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TMA
TANZANIA METEOROLOGICAL AUTHORITY

Statement on the Status of Tanzania Climate in 2022

March, 2023

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(TMA)

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Abbreviations

ENSO	El Niño Southern Oscillation
GIS	Geographical Information System
IDW	Inverse Distance Weighting
IOD	Indian Ocean Dipole
ITCZ	Intertropical Convergence Zone
JF	January to February
JNIA	Julius Nyerere International Airport
KIA	Kilimanjaro International Airport
MAM	March to May
MJO	Madden Julian Oscillations
NDJFMA	November to April
DMD	Disaster Management Department
OND	October to December
PMO	Prime Minister's Office
SSTs	Sea Surface Temperatures
SSTA	Sea Surface Temperature Anomalies
SWFDP	Severe Weather Forecasting Demonstration Project
TC	Tropical Cyclone
TMA	Tanzania Meteorological Authority
Tmax	Maximum temperature
Tmean	Mean temperature
Tmin	Minimum temperature
WMO	World Meteorological Organization
ZDMC	Zanzibar Disaster Management Commission

Foreword

The impact of climate change and variability are increasingly becoming widespread with devastating socio-economic and ecological implications across the world. The impacts are uneven across the world, region, country, and even within a single community.

Every year, the Tanzania Meteorological Authority (TMA) conducts robust and comprehensive climate analysis and provides an authoritative statement on the status of Tanzania's climate. The climate statement serves as a tool for climate monitoring and assessment of the state of the earth's climate in near real-time at national scale. In addition, it provides science based information and knowledge on observed climate trends to decision-makers for informed decision making in planning and implementation of various socio-economic activities including in climate change mitigation and adaptation. TMA continues to monitor and document weather and climate patterns and the associated extremes that is critical for understanding the dynamic of climate variability and change in the country. 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.

The 2022 annual statement on the status of climate is the 12th report in the series of climate statements produced by TMA since 2011. It presents a collection of monthly, seasonal, and annual summaries of weather and climate events that occurred in the country in 2022. The statement focuses on trends of key climate indicators (rainfall and temperature), and extreme weather and climate events which were recorded in 2022 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 take this opportunity to congratulate all individuals who contributed to the preparation of this highly informative report.

Dr. Ladislaus B. Chang'a

Acting Director General

Tanzania Meteorological Authority

1. Introduction

Global warming is increasing fast, and is projected to keep increasing over this century and beyond with increasing emission of greenhouse gases. Warmer temperatures are expected to change weather patterns, disrupting the usual balance of nature. Leading to many 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. The country has continued to experience impacts of climate change and variability, especially, extreme rainfall and floods, drought, strong winds, and high temperatures. These weather and climate extreme events have greatly threatened people's livelihoods, especially those with limited adapting 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 hydro meteorological hazards. This 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 2022 climate statement provides a comprehensive summary of the main weather and climate events that occurred in the United Republic of Tanzania from January to December 2022 and their associated impacts by placing them into historical perspective. The major weather and climate events are documented using various weather and climate observation networks as well as information obtained from other reliable sources such as newspapers, media, and reports from the Prime Minister's Office–Disaster Management Department (PMO–DMD) and the Zanzibar Disaster Management Commission (ZDMC).

This report presents monthly, seasonal, and annual trends and temperature and rainfall anomalies for the year 2022. All maps and graphs presented in this report characterize the climate status observed in 2022 relative to the 1991–2020 baseline climatology. Moreover, the major drivers of weather and climatic events that have contributed to severe and extreme climate events are included in this report.

2. Temperature distribution

In 2022, the country's average air temperature (Tmean), minimum and maximum temperatures were slightly warmer than the long-term average for all months. On average, March, April, and May were the warmest months of the year. In these months, the country's average air temperature anomalies were 0.5 °C, 0.7 °C, and 0.7 °C above the long-term average (1991-2020), respectively. In addition, higher temperature anomalies between 0 °C and 1°C above the long-term average were recorded over a large part of the country in January, March, April, and May, except for parts of the northern coast, northeastern highlands, and southern regions, whose daytime temperatures (Tmax) anomalies were between 1 °C and 2 °C. Unlike other months, February 2022 was unusually cool, with daytime temperature anomalies ranging from -2 °C to -1 °C in most parts of the country.

2.1 Annual Mean, Maximum and Minimum Temperature anomalies

The country's annual mean air temperature (Tmean) for 2022 was 23.9 °C, which is 0.2 °C warmer than the 1991–2020 long-term average and ranked as the 5th warmest year on record since 1970. The annual mean temperature anomalies across the country (Figure 1) ranged between 0 °C and 1 °C in most areas of the country except some parts of the central, western, southwestern highlands, and Morogoro region, whose temperatures were below the average in the range of -2 °C to -1 °C.

The observed below-average air temperature anomalies in Figure 1 were influenced by the extended anomalous cool condition during the day in most areas of the country and during the night for western parts of the country as seen in Figure 2.

The country's mean annual maximum temperature was 28.9 °C, which is nearly equal to the long-term average. The Tmax anomalies (Figure 2, right panel) were mostly cooler than average in the range between -2 °C and -1 °C, mostly in western parts of the country. However, in the coastal areas (excluding Lindi region), the northeastern highlands, and the western and southern parts of Lake Victoria, recorded Tmax anomalies ranged from 0 °C to 1 °C.

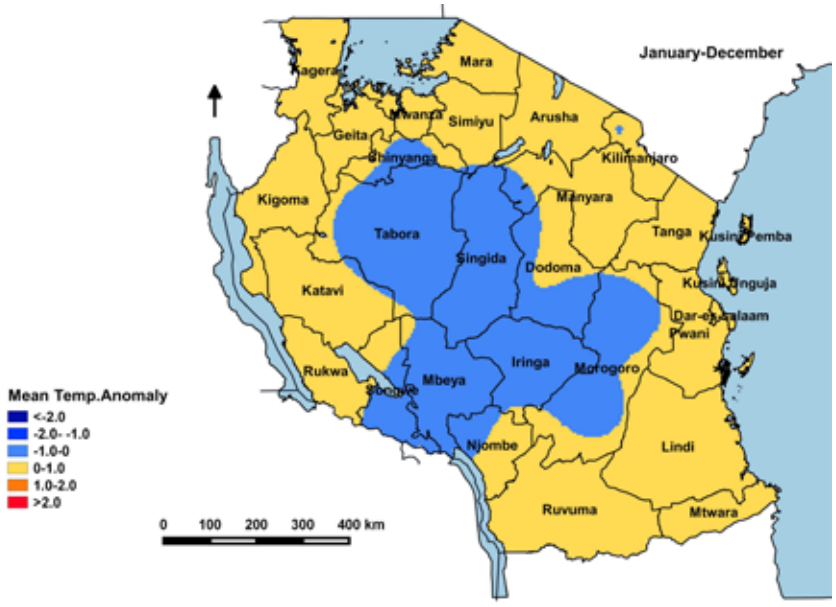


Figure 1: Annual mean temperature departures (°C) for 2022 from long-term average.

On the other hand, the country's annual minimum temperature (Tmin) was 18.9 °C, which is 0.4 °C warmer than the long-term average. The annual Tmin anomalies (Figure 2, left panel) were above the long-term average in the range of 0 °C and 1 °C for the entire country except for the few locations in Tabora, Singida, Shinyanga, and Katavi, where the minimum temperature anomalies ranged from -1 °C to 0 °C, indicating that slightly warmer nights were observed.

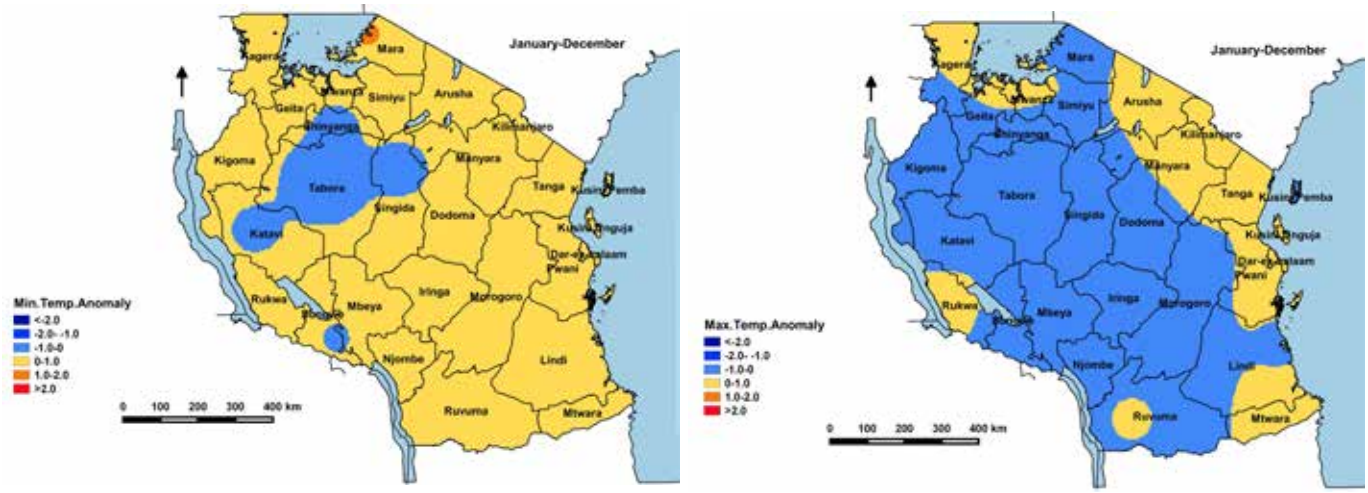


Figure 2: Annual minimum (left panel) and maximum (right panel) temperature departures (°C) for 2022 from the long-term average.

2.2 Monthly Mean Temperature anomalies

The country's monthly average Tmean in 2022 were relatively warmer during March, April, and May, with mean temperature anomalies of 0.5 °C, 0.7 °C, and 0.7 °C above the long-term average, respectively. In this regard, April and May are ranked as the third warmest of their respective months since 1970.

The observed warming in March and April is much contributed by the higher Tmax anomalies (0.9 °C and 0.8 °C) as compared to Tmin anomalies (0.6 °C and 0.5 °C) above the long-term average, respectively.

2.3 Monthly Maximum Temperature anomalies

The country's monthly Tmax anomalies in 2022 were higher for some months, reaching 0.6 °C, 0.9 °C, and 0.8 °C above average during March, April, and May, but were below average, reaching -1.3 °C and -0.5 °C during February and July, respectively.

The spatial distribution of monthly, Tmax departures from the long-term average in Figures 3a and 3b show that the period from January to May (except February) was characterized by warmer than average Tmax anomalies ranging between 0 °C and 1 °C, over most areas of the country. The warmer than average Tmax anomalies, ranging between 1°C and 2°C, were observed mostly over the northeastern highlands and northern coast during March, April, and May (Figure 3a).

On the other hand, during the period from June through September, most parts were cooler than average, with recorded temperature anomalies between -1°C and 0 °C (Figures 3a and 3b). As for the months of June,

October, November, and December, the distribution of Tmax anomalies appeared to be aligned in eastwest directions. The Tmax anomalies for October and December were warmer than average between 0 °C and 2 °C for the western parts, and between -1°C and 0°C for the eastern parts, while the opposite was seen in November and June whereby warmer than average temperatures between 0 °C and 1 °C were recorded for the eastern parts and cooler than average between -1°C and 0°C for the western parts.

Notably, the month of February recorded extremely cooler than average Tmax, with anomalies ranging from -2°C to -1°C in most areas of the country. However, anomalies lower than -2°C were recorded in the central and western parts of the country and extended to a few parts of the Lake Victoria and northeastern highlands. For instance, Tmax anomalies of -3.4°C, -2.8°C, -2.6°C, and -2.6°C were recorded at Shinyanga, Singida, Dodoma, and Arusha meteorological stations, respectively. In this regard, the monthly Tmax anomaly recorded at Shinyanga in February 2022 was the record break temperature anomaly in February since the station was established in 1986. The observed cooling condition in February may partly be linked to reduced incoming solar radiation due to cloud cover associated with rainfall events observed in this month, as it is portrayed in Figure 7a. On the other hand, warmer Tmax anomalies of at least 2°C were recorded at the northern coastal strip and northeastern highlands in May (Figure 3a).

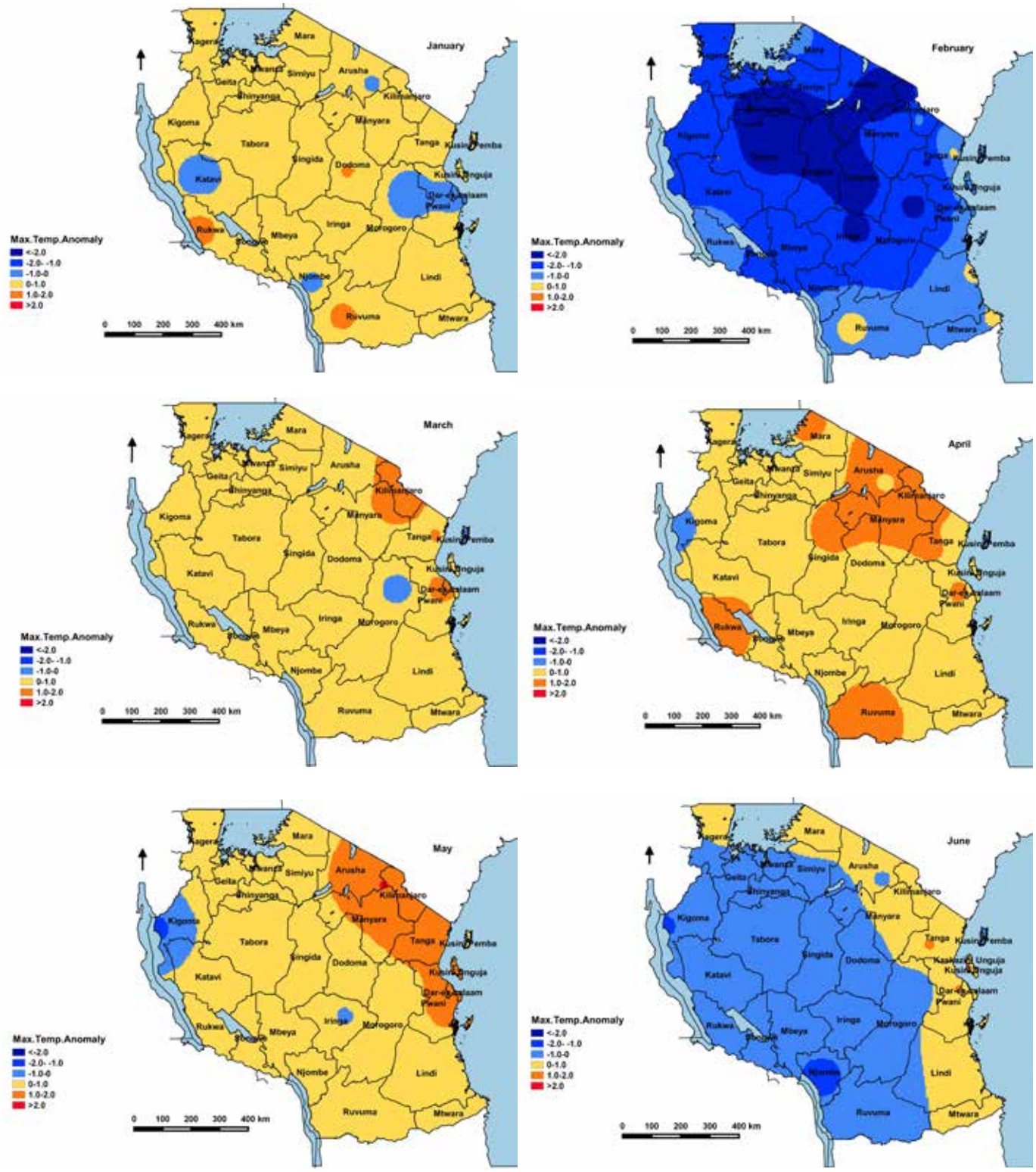


Figure 3a: Monthly maximum temperature departures from the long-term average (°C) for January–June 2022.

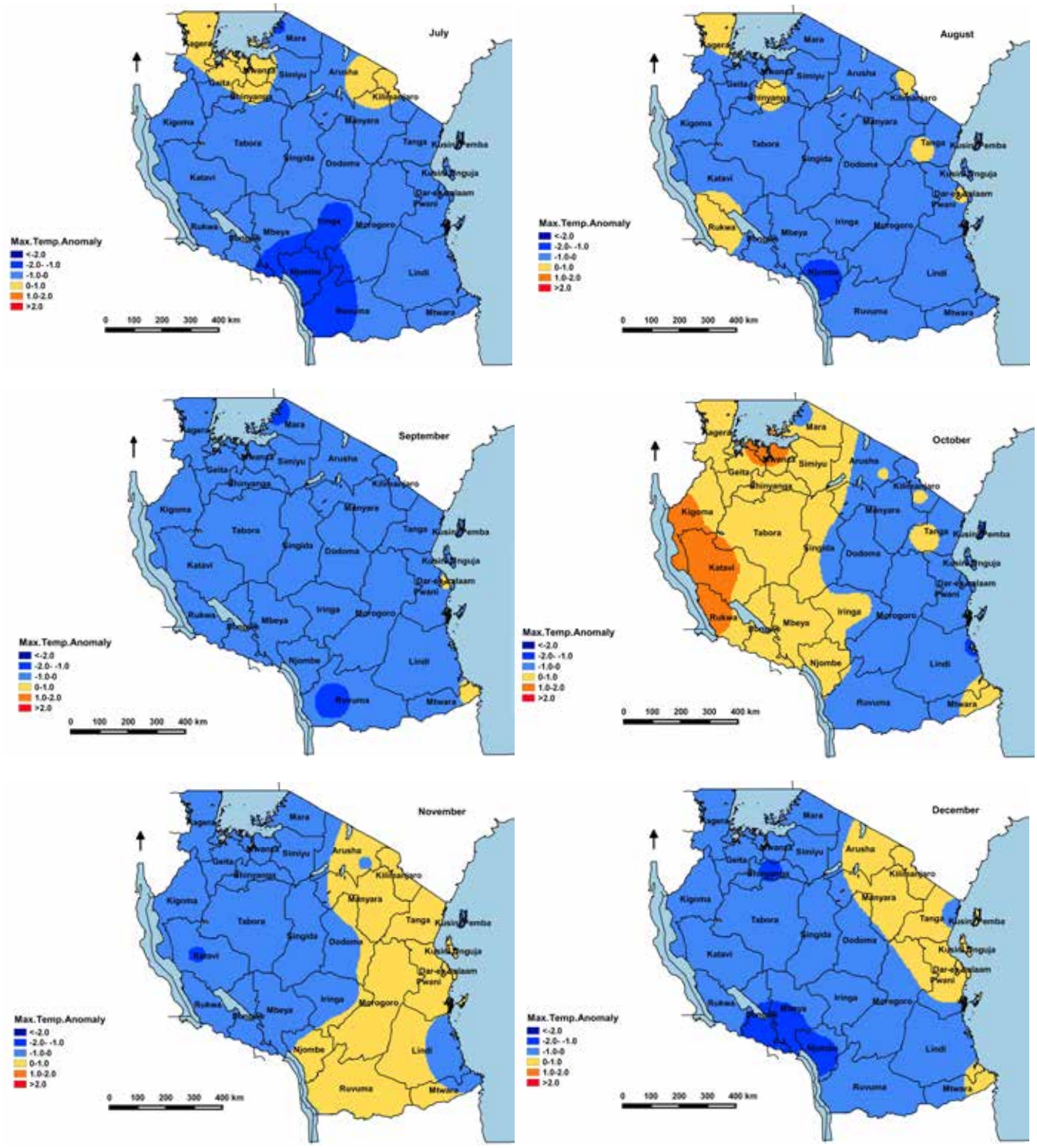


Figure 3b: Monthly maximum temperature departures from the long-term average (^{0}C) for July–December 2022.

2.4 Monthly Minimum Temperature anomalies

The country's mean monthly minimum temperature (Tmin) was 18.9°C and was higher than the long-term average by 0.4°C, while the monthly Tmin anomalies for all months (except February and October) were higher than the long-term average, with the highest anomalies occurring during April and July, with Tmin anomalies of 0.6°C and 0.7°C, respectively.

The spatial distribution of minimum temperature across the country (Figures 4a and 4b) indicates that warmer than average temperatures between 0°C and 1°C were recorded over large parts of the country during all months except October, which recorded a lower than average temperature anomaly ranging between -2°C and 0 °C, over the southwestern highlands. Notably, temperature anomalies between 0°C and 1°C were recorded in July over several locations in the country, especially over areas surrounding Lake Victoria, the northeastern highlands, the southwestern highlands, and the southern region. However, cooler than average temperatures between -1°C and 0°C and up to -2°C were recorded over a large part of the central and western regions (Tabora and Kigoma) during January, February, November, and December.

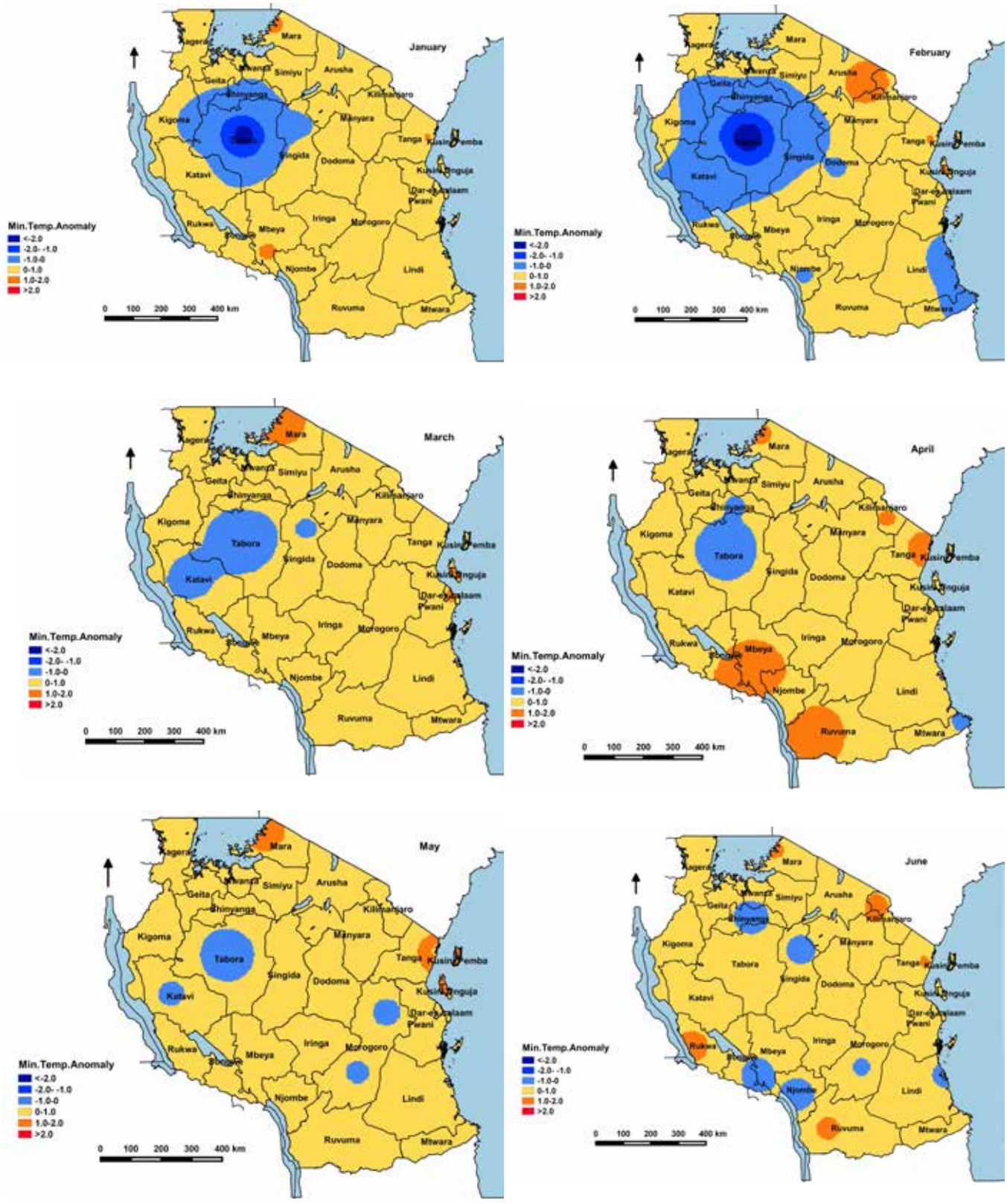


Figure 4a: Monthly minimum temperature departures from the long-term average (°C) for January to June 2022.

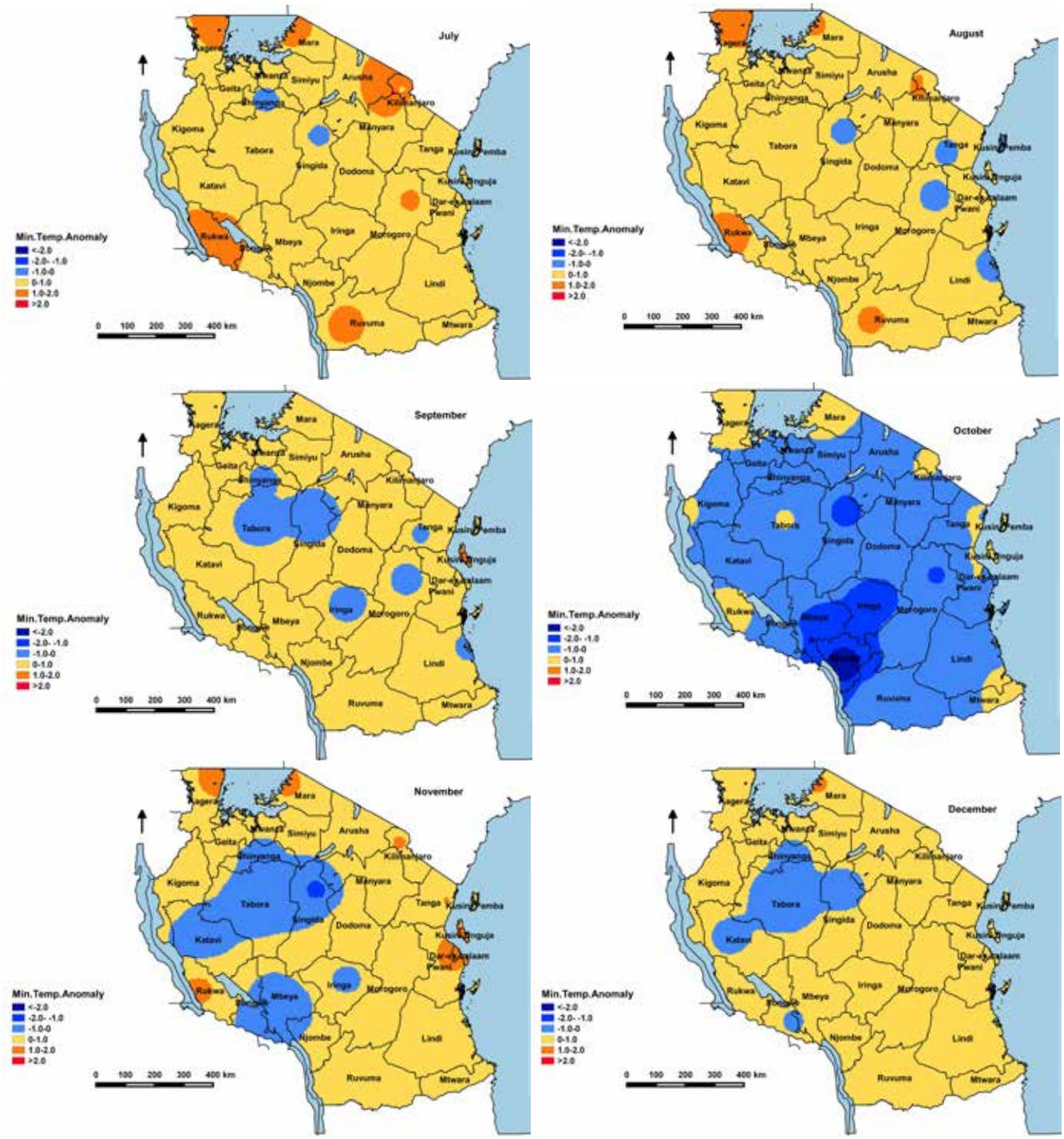


Figure 4b: Monthly minimum temperature departures from the long-term average (°C) for July to December 2022.

3. Rainfall distribution

The year 2022 was characterized by rainfall deficits especially during the March–May (MAM) and October–December (OND) rainy seasons. The significant deficiency was mostly discernible over the northern coast and northeastern highlands. Notwithstanding, the rainfall deficits for these two seasons are clearly seen in the months of March, April, May, and October 2022. These months are ranked among the ten driest respective months on record since 1970. Specifically, October was the driest month of the year and a record break since 1970, while May 2022 was the fourth driest May since 1970.

On the other hand, mainly normal rainfall was observed during November 2021 to April 2022 (NDJFMA) rainy season, but above normal rainfall was observed over the large part of the country during January to February 2022. As such, February was the wetter month of the year 2022 and the wettest February on record since 1970, while January 2022 is ranked as the 10th wettest January since 1970.

3.1 Annual Rainfall distribution

The country's total rainfall for 2022 was 926.8 mm, which is 14.4 mm higher than the long-term (1991–2020) average and equivalent to 111% of the average. Most parts of the country received normal rainfall ranging between 75% and 100% of the long-term average except the southwestern highlands, which received rainfall ranging between 100% and 125% of the long-term average. However, few parts of the northern coast including Zanzibar Islands and the northeastern highlands received below normal rainfall ranging between 50% and 75% of the long-term average. Notably, some parts of the Ruvuma region received above-normal rainfall between 125% and 150% of the long-term average. Consequently, the year 2022 is ranked as the 15th driest year on record since 1970.

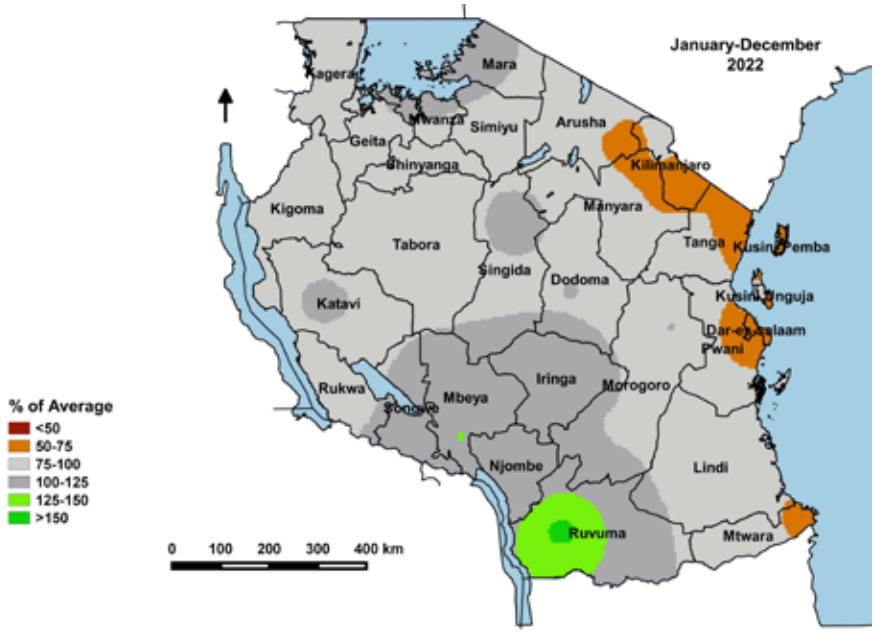


Figure 5: Annual rainfall anomalies for 2022 expressed as a percentage of the long-term average.

3.2 Seasonal Rainfall distribution

Mainly normal rainfall was observed over a large part of the country during the NDJFMA (2021 - 2022) and OND 2022 rainy seasons, while below normal rainfall ranging between 50% and 75% was observed over a large part of the country during the MAM 2022 rainy season. As for the NDJFMA and OND rainy seasons, the observed rainfall amounts were between 75% and 100% of average over the large part of the country, but with patches of below-normal rainfall amounts ranging between 50% and 75% of average over the coastal areas during OND season (Figure 6).

Notably, extremely below normal rainfall (less than 50% of the average) was observed over the northern coast and northeastern highlands during the MAM rainy season. Most stations in this area received a deficit of rainfall of almost half of the long-term seasonal mean, except for Same and Kilimanjaro International Airport (KIA) meteorological stations (northeastern highlands), which recorded a deficit of up to three times of the long-term mean. The recorded seasonal rainfall amounts in 2022 at these stations were 81 mm and 64.9 mm lower compared to the long-term average rainfall amounts, which were 240 mm and 298 mm, respectively.

In contrast, above normal rainfall ranging between 125% and 200% was observed over the eastern half of the country (especially in those areas receiving two rainy seasons) during the transition period of January to February 2022 (Figure 6). Rainfall amounts exceeding 200% of the long-term average were observed mostly over northern Morogoro, southern parts of the Tanga region, Unguja, and northern Kilimanjaro. The recorded rainfall amounts in these areas were nearly twice the long-term seasonal average. For example, the January–February total rainfall amounts recorded at Morogoro, Moshi, Handeni, and Zanzibar were 483.1 mm, 247 mm, 306 mm, and 305 mm, compared to 178 mm, 80.4 mm, 131 mm, and 124 mm of the long-term average, respectively.

Based on the historical observational records, the 2022 MAM rainy season is ranked as the second driest MAM season on record since 1970, by receiving rainfall amounts of 131 mm less than the long-term average, while the NDJFMA and OND rainy seasons are the 26th and 19th driest seasons on record, respectively, since 1970.

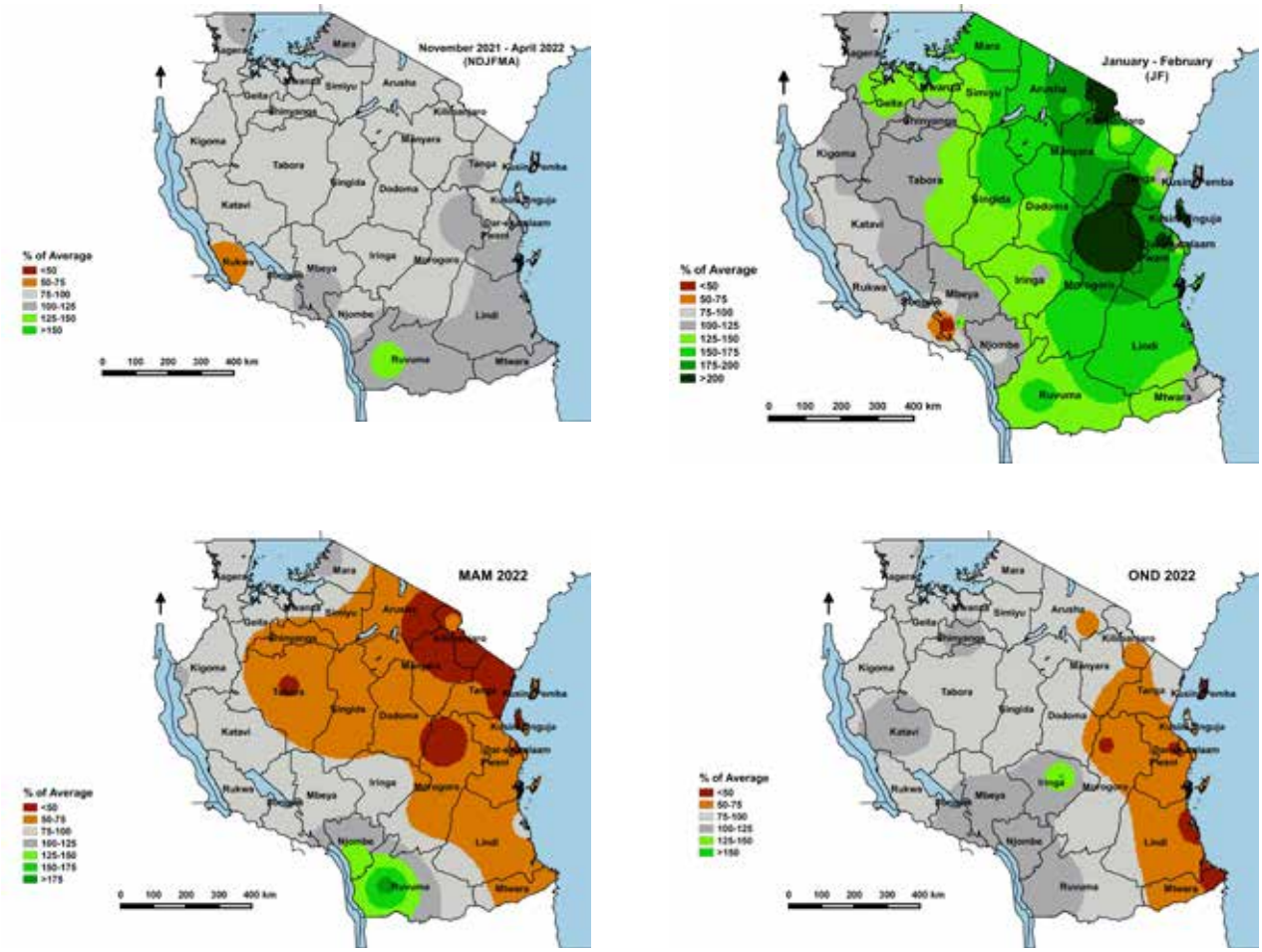


Figure 6: Seasonal rainfall distribution during 2022, expressed as a percentage of the long-term average for November 2021 to April 2022 (top left panel), January and February 2022 (top right panel), March to May 2022 (bottom left panel), and October to December 2022 (bottom right panel).

3.3 Monthly Rainfall distribution

In 2022, insufficient rains were experienced in many areas in almost all months except January, February, and December, where large parts of the country were relatively wet (Figures 7a and 7b). The rainfall deficit was mostly pronounced within the MAM and OND rainy seasons. Notably, October was the driest month, recording only 21% of the long-term average for October rainfall, while February was the wettest month, by recording 158.2% of the long-term average for February. Based on historical observation, February and October 2022 are ranked as the wettest and driest in their respective months since 1970.

Rainfall distribution across the country (Figures 7a and 7b) shows that most parts of the country were relatively wet during January and February, where above normal rainfall exceeding 125% of the long-term average was recorded in large parts of the country. Nevertheless, rainfall amounts exceeding 200% of the average were observed over the northeastern highlands, central and northern coast, including Zanzibar. In January 2022, Mahenge and Kisauni Airport (Zanzibar) meteorological stations recorded monthly rainfall amounts of 564.6 mm and 241.2 mm, respectively, which were approximately twice and three times their respective January long-term averages.

In February, mainly above normal rainfall between 125% and 200% of the long-term average was observed over many parts of the country but exceeded 200% over the northeastern highlands, extending to parts of the northern coast and central areas. The highest monthly rainfall record for February 2022 was 428.2 mm at Songea meteorological station. This record is almost twice its February average rainfall, equivalent to 193.8% of the long-term average for February. Moreover, a rainfall amount of 113.8 mm was recorded at Mahenge meteorological station on February 22, 2022, and was ranked as the 3rd highest amount for February since the establishment of the station in 1993.

In January and February, higher rainfall amounts recorded in the southern part of the country were within the NDJFMA rainy season. However, the highest percentage of rainfall recorded in the northeastern highlands and northern coast does not imply higher amounts of rainfall observed in those areas, as the area is relatively dry during January and February. Rather, it indicates that these areas received off-season rains that continued after the OND 2021 season had ended.

Mainly, below normal rainfall ranging between 50% and 75% of average was observed over the northeastern highlands, northern coast extending to southern coast, central and western parts of the country during March and April, but extremely below normal rainfall (less than 50% of long-term average) was observed in May over the large part of the country (Figure 7a). In contrast, mainly normal rainfall ranging between 75% and 100% but with patches of above normal rainfall was observed over the areas surrounding Lake Victoria, southern parts of the country and southwestern highlands. The rainfall deficit recorded in these months reveals March, April, and May, to be the 10^{th}, 11^{th}, and 4^{th} driest months in history since 1970, respectively.

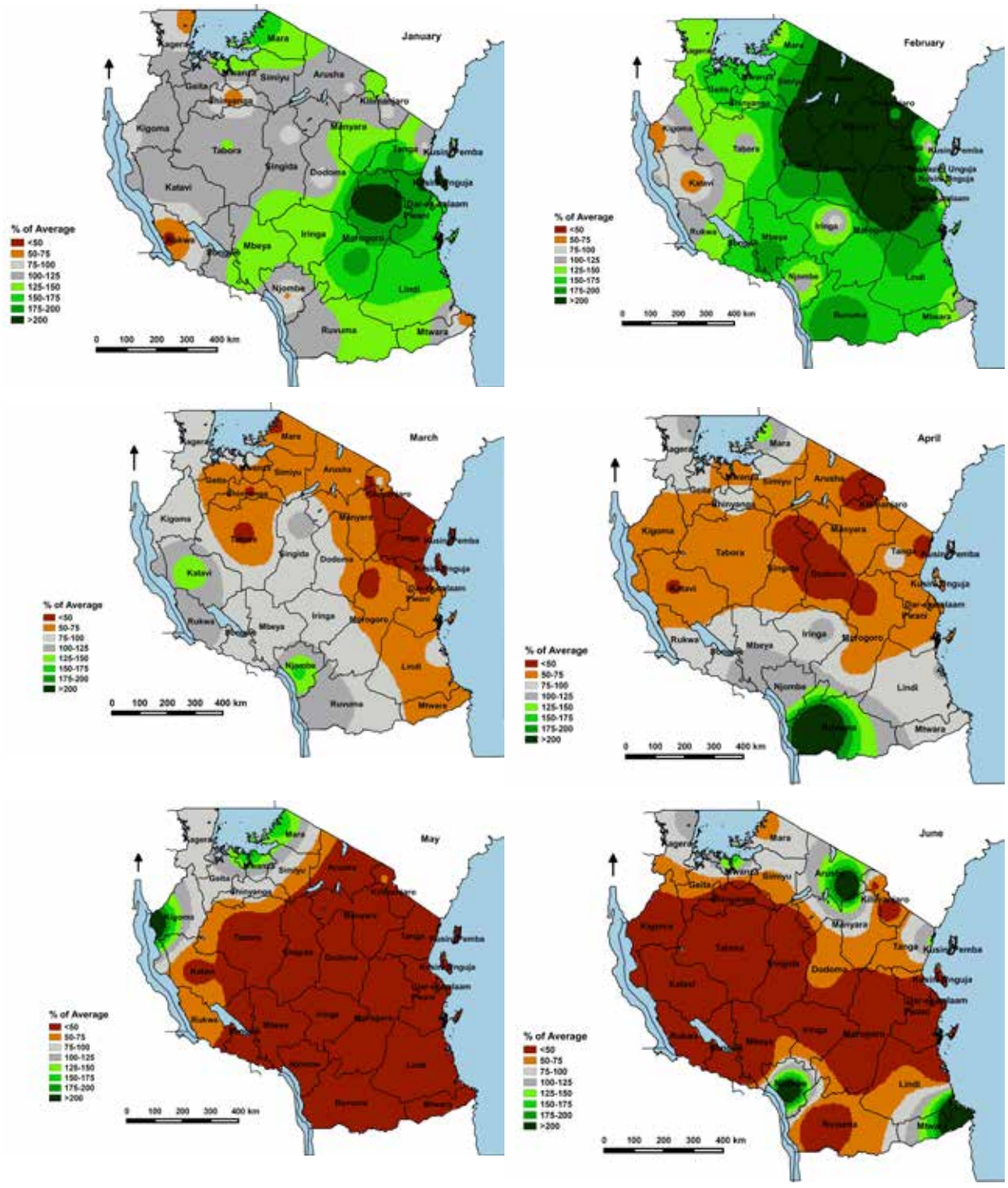


Figure 7a: Monthly rainfall distribution expressed as a percentage of the long-term average for January to June 2022.

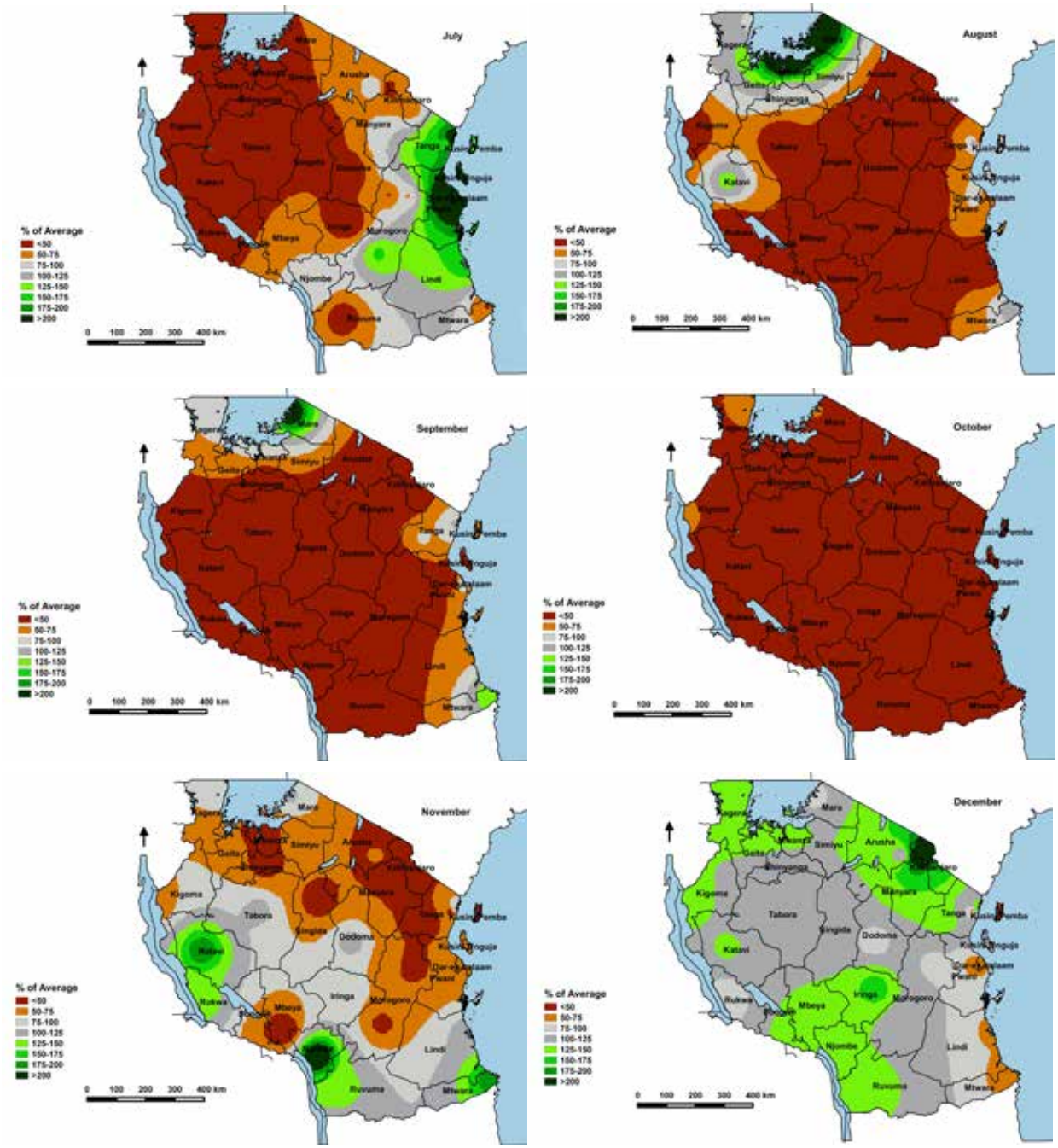


Figure 7b: Monthly rainfall distribution expressed as a percentage of the long-term average for July to December 2022

Besides, the country was somewhat dry during June, July, and August, and to a lesser extent in September, 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, mainly normal rainfall with patches of above-normal rainfall was observed over the Lake Victoria regions and northeastern highlands during June, August, and September, as well as over the coastal areas during July. 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.

During October, the entire country was extremely dry, with recorded rainfall amounts less than 50% of the long-term average. Likewise, below normal rainfall ranging between 50% and 75% was also recorded over the northern coast, the northeastern highlands, and many areas surrounding Lake Victoria during November (Figure 7b). The northern coast, northeastern highlands, and areas surrounding Lake Victoria experienced a delayed onset of the OND 2022 rainy season.

In contrast, December was slightly wet, recording 14.4 mm higher than the country's long-term average rainfall for December, and was ranked as the 18th wet December since 1970. Mainly normal rainfall ranging between 100% and 125 % of the average was observed over the large part of the country. However, above normal rainfall ranging between 125% and 150% was observed over the western part of Lake Victoria and the northeastern and southwestern highlands, while below normal rainfall was recorded over the southern coastal strip and the Dar es Salaam region.

3.4 Cumulative Rainfall

The cumulative rainfall presentation describes the performance and trends of observed rainfall for different areas in the country. The cumulative rainfall departure from the long-term average indicates that either a deficiency or abundance of rainfall was observed during the season.

During the NDJFMA (2021-2022) rainy season, the cumulative rainfall plots indicate that rainfall deficit was observed over almost all areas receiving one long rainy season except Ruvuma region (represented by Songea meteorological station). Generally, the cumulative rainfall plots for NDJFMA (2021-2022) season for the selected stations (Figure 8a) indicate that lower than average total rainfall (insufficient rainfall) was observed over many stations in the west, central, and southern coast, but nearly average total rainfall was observed over southwestern highlands.

The deficit of rains exceeding 100 mm was recorded over Dodoma, Kigoma, Tabora, and Mtwara regions. However, a substantial deficit of rainfall was apparent over Mtwara meteorological station, where a rainfall deficit of 266 mm to the long-term average was recorded. Notwithstanding, higher than average total rainfall was recorded over Ruvuma region (Songea meteorological station). The recorded rainfall amount at Songea meteorological station was 371 mm higher than the long-term average (Figure 8a), which is around one third of the seasonal long-term average.

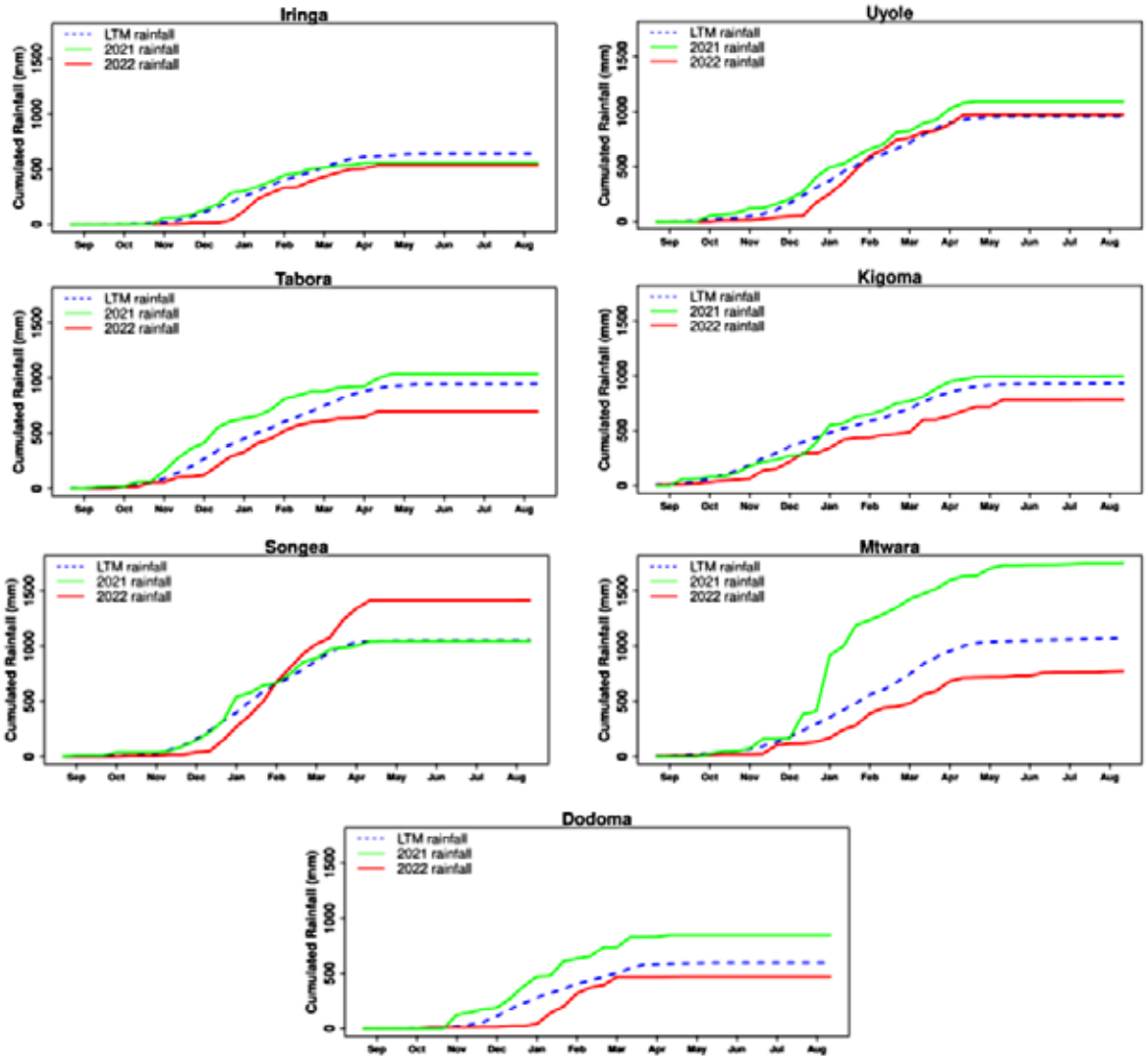


Figure 8a: Cumulative rainfall plots for the NDJFMA season for Dodoma, Tabora, Kigoma, Iringa, Mtwara, Uyole, and Songea meteorological stations, presented as accumulation of dekadal rainfall totals for each month starting from September 2021 to August 2022.

During MAM rainy season, a significant rainfall deficit was apparent for northern coast stations (Dar es Salaam, Tanga and Zanzibar) and northeastern highlands (Arusha and Moshi) (Figure 8b). For instance, Dar es Salaam, Tanga, Unguja and Pemba meteorological stations recorded a deficit of rainfall by 315 mm, 355 mm, 458 mm, and 378 mm respectively as compared to long term average. Generally, the rainfall amounts recorded in Dar es Salaam and Zanzibar were almost half the long-term average, while that of Pemba was almost one third of the long-term average. In contrast, sufficient rains (near to a slightly higher than long term average) were recorded over the areas surrounding Lake Victoria (Mwanza, Musoma, Bukoba) and Morogoro region.

During OND 2022 rainy season, a significant rainfall deficit was also recorded over the northern coast and northeastern highlands (Dar es Salaam, Tanga, Morogoro, Zanzibar, Moshi and Arusha) (Figure 8c) but sufficient rains were recorded over some areas surrounding Lake Victoria (Musoma and Shinyanga). Also, the rainfall deficit was apparent for stations in northern coast. For example, Dar es Salaam meteorological station recorded a rainfall deficit of 131 mm, while Pemba recorded a deficit of 209 mm with respect to long term average of 302 mm and 273 mm, respectively. Notably, the rainfall deficit at Pemba station was almost three quarters of the Pemba's OND long term average rainfall. Generally, insufficient rainfall was recorded over the northern coast and northeastern highlands in two consecutive years, 2021 and 2022 with respect to long term average. Thus, the observed rainfall deficiency during MAM and OND rainy seasons in the year 2021 and 2022 could be explained as the signal of impacts of climate variability.

In addition, the temporal evolution of rainfall during the seasons indicates that the rainfall events were fairly distributed throughout the NDJFMA and MAM seasons, but only in March and April. However, during the OND rainy season, the rains were poorly distributed and characterized by a late onset.

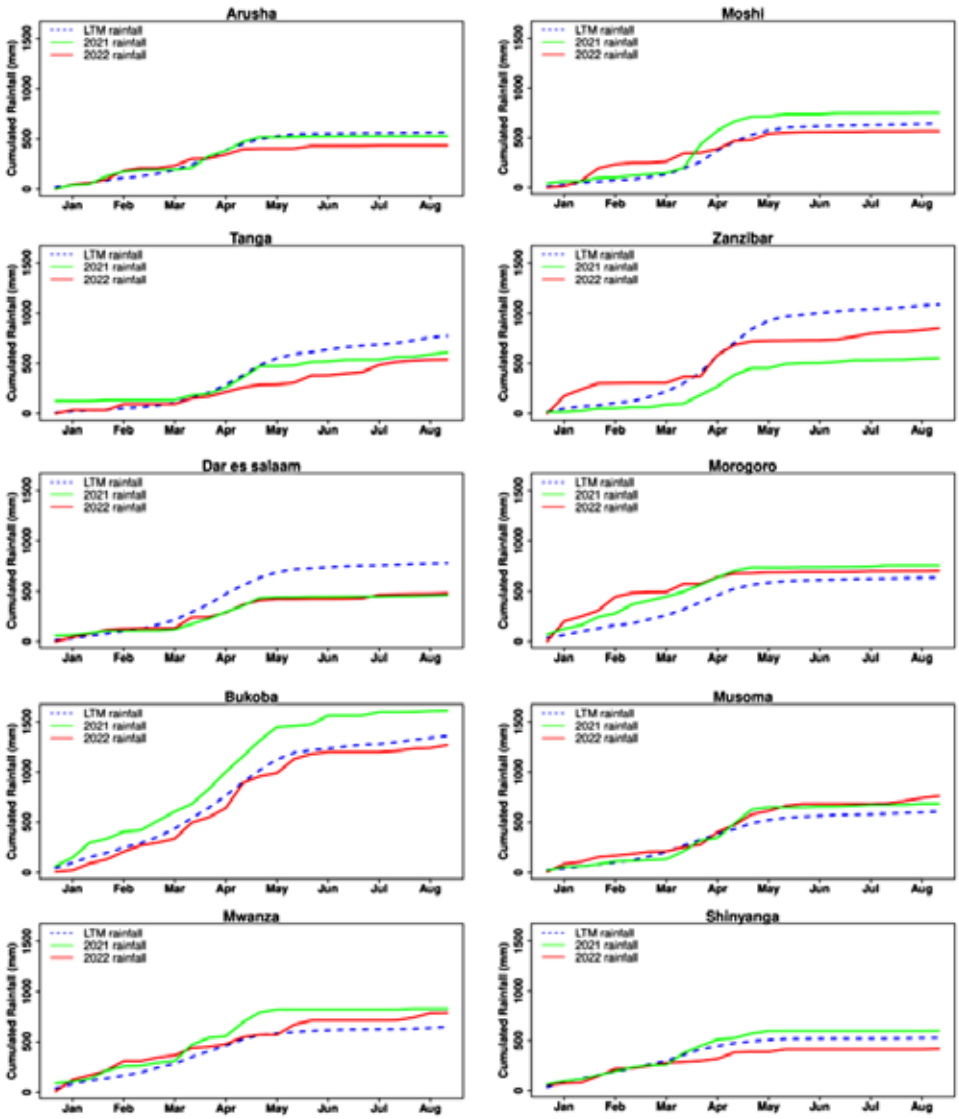


Figure 8b: Cumulative rainfall plots for MAM season for Bukoba, Mwanza, Musoma, Shinyanga, Dar es Salaam, Morogoro, Tanga, Zanzibar, Arusha, and Moshi meteorological stations, presented as accumulation of dekadal rainfall totals for each month starting from January to August 2022.

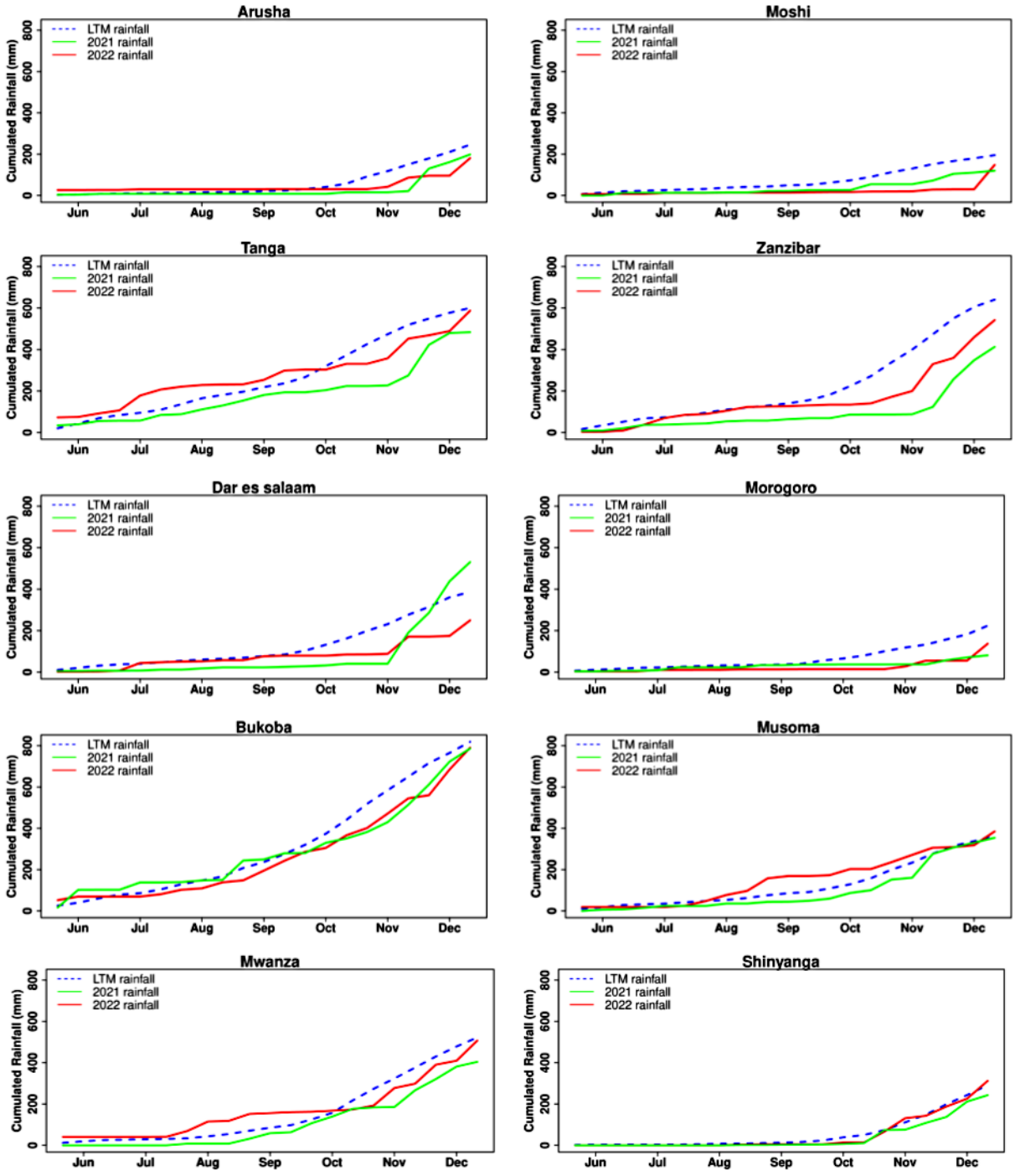


Figure 8c: Cumulative rainfall plots for OND season for Bukoba, Mwanza, Musoma, Shinyanga, Dar es Salaam, Morogoro, Tanga, Zanzibar, Arusha, and Moshi meteorological stations, presented as accumulation of dekadal rainfall totals for each month starting from June to December 2022.

4. Extreme Weather and Climatic events

The year 2022 was mainly dominated by dry conditions, especially for regions receiving two rainy seasons. However, extreme weather events, particularly heavy rains, localized thunderstorms with rain, and high temperatures were reported in different parts of the country. These events have had impacts on people's livelihoods, including the loss of lives and properties, and destruction of infrastructure.

4.1 Extreme Rainfall and Flood events

In 2022, unusual heavy rains were observed in January and February over the southern parts and in April and May over the northern parts of the country. However, extreme events were observed over the entire country during December. In general, a considerable number of heavy rains and flooding events were reported in different parts of the country. This section presents some of the extreme rainfall events that exceeded 100 mm in 24 hours and the rainfall events that were less than 100 mm but exceeded 50 mm in the view that they were exceptional from historical perspectives and they caused significant impacts.

On January 18, 2022, 92.5 mm of rainfall was recorded at the Zanzibar meteorological station. This rainfall event is ranked as the 3rd highest for January since the station started its operation in 1952. On the other hand, a 24-hour rainfall reaching 178.5 mm was observed over Mahenge meteorological station on January 30, 2022, which is the highest amount recorded for January at this station but the 3rd on record since the station was established in 1993. More extreme rainfall events for January were observed at Unguja and Pemba stations which include 101. 4 mm (on 19th January) and 71.5mm (on 31st January) at Victoria Garden, and Kisongoni stations, respectively.

On 22nd February 2022, Mahenge meteorological station recorded a 113.8 mm of rainfall, which is the third highest amount for February since the station's inception in 1993. In addition, rainfall of 70.5 mm was recorded at Kisongoni station on 22nd February 2022.

Moreover, a heavy rainfall totaling 96.7 mm was recorded at Kigoma meteorological station on 21st March 2022. This was the second highest amount of rainfall recorded for March in this station, but the fourth on record since the establishment of the station in 1937. Furthermore, a localized and record break rainfall of 137 mm was recorded on 29th April 2022 at Ukiriguru agro-meteorological station in Mwanza region. This is the highest rainfall recorded for this station since its establishment in 1969. As for Zanzibar Islands, the recorded extreme rainfall events were 200 mm on 20th April at Kisongoni, 93.2 mm on 21st April at Matangatuani, 88.1 mm on 16th at Kisauni, and 86.3 mm on 29th at Karume Airport, respectively.

On 7th November 2022, Mlingano agro-meteorological station recorded an extreme rainfall event of 68.1 mm. which is the 3rd highest amount in the recent decade. On the other hand, in December 2022, a 24-hour rainfall amount of 118.3 mm was recorded at Mahenge meteorological station in Morogoro region. This amount is the 24th on record since the station was established in 1993, but it is the 6th highest for December. In addition, 103 mm of rainfall was recorded at Moshi meteorological station in Kilimanjaro region on 26th December 2022, being the 50th on record since the station was established in 1929, but the 2nd on record for December. Generally, December was ranked the 3rd month for recording a large number of rainy days with rainfall amounts exceeding 50 mm (13 events), after January (19 events) and February (16 events).

Apart from the recorded values 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. For instance, localized heavy rainfall associated with thunderstorms and strong winds occurred in southwestern part of Tanzania on 21st January 2022. In addition, frequent and widespread thunderstorms associated with localized heavy rainfall, lightning, and strong winds occurred in the southwestern part of the country on 29th February 2022.

Moreover, heavy rains that occurred from April 26th through 28th, 2022, caused severe flooding in Mbeya and Songwe regions. These events together had adverse impacts on the community, such as the destruction of infrastructure and the loss of lives and properties.

4.2 Extreme Temperature events

In 2022, a large number of hot days with Tmax exceeding 35 °C were mostly recorded in northeastern parts of the country during January (40 events), February (12 events), March (46 events), November (4 events), and December (13 events). Besides, the same condition was observed over the central and western parts of the country during October, where 20 events of higher Tmax were recorded. This may partly be linked to the prolonged dry spells that were observed during October for a large part of the country. The highest daily temperatures in 2022 were 36.9 °C and 36.8 °C recorded at Kilimanjaro International Airport (KIA) and Mpanda meteorological stations on 13th January and 26th October 2022, respectively. The highest daily temperature recorded at KIA is ranked as the 10th highest for January since the establishment of the station in 1972, while that of Mpanda is the 2nd highest for October since the station was established in 2011.

On the other hand, a large number of events with warmer night temperatures (Tmin) greater or equal to 26 °C were observed in January (74 events), February (25 events), March (30 events), April (10 events), May (21 events), November (20 events), and December (42 events). These events were recorded especially at stations aligned closer to the Indian Ocean, namely, Mtwara, Kilwa, Naliendele, Tanga, Zanzibar, Pemba, Mlingano, and Dar es Salaam. These observations indicate that more warm nights were recorded at the beginning and end of the year. The highest night temperatures (Tmin) were 28 °C and 27.5 °C recorded on 20th December 2022 and 21st February 2022 at Kilwa and JNIA, respectively. The highest night temperature recorded at Kilwa is a record break temperature in December, but the 8th highest ever recorded night temperature since the station's establishment in 2005, while that of JNIA is the 15th on records for February since the station establishment in 1958. However, out of the mentioned stations with temperatures exceeding 26 °C, Kilwa is leading by recording a larger number of events exceeding this threshold, mainly in January and December 2022.

In contrast, the country was cool during May, June, July, and August 2022, especially over the southwestern highlands, and was extremely cooler during June and July, where cold nights with temperatures lower than 5 °C were recorded. At least 7 events with cold nights were recorded in June and 3 events in July. The lowest night temperature in 2022 was 3.5 °C, recorded at Uyole agrometeorological station on 19th June 2022, and is ranked as the 9th event of cold temperatures recorded in the recent decade for the month of June. Generally, temperatures over this station have drastically increased especially during the 2000's.

5. Major Drivers of Weather and Climate Events in 2022

In 2022, the eastern and central Pacific Oceans were cool while the western Pacific Ocean was warm throughout the year (Figure 9, black circled area). Thus, the La Niña condition persisted over the Pacific Ocean from January through December, thereby suppressing rainfall over the East Africa region, including parts of Tanzania, especially those receiving the two rainy seasons of MAM and OND. This is marked in Figures 6 and 7, whereby the northern coast and northeastern highlands received below-normal rainfall during both the MAM and OND rainy seasons.

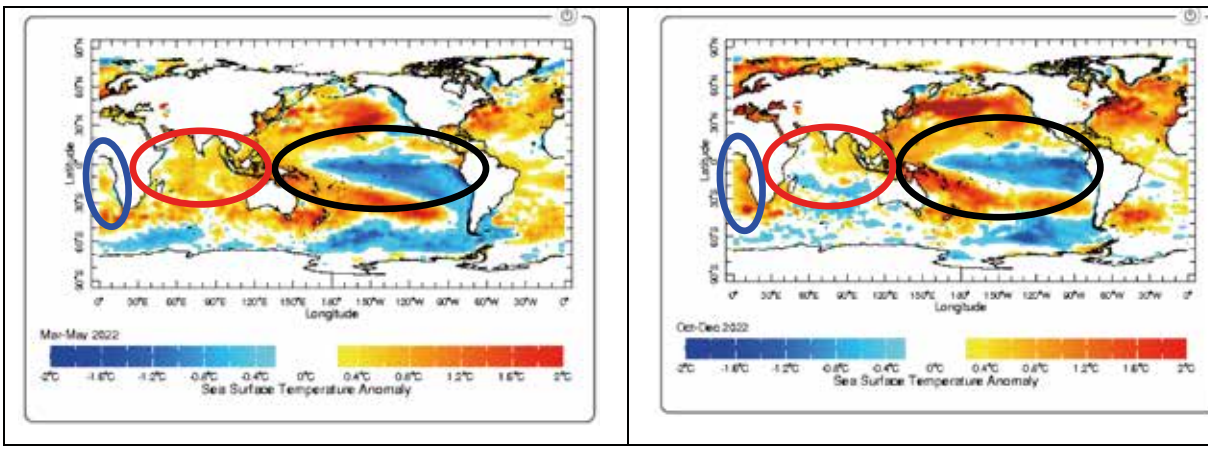
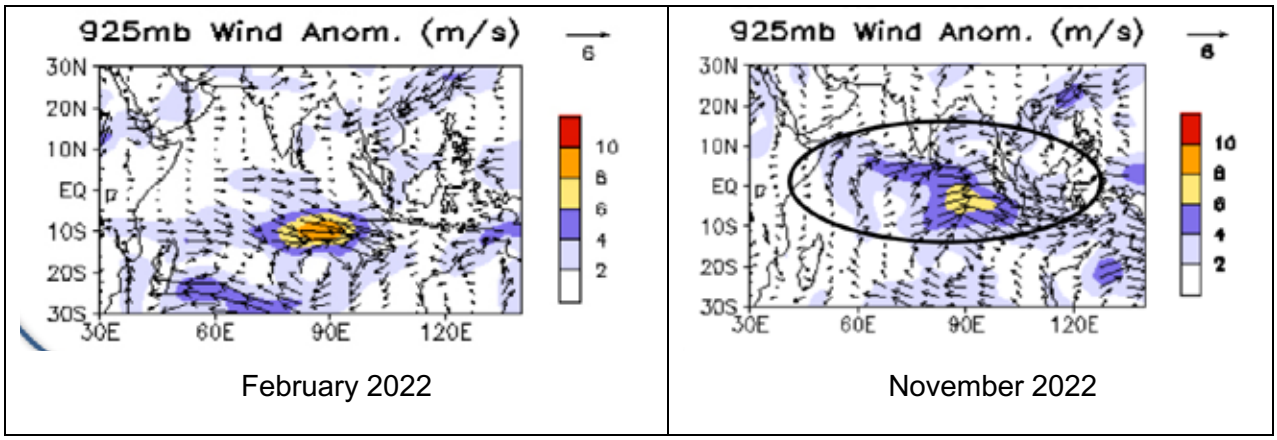


Figure 9: Sea surface temperature anomalies for March-May (left) and October-December (right) 2022, showing Atlantic Ocean (blue circled), Indian Ocean (red circled) and central Pacific Ocean (black circled).

Source:https://iridl.ldeo.columbia.edu/SOURCES/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.GLOBAL/.Reyn_SmithOIv2/.monthly/.ssta/

On the other hand, the SST anomalies in the Indian Ocean (Figure 9, red circled) were generally negative in the west and positive in the east, signifying the existence of a neutral to negative Indian Ocean Dipole (IOD), resulting in enhanced (suppressed) convection over the eastern (western) Indian Ocean. In addition, enhanced low-level easterly wind anomalies were observed over the southern parts of the country in April, while weak to enhanced low-level westerly wind anomalies persisted over the country and the adjacent Indian Ocean from April through December (Figure 10). This condition slowed or deflected moisture from reaching the country. Altogether, the impacts include the observed suppressed rainfall across the country, especially during the rainy months, as depicted in April, May, October, and November (Figures 7a and 7b).

Moreover, the SSTs in the Tropical Southern Atlantic Ocean (over the Angola coast) were near to cooler than average from January to August but were warmer than average from September to December (Figure 9, blue circled area). This condition was associated with the observed low-level easterly wind anomalies along the Angolan coast (not shown), which hindered the moisture influx from Congo forest towards the country, especially during October and November, causing reduced rainfall activities over different parts of the country as shown in Figures 7a and 7b.



February 2022 | November 2022

Figure 10: Low-level wind vector anomalies at 925 hPa for February (left) and November (right) 2022. Anomalies are departures from the 1991–2020 base period mean.

Source: global_ocean_monitoring_2022_12.pdf (noaa.gov).

While the impacts of the ENSO and IOD conditions on the East African rains are well established, these conditions cannot fully explain variation in rainfall across the country. Other drivers, such as synoptic systems and their movements and local factors, are responsible for variations in day-to-day weather conditions observed across the country as described below.

The development and position of tropical cyclones and depressions over the southwestern Indian Ocean in the period of January to April brought significant rains to some areas and dry conditions to others. For example, moderate tropical storm ANA (20th–25th January 2022) and tropical cyclone BATSIRAI (24th January–8th February 2022), which occurred in the western part of Madagascar, pulled moist winds from the Congo basin toward the country, causing convergence of westerlies and easterlies over the southern part of the country.

This condition was associated with the reported heavy and record-break rainfall over Mahenge meteorological station and the generally normal to above-normal rainfall observed over southeastern parts of the country. Likewise, the tropical storms DUMAKO (10th–18th February 2022) and EMNATI (15th–24th February 2022) brought the same impacts over the country as the preceding storms, as supported by the observed heavy and above-normal rainfall in different parts of the country.

In contrast, the presence of severe tropical storms VERNON, which entered the southwestern Indian Ocean basin on 26th February – 3rd March 2022 and GOMBE, which occurred on 5th – 17th March 2022, affected rainfall activities across the country, especially in the coastal areas, northeastern highlands, and Lake Victoria areas. Their orientation and location induced a northerly to northwesterly wind flow at low levels that deflected moisture from reaching the country.

Other drivers and synoptic patterns such as the Madden Julian Oscillations (MJO), the near equatorial trough and surface convergence associated with the presence of the Inter-tropical Convergence Zone (ITCZ) also brought significant weather conditions over different parts of the country.

6. Weather and Climate related impacts

The extreme weather events observed in 2022 caused adverse impacts on communities, including population displacement, destruction of infrastructure, and loss of lives and properties. Heavy rain associated with strong winds and thunderstorms that occurred on 20th January 2022 caused the destruction of four classrooms in Ndolwa ward, Handeni district (Tanga region), leaving 300 students without classrooms for 7 days, as shown in Figure 11.

Figure 11: The removal process of affected roofs from the classrooms at Luye Primary School, in Ndolwa ward, Handeni district (Tanga region). The roof was destroyed by heavy rainfall that was accompanied by strong winds on 20th January 2022. (Source: Mwananchi Newspaper, 22nd January 2022).

On the other hand, the unusual localized heavy rains (some not recorded by TMA observation network) that occurred over the southern parts of the country during January and February 2022 brought adverse impacts to different levels in the community. According to the data from the PMO–DMD, the recorded events of heavy rainfall associated with floods, thunderstorms, and strong winds caused massive impacts to the community. For instance, between 21st and 22nd January 2022, two people were injured and 595 affected, and 119 houses were damaged by heavy rainfall with thunderstorms and strong winds over Makambako, Wanging'ombe and Ludewa districts in Njombe region. Besides, 45 households and 45 residents including 144 houses were affected by heavy rainfall that occurred between 19th and 22nd January 2022 in Chalinze district and Mafia Island in Pwani region.

Likewise, on 26th February 2022 heavy rainfall associated with thunderstorms caused the deaths of eight people and left 14 injured and 14 displaced over Sumbawanga, Nkasi, and Kalambo districts in Rukwa region.

Also, the daily newspaper known as Nipashe reported that "heavy rainfall that occurred between 22nd and 23rd, February 2022 at Ludewa district (Njombe region) caused the destruction of four bridges, namely the Nyapinda, Muhoro, Chuma, and Ludewa bridges" (Figure 12). This incident resulted in the road transport cutoff between Ludewa and Njombe districts, leading to a delay in transport for some hours before the situation settled back to normal.

Figure 12: Nyapinda Bridge was damaged because of heavy rainfall that occurred on 22nd and 23rd February 2022 (Source: Nipashe Newspaper, 24th February 2022).

On the other hand, heavy rains that occurred between 26th and 28th April 2022 caused severe and widespread flooding in Mbeya and Songwe regions (southern Tanzania), resulting to a death toll of at least 5 people, 21 injured, 5 missing, and 3150 people displaced. Moreover, over 400 houses were damaged, of which 318 were totally destroyed. Among the affected buildings were 35 schools and 16 religious buildings. In addition, 24,700 acres of farm fields, which include paddy, maize, and banana farms, were destroyed, and 2,362 livestock were reported dead. Other impacts include the destruction of four bridges and three roads, which resulted in interruptions to road communications in various areas. For instance, Figure 13 indicates the impacts of flooding in Kyela district.

Figure 13: The effects of floods in Mwaya village, Kyela district. The flood was the result of heavy rainfall that lasted for three days over southwestern highlands from 26th to 28th April 2022.
(Source: Kelvin Mwambambale, Mwaya Village in Kyela district)

7. Summary and Conclusion

The country's average air temperature for 2022 was slightly warmer than the long term average for all months except February, September, and October. On average, March, April, and May were the warmest months of the year, while February 2022 was exceptionally cooler than the long term average. The country observed warmer night temperatures compared to day temperatures for almost all months. However, warmer than the long-term average daytime temperatures were recorded during March, April, and May.

Although October was the driest month of the year, cooler than the long-term average temperatures were recorded over a large part of the country during the day and night. The cooling over the night may be associated with enhanced outgoing long-wave radiation because of the clear skies.

In terms of rainfall, the year 2022 is ranked as the 15th driest year on record since 1970. Rainfall deficiency was experienced during the MAM and OND rainy seasons, especially over the northern coast and northeastern highlands. Extremely below-normal rainfall of less than 50% of the long-term average was observed over the northern coast and north-eastern highlands during the MAM rainy season. This condition made the 2022 MAM rainy season the 2nd driest MAM season on record since 1970.

A notable deficiency of rainfall was observed in the months of March, April, May, and October 2022. Specifically, October was the driest month of the year and a record-breaking dry October since 1970, while May was the 4th driest May in rainfall records since 1970.

The spatial distribution of rainfall across the country indicated mainly normal rainfall over the large part of the country during the NDJFMA (2021–2022) and OND 2022 rainy seasons, while below-normal rainfall was observed during the MAM 2022 rainy season. In contrast, above normal rainfall was observed over the large part of the country during the transition period of January to February 2022, especially in the eastern part, with February being the wettest month in the record of February rainfall since 1970.

The observed SSTs over the global oceans had a large contribution to the weather and climate conditions that were observed over different parts of the country. The existence of the observed SSTs over the global oceans had a large contribution to the weather and climate conditions that were observed over different parts of the country. The existence of Laniña condition over the equatorial Pacific Ocean and the negative to neutral IOD throughout the year are largely associated with the rainfall deficit that was observed over the country, especially over the northern coast and north eastern highlands.

Moreover, extreme weather events, especially heavy rainfall accompanied by strong winds, were observed over many parts of the country during the year 2022. These events had significant impacts on the community. Among others, it includes the loss of lives and properties, destructions to infrastructure (i.e., bridges and roads); people's settlements, and the destruction of hundreds of acres of farm fields.

The impacts of extreme weather events that were experienced in different parts of the country could have been much reduced if the weather and climate forecasts, advisories, and warnings issued by TMA were closely followed and used by the public and different government sectors for decision-making 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 cold 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 East African Monsoon, El-Niño Southern Oscillation (ENSO), and westerlies from Congo, tropical cyclones, and Inter-Tropical Convergence Zone (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 migrates to southern regions of Tanzania in October to December, reaching the 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 (NDJFMA, 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 rainfall seasons. The long rain season (also known as *Masika*), which starts mainly in March and continues through May (MAM) and the short rainfall 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 (period between 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 mean. Anomalies are computed with respect to the 1991-2020 base period means.

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 accumulated 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 2022 was calculated by observing the following procedures:

i. For areas characterized by unimodal rainfall regime, rainfall from September 2021 to August 2022 was accumulated, because the rainfall season over these areas starts from November in the previous year to April in the following year (NDJFMA). While,

ii. For areas characterized by bimodal rainfall regimes, accumulated rainfall from January to August 2022 was used to characterize rainfall for MAM season and rainfall from June to December 2022 was used to characterize rainfall for OND seasons.

iii. Dekadal baseline climatology from 1991-2020 was calculated by following the 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. 31 stations were used for rainfall analysis and 25 stations for temperature analysis. They were analyzed by the Inverse Distance Weighting (IDW) interpolation method in Quantum GIS to generate spatial distribution maps. The IDW interpolator assumes each input point has local influence that diminishes with distance. It weighs 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 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 forms and effects of severe weather. According to the WMO, severe weather can be categorized into two groups; general severe weather (e.g. windstorms and its accompanying 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 threshold 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 threshold.