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TMA
TANZANIA METEOROLOGICAL AUTHORITY

Statement on the Status of Tanzania Climate in 2023

March, 2024

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Abbreviations

CEPO	Central Equatorial Pacific Ocean
CPC	Climate Prediction Center
ENSO	El Niño Southern Oscillation
IDW	Inverse Distance Weighting
IOD	Indian Ocean Dipole
ITCZ	Inter Tropical Convergence Zone
JF	January to February
JNIA	Julius Nyerere International Airport
KIA	Kilimanjaro International Airport
MAM	March to May
NCEP	National Centre for Environmental Prediction
NDJFMA	November to April
OND	October to December
PMO – DMD	Prime Minister's Office – Disaster Management Department
SSTs	Sea Surface Temperatures
SSTA	Sea Surface Temperature Anomalies
SWFDP	Severe Weather Forecasting Demonstration Project
TMA	Tanzania Meteorological Authority
Tmax	Maximum temperature
Tmean	Mean temperature
Tmin	Minimum temperature
URT	United Republic of Tanzania
WMO	World Meteorological Organization
ZDMC	Zanzibar Disaster Management Commission

Foreword

The adverse impacts of climate change and variability are the major challenge to the socio-economic development especially for the Developing Countries and are vividly seen throughout every aspect of the world we live in today. Continual monitoring and documenting weather and climate parameters will support the general understanding of climate for an area and may support addressing the challenges posed by the climate change crisis.

In this regard, the Tanzania Meteorological Authority (TMA) has continued to monitor and document weather and climate information in the country and performs comprehensive analysis to understand, monitor and describe changes in the country's climate with time. This information is kept available to the public, the government, policy and decision-makers, academia, the scientific and research communities, and planning agencies in and outside the country.

TMA in each year has dedicated efforts and resources to conduct a robust and comprehensive climate analysis and then provides an authoritative statement on the status of Tanzania's climate. The statement serves as a tool for climate monitoring and assessment of the state of the earth's climate in near real-time, and at national scale, and it also reflects the TMA firm dedication to join the world in tackling the impacts of climate change with consideration and determination.

The 2023 country's annual statement on the status of climate is the 13th report in the series of climate statements published by TMA. The statement focuses on trends of key climate indicators (rainfall and temperature), and extreme weather and climate events which were recorded in 2023 by putting them into historical perspectives.

I would like to express my sincere gratitude to all stakeholders for their continuous support, constructive comments, ideas, and feedback towards improving this publication on the status of Tanzania's climate. In addition, I would like to take this opportunity to congratulate all individuals who contributed to this report, including the statement review expert team.

Dr. Ladislaus B. Chang'a
Acting Director General
Tanzania Meteorological Authority

1. Introduction

The Earth's climate is changing, and the global climate is projected to keep on changing over the current century and beyond. Warmer temperatures are expected to change weather patterns, and disrupting the usual balance of nature. This in turn poses significant risks to human beings and all other forms of life on earth.

Tanzania, like many other developing countries, is vulnerable to the impacts of climate change and variability, especially Islands and coastal areas being highly vulnerable to sea level rise. The country has continued to experience impacts of climate change and variability, such as extreme rainfall and floods, droughts, strong winds, and high temperatures. These weather and climate events have greatly threatened people's livelihoods, especially those with limited adaptive capacity.

As such, TMA ensures continual monitoring of weather and climate parameters and the provision of accurate, timely, and reliable climate services, including early warnings on adverse atmospheric and hydro-meteorological hazards. The climate statement significantly contributes to resilience building, planning for adaptation, and implementing efforts to reduce the increasing negative social, environmental, and economic consequences of climate change and variability.

The 2023 climate statement provides an overview of the main weather and climate parameters and severe weather events that occurred in the United Republic of Tanzania (URT), from January to December 2023 and their associated impacts by placing them into historical perspective.

The analysis of weather and climate events for the year 2023 relied on diverse sources, encompassing weather and climate observation networks, reputable media outlets and official reports form entities such as the Prime Minister's Office–Disaster Management Department (PMO–DMD) and the Zanzibar Commission for Disaster Management (ZCDM).

The report presents the monthly, seasonal, and annual trends of temperature and rainfall for the year 2023. All maps and graphs presented in this report characterize the climate status observed in 2023 relative to the 1991–2020 baseline climatology. Moreover, the major drivers of weather and climatic conditions that have contributed to severe and extreme climate events are included in this report.

2. Temperature distribution

In 2023, the country experienced its warmest year since 1970, with notable nighttime warmth, particularly in August, September, and October. During these months, air temperature anomalies recorded were 1.1 °C, 1.0 °C, and 1.2 °C, respectively. Likewise, the country's average minimum temperature (Tmin) anomalies were 1.4 °C, 1.5 °C and 1.5 °C, respectively. Concurrently, average maximum temperature (Tmax) anomalies were 0.7 °C, 0.5 °C, and 0.9 °C, highlighting warmer nights compared to daytime temperatures.

2.1 Annual mean, maximum and minimum temperature anomalies

The country average mean temperature (Tmean) for 2023 was 24.5 °C which is 0.6 °C above the long term average (1991-2020). The annual mean temperature anomalies across the country (Figure 1, top left) ranged between 0 °C and 1 °C. As such, 2023 was the record break warmer year in the history of Tanzania meteorological observation since 1970.

On the other hand, the country average annual maximum temperature (Tmax) was 28.6 which is 0.2 °C warmer than long term average. Similar to Tmean, the Tmax anomalies (Figure 1, top right) were between 0 °C and 1 °C across the country except few locations in Tanga, Morogoro and Tabora regions whose temperature anomalies were between -1 and 0 °C.

Likewise, the country's average annual minimum temperature (Tmin) was 19.5 °C, which is higher than the long term average by 1 °C. The annual Tmin anomalies (Figure 1, bottom left) were between 0 °C and 1 °C for large part of the country, especially central, west and southwestern highlands, but ranged between 1 °C and 2 °C for most areas surrounding Lake Victoria, northern coast including Zanzibar islands, northeastern highlands, Ruvuma and Rukwa regions, and parts of Morogoro, Mtwara and Dodoma regions, respectively. Generally, the country experienced a higher anomaly in minimum temperatures compared to maximum temperatures.

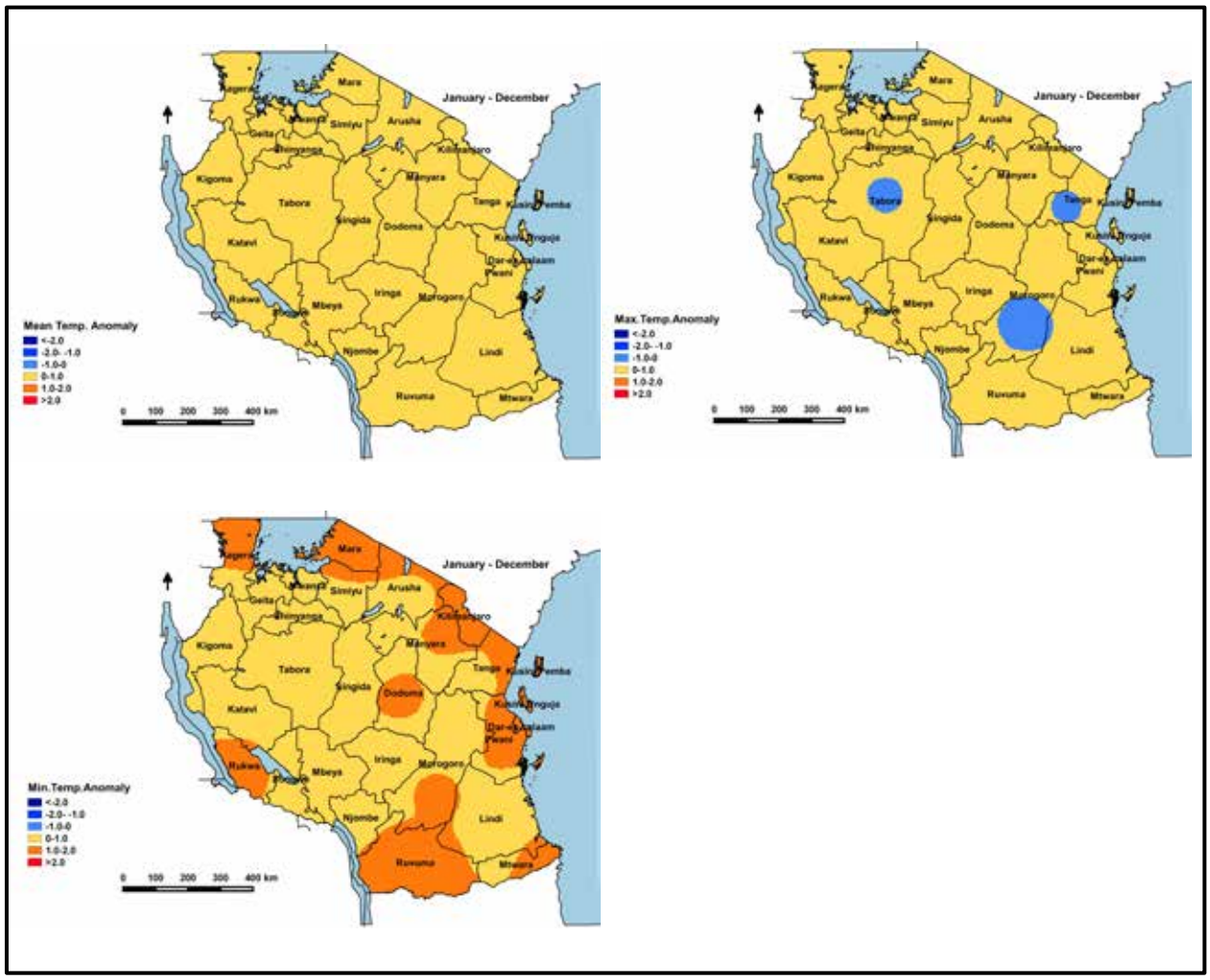

Figure 1: 2023 annual average temperature anomalies (°C) relative to long term average (1991–2020) for mean (top left), maximum (top right) and minimum (bottom left) temperature

2.2 Monthly mean, maximum and minimum temperature anomalies

The country's monthly mean Temperature (Tmean) in 2023 were slightly warmer than average from January to April, but the warm anomalies were seen to gradually increase from May through October where the highest anomalous warming of 1.2 °C was recorded (Figure 2). The observed anomalous warming gradually decreased towards the end of the year.

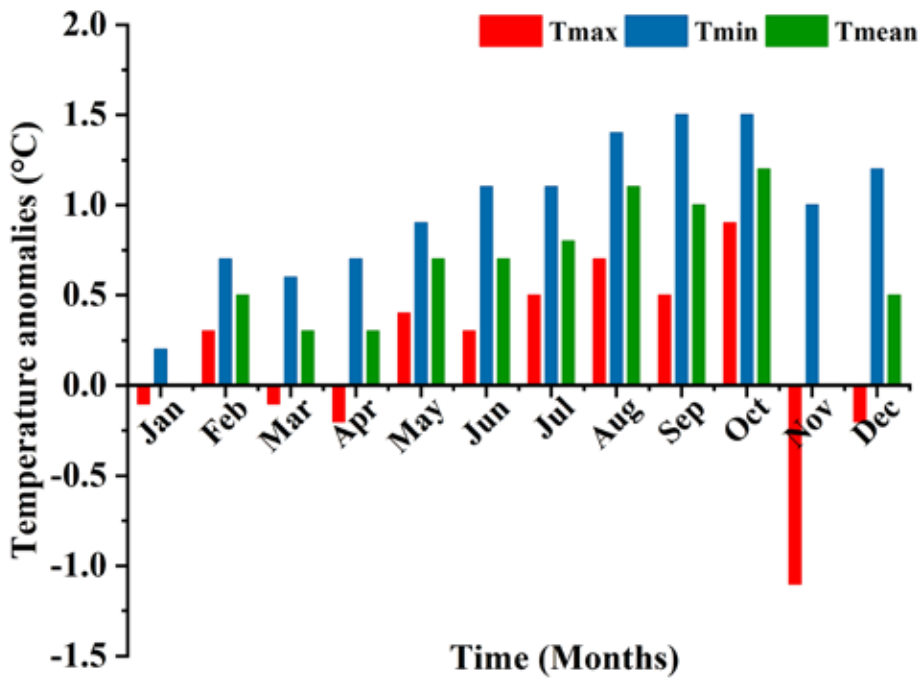

Figure 2: Monthly mean temperature (Tmean), maximum temperature (Tmax) and minimum temperature (Tmin) anomalies (°C) for 2023 relative to long term average (1991–2020)

Notably, the country was considerably warmer than usual during August, September and October with temperature anomalies of 1.1 °C, 1.0 °C, and 1.2 °C, respectively. As such, August, September and October 2023 were the warmest on record, surpassing all previous August, September and October temperatures in the historical records since 1970.

On the other hand, the country's average monthly Tmax anomalies in 2023 were slightly warmer than long term average during February, May, June and September, but were significantly warmer reaching 0.5 °C, 0.7 °C, and 0.9 °C during July, August and October, respectively. In contrary, the country average Tmax were slightly cooler than average during January, March, April and December, but significantly cooler than average reaching -1.1 °C, during November (Figure 2).

Moreover, the country's average monthly minimum temperature (Tmin) was slightly warmer than average during January, but significantly warmer than average from February through December. Higher Tmin anomalies reaching 1.4 °C was observed in August, and 1.5 °C in September and October (Figure 2).

2.3 Spatial monthly maximum temperature anomalies

The spatial distribution of monthly Tmax anomaly in Figures 3a and 3b show that cooler than average Tmax ranging between -1 °C and 0 °C dominated a larger part of the country during January, March, April and November. In addition, the Tmax anomalies were significantly cooler in the range between -2 °C and -1 °C during November, especially over the northern coast including Zanzibar Islands and northeastern highlands but extending to few areas near Lake Victoria and central part of the country. This abnormal behavior may be explained by the presence of cloudy conditions associated with heavy and persistent rainfall over those areas, hindering solar radiation reaching the surface.

On the other hand, warmer than average Tmax, ranging between 0 °C and 1 °C, was dominated over much of the country during February, May, June, July, August, September and October. Notably, a significant Tmax warming anomaly between 1 °C and 2 °C was observed over the western sector of the country extending to central parts of the country, and towards Morogoro, Pwani and Dar es Salaam regions during October. However, similar anomalous warming was observed during other months and at different locations. For example, during February and March anomalous warming was confined over the northeastern highlands while during May, June, July and August the warming was observed at different locations over the Lake Victoria basin, southwestern highlands and southern region.

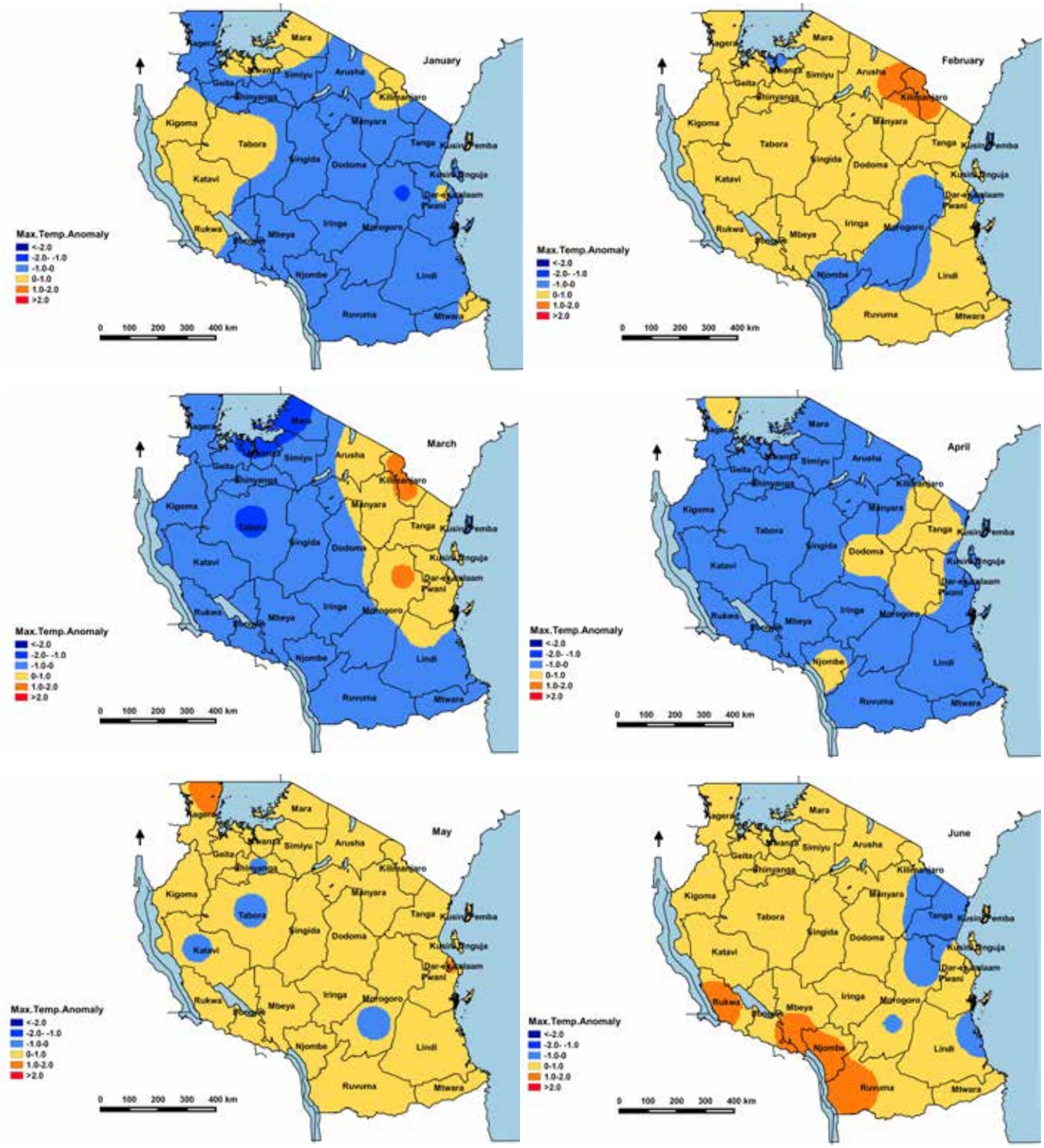

Figure 3a: Monthly maximum temperature anomalies (°C) for January–June 2023 relative to long term average (1991–2020)

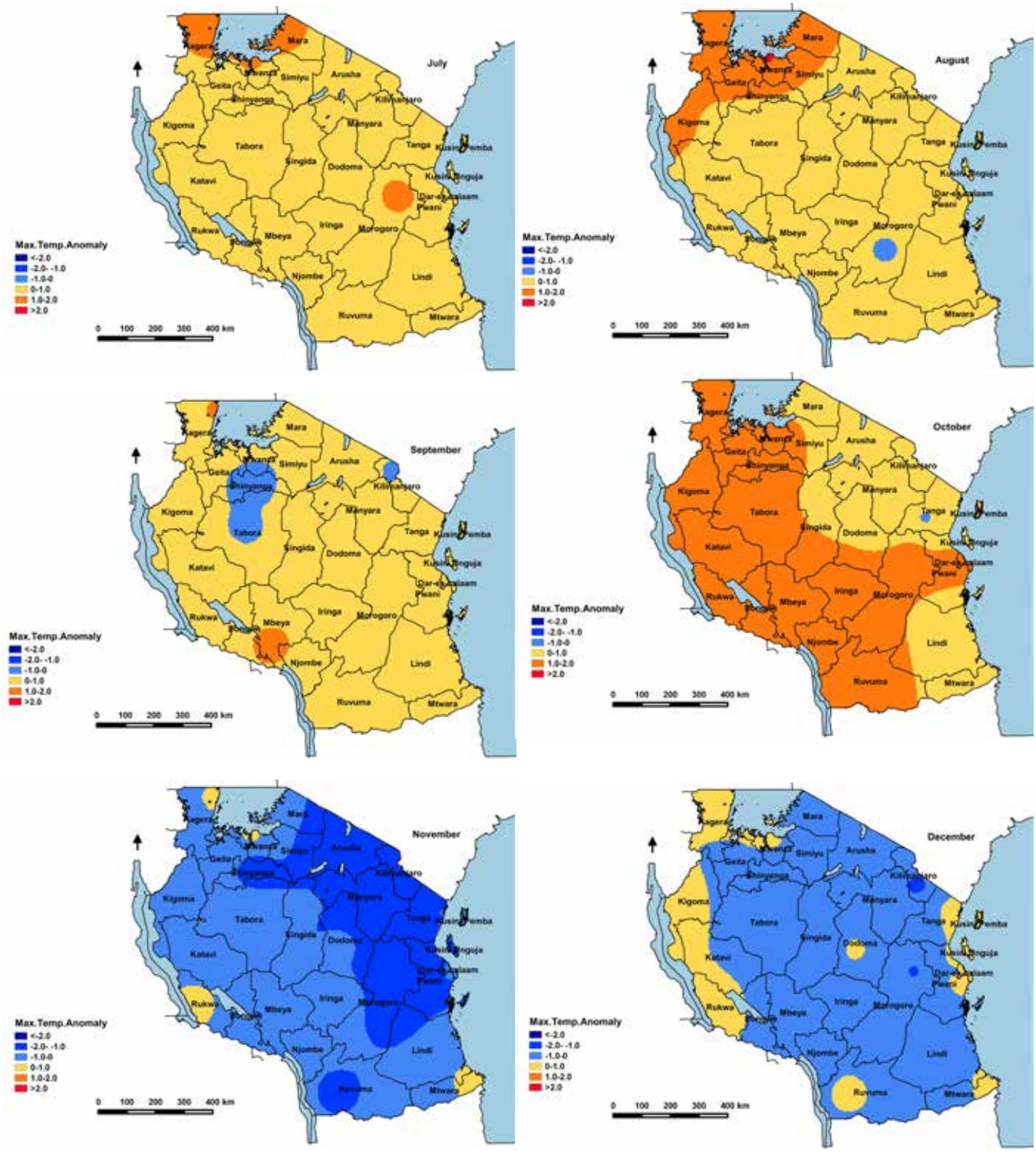

Figure 3b: Monthly maximum temperature anomalies (°C) for July–December 2023 relative to long term average (1991–2020)

2.4 Spatial monthly minimum temperature anomalies

The spatial distribution of minimum temperature across the country (Figures 4a and 4b) indicates that a significant warmer than average Tmin between 1 °C and 2 °C was observed over a large part of the country during August, September and October, and to a lesser extent over the eastern sector extending to areas surrounding Lake Victoria, and the northeastern highlands during June, July, November and December 2023. On the other hand, the Tmin anomaly ranging between 0 °C and 1 °C was dominated over the lager part of the country during February, March, April and May, while cooler than average Tmin ranging between -1 °C and 0 °C was observed over the western sector of the country during January. Thus, the observed Tmin patterns indicate that warmer than average nights were observed over different parts of the country throughout the year.

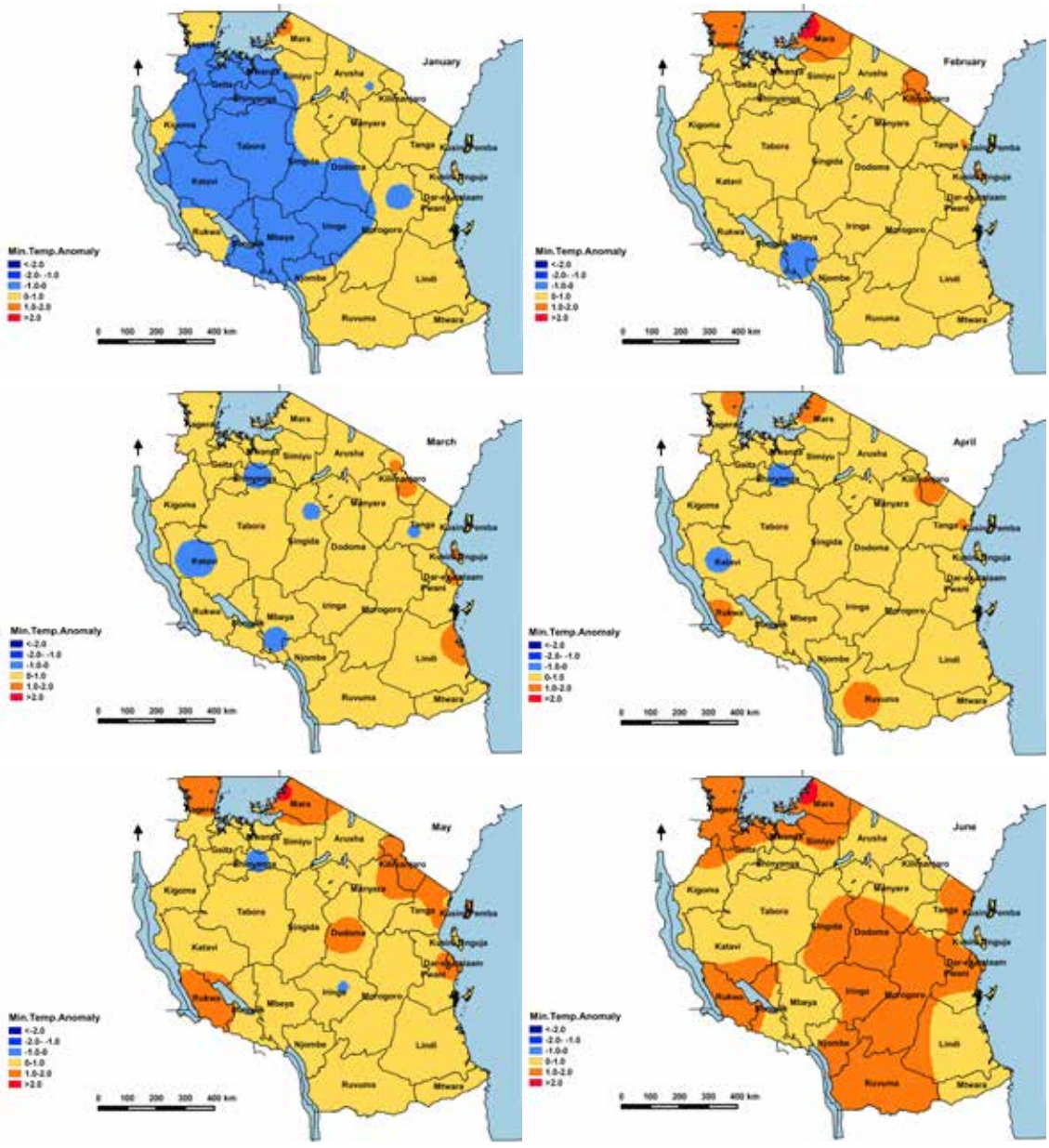

Figure 4a: Monthly minimum temperature anomalies (°C) for January–June 2023 relative to long term average (1991–2020)

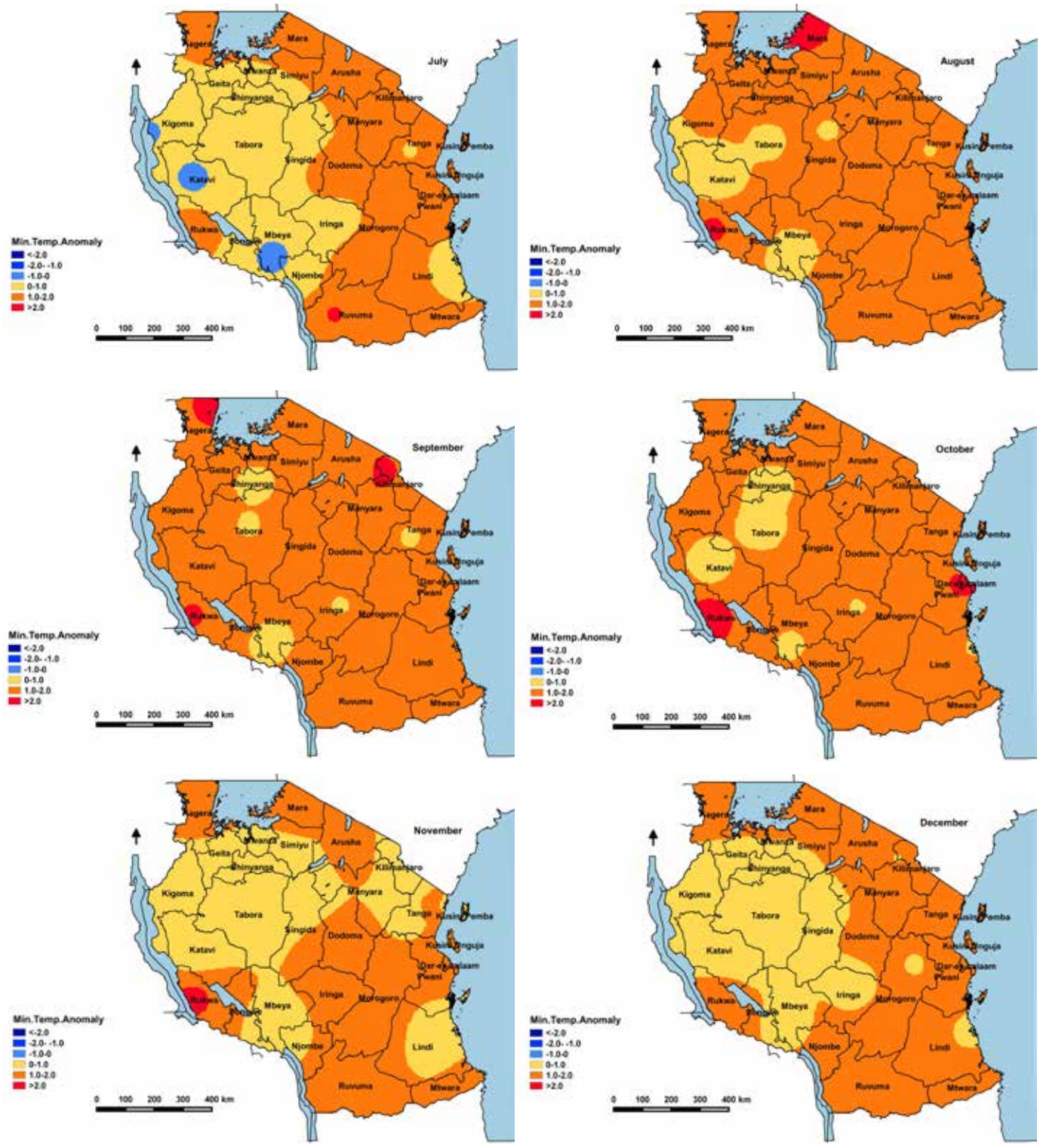

Figure 4b: Monthly minimum temperature anomalies (°C) for July–December 2023 relative to long term average (1991–2020)

3. Rainfall distribution

In 2023, mainly normal rainfall was observed during the November 2022-April 2023 (NDJFMA) and March-May (MAM) 2023 rainy seasons, while above normal rainfall was observed over the large part of the country during October to December (OND) rainy season. A significant rainfall deficit was observed over a large part of the country in May 2023, whereas sufficient rains were observed in November. Contrasting, the northern coast and northeastern highlands were wetter during June in spite of June being climatologically dry.

3.1 Annual rainfall distribution

The country's total rainfall for 2023 was 1170.5 mm, which is 154 mm higher than the long-term average and equivalent to 115% of the average. Mainly normal rainfall ranging between 100% and 125% of the long-term average was observed over the southern sector of the country extending to central parts and few parts of Kilimanjaro and Kagera regions (Figure 5). In contrast, above normal rainfall ranging between 125% and 150% was observed over the northern parts of the country including Mafia and Zanzibar Islands. The year 2023 is ranked as the 8th wetter year on record since 1970.

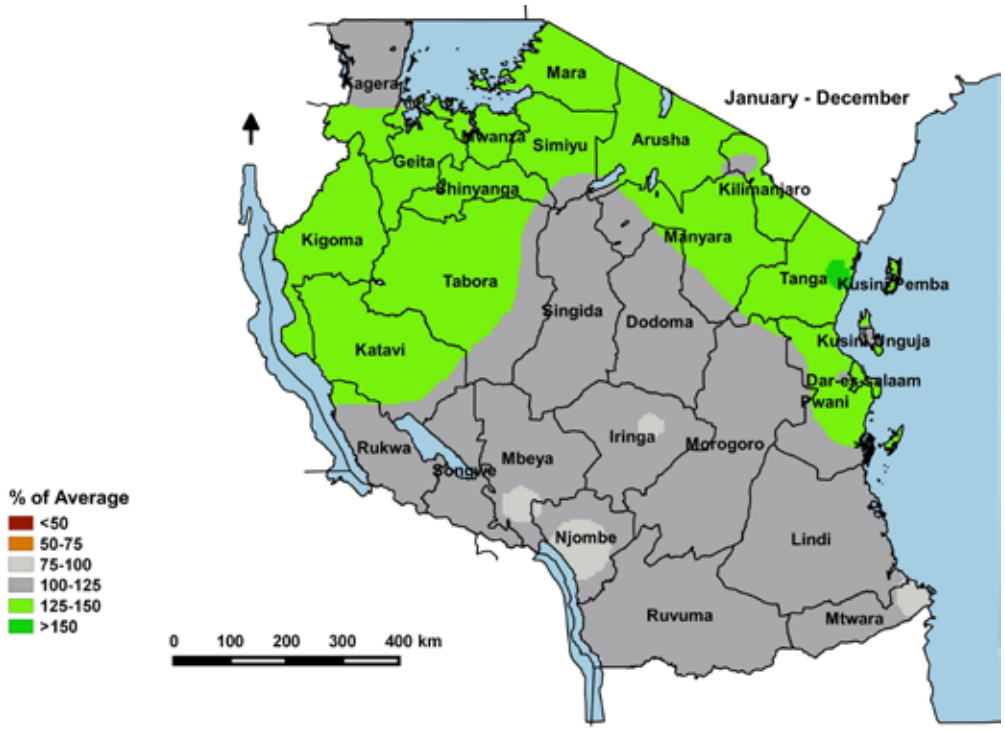

Figure 5: Annual rainfall anomalies for 2023 expressed as percentage of the long term (1991–2020) average

3.2 Seasonal rainfall distribution

Mainly normal rainfall (75% to 125% of long term average) was observed during the November 2022-April 2023 (NDJFMA) and March-May (MAM) 2023 rainy seasons while above normal rainfall (greater than 125% of long term average) was observed over the large part of the country during OND rainy season (Figure 6). As for January-February (JF), mainly normal rainfall ranging between 75% and 100% of long-term average was observed over the large part of the country with the exception of northeastern highlands, northern coast and eastern part of Lake Victoria that observed below normal rainfall (less than 75 % of long-term average).

On the other hand, rainfall distribution during OND rainy season indicated that coastal areas including Mafia and Zanzibar Islands were significantly wetter by observing rainfall over 200% of the long-term average. Likewise, the rest of the country observed rainfall amount ranging between 150% and 200% of long-term average.

The MAM and OND rainfall seasons are typical for areas that exhibit a bimodal rainfall regime. These areas include the northern coast (Tanga, Dar es Salaam, north Morogoro, and Coast regions, and Zanzibar Islands), northeastern highlands (Kilimanjaro, Arusha, and Manyara regions), and areas surrounding Lake Victoria (Mara, Kagera, Simiyu, Shinyanga, Geita, and Mwanza regions). These seasons also partly coincides with the long rainy season (November-April) that is specific for the southern (Mtwara, Lindi, and Ruvuma regions and southern Morogoro), western (Tabora and Kigoma regions), and central parts of the country (Dodoma and Singida regions). Based on the historical meteorological records in Tanzania, the 2023 OND rainy season is ranked as the third wettest OND season on record since 1970, by receiving rainfall amounts of 255 mm higher than the long-term average. Thus, the recorded rainfall amount was almost twice as much as the normal OND rainfall. Unlike the OND 2023 rainy season, the MAM 2023 rainy seasons was the 17th driest seasons on record since 1970.

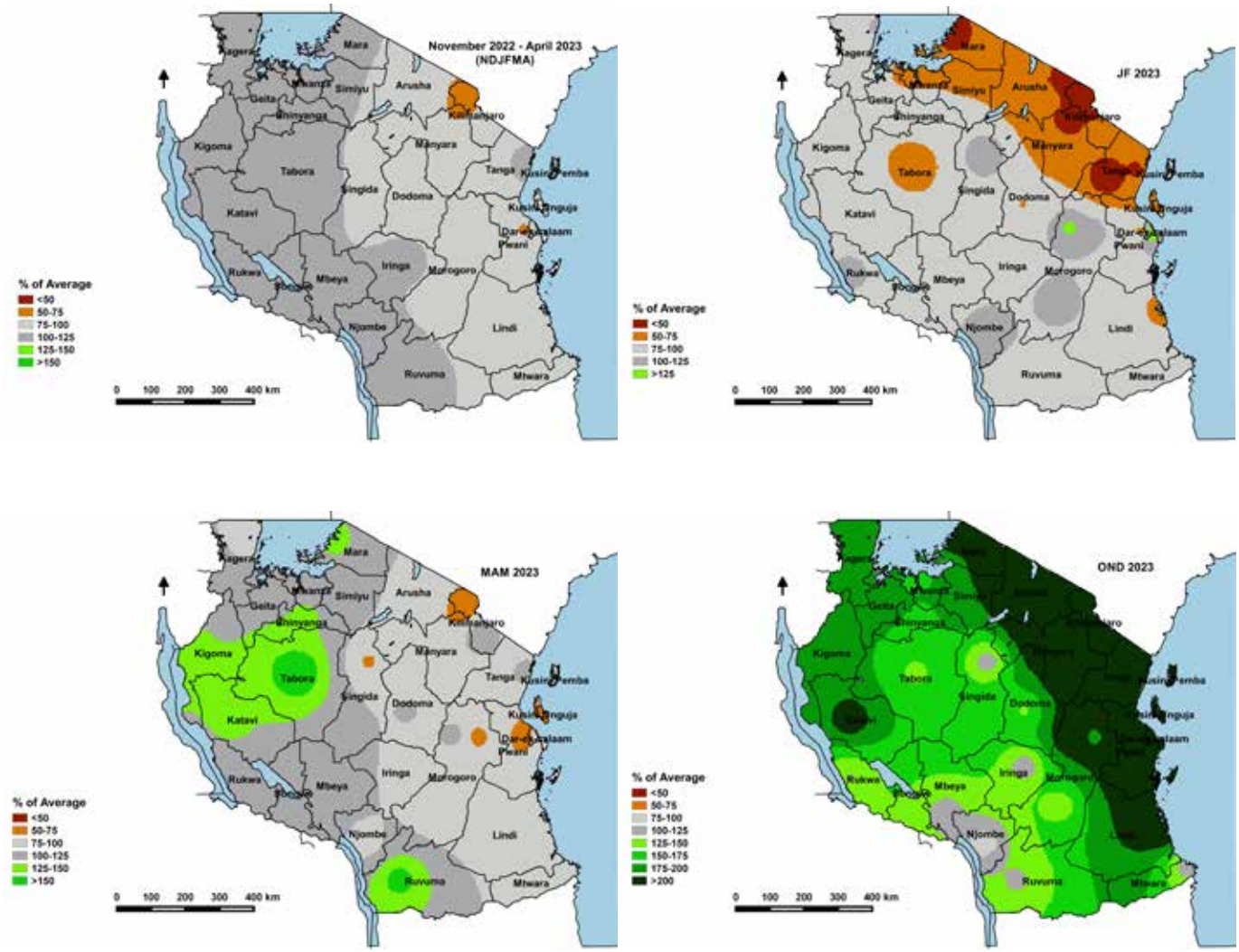

Figure 6: Seasonal rainfall anomalies as percentage of long term average (1991–2020) for November 2022 to April 2023 (top left panel); January and February 2023 (top right panel); March to May 2023 (bottom left panel); and October to December 2023 (bottom right panel)

3.3 Monthly rainfall distribution

In 2023, the country average rainfall was mainly normal except during June, November and December where the recorded rainfall indicated wetter conditions especially during November and December. The recorded monthly rainfall in these months was 256%, 309%, and 141% of long-term average rainfall, respectively. As such, May was the driest month by recording only 60% of May long term average. In this regards, May and November 2023 are marked as the driest and wettest months in the year 2023. Notably, November was a record break wet November since 1970, while May was ranked the 8th driest May since 1970.

The spatial distribution of rainfall (Figures 7a and 7b) indicates that mainly normal rainfall ranging between 75% and 125% was observed over the large part of the country during January and April. In February, below normal rainfall ranging between 50% and 75% of the long-term average was

observed over the central parts of the country, parts of southwestern highlands and Lake Victoria basin, Lindi region as well as Pemba and Mafia islands. Conversely, extremely below normal rainfall, falling below 50% of long-term average was observed over the northeastern highlands, Tanga and Mara regions, and Unguja Island. It is essential to note that, the term “below normal” does not imply the insufficient rainfall in these regions since they are typically experience relatively dry conditions during January and February.

Likewise, below normal rainfall ranging between 50% and 75% of the long-term average was observed over the large part of the country during May except a few parts in northeastern Tanzania. However, isolated cases of extremely below normal rainfall less than 50% of long-term average was observed over the southwestern highlands, southern region, Lake Victoria areas, southern coast, northeastern highlands and northern coastal mainly over Dar es Salaam and Pwani regions, and Unguja Island.

In March, below normal rainfall ranging between 50% and 75% of long-term mean was observed over the coastal area extending to Morogoro, Kilimanjaro and Manyara regions. While above normal rainfall ranging between 125% and 150% was observed over the western part of the country extending to areas surrounding Lake Victoria. However, mainly normal rainfall between 75% and 125% was observed over the central part of the country extending to northeastern highlands, southwestern highlands and southern parts of the country.

Furthermore, large part of the country was relatively wetter during November, but slightly wet during December. As such, rainfall amount exceeding 200% of long-term average was observed across the country during November, while rainfall amount exceeding 150% of the long-term average was observed mainly over the areas surrounding Lake Victoria extending to western part of the country during December. While June, July, August, and September are climatologically dry months for most areas in the country, but for the year 2023, above normal rainfall exceeding 200% of the long-term average was observed in June over the eastern half of the country and western parts of Lake Victoria (Figure 7a).

On 1st June 2023, the rainfall amount of 56.0 mm was recorded at Moshi meteorological station, which is ranked third highest in the month of June since the station’s establishment in 1929. Noting that, the rainfall events in June were mainly observed in the first dekad of the month, signifying the continuation of the MAM 2023 rains.

Besides, the country was somewhat dry during July and August and to a lesser extent in September especially over the southern parts of the country, yet extremely below-average rainfall lower than 50% of the long-term average was observed over many parts of the country (Figure 7b). In contrast, above normal rainfall was observed over the western parts of the country, northeastern highlands and eastern part of the Lake Victoria during September. This condition, however, should not be translated to drier or wetter conditions experienced in the country because these months are normally dry, although occasional rains associated with atmospheric perturbations do occur.

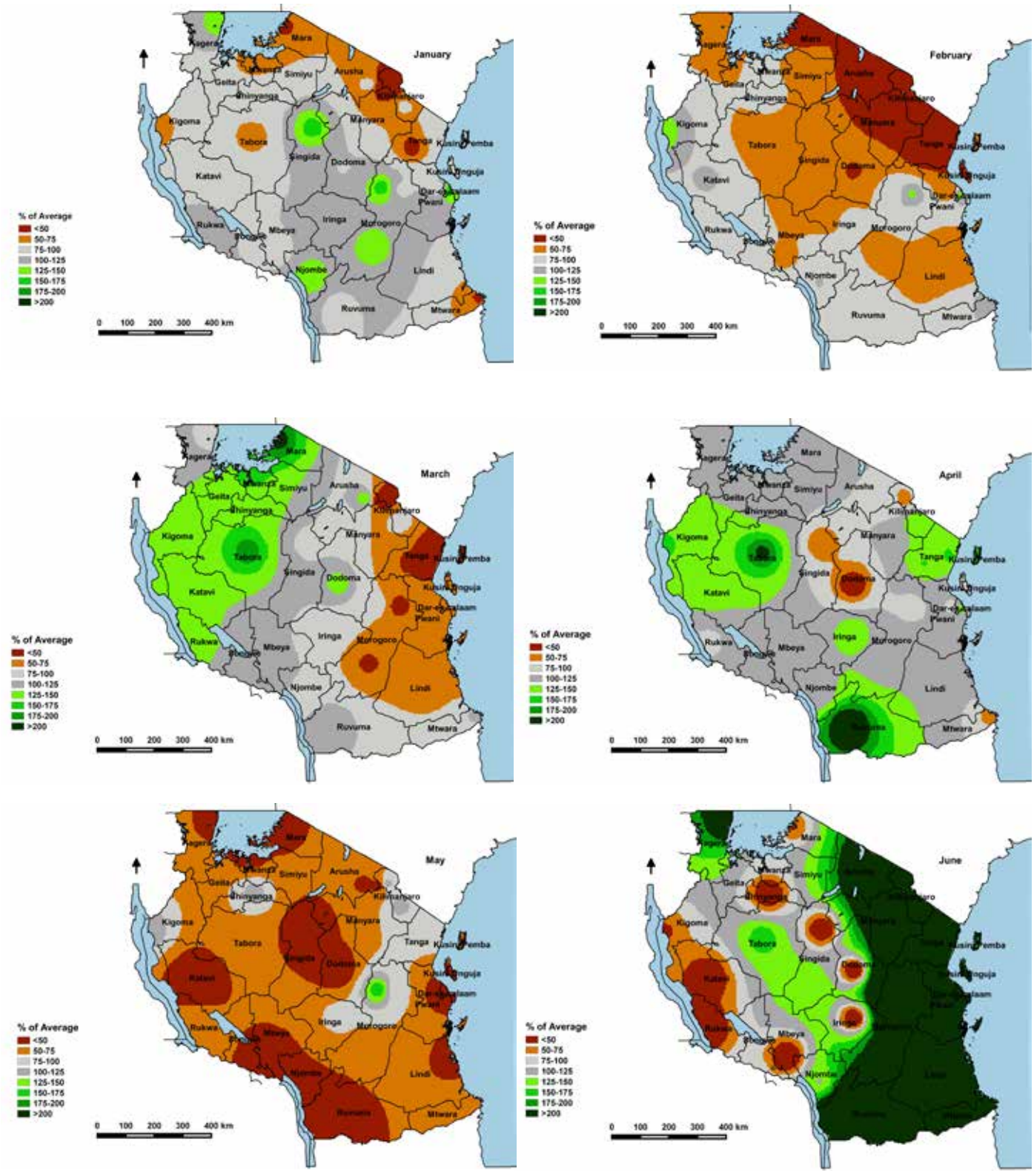

Figure 7a: Monthly rainfall anomalies as percentage of long term average (1991–2020) for January to June 2023

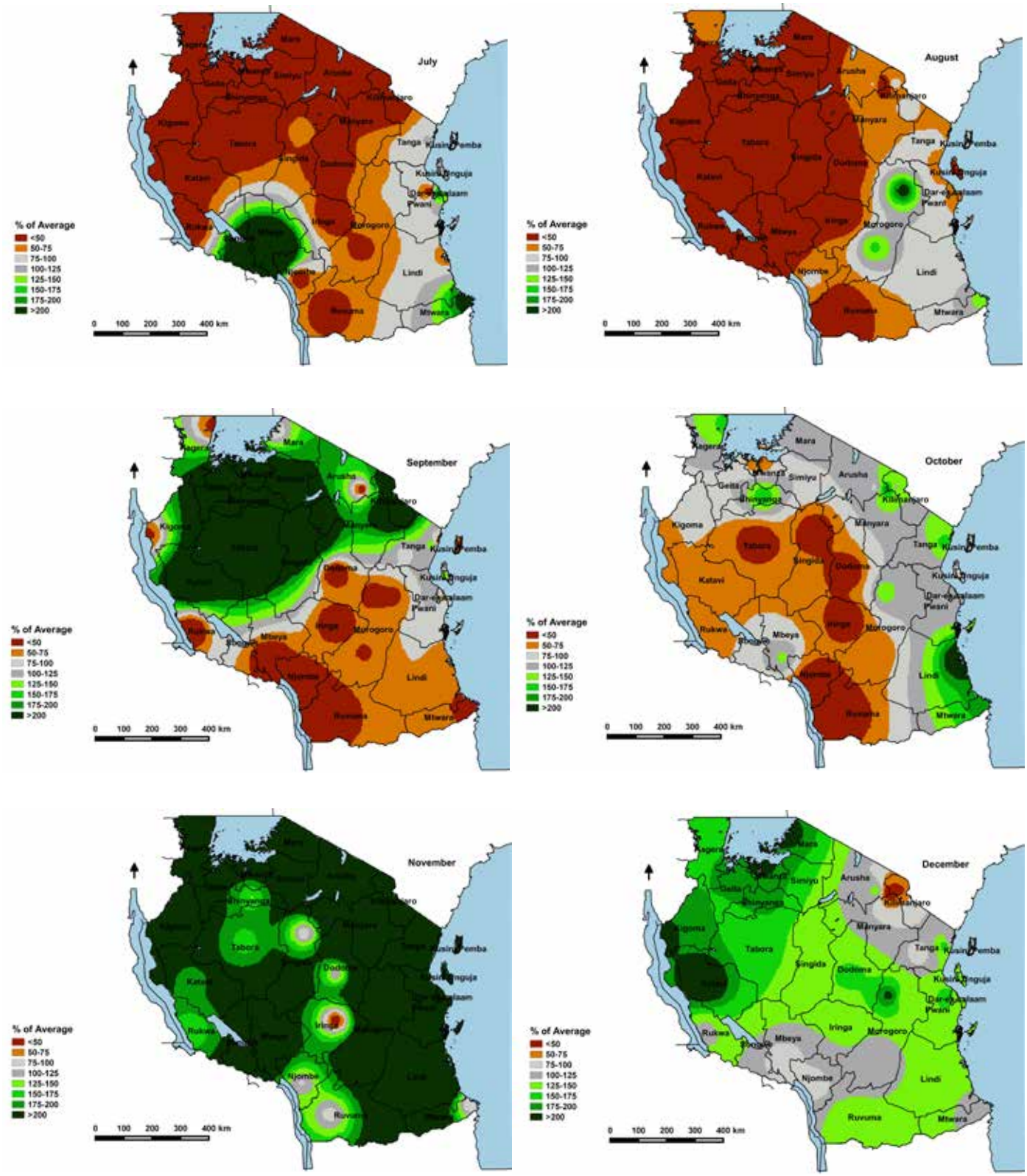

Figure 7b: Monthly rainfall anomalies as percentage of long term average (1991–2020) for July to December 2023

3.4 Cumulative rainfall

The cumulative rainfall presentation is used here to describe the performance and trends of observed rainfall for different areas in the country. The observed deficit or large quantity of rainfall in 2023 is indicated by the deviation of observed cumulative rainfall from the long-term average cumulative rainfall for the respective season. Thus, when the observed cumulative rainfall is lower than the long-term average cumulative rainfall then a deficit of rainfall was observed in a respective season and vice versa.

During the NDJFMA (2022-2023) rainy season, the observed cumulative rainfall was close to long-term average for most stations except for Dodoma, Mtwara and Mahenge meteorological stations whose rainfall was slightly lower than the long-term average (Figure 8a). Notably, a considerable rainfall deficit of about 230 mm was observed at Mtwara meteorological station. Unlike, Igeri station in the southwestern highlands indicated rainfall total that was slightly higher than the long-term average. In addition, rainfall was fairly distributed during the season for most stations.

During the MAM rainy season, a significant rainfall deficit was apparent for a few stations in the northern coast stations (represented by Zanzibar) and northeastern highlands (represented by Moshi) (Figure 8b). Thus, recorded rainfall deficit in these stations were 337 mm and 200 mm respectively as compared to long term average. However, other stations in the area characterized by bimodal rainfall regime recorded the rainfall total amounts that were nearly similar to the long-term average.

For the OND season, mainly greater amount of cumulative rainfall was recorded in all stations receiving two distinct rainy seasons (Bimodal regime) compared to the long term average as shown in Figure 8c. Significant amount of rainfall was observed over the large part of northeastern highlands and northern coast. As such, Julius Nyerere International Airport (JNIA) (Dar es Salaam), Tanga, Kisauni (Zanzibar), Karume airport (Pemba), Moshi and Arusha meteorological stations recorded total rainfall amounts which were about three to four times higher than the usual OND rainfall totals. In contrast, areas surrounding Lake Victoria (represented by Mwanza, Musoma, and Bukoba stations) and Morogoro region (represented by Morogoro station) received slightly higher than average rainfall as compared to the northern coast and northeastern highlands.

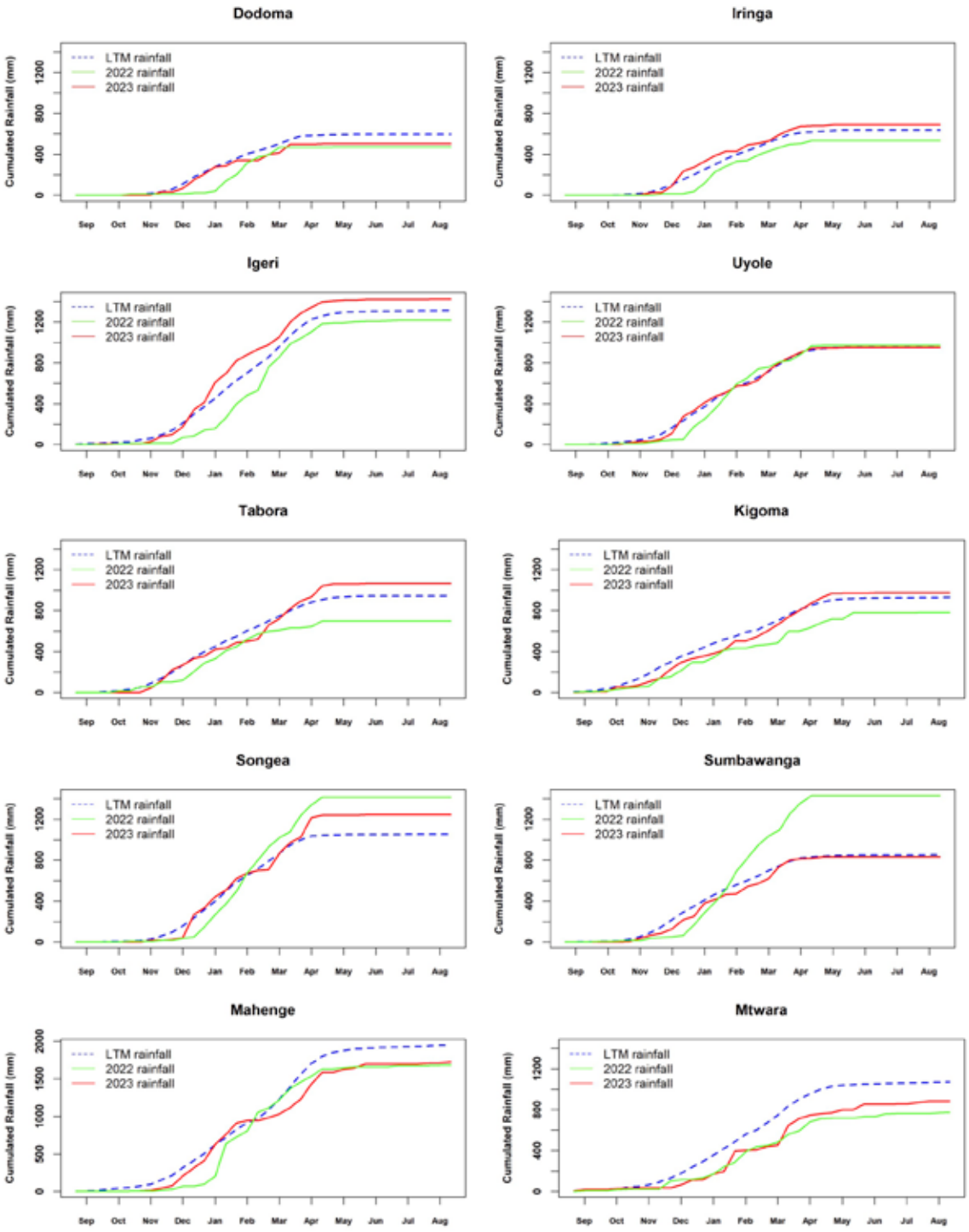

Figure 8a: Cumulative rainfall for the NDJFMA season for Dodoma, Tabora, Kigoma, Iringa, Mtwara, Uyole, and Songea meteorological stations, presented as accumulation of dekadal rainfall totals for each month starting from September 2022 to August 2023

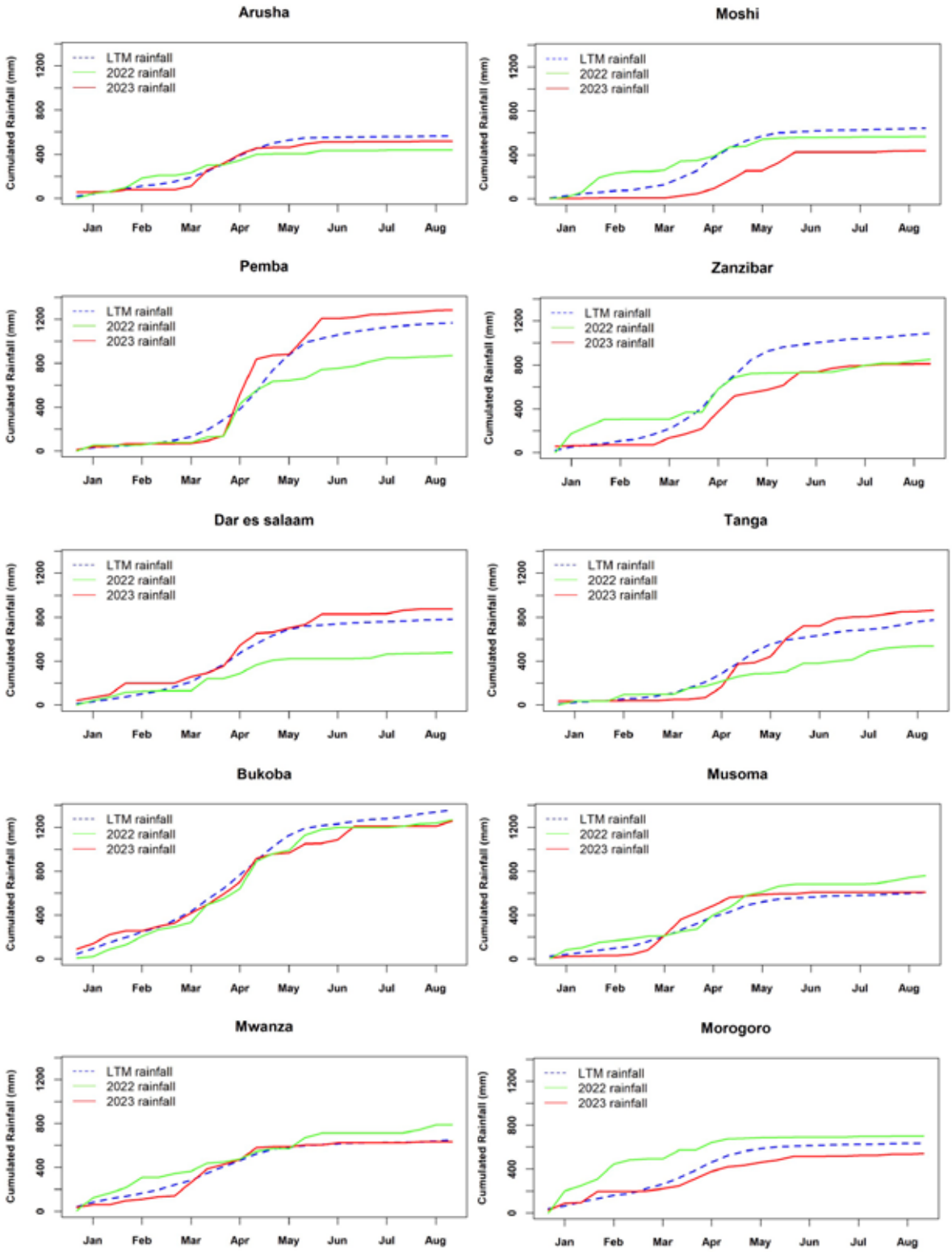

Figure 8b: Cumulative rainfall for MAM season for Bukoba, Mwanza, Musoma, Shinyanga, Dar es Salaam (JNIA), Morogoro, Tanga, Zanzibar (Kisauni), Arusha, and Moshi meteorological stations, presented as accumulation of dekadal rainfall totals for each month starting from January to August 2023

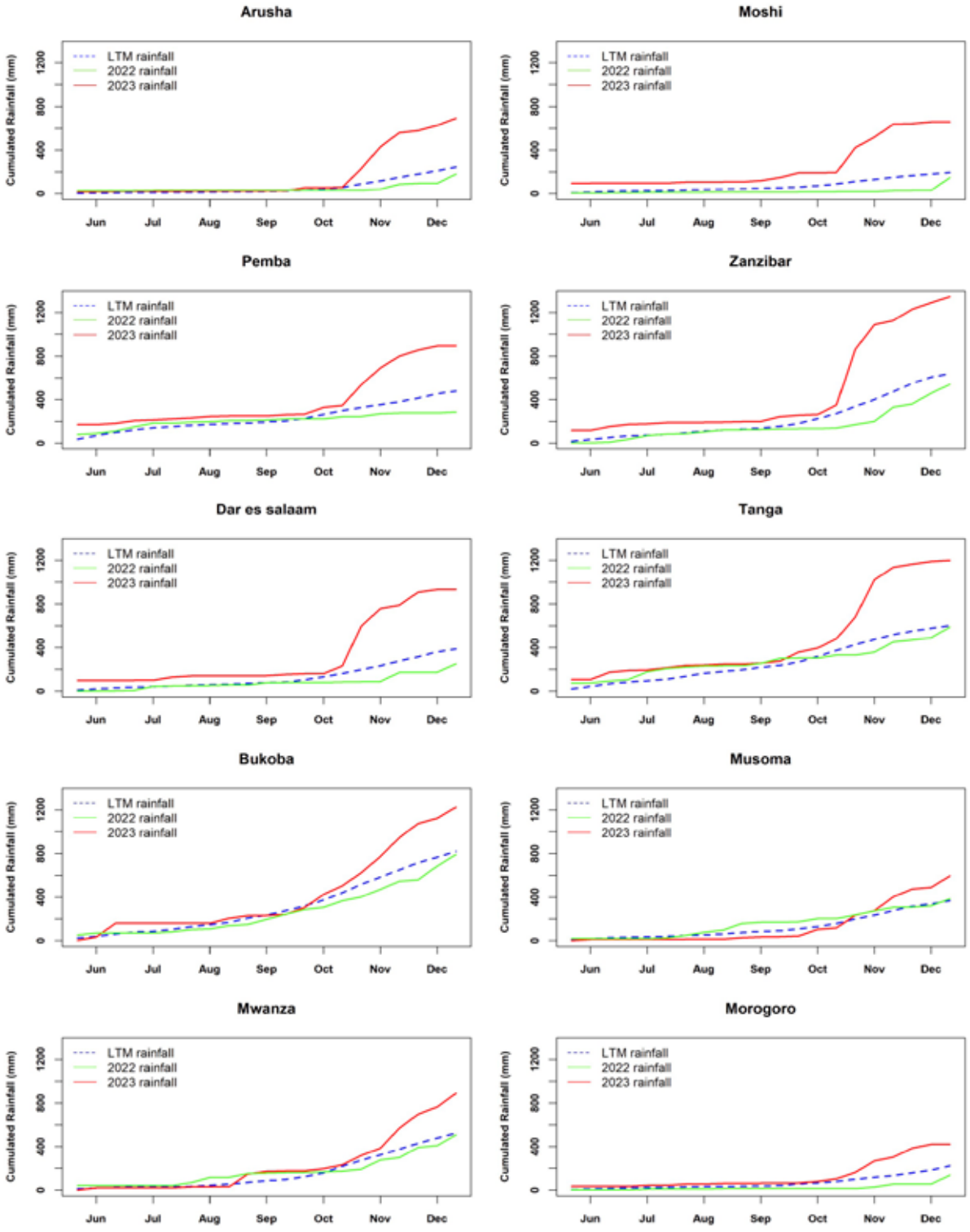

Figure 8c: Cumulative rainfall for OND season for Bukoba, Mwanza, Musoma, Shinyanga, Dar es Salaam (JNIA), Morogoro, Tanga, Zanzibar (Kisauni), Arusha, and Moshi meteorological stations, presented as accumulation of dekadal rainfall totals for each month starting from June to December 2023

4. Extreme weather and climatic events

In 2023, several cases of heavy rainfall associated with widespread floods were reported detrimental. However, not all extreme rainfall events were quantified due to insufficient meteorological observation networks in urban and remote areas. The recent deadly mudslide in the northeastern part of the country (Hanang, Manyara region) is an example of events whose rainfall amounts were not measured but had significant impacts in history. The extreme weather events, particularly heavy rains, mudslides and localized thunderstorms were mainly observed in the beginning of the year and in the end of the year. Some of the events especially near the end of the year were exacerbated by the presence of El Niño condition and positive Indian Ocean Dipole (IOD). Extreme high temperatures were also reported in different parts of the country.

4.1 Extreme rainfall and flood events

In 2023, heavy rains in January and February were mainly observed over the southern, western and central parts of the country consistent with the passage of the ITCZ over those areas. The recorded incidences of heavy rainfall activities were seen to spread to the northern part of the country from March through June and later from October through December as the ITCZ migrated to those areas. However, during December the extreme events were mainly confined over the southern, central, and western part of the country. In general, a considerable number of heavy rains and flood events were reported in different parts of the country. This section presents some of the extreme rainfall events that exceeded 100 mm within 24 hours and the rainfall events that were less than 100 mm, but considered exceptional in history or due to the impacts they have caused.

On 12th January 2023, torrential rain that fell for approximately four hours caused floods and affected many areas in the Morogoro urban district. With this event, 48.8 mm of rainfall was recorded at Morogoro meteorological station. Generally, eight events of rainfall exceeding 50 mm were recorded over the country, mostly in the southwestern highlands, west, and central parts. For-instance, 95.8 mm was recorded at Mahenge meteorological station on 16th January 2023 which is the 10th highest for January since the establishment of the station in 1994, while 79.4 mm of rainfall was recorded at Hombolo meteorological station on 21st January 2023, and is the second highest for January since the station was established in 1974.

In February, about 11 events of rainfall exceeding 50 mm were recorded across different parts of the country, especially in the western parts, southwestern highlands, and a few parts of the northern coast. For example, rainfall amount totaling 111.2 mm and 97.5 mm was recorded in two hours from Dar es Salaam Port and (JNIA) meteorological stations respectively. These amounts are the highest in February for these stations but the 16th and 23rd on record for these stations since their establishment in 1990 and 1940, respectively. Furthermore, 105 mm of rainfall was recorded at Songwe meteorological station in four hours on 25th February 2023. This is the record break for the station since its establishment in 2012.

During March 2023, cases of heavy rainfall were mainly recorded over the northern parts of the country. For example, on 19th March 2023, 117.8 mm of rainfall was recorded at Dar es Salaam Port meteorological station in seven hours, which is a record break event for the month of March but the 14th on record since the station was established in 1990. In addition, 127 mm of rainfall was recorded at Ukiriguru meteorological station in four hours on 23rd March 2023. This is a record break for March but the third highest for the station since its establishment in 1963. Furthermore, 106.7mm of rainfall was recorded at Arusha meteorological station on 22nd March 2023 which is ranked the fourth highest for March but the 13th on record since the station's establishment in 1946. Generally, there were 10 events of rainfall exceeding 50 mm recorded across different parts of the country.

On April 25th 2023, heavy rainfall in Arumeru districts and the surrounding regions caused floods that washed away a car with five people. Although rainfall records on the day of events were less than 50 mm for the area and the surrounding stations the region experienced continuous rains for about 10 days prior to the events a scenario that contributed to the observed floods in different parts. On the other hand, two districts in Katavi (Mpimbwe) and Rukwa (Sumbawanga) were affected by floods on April 12th 2023 as a result of continuous heavy rains over those areas. The flood destroyed riverbanks allowing water to flood to the settlement and causing massive destruction.

Furthermore, several cases of extreme rainfall events were observed in different locations in the country. For example, 134.5 mm was recorded at Lyamungo meteorological station on 24th April 2023 which is ranked as the 13th highest for the month of April but the 22nd overall since the establishment of the station in 1935. Moreover, 100.5 mm of rainfall was recorded at the same station on 29th April 2023 and is ranked 46th for April since the station's establishment.

On the other hand, 128.4 mm of rain was recorded at Pemba meteorological station on 17th April 2023 and is ranked as the 29th highest for the month of April since the station's establishment in 1974. Generally, there were 30 events of rainfall exceeding 50 mm recorded across different parts of the country.

May 2023 was the relatively dry with the recorded 5 events of rainfall exceeding 50 mm across different parts of the country. However, 89.6 mm of rain was recorded at Mlingano meteorological station on 28th May 2023, this event is ranked the 10th highest for the month of May since the establishment of the station in 1936. On 1st June 2023, 56 mm of rain was recorded at Moshi meteorological station, which is ranked as the third highest in the month of June since the station's establishment in 1929.

In November 2023, persistent rainfall and heavy at times were observed in the first and second dekad especially over many areas in Dar es Salaam, Pwani, Zanzibar, and Tanga, as well as in the northeastern highlands. Specifically, 185.0 mm of rain was recorded at Lyamungu on 1st November 2023, which is a record break for November and ranked number 7 on record since the establishment of the stations in 1935. For the other areas, the recorded rainfall amounts and their ranks for each station (in brackets) for the month of November were; 100 mm (6th) recorded at Zanzibar on 1st

November 2023, 120.4 mm (4th) at Dar es Salaam on 2nd November 2023, 133.1 mm (3rd) recorded at Zanzibar on 4th November 2023 and 146.1 mm (2nd) at Zanzibar on 5th November 2023. During this period of a rainstorm, cases of floods were reported in different parts of the northern coast especially Dar es Salaam and Zanzibar. Furthermore, 134 mm and 109.8 mm of rain were recorded at Tanga meteorological station on 15th and 16th November 2023. Generally, November 2023 was a record break month for recording greater number of days with rainfall amounts exceeding 50 mm (44 events) followed by April (30 events).

In December 2023, about 21 events of rainfall exceeding 50 mm was recorded of which higher rainfall amounts exceeding 80 mm were mainly recorded at Kibaha, Dodoma, Kigoma, Tabora, Mpanda, and Ilonga meteorological stations. As such, 112.8 mm was recorded at Ilonga meteorological station on 9th December 2023, while 106.6 mm of rain was recorded at Mpanda meteorological station on 26th December 2023.

Apart from the recorded rainfall amounts from the stations, localized thunderstorms associated with heavy rains (not recorded at meteorological stations) and strong winds were reported in different parts of the country. These events caused massive destruction of infrastructure and people's properties, as well as casualties and even deaths.

4.2 Extreme temperature events

In 2023, greater number of hot days with Tmax exceeding 35 °C was mostly recorded in northeastern parts of the country during February and March and over the central and western parts of the country during October. Thus, TMA has recorded 54 events of daily temperature exceeding 35 °C in February, 44 events in March and 30 in October. The observed higher Tmax may be linked to the prolonged dry spells for a large part of the country during October. The highest daily temperatures in 2023 were 37.1 °C recorded on 5th February at Kilimanjaro International Airport (KIA) and 37.0 °C recorded on 6th and 9th March 2023 at Moshi meteorological station. The highest daily temperature recorded at KIA is ranked the 10th highest for February since the establishment of the station in 1972, while that of Moshi is ranked the 21st highest temperature for the month of March since station establishment in 1934.

On the other hand, a large number of warmer night temperatures (Tmin) events exceeding or equal to 26 °C were observed in March (127 events), December (54), April (43 events), January (38), and February (37 events), indicating that more warm nights were recorded at the beginning, and at the end of the year. Notably, the events were recorded especially at stations located along the coast which includes Mtwara, Kilwa, Naliendele, Tanga, Zanzibar, Pemba, Mlingano, and Dar es Salaam.

In contrast, cool nights with temperatures lower than 10 °C were observed over the southwestern highlands during May, June, July, August, and September 2023, whereas June and July 2023 had higher records of cool nights with temperatures lower than 10 °C and 5 °C, respectively. TMA records shows that at least 11 events with cold nights were recorded in July and 5 events in June. The lowest

night temperature record in 2023 was 2.5 °C, recorded at Uyole agro-meteorological station on 5th July 2023, and is ranked as the 13th lowest minimum temperature for the recent decade. Notably, no temperature event lower than 2.5 °C has ever been recorded at this station after 2013 indicating that minimum temperatures over this station have drastically increased from the 2000's.

4.3 Extreme climatic events

Rainfall deficit was observed over a large part of the country in May during 2023. Generally, May was relatively dry, especially for the northeastern highlands, northern coast and areas surrounding the Lake Victoria. Thus, May 2023 is ranked as the eighth driest May since 1970. Notably, most meteorological stations in these areas except the northeastern highlands and Tanga region recorded a rainfall deficit in May that was one-half to one-third of the long term average for May rainfall.

On the other hand, November was the wetter month of the year and a record break wet November since 1970. Sufficient rains were recorded across the country during November 2023. As such, the rainfall amount of 286.4 mm was recorded in November in the country, which is 193.2 mm higher than the long-term average and is equivalent to 307 % of the November long term average. Specifically, many meteorological stations located in the northeastern highlands (Kilimanjaro and Arusha regions) had reported rainfall totals that were five to six times higher than the usual November rainfall with the exception of Moshi meteorological station (Kilimanjaro region) which reported the total rainfall that was almost seven times higher than the usual November rainfall. Likewise, areas in the northern coast (Dar es Salaam, Coast, Tanga, and Lindi regions, and Unguja and Pemba Islands) had reported rainfall totals that were four to five times higher than the usual November rainfall, whereas, stations surrounding Lake Victoria (Mwanza, Musoma, and Bukoba regions) reported rainfall totals that were two times higher than the usual November rainfall for the respective areas.

On the contrary, although June is a relative dry month for the whole country, unusual rainfall was observed over some parts of the country particularly, the northern coast and northeastern highlands. Most meteorological stations in the northern coast, such as Tanga, Zanzibar, Mlingano (Tanga region), Pemba, Ilonga (Morogoro region), and Bukoba reported rainfall totals that were two to three times higher than the usual June rainfall. The exception was for Moshi station (Kilimanjaro region) which reported the total rainfall that was about five times higher than the usual June rainfall. Noting that, the rainfall events in June were prominently in the first dekad of the month, signifying the continuation of the MAM 2023 rains.

5. Major drivers of weather and climate events in 2023

The observed seasonal rainfall and their extreme events in the year 2023 were linked to several factors including the presence of the Inter Tropical Convergence Zone (ITCZ), active phases of the Madden Julian Oscillations (MJO), and tropical cyclones over the southwestern Indian Ocean and the variation of Sea Surface Temperatures (SSTs) over the Atlantic, Indian, and Pacific Oceans. Normally the country gets more rainfall activities in the beginning of the year through May, followed by a relative dry condition from June to September before the rain resumes in October through December.

In the beginning of the year, few tropical cyclone cases were observed over the southwestern Indian Ocean some of which enhanced or denied rainfall activities over some parts of the country. In January for example, the occurrence of the tropical cyclone Cheneso over the Mozambique Channel during the third dekad of month enhanced the influx of moisture from the Congo basin towards the country. This cyclone brought significant rainfall over the country especially the southwestern highlands, central, and southern regions.

Furthermore, the presence of tropical cyclone Freddy over the eastern part of Madagascar in the second dekad of February and later over the Mozambique Channel in the third dekad brought significant rainfall over the western and southwestern parts of the country, but denied rainfall activities, especially over the eastern sector of the country. This denial of the rainfall activities is well supported by the low-level wind anomaly in February (Figure 9) such that an enhanced low-level easterly wind anomaly was seen over the southwestern Indian Ocean extending to the coast of Tanzania. The winds deviated as they approached the coast especially in the southern parts of the country weakening the influx of moisture especially over the southern coast.

In addition, weak to enhanced low-level easterly wind anomalies was observed over the tropical Indian Ocean during March and April 2023. However, a divergent wind anomaly was observed across the central Tropical Indian Ocean (Figure 9, right panel) in May 2023, a condition that reduced the influx of moisture from the ocean towards the country. This condition may partly explain the unusual dry condition observed over the country during May 2023 as depicted in Figure 7a.

In addition, the variations of SSTs in the adjacent Indian Ocean and Central Equatorial Pacific Ocean (CEPO) also played a big role in describing the rainfall behavior over the country in 2023. Generally, near average SST were observed over the western Indian Ocean, along the coast of Tanzania from January 2023 to May (Figure 9, left panel).

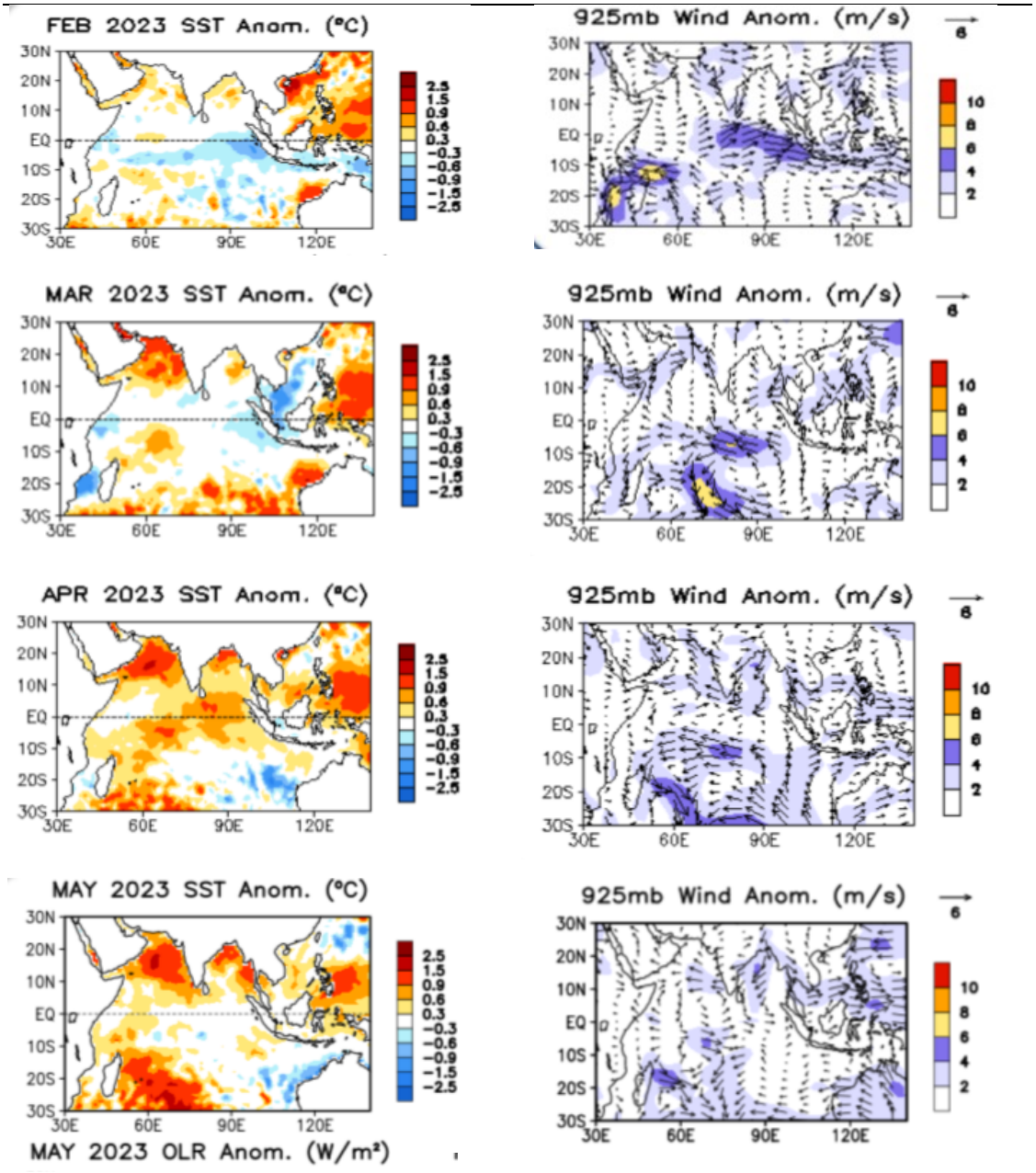

Figure 9: Sea Surface Temperature Anomalies (left panel) and 925 mb wind anomaly vector and its amplitude (right panel) for February, March, April and May. Anomalies are departures from the long term average (1991–2020). Source: https://www.cpc.ncep.noaa.gov/products/GODAS/ocean_briefing_archive_pdf.shtml

Moreover, in the tropical Indian Ocean the warming gradually increased from August through December 2023 (Figure 10 left panel). The highest level of warming was observed over the western Indian Ocean which indicated the existence of a positive Indian Ocean Dipole (IOD) event. In support, the easterly wind anomaly over the central tropical Indian Ocean extending to the East African coast (the purple circled areas in Figure 10 right panel) intensified progressively from September to November, which favoured the vast influx of moisture to the country especially during November. This is consistent with increased level of convection over the northwestern equatorial Indian Ocean during September through November (blue colour shade inside the black circled areas in Figure 10 right). The enhanced convection spread to the horn of Africa in October and further south to the northern Tanzania during November.

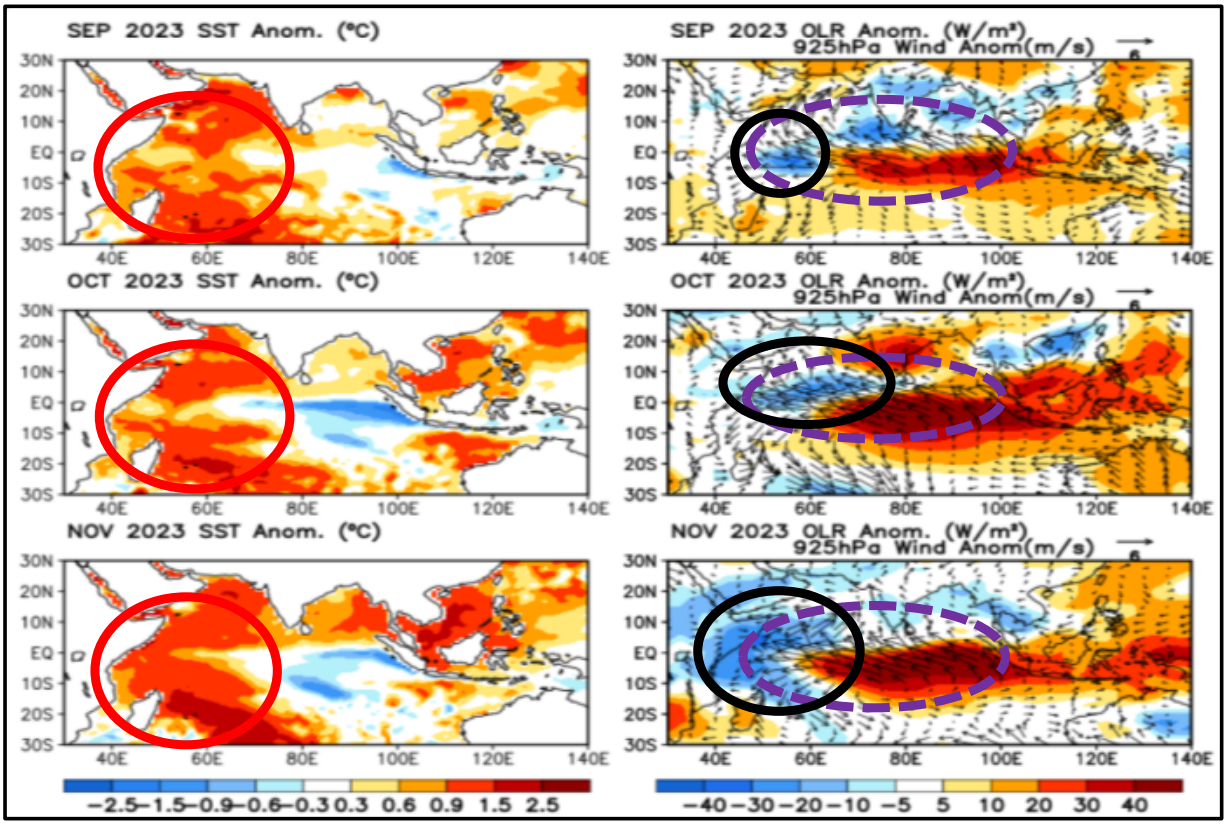

Figure 10: Tropical Indian Ocean SST (left panel), Outgoing Long wave Radiation (colored shades (right panel), and Low-level wind vector anomaly at 925 mb (right panel) for September, October and November 2023. Anomalies are departures from the long term average (1991–2020). Source: https://www.cpc.ncep.noaa.gov/products/GODAS/ocean_briefing_gif/global_ocean_monitoring_2023_12.pdf

In addition, the evolution of Indian Ocean SST indices in 2023 indicated that the IOD, was in a neutral phase from January to July, and it transformed to Positive phase from August through December. According to the Climate Prediction Center (CPC) of the National Centers for Environmental Prediction (NCEP) international desk data, the IOD observed the highest values in October through December with its peak of 1.5 ºC observed in November.

On the other hand, the evolution of Sea Surface Temperature Anomalies (SSTAs) over the CEPO indicated that mainly Neutral ENSO condition was observed between February to May and El Niño phase from June through December 2023. According to the CPC/NCEP Ocean briefing reports, the El Niño condition (explained by Niño3.4 index) strengthened more in November and December 2023, with the Niño3.4 index reached 1.9 ºC and 2.0 ºC, respectively.

The impacts of ENSO and IOD conditions on the East African rains have been established and they are linked to enhanced or suppressed rainfall activities over much of the Eastern Africa countries including Tanzania. Thus, the presence of El Niño condition and positive IOD especially during the OND 2023 rainy season enhanced rainfall activities over many parts of the country particularly areas surrounding Lake Victoria, northeastern highlands and northern coast. This is clearly seen in Figures 6 and 7b, whereby the northern coast, northeastern highlands and areas surrounding Lake Victoria have received normal to above-normal rainfall during the OND rainy season.

6. Weather and climate related impacts

In 2023, several cases of heavy rainfall associated with widespread floods were reportedly detrimental. These events had impacts on livelihoods, including the loss of lives and properties, destruction of infrastructure, and displacement of people. For example, the recent tragic mudslide in the northeastern part of the country (Hanang, Manyara region) on Sunday, 3/12/2023 had historic significant impacts, though the rainfall amounts were not officially recorded. In that event, the mudslides from Mount Hanang, which was the result of heavy rainfall eroded and buried nearby homes and farm fields in Katesh and Gendabi ward.

According to data from the PMO-DMD, the mudslides resulted in 89 reported fatalities, 139 injuries, and the displacement of 5600 individuals. Additionally, 1166 households and their properties were affected, with 724 houses and 496 acres of farm fields destroyed. Furthermore, a number of livestock perished, and infrastructures such as road, water points, electricity, communication networks, health and education services were also destroyed (Figure 11).

Figure 11: The aftermaths of mudslides that impacted Katesh town on Sunday, 3/12/2023

In November 2023, the observed continual and heavy rains caused devastating floods and affected many areas in Dar es Salaam, Zanzibar, and Tanga. In Dar es Salaam, the rains on 11th November 2023 affected several households and their properties as shown in Figure 12. The data from the PMO–DMD indicates that atleast 14 people were confirmed dead, 17 injured, 6785 households with 29,830 people affected and some displaced. Furthermore, 2916 houses were affected by the flooded water among them 213 were completely destroyed while 2703 faced minor damages due to the surrounded water.

In addition, 130 acres of vegetable gardens were destroyed, 120 livestock died, and nine schools along with two local government offices were affected. Moreover, about 292 Km of roads connecting the city were destroyed along with the riverbanks of 13 rivers in the city. These consequently affected peoples settled near these rivers' banks. According to the Mwananchi newspaper dated 28th November 2023, eight people died from floods due to continuous rainfall in Tanga region that month. Furthermore, the Mwananchi newspaper dated 13th November 2023, reported that heavy rainfall in Arusha on 12th November 2023, led to the death of about five people, while 90 people were displaced within seven hours. At least 23 houses and infrastructure such as roads and bridges were affected by floods.

Figure 12: Houses surrounded by the flooded water at Kigogo (left top panel) and destroyed bridge by flooded water at Msumi (right top panel) both in Dar es Salaam, and Lake Maboga in Zanzibar (bottom left and right panels) in November 2023

On 12th January 2023, the floods affected many areas in the Morogoro urban district, with 200 houses affected by the flooded water and children did not go to school for about 10 days. Furthermore, five people lost their lives on 25th April 2023 after their car being washed away by the flooded river in Arumeru district as indicated in Figure 13.

Figure 13: The rescue of the car that was carried away by floods in Arumeru district on 25th April 2023. In this event five people died. Source: https://www.instagram.com/p/Crd5B6RtYMH/

Likewise, two districts namely Mpimbwe (Katavi) and Sumbawanga (Rukwa) were affected by floods as a result of continuous heavy rains over those areas on 12th April 2023. The flood destroyed riverbanks letting flooded water to penetrating to the people's settlement and causing massive destruction. As a consequence, several houses were surrounded by the flooded water out of which 10 were completely destroyed. In addition, about 22 households were affected and displaced, destruction of bridges, roads, and loss of properties were also reported during this event.

Moreover, the report from the Tanzania Police Force indicated that 37 children were reported dead in nine regions of Tanzania (Arusha, Kilimanjaro, Dar es Salaam, Kigoma, Mwanza, Pwani, Katavi, Morogoro and Rukwa) from January to April 28th, due to heavy rainfall in those regions. The report indicated that, the deaths were mainly due to some being carried away by flooded water and some drawn in open wells and dams that were flooded by heavy rains.

7. Summary and conclusion

The climate of Tanzania for 2023 was characterized by the record break temperatures and rainfall events at the annual and monthly time scales as well as the detrimental climate extremes. As such 2023 was the warmest year on record since 1970 by recording annual air temperature of 0.6 °C above the long-term average (1991-2020). The observed country temperature is consistent with the observed record break global annual temperature for 2023. Notably, the global temperature of 1.45

°C above the pre-Industrial temperature level (1850-1900) was observed in 2023 as portrayed by World Meteorological Organization (WMO). On average, August, September, and October were the warmest months of the year and record break warmer since 1970, while January and November were slightly cool months in the year. Furthermore, the large part of the country was anomalously warmer during the night (Tmin) compared to day-time (Tmax) especially from June through December. However, a substantial cooling during the day with anomaly of up to -2 °C was observed over the northeastern part of the country in November, the condition which may partly be explained by the observed above normal rainfall over those areas, and could be associated with enhanced rainy and cloudy cover conditions that hindered the incoming solar radiation.

The year 2023 was ranked the 8th wetter year on record since 1970. Mainly normal rainfall was observed during the November 2022-April 2023 (NDJFMA) and MAM 2023 rainy seasons while above normal rainfall was observed over the large part of the country during OND rainy season, consistent with the presence of El Niño and positive Indian Ocean Dipole. Based on the historical meteorological records, the 2023 OND rainy season is ranked the third wettest OND season on record since 1970. In addition, a rainfall deficit was observed over a large part of the country in May 2023, whereas sufficient rains were observed in November. As such, May was the driest month in a year while November was the wettest month in a year and a record break wet November since 1970.

The presence of major oceanic mode of variability, El-Niño condition over the equatorial Pacific Ocean and the positive IOD during the second half of the year caused extremely wet condition especially during November and December, mainly over the northern coast and northeastern highlands and areas surrounding the Lake Victoria. These rainfall events in one way or another brought significant impacts to the community including floods and landslides over the northeastern highlands. The impacts among others includes the loss of lives and properties, injuries, displacement from homes, destruction of infrastructures and people's settlements, and the destruction of hundreds of acres of farm fields.

Moreover, extreme weather events, especially heavy rainfall accompanied by strong winds were also observed across large part of the country and throughout the year except for the months of June-September. The increased vulnerability to the impacts of extreme weather events would largely be reduced if the weather and climate forecasts and warnings/advisories issued by TMA are closely followed, and proper mitigation actions are taken or put in place timely. Furthermore, the effective use of these information by the public and different government sectors for decision-making could have reduced the impacts in their day-to-day socio-economic activities.

8. Appendix

8.1 Climate of Tanzania

8.1.1 Temperature distribution

Temperatures across the country are normally characterized by relatively less fluctuation throughout the year. The annual long-term average temperature over different stations in the country ranges from 14.7 °C to 27.5 °C. Regions with the highest temperatures are along the coast and in the western parts of the country. The season with high temperatures starts in October and continues through February or March, while the cool season is from May to August. The annual minimum air temperature (Tmin) and maximum air temperature (Tmax) across the stations range from 9.9 °C to 24 °C and 19.5 °C to 31.2 °C, respectively.

8.1.2 Rainfall distribution

The rainfall distribution and variability are driven by multiple factors including the East African Monsoon, ENSO, and westerlies from Congo, tropical cyclones, and ITCZ. The migration of ITCZ north and south across the equator are among the main factors affecting distribution and variability of rainfall in Tanzania and the entire East Africa. The migration of ITCZ lags the overhead sun by 3-4 weeks over the region. The ITCZ migrate to southern regions of Tanzania in October to December, reaching southern part of the country in January-February and reverses northwards in March, April and May. Due to this movement, some areas experience single and double passages of the ITCZ. The areas that coincide with single passage are known as unimodal areas. These include the southern, southwestern, central, and western parts of the country, which receive rainfall from November to April or May in the subsequent year, (also known as *Msimu*). Areas that experience double passage are known as bimodal, and include northern coast, northeastern highlands, Lake Victoria basin, and the Islands of Zanzibar (Unguja and Pemba). These regions receive two distinct rainy seasons. The long rainy season (also known as *Masika*), which starts mainly in March and continues through May (MAM) and the short rainy season (also called *Vuli*) which starts in October and continues through December (OND). January and February are the transition period (relatively dry) for bimodal areas while June, July, August, and September are dry months for the entire country.

8.2 Percentage rainfall

Percentage rainfall is obtained by taking the ratio of the (monthly/seasonal/annual) rainfall of the current year to long-term average (1991-2020) of monthly/seasonal/annual rainfall multiplied by 100. The percentage value greater than 125 is regarded as above normal rainfall and that between 75 and 125 is normal rainfall. The percentage value less than 75 is below normal.

8.3 Temperature anomaly

Temperature anomaly is calculated by taking the difference between the observed values (monthly/seasonal/annual) for the current year and the long-term average (1991-2020).

8.4 Cumulative rainfall analysis

Cumulative rainfall is defined as the rainfall that has accumulated in a prescribed period (e.g. 10 day or monthly interval). Cumulative rainfall analysis is used to characterize observed rainfall performance and trends for different areas in the country. The cumulative rainfall departure from long-term average is a concept used to evaluate the temporal correlation of the seasonal rainfall with the long-term average rainfall. Cumulative rainfall is used to see how much rain has fallen in the region within the prescribed period such as previous week, month, or year. The concept has hydrological meaning in the short term as a generalized evaluation of either insufficient or abundant rainfall. In addition, the cumulated rainfall saves as a tool to detect the start and end of the seasons and the presence of wet or dry spells in the season.

In this report, cumulative rainfall is an accumulation of observed dekadal rainfall from a selected reference point. Dekadal rainfall for 2023 was calculated by observing the following procedures:

- Areas characterized by unimodal rainfall regime, rainfall from September 2022 to August 2023 was accumulated, because rainfall season over these areas starts from November in the previous year to April in the following year (NDJFMA).
- Areas characterized by bimodal rainfall regimes, accumulated rainfall from January to August 2023 was used to characterize rainfall for MAM season and rainfall from June to December 2023 was used to characterize rainfall for OND seasons.
- Dekadal baseline climatology from 1991-2020 was calculated by following same procedure as it is done in calculating dekadal values for individual season.

8.5 Spatial analysis for temperature and rainfall distribution

Temperature and rainfall were analyzed as point data for the selected stations across the country. About 29 and 28 meteorological stations were used for rainfall and temperature analysis, respectively. The Inverse Distance Weighting (IDW) interpolation method in Quantum Geographical information system (QGIS) was used to generate spatial distribution maps. The IDW interpolator assumes each input point has local influence that diminishes with distance. It weights the points closer to the processing cell greater than those far away. The IDW algorithm is a moving average interpolator that is usually applied to highly variable data.

8.6 Severe weather

Severe weather is defined as any aspect of the weather or climate that poses risks to life, property or requires the intervention of authorities. Types of severe weather phenomena vary, depending on the latitude, altitude, topography, and atmospheric conditions. Strong winds, hail, excessive precipitation, and wildfires are the forms and effects of severe weather. According to WMO, severe weather can be categorized in to two groups; general severe weather (e.g. windstorms and its accompanied phenomena), and localized severe weather (e.g. downbursts and tornadoes). Extreme weather is described as unusual weather events that are at the extreme of historical distribution for a given area.

Rainfall thresholds in this statement adopted those prescribed by Severe Weather Forecasting Demonstration Project (SWFDP) in East and Southern Africa which is 50 mm or more recorded in 24 hours. However, extreme weather and climatic events can also be described by other statistical terms such as percentiles and on the magnitude of impact caused even if it does not reach the prescribed thresholds.

8.7 Calculations of Sea Surface Temperature anomaly for the IOD and ENSO

The IOD is calculated by taking the difference between the area-averaged monthly mean Sea Surface Temperature Anomaly (SSTA) for the South East Tropical Indian Ocean (SETIO) [90ºE-110ºE, 10ºS-0] and West Tropical Indian Ocean (WTIO) [50ºE-70ºE,10ºS-10ºN], while the Niño 3.4 index (ENSO), is calculated as the area-averaged monthly mean SSTAs (ºC) for the region (5ºN-5ºS, 170ºW-120ºW) over CEPO. Anomalies are departures of observed SSTs from the long-term average (1991-2020).