There have been more heat waves and hot days since 1901, and over 1 °C of warming has already occurred across parts of Africa. According to some research, a temperature increase of 10 °C would result in a 10% drop in runoff while maintaining the same level of rainfall (https://www.uneca.org/acpc). Africa's temperatures rising, given the present emissions trajectory, are 2.7 degrees Celsius by the 2040s. Minimum and Maximum temperature predictions showed that Africa would experience harsher temperatures than previously recorded in the historical years. A high average maximum temperature is predicted across the sub-Sahara Africa, South Africa, Somalia, and Madagascar under SSP 245 and SSP 585. Similarly, Morocco, Algeria, and Tunisia would record an extremely average minimum temperature within the studied timeline under SSP 245 and 585. The averaged minimum and maximum temperature change is not uniform across the Africa (Fig. 4).

Carbon Footprints Estimation in Changing African Environment

The total amount of greenhouse gasses emitted into the atmosphere and caused by the activities of organizations, communities, or individuals is referred to as a carbon footprint. These gasses include methane, nitrous oxide, ozone, carbon dioxide, and water vapor (https://www.dbsa.org/article/dbsas-plan-reduce-africas-carbon-footprint-through-green-transport). The overall carbon emission contribution for African continent is far lower than other continents. In fact, only 3.8% of the world's greenhouse gas emissions are produced in Africa. The World Resources Institute estimates carbon dioxide emissions in Africa are 0.8 metric tons

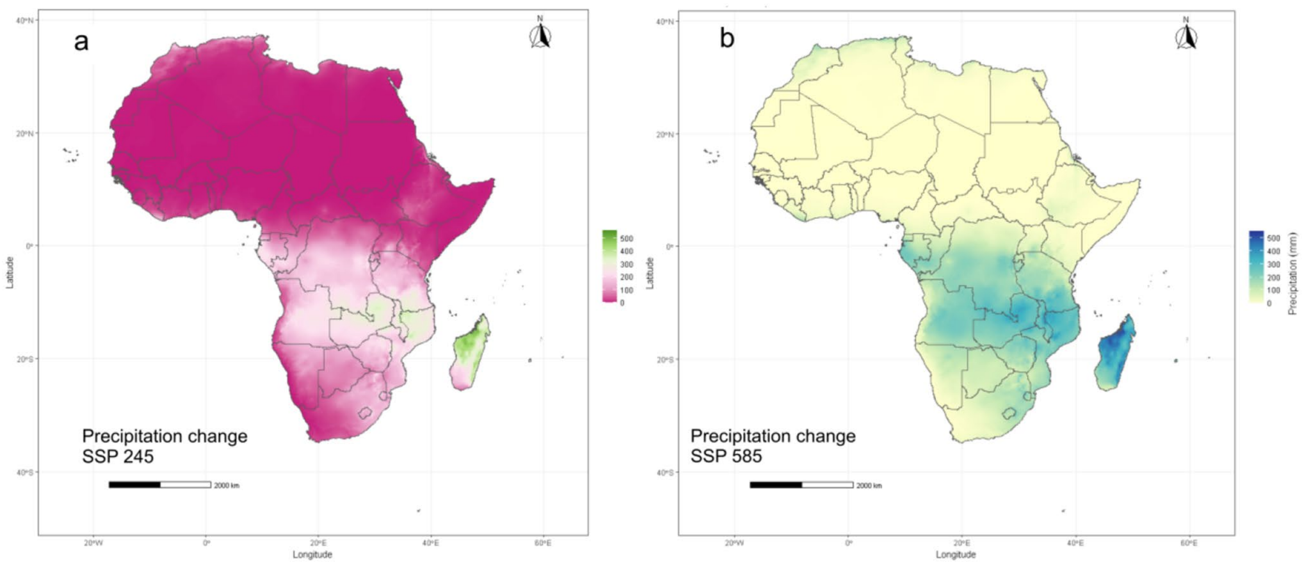

Fig. 2 Precipitation change projection (2021–2040) under SSP 245 and 585 scenarios

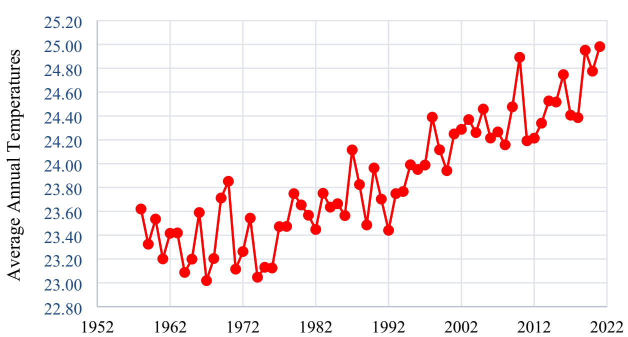

Fig. 3 Annual Temperature (2009–2022). Source: Terra Climate datasets, Earth Engine platform

per person, compared to 3.9 tons globally (Change 2006). Despite the fact that Africa contributes a negligible amount to global greenhouse gas emissions, the effects of climate change will be felt severely in Africa, and therefore, African cities are preparing themselves to engage in low-carbon sustainable development, according to CPD Report 2019 (Al-Zu'bi et al. 2022) https://cdn.cdp.net/cdpproduction/cms/reports/documents/000/005/023/original/CDP_(Africa_Report_2020.pdf?1583855467). In total, African Carbon emission in 2020 is 1.33 billion tons with a relative change about + 6.301% compared with 2019. Table 2 explains CO_2 emissions for Africa from (2017–2020) with relative change of each year (https://ourworldindata.org/co2/country/lesotho) (Table 3).

Climate Change Perspective in the Other Continents

Asia's glaciers are receding more quickly than has ever been recorded in the past. Some glaciers now encompass 20% of the area they did one hundred years ago. Flooding and rock avalanches from unstable slopes are dangers that are increased by melting glaciers. Coastal areas are at risk from increased flooding from the sea and, in some cases, from rivers, particularly in densely populated delta regions in south and Southeast Asia. Additionally, climate change may increase crop output in east and southeast Asia by up to 20% by the middle of the twenty-first century, while decreasing yield in central and south Asia by up to 30%. Due to anticipated changes in the water cycle brought on by climate change, illness and fatalities from diarrheal disease are likely to rise in east, south, and southeast Asia (Pörtner et al. 2022).

Regarding Australia and New Zealand, water security issues are predicted to worsen with a 1 °C world average warming in the northern and some eastern regions of New Zealand, as well as in southwestern and southeastern Australia, A large portion of southern Australia as well as the northern and eastern regions of New Zealand are expected to experience declines in agricultural and forestry output due to increased drought and fire. Further, coastal regions will continue to be affected by sea-level rise, stronger storms, and coastal flooding. More people and infrastructure would be at danger as a result of coastal development and population growth in places like Cairns and Southeast Queensland (Australia) and Northland to Bay of Plenty (New Zealand). By 2050, some ecologically rich areas, such as the Great

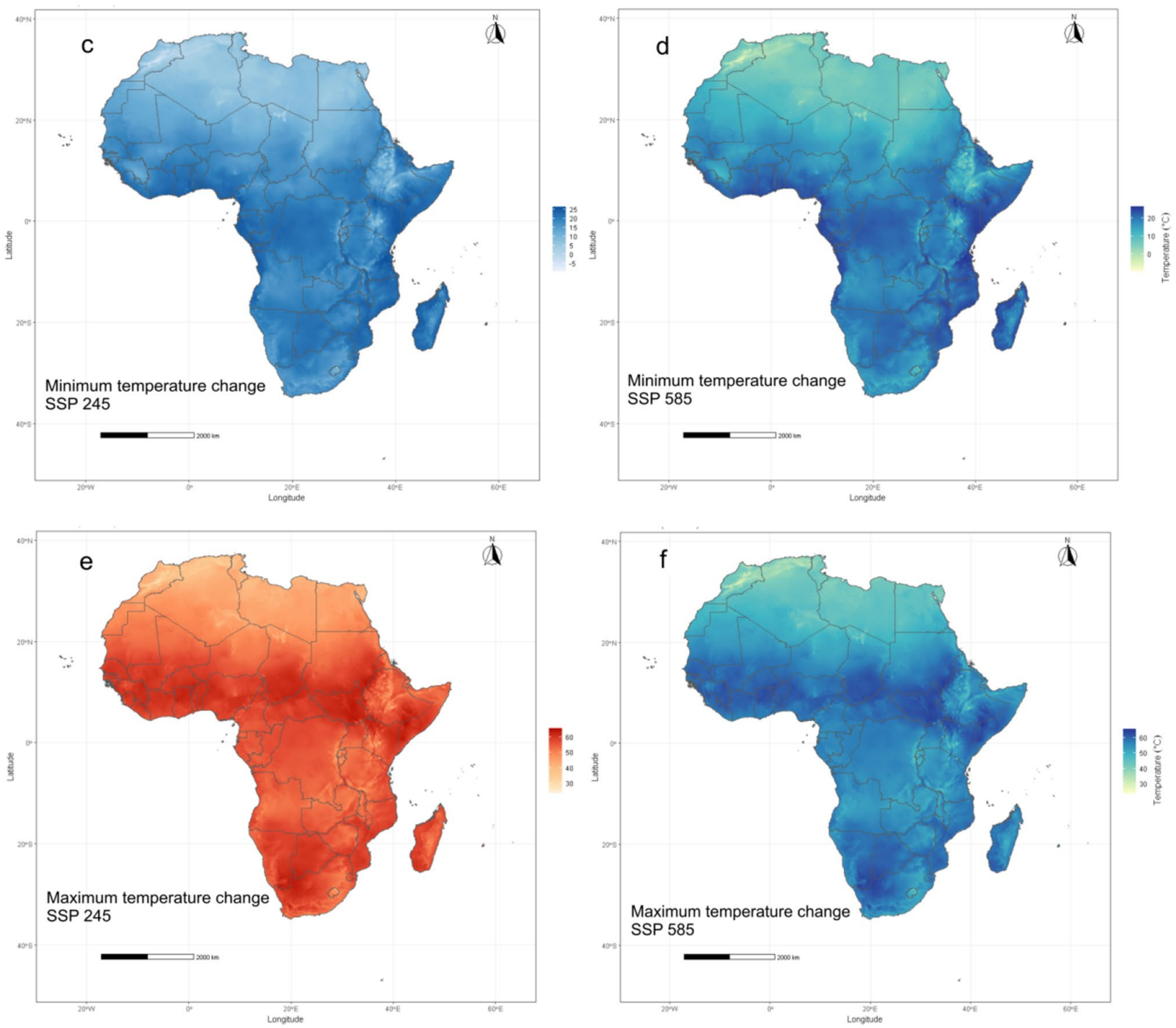

Fig. 4 Anticipated changes in annual mean minimum and maximum temperatures (in °C) and for the African continent under 245 and 585 SSP

Table 2 CO_2 emissions per billion tones for Africa during period (2017–2020).h

Year	Amount	Relative Change
2017	1.38	+ 6.297,080%
2018	1.39	+ 6.302,869%
2019	1.41	+ 6.460,736%
2020	1.33	+ 6.301,757%

Barrier Reef and Queensland Wet Tropics, will have a major risk to their biodiversity (Pörtner et al. 2022; UN 2007).

In Europe, wide-ranging effects of climate change, such as receding glaciers, rising sea levels, lengthening growing seasons, shifting species' ranges, and health effects linked to heat waves, have already been observed. Higher temperatures and drought in southern Europe could decrease water availability, hydropower potential, summer tourism, and agricultural output, impeding economic activity more than in other parts of Europe. Moreover, the summer precipitation is expected to decline in Central and Eastern Europe, increasing water stress. Forecasts indicate a decrease in forest productivity. It is anticipated that wetland fires will occur more frequently (Pörtner et al. 2022). Initial predictions for climate change in northern Europe include a range of outcomes, including some advantages like decreased demand for heating, increased agricultural yields, and increased growth of the forest. Benefits are likely to exceed drawbacks as long as climate change persists. These include rising ground instability brought on by thawing

Table 3 Carbon Emission for African Countries during the period 2016–2022

	Activities	Value	Unit	Co2 tons per capita	References
South Africa	High reliance on coal	435.17	Million metric tons	7.41	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa; https://www.carbonbrief.org/the-carbon-brief-profile-south-africa/)
Libya	Fossil fuels and cement electricity and transportation sectors	52.6	Million metric tons	7.90	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa) (Moussa 2022)
Equatorial guinea	Fossil fuel combustion and cement production	4.3	Million metric tons	3.04	(https://ourworldindata.org/co2/country/lesotho; https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Egypt	Road transportation, cement production and gas flaring	269.545	Million metric tons	2.62	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa) (Moussa 2022)
Seychelles	Energy production, industrial production of plastic	1.2	Million metric tons	12.25	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Algeria	Energy production, economic growth	163.473	Million metric tons	3.77	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa) (Chekouri et al. 2021)
Mauritius	Power industry, transport	3.628	Million metric tons	2.85	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Botswana	Electricity, Energy	7.055	Million metric tons	2.92	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)(Maswabi et al. 2021)
Morocco	Power industry and economic growth	67.752	Million metric tons	1.83	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Lesotho	Liquid and solid fuel consumption	0.653	Million metric tons	0.28	(https://ourworldindata.org/co2/country/lesotho) (Olubusoye and Musa 2020)
Cape Verde	Burning wood and garbage, as well as gas, coal, and oil for energy	0.803	Million metric tons	1.42	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Angola	Energy Sector and deforestation	22.514	Million metric tons	0.69	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Senegal	Energy, forestry, trash, and industrial processes industries, as well as land use change	10.061	Million metric tons	0.58	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Sudan	Agriculture, deforestation, energy use and municipal wastes	19.951	Million metric tons	0.35	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Kenya	Mainly caused by deforestation	16.414	Million metric tons	0.31	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Ghana	Fossil fuel consumption and agricultural development	16.520	Million metric tons	0.54	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa) (Lin and Agyeman 2019)
Ethiopia	Economic growth and Energy sector	17.009	Million metric tons	0.15	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa) (Tenaw 2021)
Tanzania	Energy consumption	11.468	Million metric tons	0.18	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Zimbabwe	Land use change and forest sector	11.559	Million metric tons	0.65	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)

Table 3 (continued)

	Activities	Value	Unit	Co2 tons per capita	References
Cote d'ivoire	The industrial sector's share of GDP and trade openness	12.098	Million metric tons	0.46	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Cameroon	Electricity, Energy, industry and transport	9.314	Million metric tons	0.36	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Benin	Energy consumption and economic growth	7.346	Million metric tons	0.61	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Zambia	Energy consumption,economic growth and agricultural sector	7.501	Million metric tons	0.40	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Mozambique	Charcoal production and deforestation	9.937	Million metric tons	0.31	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Gambia	Biomass energy consumption and economic growth	0.518	Million metric tons	0.23	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Eritrea	Energy use	0.339	Million metric tons	0.18	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Liberia	Economic growth and energy use	1.261	Million metric tons	0.25	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa) (Osadume 2021)
Burkina Fuso	Energy use	3.250	Million metric tons	0.16	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Mali	Agriculture is the largest industry, followed by forestry, energy, garbage, and industrial processes	3.482	Million metric tons	0.17	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Madagascar	Deforestation and assessment of biomass	4.252	Million metric tons	0.15	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Rwanda	Agriculture, waste, energy and industry	1.014	Million metric tons	0.08	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Niger	Gas flaring Activity	2.162	Million metric tons	0.09	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Chad	Agriculture,land use, electricity, waste and industry	0.821	Million metric tons	0.05	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa; https://ourworldindata.org/co2/country/lesotho)
Burundi	Agriculture, forestry and land use	0.287	Million metric tons	0.02	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Somalia	Transport, waste, agriculture and heat production	0.774	Million metric tons	0.05	((https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa; https://ourworldindata.org/co2/country/lesotho)
Congo	Energy consumption and economic activity	6.183	Million metric tons	1.09	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Central African republic	Power, transport, building and industrial sector	0.354	Million metric tons	0.07	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)

Table 3 (continued)

	Activities	Value	Unit	Co2 tons per capita	References
Malawi	Biomass Energy, electricity and food processing	1.385	Million metric tons	0.07	((https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa; https://pdf.usaid.gov/pdf_docs/PA00VPMK.pdf)
Uganda	Gross domestic product and energy consumption	5.352	Million metric tons	0.11	((https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa) (Otim et al. 2022)
Sierra Leone	Agricultural sector and energy	1.008	Million metric tons	0.13	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Togo	Electricity and energy consumption	2.837	Million metric tons	0.34	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Comoros	Land use change and forestry	0.250	Million metric tons	0.29	((https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa; https://climate-box.com/textbooks/the-problem-of-climate-change/2-2-effects-on-plants-and-animals)
Djibouti	Energy consumption and economic activity	0.855	Million metric tons	0.85	((https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa; https://ourworldindata.org/co2/country/lesotho)
Democratic republic of Congo	Tropical deforestation	3.233	Million metric tons	0.04	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
São Tomé and Príncipe	Fossil and waste management	0.135	Million metric tons	0.62	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Mauritania	Coal, oil, gas and cement	2.666	Million metric tons	0.56	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa; https://ourworldindata.org/co2/country/lesotho)
Namibia	Electricity and heat production	4.013	Million metric tons	1.49	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Guinea	Forestry and land-use change come first, then agriculture, energy, garbage, and industrial processes	2.774	Million metric tons	0.20	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa)
Tunisia	Energy, waste and land use change	28.589	Million metric tons	2.40	(https://countryeconomy.com/energy-and-environment/co2-emissions/south-africa; https://pdf.usaid.gov/pdf_docs/PA00VPMK.pdf)

permafrost, more frequent winter floods, and threatened habitats (Lavalle et al. 2009).

In eastern Amazonia, Savanna is expected to progressively take the place of tropical forest by the middle of the century as a result of rising temperatures and falling soil moisture (Funatsu et al. 2019). In drier regions of South America, climate change will probably make droughts worse, which will degrade arable land and cause salinization (increased salt content) (Mushtaq et al. 2020) and desertification (land degradation). In some regions, it is anticipated that the productivity of livestock and some significant commodities, like maize and coffee, will decline, with detrimental effects on food security (Porter et al. 2014). Soybean harvests are expected to rise in temperate regions. The availability of water for human consumption, agriculture, and energy production is expected to be greatly impacted by changes in precipitation patterns and the melting of glaciers (Grimm 2011; Pörtner et al. 2022).

Regarding North America, warming in western mountains will decrease snowpack, increase winter flooding, and reduce summer flows, exacerbating competition for over-allocated water resources (Pörtner et al. 2022). Crops, such as corn, soy, and cotton, which are near the warm end of their suitable range or that depend on highly utilized water resources will likely face major challenges. High emissions scenarios project reductions in yields by as much as 80% by the end of the century (Overpeck and Udall 2020).

Climate change in the Arctic will probably result in less sea ice and permafrost, which may or may not have an impact on human settlements. Infrastructure damage and modifications to winter pursuits like ice fishing and ice road travel could both have negative effects. More navigable northern sea paths could be one of the benefits. Consequently, it is projected that sea-level rise will make erosion, storm surge, and other coastal dangers worse (Falardeau and Bennett 2020). These effects would put at risk the settlements, facilities, and infrastructure that are essential to the survival of island populations (Pörtner et al. 2022). In fact, Europe and North America recorded the highest rise in average temperature by 0.8 °C in the recent 10 years, compared to Africa (0.7 °C), Oceania, Asia, and Australia (0.6 °C) (https://www.worlddata.info/global-warming.php).

Causes of Climate Change in Africa

Complex origins and effects of climate change make them issues deserving of social study (Dietz et al. 2020). According to the US National Climate Assessment, human activity is mostly to blame for how quickly the earth's climate is changing right now compared to any other time in our civilization (Dietz et al. 2020). Crop residue burning, the transport sector, and the use of fossil fuels for electricity and heating are major contributors to worldwide emissions (Najjar 2011).

In fact, savannah burning and forest fires (grass plains in tropical or subtropical countries) are natural events that cause air pollution (Mathur and Srivastava 2019). According to the 1997 Kyoto Protocol, forest loss has historically been a major source of greenhouse gas emissions, accounting for an estimated 47% of all emissions since 1750 (Le Quéré et al. 2015). Deforestation and forest loss continue, notwithstanding a decline in tropical deforestation rates still contribute significantly to global emissions degradation (Le Quéré et al. 2015). In order to combat climate change, forests are essential. Since it was first realized that forests play a significant role in the world's carbon cycle, the use of forest-based mitigation has been introduced into international policy frameworks (Canadell and Raupach 2008).

Surprisingly, over 60% of the fires of all fires worldwide in are caused by sub-Saharan Africa savannas (Russell-Smith et al. 2021). The tropical savannas, which today account for about 90% of the world's burned land and 62% of global fire carbon emissions each year, are the most prone to fires (Giglio et al. 2018). The majority of savanna fires are caused by human ignitions, and they often occur under particularly harsh fire weather conditions (hot, dry conditions) in the latter months of the yearly dry season circumstances (windy, low humidity) (Russell-Smith et al. 2021). The general level of fire activity in tropical Africa has been very low this year. The fire season in northern tropical Africa lasts from November to April. Nearly every day of 2020 has seen less fire activity than the region's average from 2003 to 2019. Southern tropical Africa experiences a fire season from May to October. With the exception of a few days where activity was higher than the average for the period between 2003 and 2019, activity in this area was quite low this year. Since Copernicus Atmosphere Monitoring Service (CAMS) records have been kept, southern tropical fires have so far produced less carbon dioxide in 2020 than in any other year. The low levels of fire activity in tropical Africa are a factor in the world's overall low levels of activity and carbon production. Many of these fires occur in the savannah, where they are an essential component of ecosystem renewal despite the fact that they can harm human habitation, ecosystems, and respiratory health (Table 4).

The monthly, 500 m worldwide gridded product with per-pixel burned-area and quality information is known as the Terra and Aqua combined MCD64A1 Version 6 Burned Area data product. The MCD64A1 burned-area mapping method makes use of 1 km MODIS active fire data along with 500 m MODIS Surface Reflectance imagery. The technique creates applied dynamic thresholds to the composite data using a burn-sensitive vegetation index (VI). The Moderate Resolution Imaging Spectroradiometer (MODIS) shortwave infrared surface

Table 4 The most remarkable forest fires in Africa in the recent 4 years

County	Forest name	Day	Month	Year	Burning duration	Burning area
Tunisia	The forests of Mount Boukernane	19	7	2022	1 day	5.3 km^2
Morocco	The forests of Beni Yusef, Al Serif, Al Saleh, Al Manzala and Al Mbeka	13	7	2022	8 days	53 km^2
Algeria	The mountain forests of Setif, Bordj Bou Arreridj and Bejaia	15	6	2022	5 days	2.7 km^2
Algeria	Ain Maimon Forest, Eurasian Mountain forests	4	7	2021	11 days	89 km^2
Algeria	Tiki Ouzou Buskiken Forest	7	8	2021	5 days	51.93 km^2
South Africa	Table Mountain Cape town	18	4	2021	–	–
Congo	Congo Basin forests	23	8	2019	–	–

reflectance bands 5 and 7 plus a temporal texture index are used to construct the VI. Each MODIS tile's 500 m grid cells have a date of burn determined by an algorithm. The date is represented as the ordinal day of the year on which the burn occurred, with values allocated to unburned land pixels and additional special values provided for missing data and water grid cells (Dataset availability: https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MCD64A1#citations) (Fig. 5).

Impacts of Climate Change on Africa

Impact on Water Resources

Complex interactions between the sea and the land can result in a range of situations in a number of places govern the continent's climate (e.g., from the sweltering tropics to the extremely dry Sahara). The water industry is very sensitive to climate change and sustained climate fluctuation. The impact of climate change on water concerns won't be

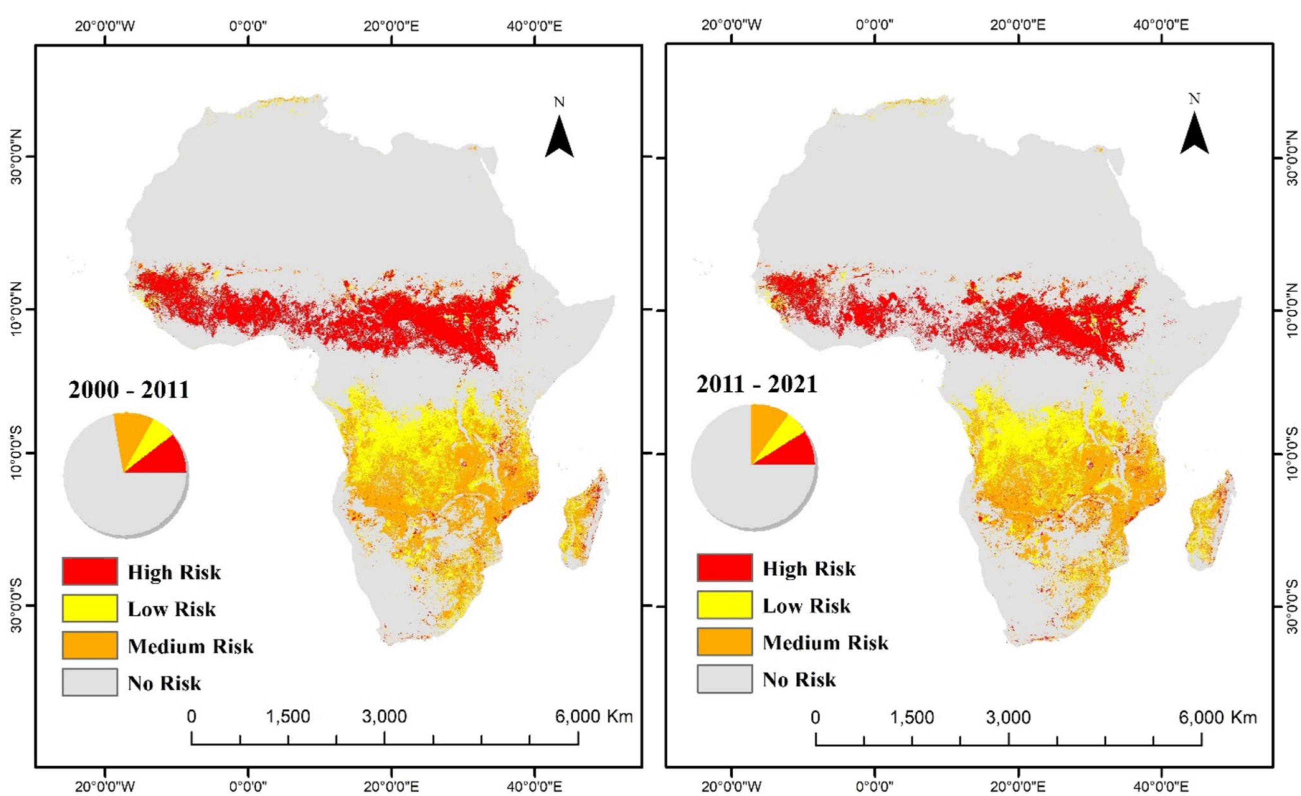

Fig. 5 Forest fire risk in Africa classification map

consistent across the continent. It will lessen water stress in certain areas while aggravating it in others. Through intricate connections, changes in runoff and hydrological components are significantly related to climate. Owing to a lack of knowledge, the relationship between climate change and groundwater is uncertain. However, there is no disputing that climate change has an impact on water flows, including groundwater recharge. As a result, it is a major worry for Africa, where groundwater is a major source of rural water supplies (Giannini et al. 2008).

Net water productivity, as opposed to gross water efficiency, is particularly helpful for tracking how efficiently vegetation and, more crucially, crops use water to generate biomass and produce. The data is made available through the FAO Water Productivity Open-access portal World Association for Public Opinion Research (WaPOR) in almost real-time from January 2009 to the present (FAO 2018). Net Biomass Water Productivity (NBWP) is calculated as follows: TBP = Ta + NBWP where Ta is the annual real transpiration in m^3/ha and TBP is the annual total biomass output in kg/ha. To aid in these procedures, with the help of particular algorithms and high-resolution satellite photos, agricultural water and land productivity can be measured regionally and over time via the WaPOR project (FAO 2021). The WaPOR database contains a variety of data elements related to biomass production, water productivity, evapotranspiration, and precipitation, as illustrated in Tables 5 and 6.

Water productivity in agriculture indicates how much product (biomass or yield) is generated per unit of water consumed by the crop. In Africa, it is possible to see the difference between areas with low and high-water productivity and monitor their variations over time to target interventions (Figs. 6 and 7).

Africa's water supply is affected by climate change, as it is in many other regions of the world (https://www.uneca.org/acpc). Africa receives about 670 mm of precipitation annually on average. However, both time and space exhibit significant variety (Fig. 8).

Table 5 A description of the WaPOR data components with the chosen temporal and spatial resolutions (Nations 2020)

Tata Type	Specified	Resolution
Water productivity (Wp)	Annual	(~250 m)
Actual evapotranspiration (AET)	Annual	(~250 m)
Precipitation (PPT)	Annual	(~250 m)
Reference Evapotranspiration (ET0)	Annual	(~250 m)

Actual Evapotranspiration

Evapotranspiration is the collective term for two processes that transport water from the land to the atmosphere: transpiration from plants and evaporation from water surfaces and soil. Actual evapotranspiration (AET) and reference evapotranspiration (ET0) are the two terminologies most frequently used to define evapotranspiration. Under atypical environmental and managerial conditions, the AET is calculated. Meanwhile, ET0 is calculated under typical circumstances—in a uniform, fully vegetated region with a continuous supply of water and shading (Tabari and Talaee 2014). In this study, the annual actual evapotranspiration data source is WaPOR. The unit is mm/year (Table 7, Figs. 9 and 10) which shows the average actual evapotranspiration rates in the African continent. Annual potential evapotranspiration (PET) averaged over Africa exhibited increasing trends across the continent.

Reference Evapotranspiration

Reference evapotranspiration (ET0) is defined as the evapotranspiration from a fake reference crop, which mimics the behavior of a grass surface that has received enough watering. Each pixel shows the reference daily evapotranspiration in millimeters per day. (Table 8, Figs. 11 and 12) show the average reference evapotranspiration rates in the African continent. Annual ET0 averaged over Africa exhibited increasing trends across the continent.

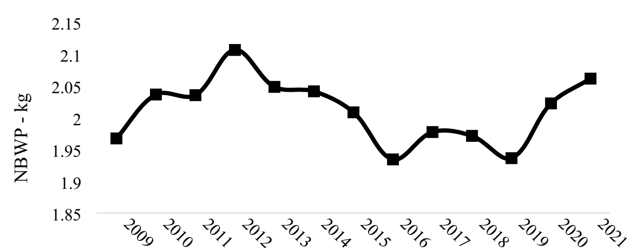

Fig. 6 Net Biomass Water Productivity (2021–2009)

Table 6 Components of the biomass water Productivity statistics overview (FAO 2020)

Data component	Unit	Range	Use	Temporal extent
NBWP	Kg/m^3	0 to < 3	Determines the dry biomass production in proportion to transpiration (or beneficial water consumption)	year (2009–2021)

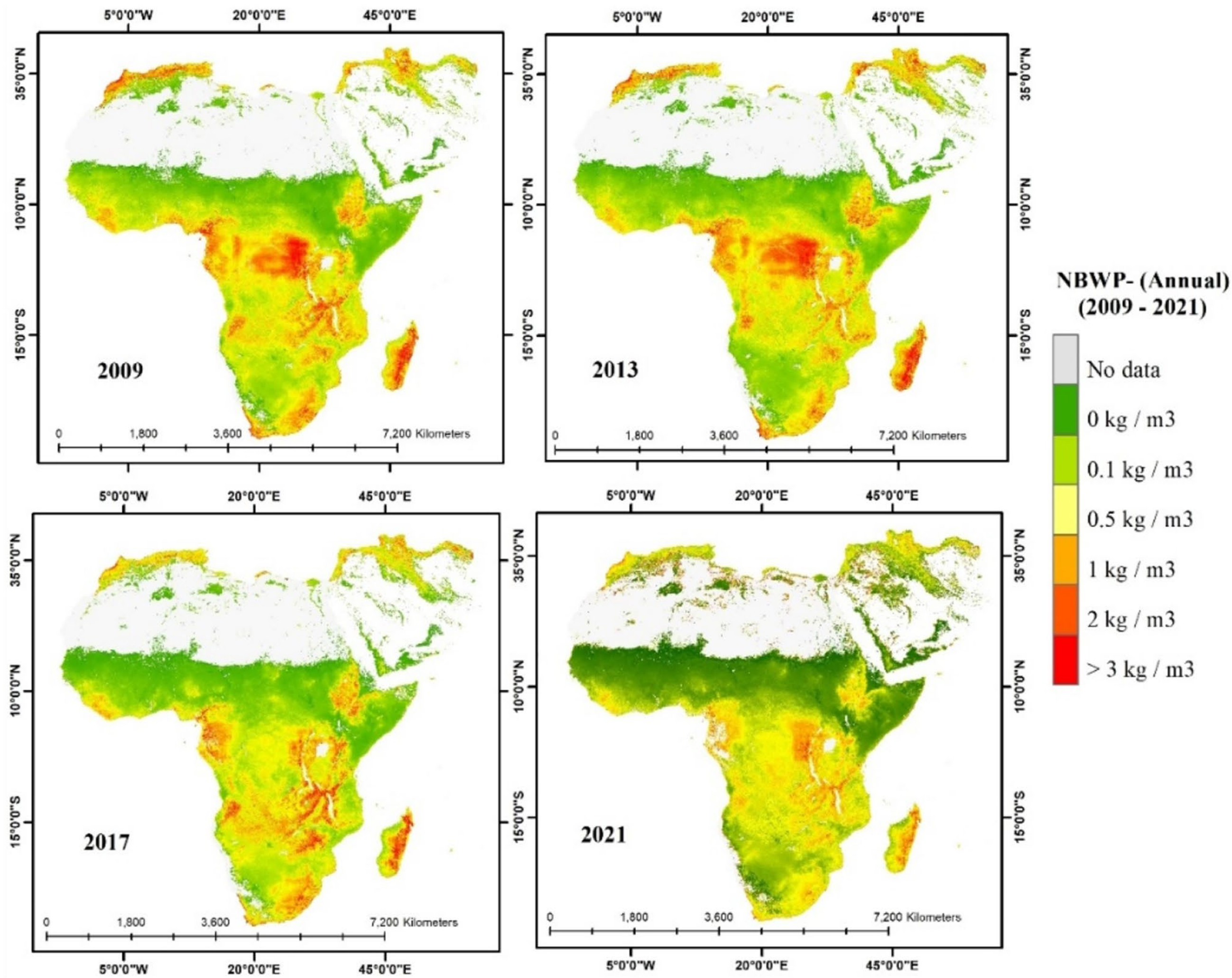

Fig. 7 Shows the change in the net productivity of biomass water (2009–2021). Source: WaPOR, remote sensing for water productivity Datasets tagged WaPOR in Earth Engine

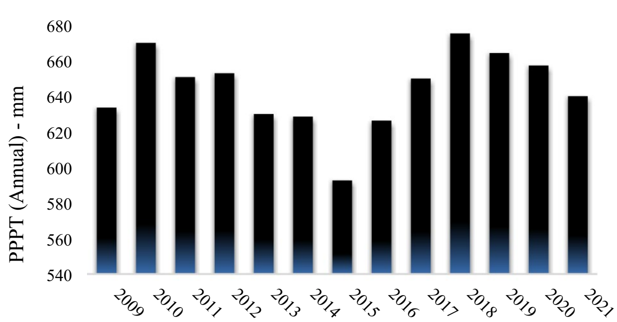

Fig. 8 Annual precipitation average in Africa for the period 2009–2021

Climate Water Deficit

Changes in rainfall and increased temperature leading to increased evaporation would directly reduce runoff levels and recharge groundwater. Soil moisture stress for forest plants can be assessed from drought conditions by calculating Climate Water Deficit (CWD), which is a measure of soil water availability, it is obtained from potential evaporation minus actual evaporation (PET-AET), an indicator of prolonged drought. With increased CWD, the moisture available to forest plants and drying corresponding to the forest fuel state decrease (Lutz et al. 2010). A surplus of water can be estimated which means that the value of precipitation is greater than the potential evaporation during a given period, while the water deficit means that the potential evaporation is greater than the precipitation. The results of water surplus and water deficit in the

Table 7 Overview of annual actual evapotranspiration data components (Nations 2020)

Data component	Unit	Range	Use	Temporal extent
AET	mm/year	>100 to <1600	Measures annual actual evapotranspiration	Year (2009–2021)

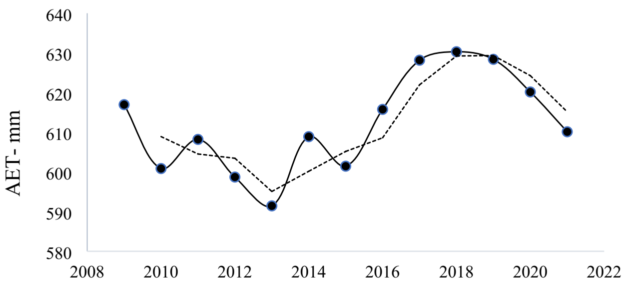

Fig. 9 Annual Actual Evapotranspiration (2009–2021)

study area are shown in Table 9. The ratio of (WS) and (WD) is calculated by:

$$WS\% = WS/P * 100WD\% = 100 - WS\% \tag{1}$$

CWD refers to the annual evaporative demand that exceeds the available water and shows the seasonal climate deficit, it indicates the demand for irrigation required to make up for the seasonal deficit (Fig. 13).

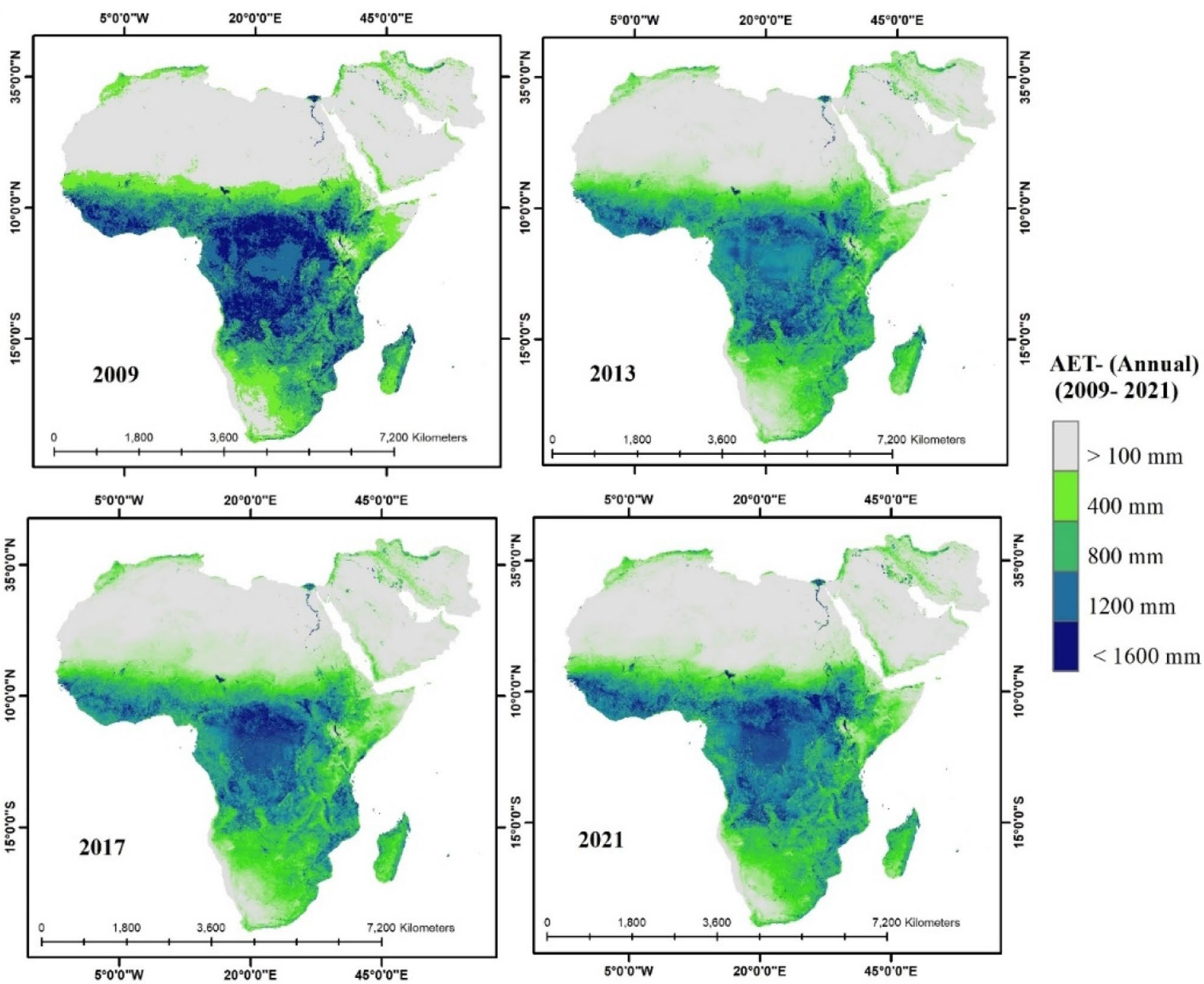

Fig. 10 Annual variability of Actual Evapotranspiration of Africa (2009–2021). Source: WaPOR, water productivity via remote sensing Datasets tagged WaPOR in Earth Engine

Table 8 Overview of annual Reference evapotranspiration data components (Nations 2020)

Data component	Unit	Range	Use	Temporal extent
ET0	mm/year	0–3500	Measures annual reference evapotranspiration	Year (2009–2021)

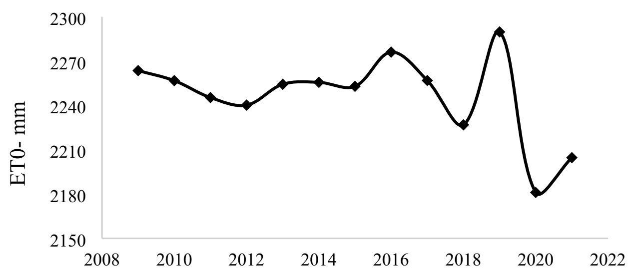

Fig. 11 Annual Reference Evapotranspiration across the continent (2021–2009)

Food Security and Agriculture Drought Monitoring

Climate change-induced effects, such as increased rainfall magnitude, severity and frequency of droughts, and floods would affect agriculture, livestock, and fisheries production, thus worsening the food insecurity situation in Africa (Africa 2013; Shaltout and Bedair 2023) (https://www.uneca.org/african-climate-policy-governance-and-climate-policy-in-africa). Reduction in agriculture productivity because of climate change-induced events does not only retard economic growth but worsens poverty levels,

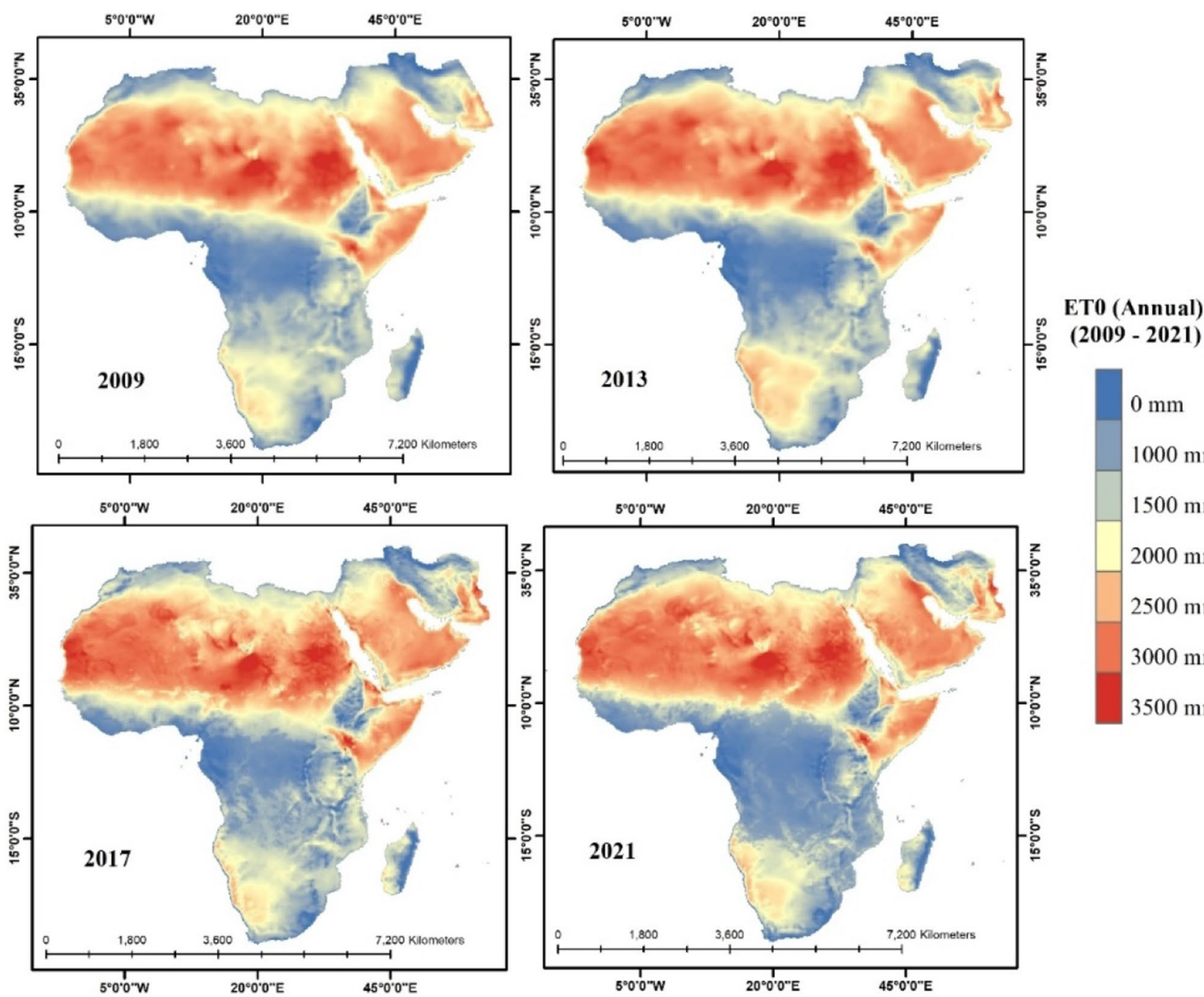

Fig. 12 TChange in annual Reference Evapotranspiration across the continent ((2009–2021). Source: WaPOR, remote sensing for water productivity Datasets tagged WaPOR in Earth Engine

Table 9 Calculation of Annual CWD and WS in Africa for the period 2009–2021

Year	PPT	AET	PET	CWD	WS	%WS
2009	632.97	616.96	2263.63	1646.67	16.01	2.53
2013	629.37	591.45	2254.37	1662.93	37.92	6.03
2017	649.19	628.16	2256.92	1628.76	21.03	3.24
2021	639.38	610.12	2204.69	1594.57	29.26	4.58
Total	2550	2446.68	8979.61	6532.93	104.22	

Source: Terra Climate datasets, Earth Engine platform

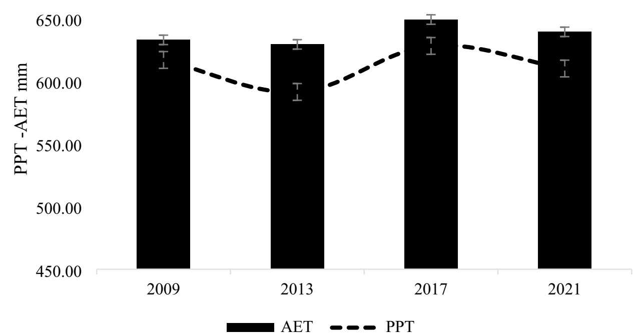

Fig. 13 The annual CWD water deficit in the African continent for the period 2009–2021

Table 10 Drought Zonation based on VHI values

Drought	Values
Extreme	> 10
Severe	20 >
Moderate	30 >
Mild	40 >
No Drought	40 ≤

and further creates new poverty traps which all conspire to affects livelihoods, as agriculture is the primary source of income for the majority of people in Africa (Change 2014). It has been reported that, the number of malnourished people in sub-Saharan Africa has increased by 45.6% since 2012 because of climate change. Similarly, climate change will cause cereal crop yield to reduce between 8 to 13% across the continent.

The pattern of distribution of the drought-affected agricultural land is determined by the VHI drought index (Vegetation Health Index) (Belal et al. 2014). The VHI index generates values between 0 and 40 that are divided into 5 categories according to the severity of the drought: not a drought, mild, moderate, severe, and extreme drought (Table 10). Figure 14 shows the evolution of drought, like areas where agricultural drought transformed from severe to moderate, and in others, the opposite is happening (Dalezios 2017).

Biodiversity Loss and Ecosystem Collapse

In Africa, evidence points to several historical periods which the climate and vegetation of Sahara has fluctuated back and forth into a desert –the last being 6000 years ago (Schuster et al. 2006) and that Sahara desert has been expanding at a rate of more than 11,000 Km^2/year between 1950 and 2022. The IUCN Red List listed 3,148 plants and 6,419 animals in Africa as being endangered in 2014. In Africa, 21% of freshwater species are classified as threatened and 58 percent of freshwater plant species, as well as 45 percent of freshwater fish, are overfished (http://cmsdocs.s3.amazonaws.com/summarystats/2014_2_Summary_StatsPage_Documents/2014_2_RL_Stats_Table8.pdf). Additionally, the African bird Red List index of the IUCN shows a reduction over the past 25 years, indicating an increase in the extinction risk for African birds (Sintayehu 2018). The overall number of vertebrate species of Africa for which statistics are available is thought to have dropped by roughly 39% since 1970 (McLellan et al. 2014). Compared to eastern or southern Africa, declines occur more quickly in Central and Western Africa (Craigie et al. 2010). Over the past twenty years, marshes, damp and occasionally dry woodlands, and mangroves have all experienced considerable decreases, with annual losses normally averaging around 1%. Numerous ecoregions in Africa were identified as "Endangered" or “Critically Endangered” in 2004 (Burgess et al. 2004).

Regional Policies and African Action to Confront Climate Problems

Africa is vulnerable because of the following reasons: 1: Sub-Saharan Africa accounts for 95% of the world’s rain-fed agriculture, 2: Agriculture accounts for a sizeable amount of Gross domestic product (GDP) and employment. 3- Four of the top 10 most affected countries in 2015 were from Africa: Mozambique (1st), Malawi (3rd), Ghana and Madagascar (joint 8th position), and 4- According to studies commissioned by United Nations Environment Programme (UNEP), the cost of adaptation to climate change in Africa could approach $50 billion year if the increase in global

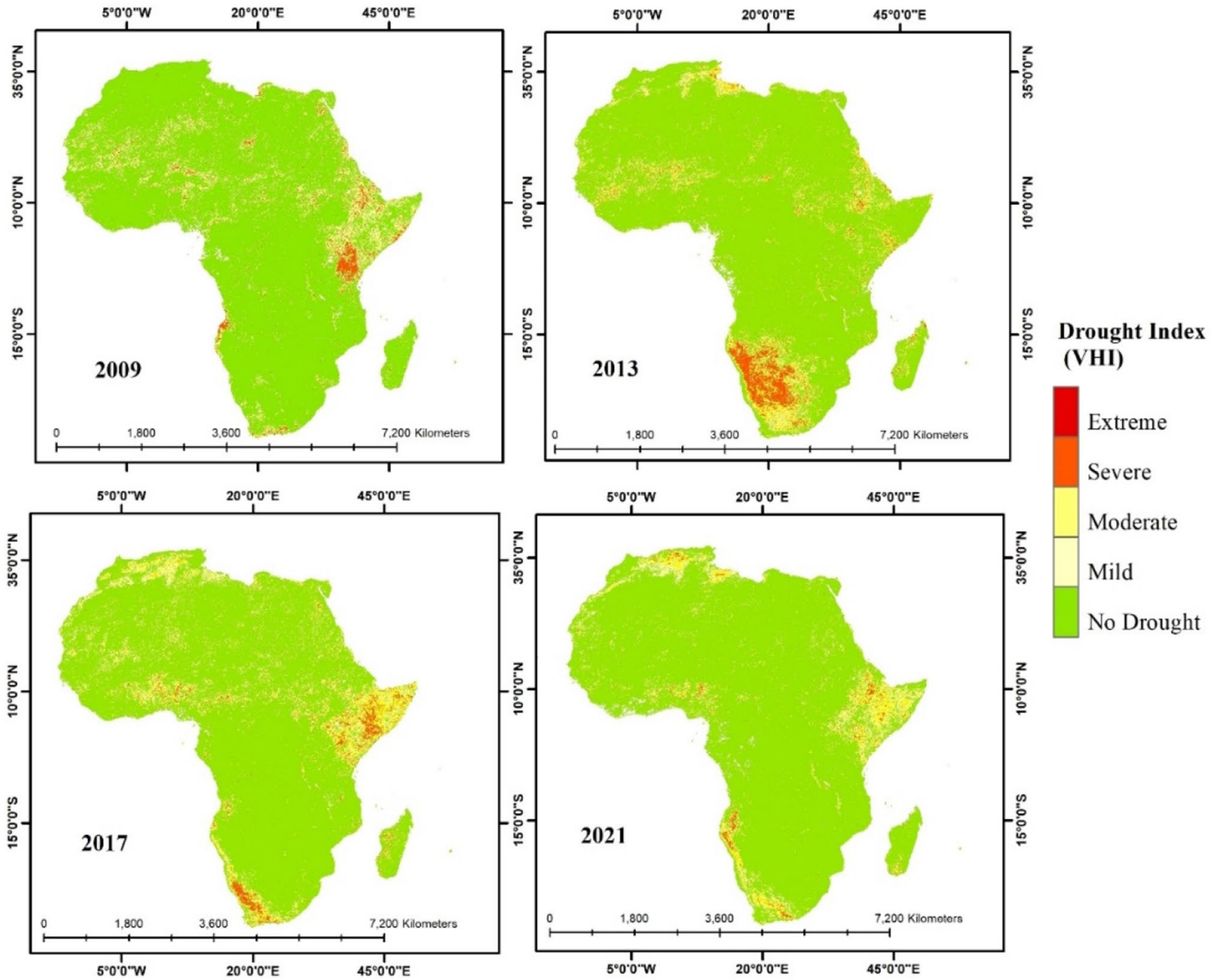

Fig. 14 The change in the annual Drought Index VHI across the continent (2009–2021). Source: Drought index, Earth Engine platform

temperature is limited to 2 °C above preindustrial levels by 2050 (Environment 2012) (https://www.afdb.org/en/cop25/climate-change-africa).

In an effort to combat climate change and environmental degradation, the collaboration aspires to foster a continental, pan-African strategy and reaction. In particular, several African countries have created climate policy frameworks like National Adaptation Programme of Action (NAPA) and Nationally Appropriate Mitigation Action (NAMA) in accordance with the United Nations Framework Convention on Climate Change UNFCCC's guidelines (https://www.uneca.org/african-climate-policy-centre/climate-governance-and-climate-policy-in-africa). In fact, the climate change work done in the region by the UNEP Africa office focuses on assisting countries in setting up a system for carrying out their responsibilities to combating climate change, also known as Nationally Determined Contributions (NDCs), in a way that satisfies the region's top socioeconomic priorities, including food security, the creation of income and entrepreneurial opportunities for economic growth, and youth (https://www.uneca.org/african-climate-policy-centre/climate-governance-and-climate-policy-in-africa).

In addition, one of the most significant initiatives is EU-UNEP Africa Low Emissions Development Project: UNEP worked with seven nations to unbiasedly demonstrate how NDC implementation through combining mitigation and adaptation activities may result in socioeconomic benefits as well as benefits for the environment and climate. (https://www.uneca.org/african-climate-policy-centre/climate-governance-and-climate-policy-in-africa).

Across the continent of Africa, several adaptation strategies have been implemented. For instance, it has been documented that farming inputs, high yielding cultivars, water harvesting, soil conservation, and agriculture are among some of the highest adaptation strategies in the Sahelian region of Africa (Epule et al. 2021). Similarly, Mushore and his colleagues found in their study(Mushore et al. 2021) that farmers in the Eastern and Southern African countries like Zimbabwe rely on cash crop production, petty trading, barter trade, selling of livestock, and migration to other countries to work as adaptation strategies to supplement household food requirements. In fact, an advanced method has now been used in restoration of several sites in Kenya, such as Ngong road forest, Karura forest, Mau forest (Sururu), and the University of Nairobi, Chiromo campus (HayaSHi et al. 2017). Moreover, the great green wall is Africa's most ambitious restoration project which kick-started in 2007 and aims to restore 780 million hectares of degraded land in an 8000 km long swath stretching from Senegal to Djibouti. Restoration of the African Forest Landscape Initiative (AFR100) is also another example of large scale restoration project in which 30 African countries in 2015 committed to restore over 100 million hectares by 2030. There are also other programs, such as Action Agenda for Pan-African Ecosystem Restoration, where nations committed to restoring nearly 200 million ha by 2030. There is a must to work more toward climate change mitigation through more tree planting programs.

To contribute toward Malawi's climate resilience and preparedness capabilities, the project Scaling up the Use of Modernized Climate Information and Early Warning systems (M-CLIMES) was launched. The project's goals include expanding Malawi's meteorological network, installing automated weather stations, hydrological monitoring stations, and lake-based weather buoys, and improving local officials' ability to detect risks and anticipate impacts. The program would help to optimize the warning period for impending climate-related disasters, giving local communities enough time to prepare. Accurate climatic data gathered through the program will be disseminated through mobile phones, ICT, and radio channels, with a focus on vulnerable farming villages and fishing communities near Lake Malawi. In general, the project has so far ensured people know what to do with this enhanced weather information (Reed et al. 2022).

Argania spinosa, also known as the argan tree, is an endemic plant of Morocco. The argan forest located in southwestern Morocco serves as a barrier against climate-induced desertification and assists indigenous people who rely on these forests for a living to adapt and retain their cultural heritage (Bedair et al. 2022a). 'The argan orchards initiative' attempts to prevent argan forest overharvesting, reducing the man-made pressure on the trees, and allowing for natural regeneration. The overall goal of the program is to plant 10,000 hectares of argan tree orchards, intercropped with medicinal and aromatic plants. Local people are being trained on how to properly cultivate argan trees in orchards on private property as part of the initiative (Shaltout and Bedair 2022).

Further, some research on climate crisis solutions by Artificial Neural Networks has been implemented in other countries and can be applied to the African continent. A novel residual neural network (RESNET)-based economy and CO_2 emissions prediction model to analyze and improve the global energy structures of various countries has provided guidance and development plans for countries or regions with low energy efficiency, which can improve energy efficiency, economic development and reasonably control CO_2 emissions (Han et al. 2023a). Another research by (Han et al. 2023b) has applied a novel production prediction and energy structure optimization model based on the long short-term memory neural network (LSTM) combining the Monte Carlo (MC) (MC-LSTM) to predict the production and optimize the energy structure of ethylene plants in the process industry. Moreover, radial basis function (RBF) neural network integrating multi-dimensional scaling (MDS) (MDS-RBF) has been developed by (Wu et al. 2022) to assess production capacity and carbon reduction modeling technology of industrial processes.

The Importance of 2022 for Climate Action

As the world intensifies its fight against climate change and advances past the 2021 Glasgow Climate Change Conference, there are 10 big global events in 2022 that have impacted crucial discussions and influenced public policy decisions about one of the most important concerns of our day (https://www.un.org/en/climatechange/why-2022-will-matter-climate-action-0).

In November 2022, Sharm El-Sheikh, Egypt has hosted the yearly UN Climate Change Conference. The main goals were to achieve the international climate negotiations, spur action, and offer a crucial chance to examine how climate change is impacting Africa. Furthermore, to address the demands of poor nations, especially Africa, LDCs, and SIDS, there is a need for more transparency of financing flows and improved access.

African action in UN Climate Change Conference (COP27), 2022

In developing the detailed schedule, the COP27 presidency has taken into account the interconnectedness of the themes with regard to adaptation, mitigation, and finance, especially in the most vulnerable countries (https://cop27.eg/#/). Initiatives are started by COP27 to let African nations invest in enhancing resilience to climate change. "Reducing the Cost of Green and Sustainable Borrowing" is an initiative launched by Addis Ababa and the United Nations Economic

Commission for Africa. Through a number of channels, this initiative will assist in establishing more substantial, dependable, and sustainable financing to hasten its post-COVID green recovery. Additionally, more green finance will be raised, private capital will be attracted, and African states' ability to borrow at reasonable rates would be strengthened. Among its programs are the Harmonization of ESG Standards, the Liquidity and Sustainability Facility (LSF), and the Proposal of a Sustainability Sovereign Debt Hub (SSDH), among others (https://www.uneca.org/Afri-Res).

Africa-based networked centre of technical competence and excellence (AFRI-RES) is another African initiative that aims to increase the ability of African institutions, such as regional economic communities, national governments, river basin organizations, and energy networks, as well as the business world (project developers and financiers), to organize, develop, and implement infrastructure projects that are resistant to climate change and fluctuation in particular industries (https://www.ena.et/en/?p=40006). Further, Ghana is setting the bar for African carbon market initiatives (ACMI) in both forests and non-forests. It's a brand new program that offers carbon credits for sale in African nations. The millions of dollars in climate finance required to fund climate change mitigation initiatives across Africa can be made available by carbon markets. In fact, Africa Just and Affordable Energy Transition Initiative (AJAETI) is another initiative that offers a chance to create a new framework for collaboration in order to fulfill the pledge to achieve universal energy access by 2030 and implement the 2063 Agenda (https://unfccc.int/news). A global group called 'Efficiency for Access' works to promote high-performing appliances that help the world's poorest people including African continent have access to clean energy.

Spectacularly, seven climate change initiatives targeting toward Africa have been unveiled by Egypt in COP27. The first initiative aims to achieve an equitable energy transition for Africa. Decent Life for Africa is the second initiative that aims at establishing a connection between adaptation, resilience, mitigation, and access to creative solutions and small-scale technologies to enhance the standard of living in rural communities in Africa by providing them with access to essential services and employment opportunities (Bedair et al. 2023b). The third one is a presidential plan that includes several national infrastructure projects that are centered on the countryside. Women and Adaptation Initiative: Increasing African women's capacity for a more resilient environment and expanding chances for green employment. In addition, the Egyptian initiative to create an early warning system and safeguard water from the effects of climate change also includes the water-focused aware program. Whereas, the sixth program emphasizes biodiversity to save the ecosystems and marine life from the effects of climate change. Natural solutions are the foundation of the program. Africa Waste 50, the seventh initiative, seeks to reach a 50 percent recycling rate for the continent by the year 2050. A fascinating initiative termed 'Bardawil & Sinai Initiative' is a cooperation through the public–private partnership (PPP) system, between Suez Canal Authority and The Weather Makers was signed to start restoration of the Bardawil lake water cycle. This project also has a crucial role in restoring Sinai's agricultural land and vegetation cover.

In fact, progress in mitigating climate change is hampered by policies that limit access to the commodities required to reach net zero, produce disparities in the cost of capital, and limit developing countries' access to concessional financing. Hence, the COP 27 Africa Pavilion served as the venue for the event, which had the topic "Empowering a Climate-Resilient Africa for the 21st Century: Articulating Vision and Opportunity". Industry leaders from the Volvo Group, IBM, the International Cooper Association (ICA), and Google were also there. As part of its promise to reduce grid losses in Africa, ICA stated that it will start the Grid Efficiency and Resiliency Partnership Initiative, and Google has committed to investing USD 1 billion to promote Africa's digital transformation (https://unfccc.int/news). Moreover, Global Environment Facility (GEF) in partnership with Green Climate Fund (GCG) have provided 4 billion USD portfolio in Africa for accelerating initiatives that inspire more climate action that strengthens communities and ecosystems in the public and private sectors. Among them, up to 250 million USD are provided to fund climate mitigation and adaptation initiatives in the East African region. In addition, the International Finance Corporation (IFC) has provided KCB Bank Kenya with a 150 million USD loan to fund climate-smart initiatives. Doubtlessly, these initiatives will support climate change mitigation and adaptation over Africa, of course, if they will take the right path and end up in the hands of the real actors, such as regenerative farmers. In addition, launch of the Africa Just & Affordable Energy Transition Initiative is a great step that presents multiple clean pathways for a long-lasting just and affordable energy transition across Africa. Finally, history was made at COP27 in Sharm El-Sheikh as parties agreed to the establishment of a long-awaited loss and damage fund for assisting developing countries that are particularly vulnerable to the adverse effects of climate change. The Loss and Damage Fund is important to Africa as it will help address the gaps that the Readiness Programme (RP) of the Green Climate Fund (GCF) could not fill (Fig. 15). On African soil, the voice of the acutely affected communities was finally heard (https://unfccc.int/news).

Recommendations and Future Priorities

In fact, it is time to stand together to mitigate the impact of global warming on Africa. Since all of the nations of Africa are equally vulnerable to climate change, greater regional

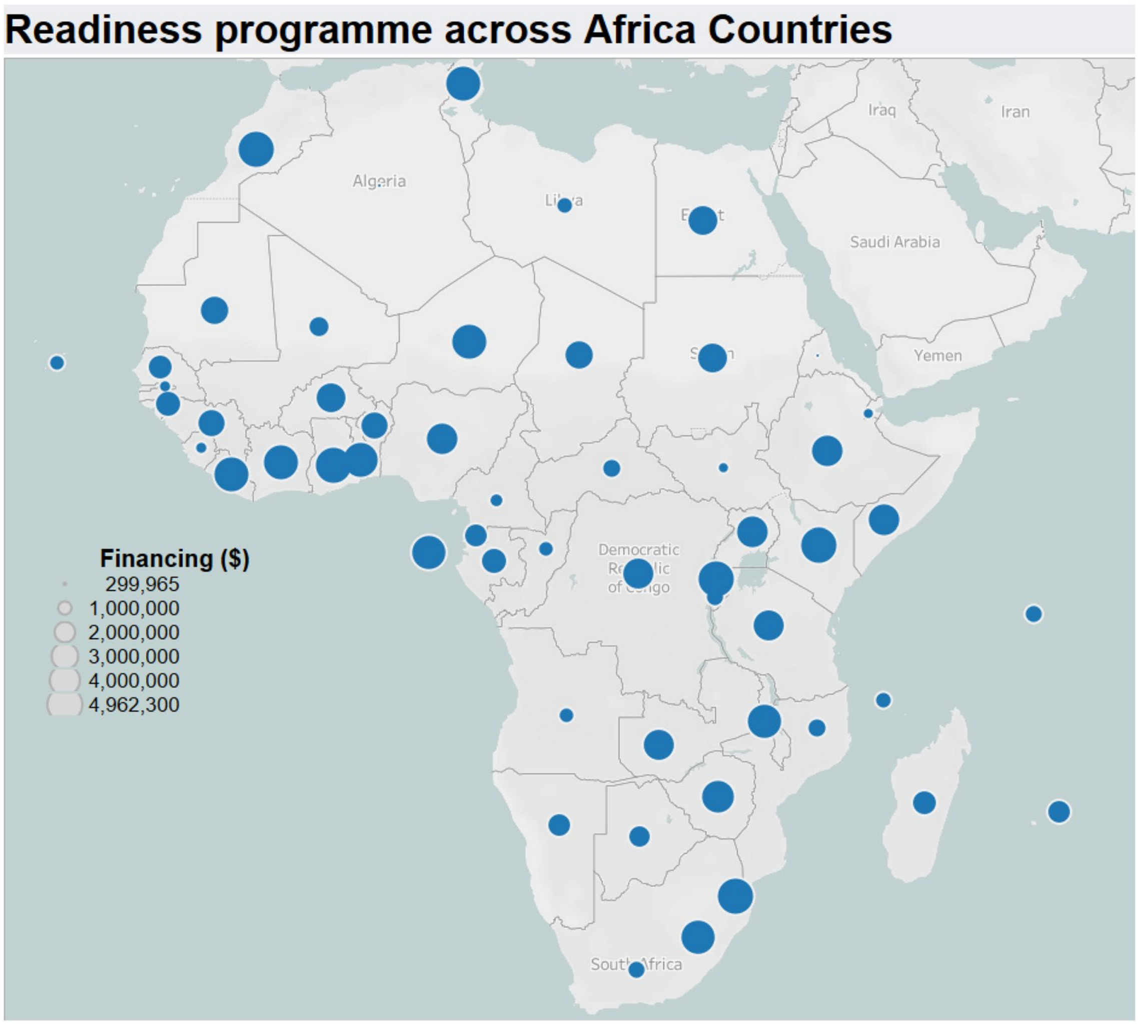

Fig. 15 The Readiness program across Africa (data source: GCF Open Data Library 2022). The Readiness Programme (RP) is part of the Green Climate Fund (GCF) aim to support country-led initiatives by developing countries to build institutional capacities, governance procedures, and planning in pursuit of a transformative long-term climate action agenda. Since the inception of GCF in 2010, a total of 142 million dollars have been disbursed as part of RP across Africa with 3.5% going to the Kingdom of Eswatini, and 0.2% to Eritrea

collaboration will be beneficial by fostering the exchange of effective strategies for reducing the effects of climate change. The creation of vulnerability indicators that capture the sub-national level and enable local comparisons of intra- and inter-country vulnerability is a promising field of research for academics. All stakeholders, both governmental and non-governmental, the commercial sector, and civil society should collaborate to lessen the negative effects of climate change. Financial institutions must mainstream resilience into investments they are making. In addition, financial innovation for adaptation must match country-level policy and market conditions. Additionally, Better cooperation among African countries is necessary in the battle against the effects of climatic change. Countries with stronger economic capabilities may help countries with weaker capabilities by exchanging knowledge and technology. All levels of government should give due consideration to migration and displacement related to climate change, and nations should implement migration-related climate change policies.

Nevertheless, it is important to reduce economic and livelihood dependence on rain-fed agriculture, strengthen sustainable land use practices, and increase the adaptive capacity using advanced methods such as climate-smart agriculture. It is crucial to introduce drought- and heat-resistant crop varieties, familiarize small farmers and pastoral communities with irrigation and water management systems, and give small farmers and pastoral communities' access to financial protection options. Information and Communication Technology (ICT) is essential for supporting small farmers and pastoral communities by offering useful research, information sharing forecasts, and capacity building. Supporting services for deforestation, soil preservation, and medicinal supply are just a few examples.

In fact, there is still a must to gather more historical and current climate data in many African regions. There are very few weather stations spread out across the continent. Critical gaps in the availability of historical climate data have been created as a result, especially over rural regions where coverage tends to be worse. Consequently, it's urgent to provide more weather stations in these regions.

Additionally, we must quickly scale up and reproduce any other climate-friendly ideas in order to deploy them in poor nations. It is crucial to establish research and development centers to examine regional and subregional climate change patterns, as well as to share study findings. Further, integrating Artificial Intelligence tools to improve energy efficiency, economic development and reasonably control CO_2 emissions in African nations is highly recommended.

While the recently concluded COP27 provided an opportunity to voice out issues related to climate adaptation and mitigation in the continent, it also helps to assess the achievements made toward supporting the local population in adapting to the devastation of climate change. To ensure the effective utilization of funds, African leaders must set up a transparency, accountability, and monitoring framework to promote the trackable impact of the grants received and safeguard the misuse of the funding facilities by countries that have weak financial management systems. Overall, the core cause of climate change must be addressed, which includes cutting emissions. Unless emissions are dramatically cut, more nations will be confronted with the devastating impacts of climate change.

Conclusions

Africa has contributed very little to the planet's changing climate—between two and three percent of global emissions—yet it stands out as the continent with the greatest vulnerability. It has been evident that Africa is already suffering from the effects of climate change since the early 1970s, and these effects have given rise to a variety of novel and unusual phenomena, including rising temperatures, poor agricultural output, extreme weather events, the spread of disease, and other things. The rates of sea-level rise along the tropical and South Atlantic coasts as well as the Indian Ocean and the Mediterranean coasts are faster than the world mean rate. Moreover, according to the Intergovernmental Panel on Climate Change, less precipitation is predicted to occur over North Africa and the south-western regions of South Africa by the end of the century. Regarding temperature, since 1901, over 1 °C of warming has already occurred across parts of Africa, resulting in increased heat waves and scorching days. Deforestation and forest degradation are still issues throughout Africa. In fact, the year 2022 has witnessed huge wildfires in northern Africa which burnt large forest areas. Consequently, global warming has impacted water resources which in turn threatened food security in Africa. Africa's biodiversity is still under decline due to continued extinctions of species and habitats. Sahara desert has been expanding at a rate of more than 11,000 Km^2/year between 1950 and 2022. Notably, it has been estimated the loss of human lives due to climate change will go up 500 times in Africa than in Europe.

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Data availability Data will be made available on request.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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