3

CLIMATIC ENVIRONMENT

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Climate, characterised by the long-term patterns and averages of elements such as rainfall, temperature, solar radiation, relative humidity, wind speed, and evaporation, is evident on both temporal and spatial scales. In South Africa, the diverse climatic conditions affecting critical sectors, including agriculture, forestry, and biodiversity, similarly influence the availability and distribution of water throughout the country. Ranging from arid conditions in the western regions to humid subtropical climates in the east, the country's varied rainfall patterns create a dynamic and complex water management landscape.

The climate classification in South Africa is often based on seasonal rainfall patterns such as winter and summer rainfall. The winter rainfall, typically occurring between May and August and concentrated primarily in the southwestern region, contrasts with the summer rainfall region, covering extensive areas of the country. The latter experiences higher rainfall amounts crucial for replenishing rivers, dams, and reservoirs, essential for sustaining numerous sectors. Moreover, the northern and western areas record the highest temperatures, while the elevated regions experience cooler climates. Coastal regions, influenced by the warm Indian Ocean, often maintain higher average temperatures, particularly at night.

The seasonal variability in the country's climate influences water availability and storage dynamics. While summer rainfall regions experience peak flows during wet seasons, winter rainfall areas heavily rely on stored water from dams and reservoirs to meet demands during dry months. Furthermore, climate change exacerbates existing challenges, introducing uncertainties such as changes in rainfall patterns, increased temperatures, and heightened frequency of extreme weather events, which pose challenges for infrastructure development, demand management strategies, and ecosystem sustainability efforts.

The Agricultural Research Council, with its extensive network of weather stations across the country and a comprehensive agroclimatic archive, provides essential data and analysis on these evolving climate trends, which are discussed in the following chapter. The rainfall and temperature data utilised in climate analysis for this study spans from 1950 to 2024, providing a long-term view of the climate's variability and trends. This data is essential for understanding the seasonal and inter-annual dynamics of water availability, particularly as the variability influences the country's water storage systems in rainfall and temperature patterns.

3.1 Temperature

South Africa experienced a new record warm year, with very hot conditions mainly in the central and northern interior. In the south, however, temperatures were closer to normal. The annual mean temperature anomaly for 2024, based on the data of 26 climate stations, was about 0.9 ºC above the average of the reference period (1991-2020), making it approximately the hottest year since 1951 (see Figure 3.1). A warming trend of approximately 0.17 ºC per decade is indicated for the country over 1951-2024, statistically significant at the 5% level.

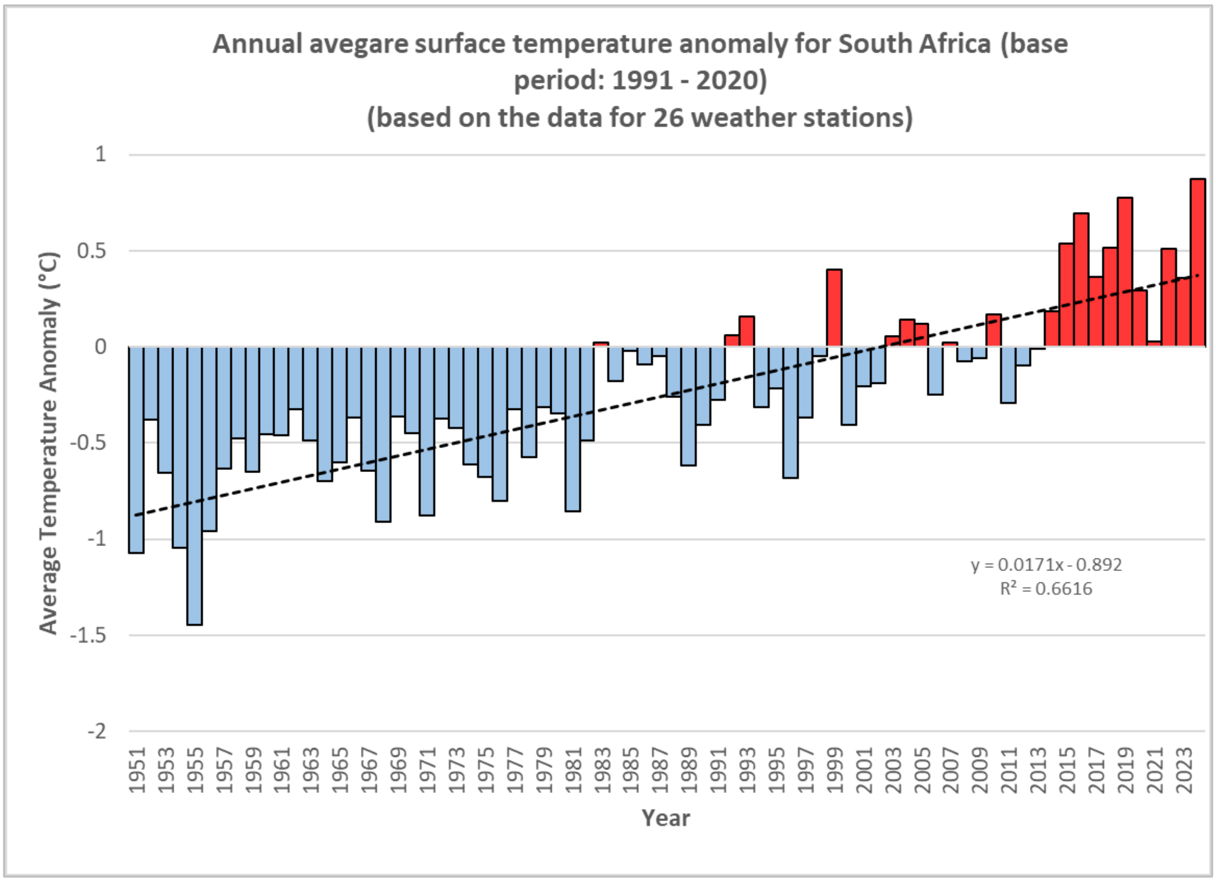

Figure 3.1. Average surface temperature deviation over South Africa based on 26 climate stations: 1951 - 2023 (base period: 1991 - 2020). The linear trend is indicated (Source: South African Weather Service).

Average observed temperatures for the 2023/24 hydrological year are shown in Figure 3.2. Average temperatures for the hydrological year followed a predictable spatial pattern, with temperatures in the lower teens dominating over the cooler southern to eastern escarpment and eastern Highveld. The highest average temperatures occurred over the traditionally warmer parts, including the Limpopo River Valley, Lowveld and north-eastern KZN, with values in the lower to mid-twenties dominating.

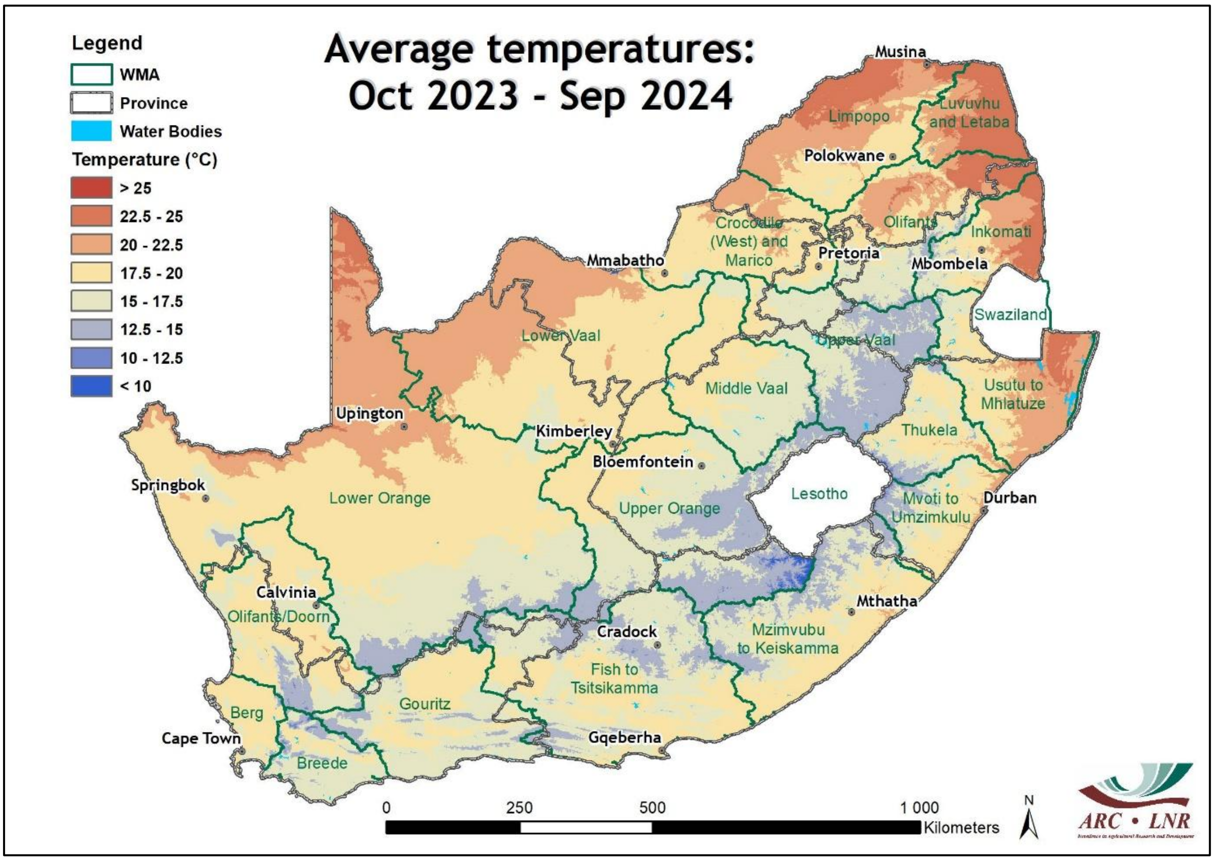

Figure 3.2 Average temperature calculated during the 2023/24 hydrological year.

Compared to the long-term average for the 12-month period covering the 2023/24 hydrological year, temperatures were on average near the long-term average over most of the central to southern parts but tended to be above average over the northern parts of the country (Figure 3.3) Relatively large areas in the north were more than 2°C warmer than the average. Deviations over the rest of the country largely ranged between -0.5 and +1°C from the long-term average during the period as a whole.

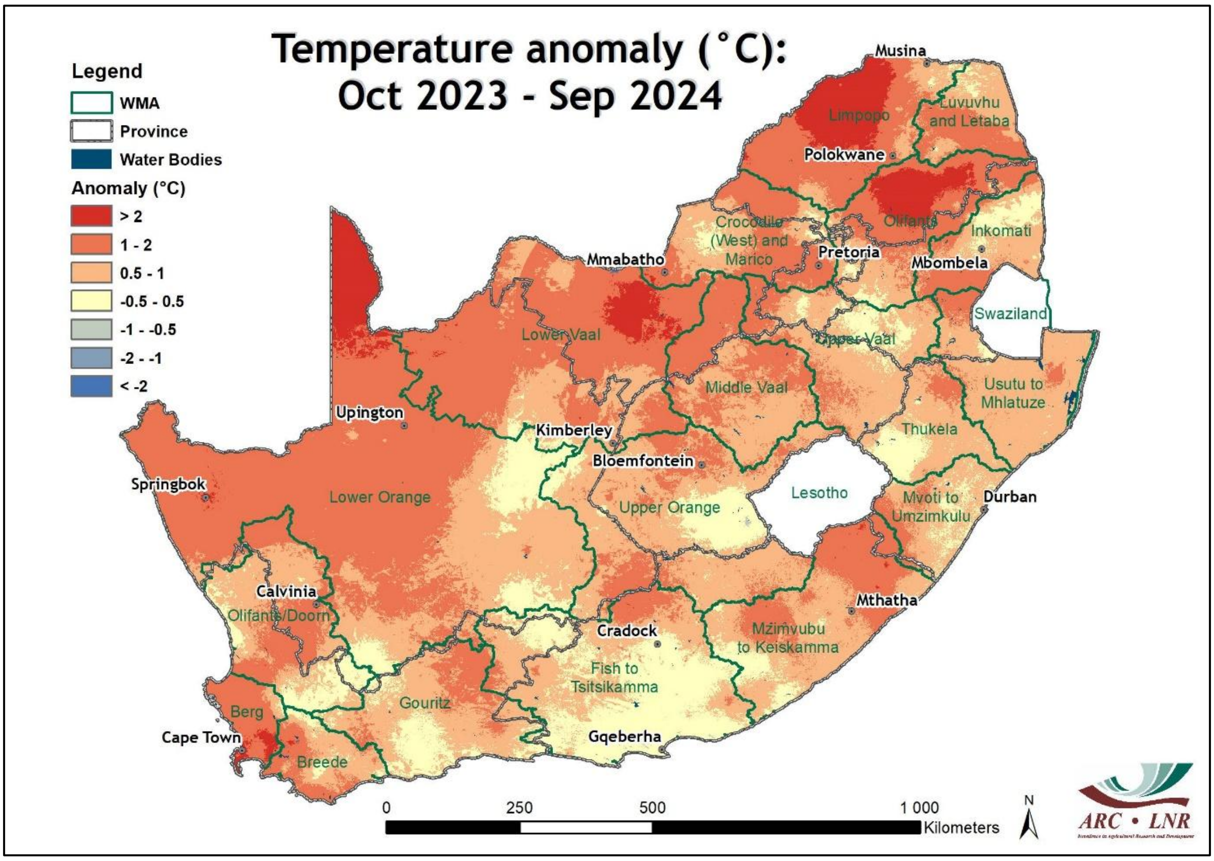

Figure 3.3 Deviation in temperature from the long-term average during the 2022/23 hydrological year.

The monthly breakdown of the average temperature anomalies is shown for the summer and winter halves of the 2023/24 hydrological year in Figure 3.4 and Figure 3.5, respectively. Months that stood out as being warmer than average across the country were November 2023, March and May 2024. February 2024 was also warm over most of the summer rainfall region and constituted part of the very dry period that lasted from mid-January until late March over the summer rainfall region. July, August and September were all anomalously cold over most of the country's southern half.

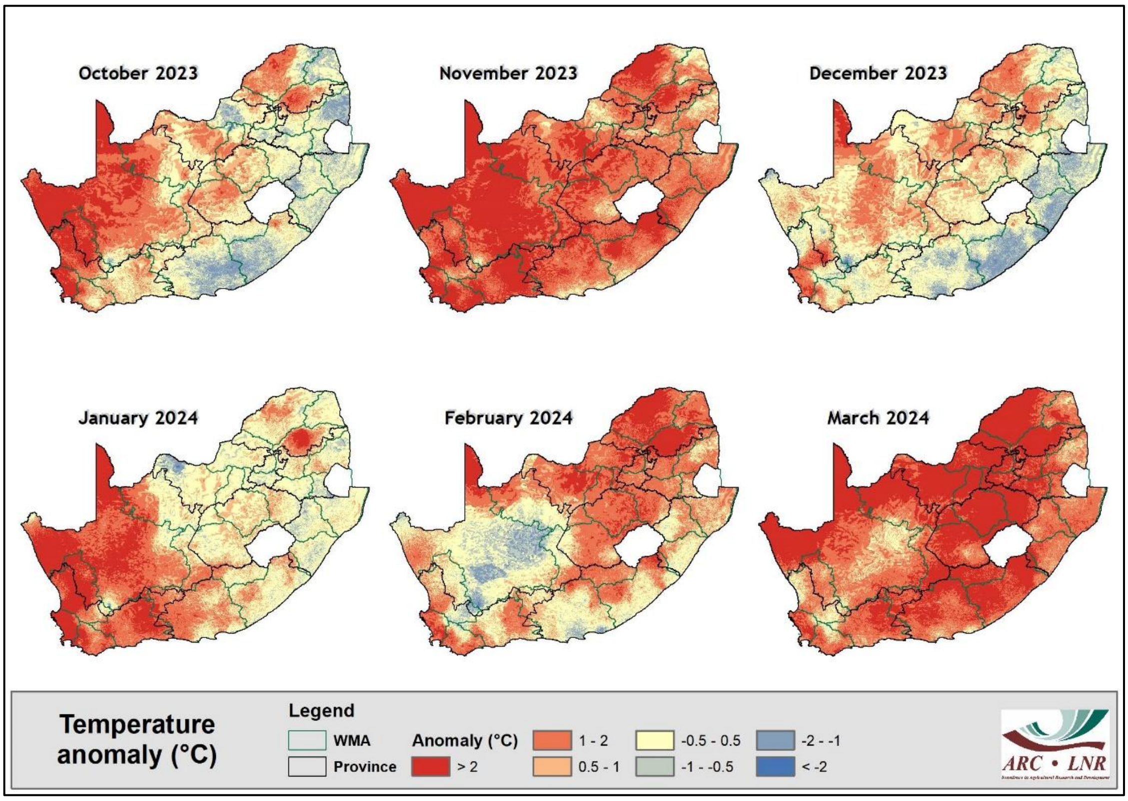

Figure 3.4 Monthly deviation in temperature from the long-term average during the summer half of the 2022/23 hydrological year.

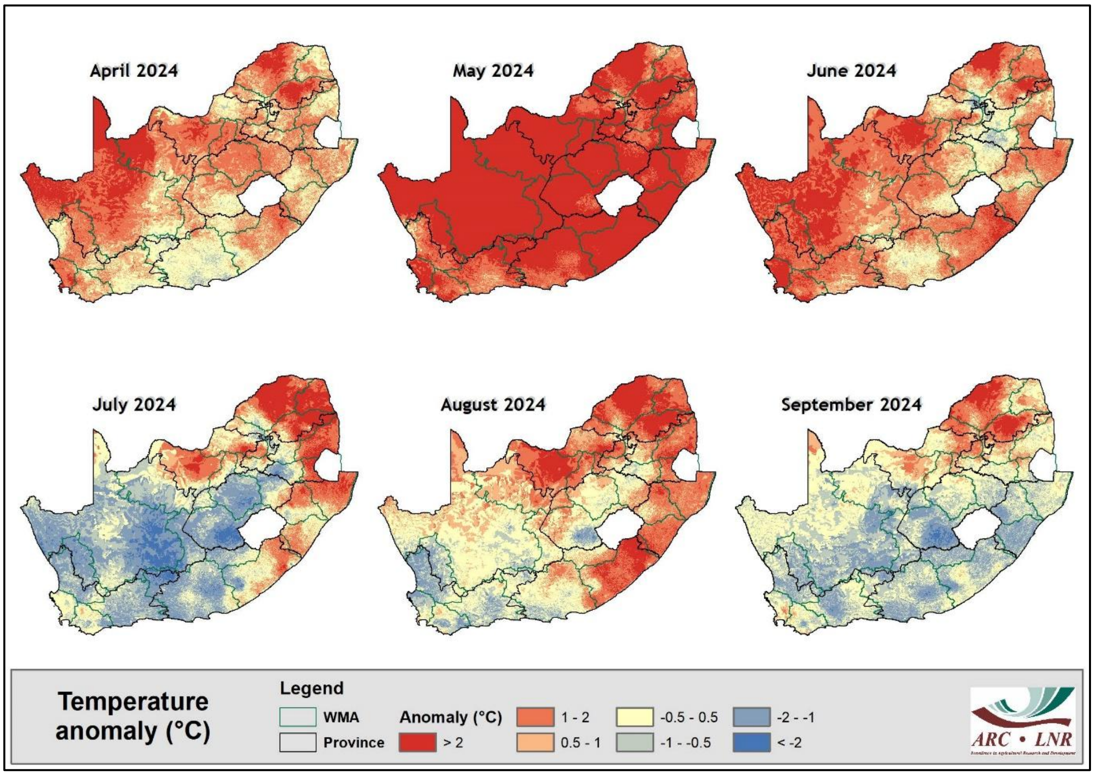

Figure 3.5: Monthly deviation in temperature from the long-term average during the winter half of the 2022/23 hydrological year.

3.2 Rainfall

The hydrological year included the 2023/24 summer, which was influenced by the occurrence of a strong El Niño event. Following three summers falling within the protracted 2020-2023 La Niña event, the 2023/24 summer was characterised by hot and dry periods in contrast to the relatively cool and wet preceding summers. The winter region experienced widespread above-average rainfall during the 2024 winter, a season largely unaffected by El Niño Southern Oscillation. These contrasting patterns resulted in the continuation of a trend that had started during the latter part of the 2022/23 hydrological year and which saw the northern to central interior continue to become drier relative to the southern parts and winter rainfall region where above-normal rainfall occurred. The total rainfall for the 2023/24 hydrological year (October 2023 – September 2024) is shown in Figure 3.6.

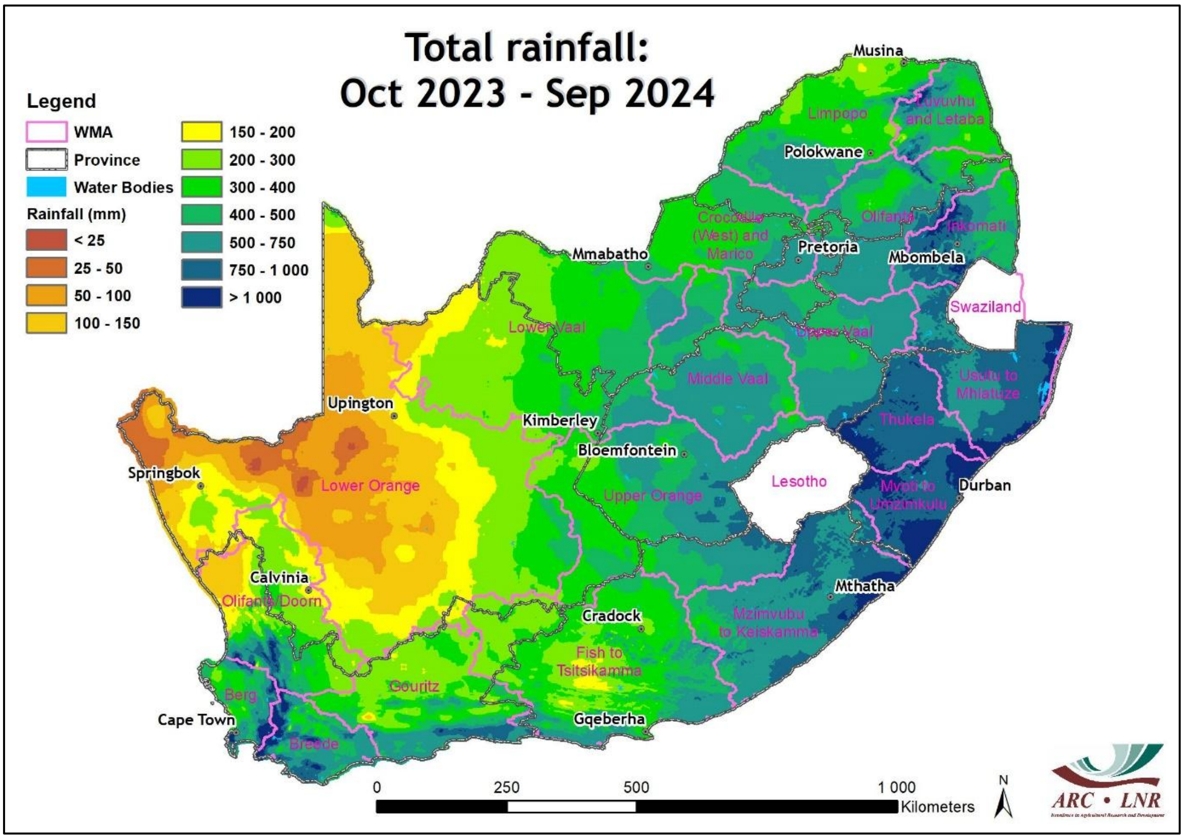

Figure 3.6 Rainfall (mm) for the water year October 2023 to September 2024.

The normal west-east gradient of increasing rainfall is visible over the interior, with the highest totals along the eastern escarpment and another maximum further east along the KwaZulu-Natal and the Eastern Cape coast. Some exceptions included large parts of the northern Free State, where totals were lower than further west, indicative of the drought conditions that dominated the region for significant stretches of the period. Higher rainfall totals were recorded over the southwestern winter rainfall region, especially the mountainous areas and the Garden Route in the south (Figure 3.7).

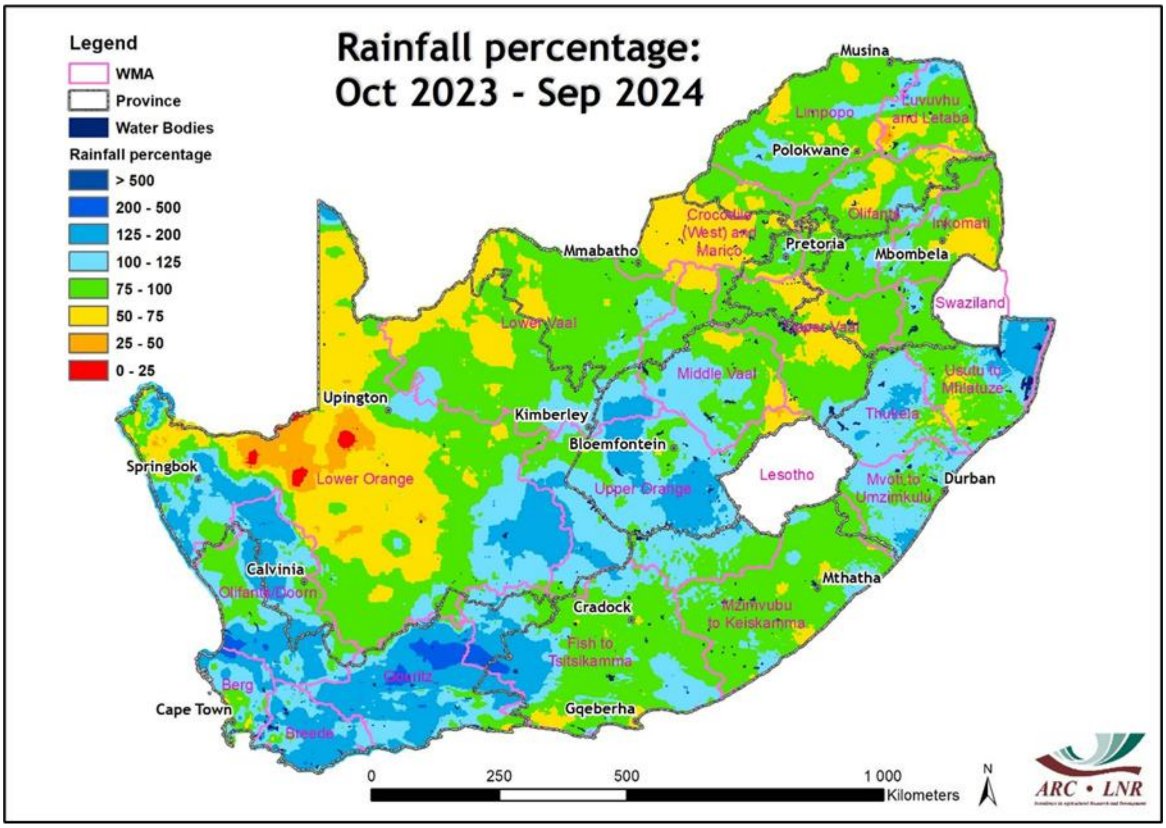

Figure 3.7 Rainfall (percentage of long-term average) for the water year October 2023 to September 2024.

Most of the country received below-average rainfall in total over the period. Notable exceptions are the winter rainfall region, the southeastern parts of the Northern Cape, the southwestern Free State, and large parts of KwaZulu-Natal. The monthly progression of rainfall anomalies is shown in Figure 3.8 and Figure 3.9, which represent the summer and winter halves of the water year.

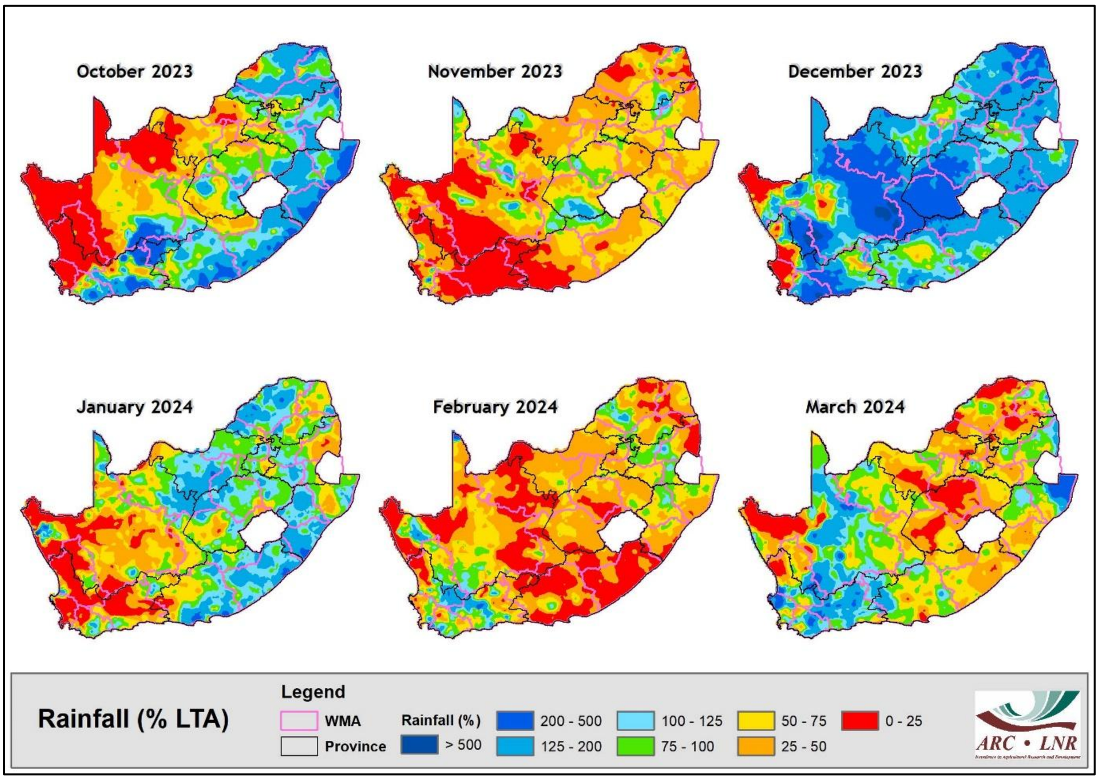

Figure 3.8 Rainfall (percentage of long-term average) per month as indicated for the summer half of the 2023/24 hydrological year (October 2023 to March 2024).

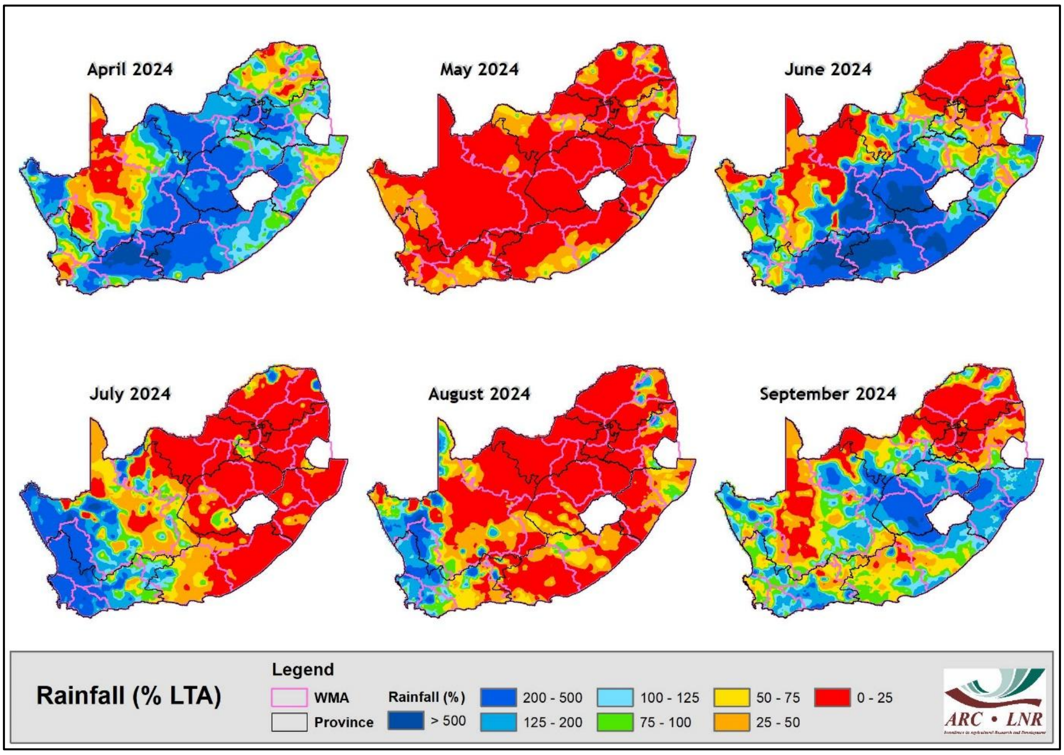

Figure 3.9 Rainfall (percentage of long-term average) per month as indicated for April to September 2024

Considering the monthly rainfall expressed as a percentage of the long-term mean during the 2023/24 hydrological year, a number of months stand out as being largely dry across the country. Over the summer rainfall region, November 2023, February 2024 and March 2024 were dry compared to the long-term average, with most of the interior receiving below 75% of the long-term average and substantial areas receiving less than 50% of the long-term average during these months. There were, however, also periods with above-average rainfall over the interior, with large parts receiving above-average rainfall in total during December, January and April. It was especially during December when extensive areas received above-average rainfall, with large parts of the interior receiving more than 200% of the long-term average. However, the contribution during the relatively wet months was insufficient, and the eventual outcome was below-average rainfall over most of the interior, as indicated earlier.

Over the winter rainfall region, rainfall was above average during most of the months from April to September. Above-average rainfall occurred, especially during July over the larger winter rainfall region and further inland over the western parts of the country. The only month during this period that was relatively dry over the winter rainfall region was May 2024, a month during which almost the entire country was dry and relatively warm.

The long-term total rainfall anomalies from the hydrological year 1922 – 2023 are presented in Figure 3.15 per water management area. The following classes were used: less than 75% is a dry year, 76-125% is a normal year, and greater than 125 % is a wet year. The Berg-Olifants, Breede-Gouritz, Mzimbvubu-Tsitsikamma and Olifants WMA have experienced a wet hydrological year. Other water management areas experienced a normal year, with no WMA, and experienced a dry year across the country.

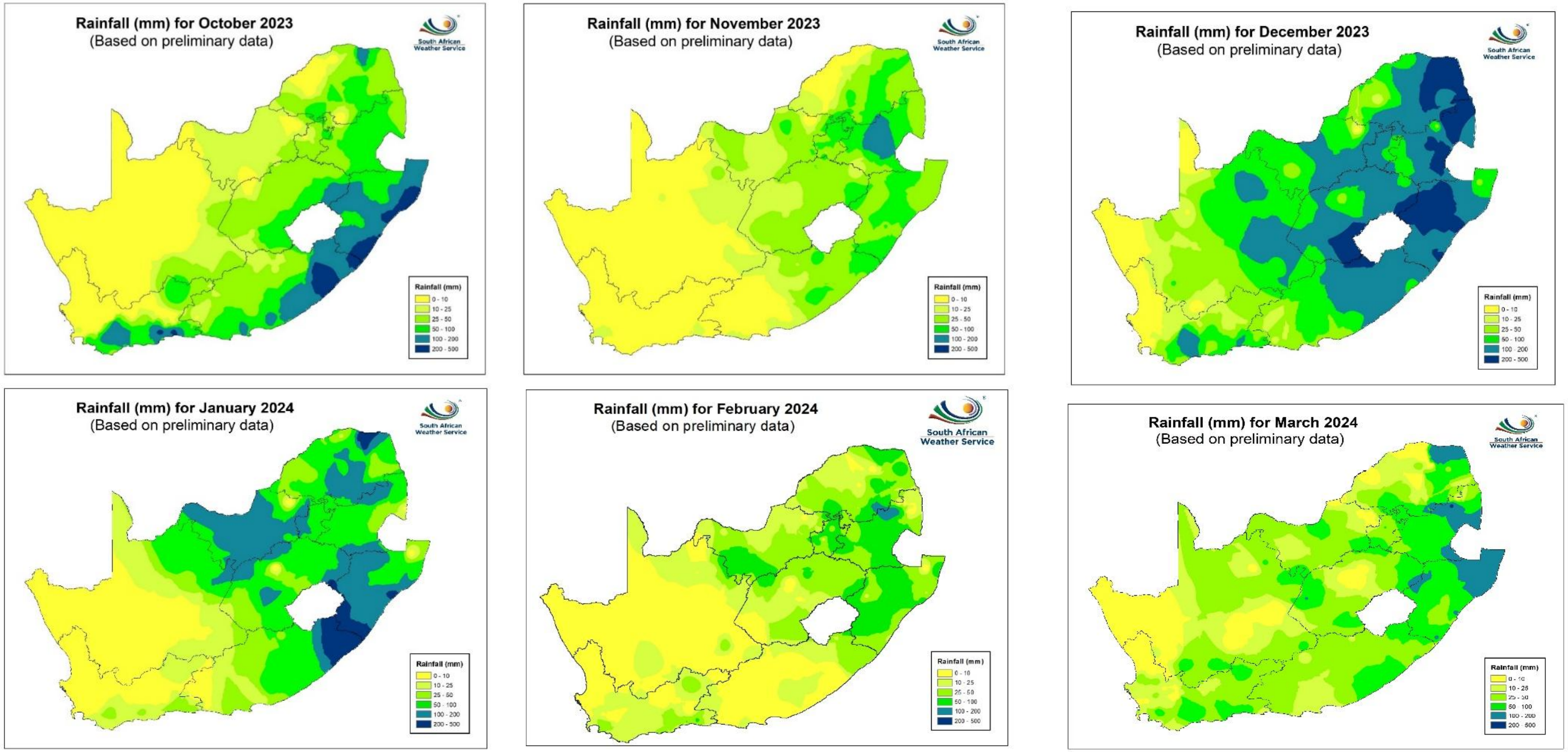

Figure 3.10 Summer season monthly rainfall distribution for October 2023 to March 2024 (Source: SAWS https://www.weathersa.co.za/home/historicalrain)

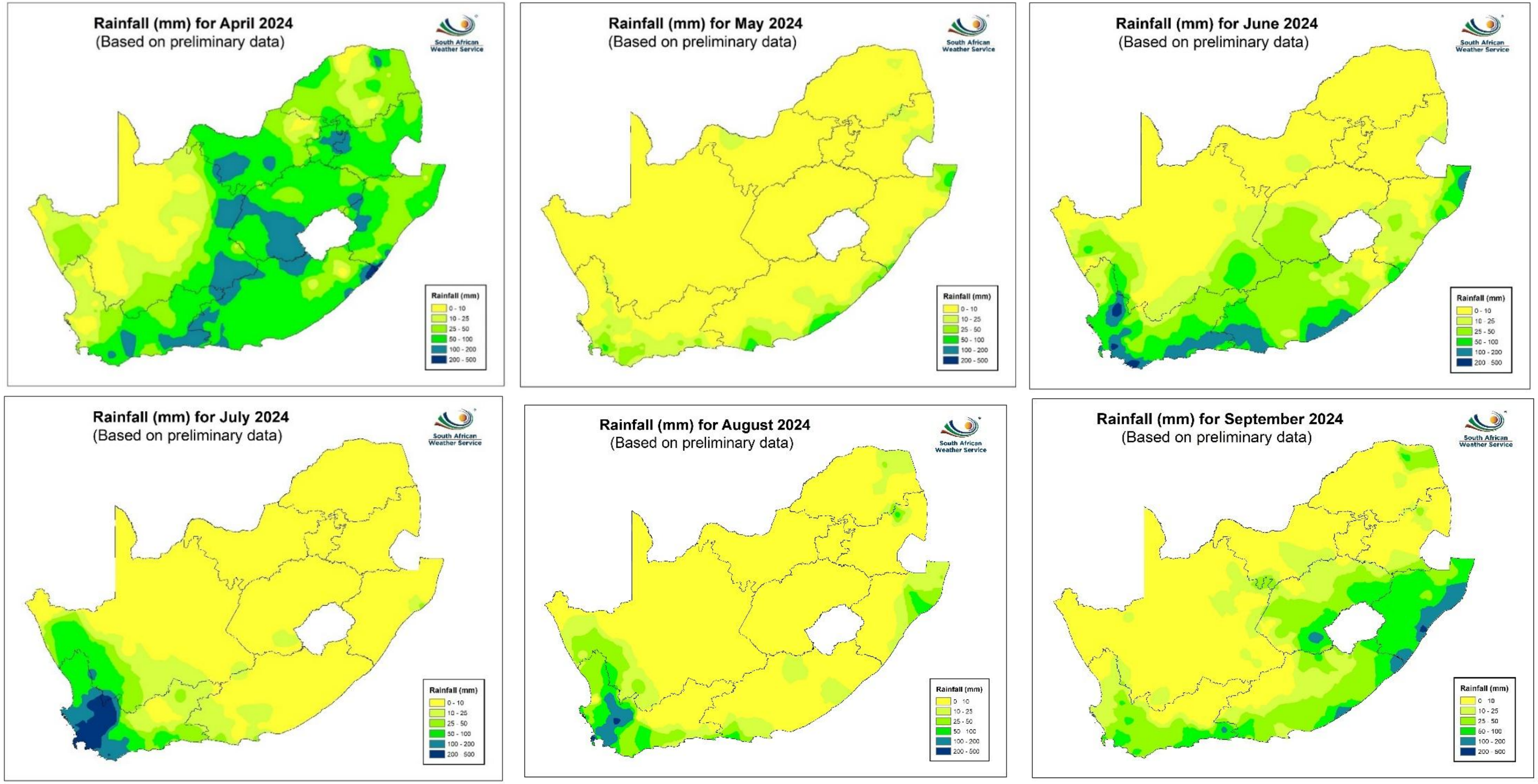

Figure 3.11 Winter season monthly rainfall distribution for April to September 2024 (Source: SAWS https://www.weathersa.co.za/home/historicalrain

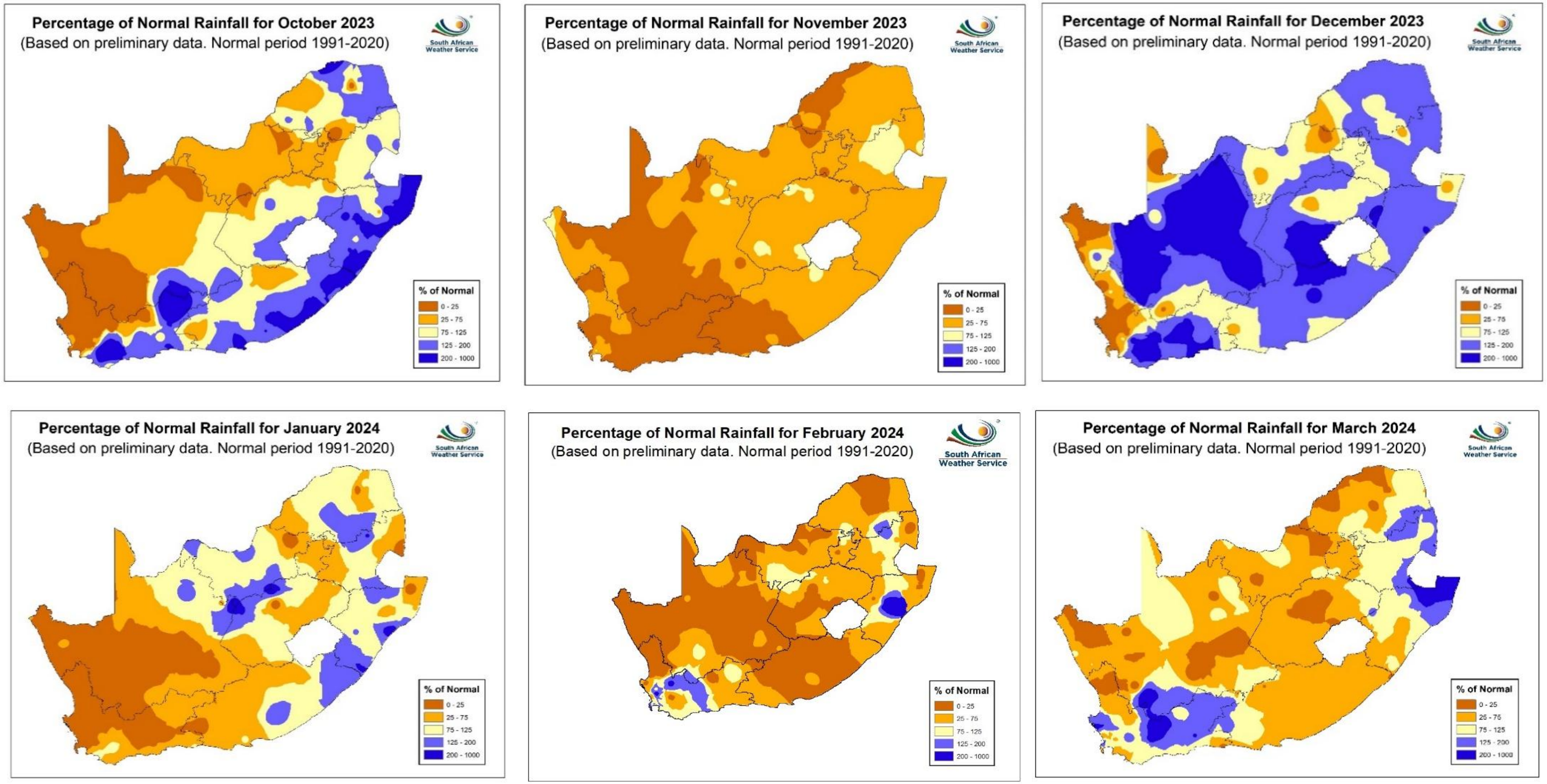

Figure 3.12 Summer season Percentage of normal rainfall for October 2023 to March 2024. Blue shades are indicative of above-normal rain, and the darker yellow shades of below-normal rainfall (Source: SAWS https://www.weathersa.co.za/home/historicalrain)

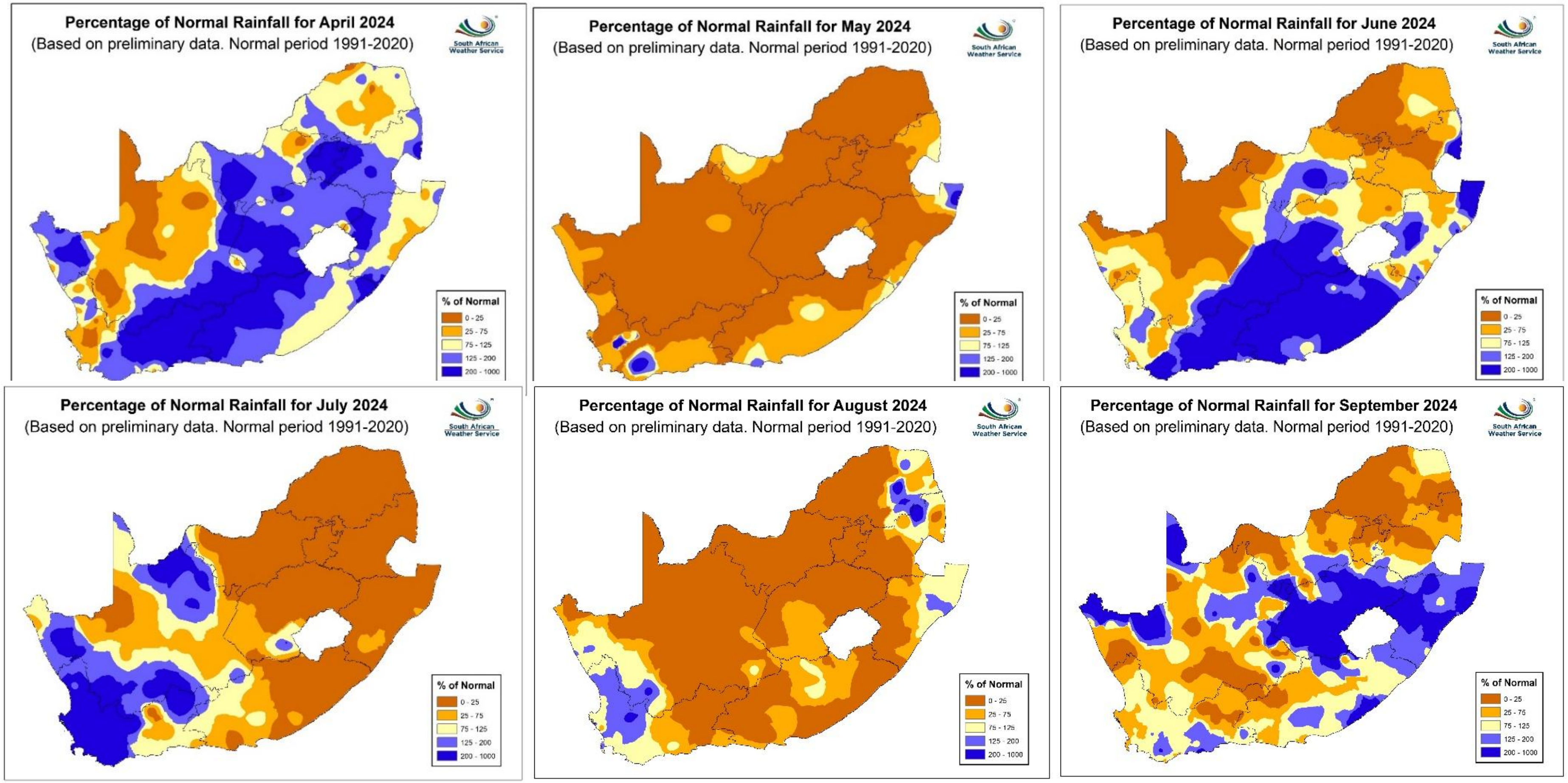

Figure 3.13 Winter season percentage of normal rainfall for April to September 2024. Blue shades are indicative of above-normal rain, and the darker yellow shades of below-normal rainfall (Source: SAWS https://www.weathersa.co.za/home/historicalrain)

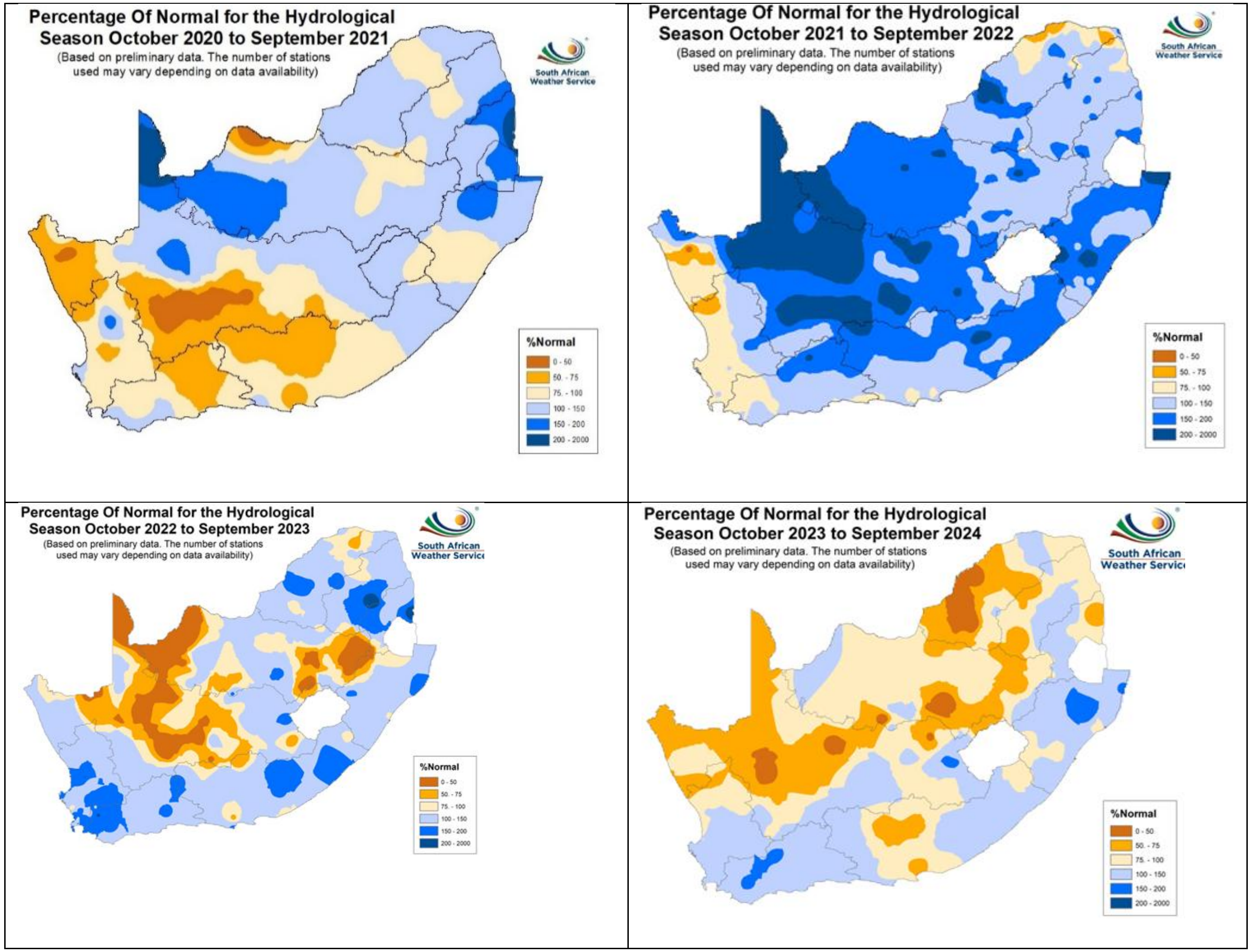

Figure 3.14: Percentage of normal rainfall for 2021/22, 2022/23 and 2023/24 Hydrological period. Blue shades are indicative of above-normal rain, and the darker yellow shades of below-normal rainfall (Source: SAWS https://www.weathersa.co.za/home/historicalrain

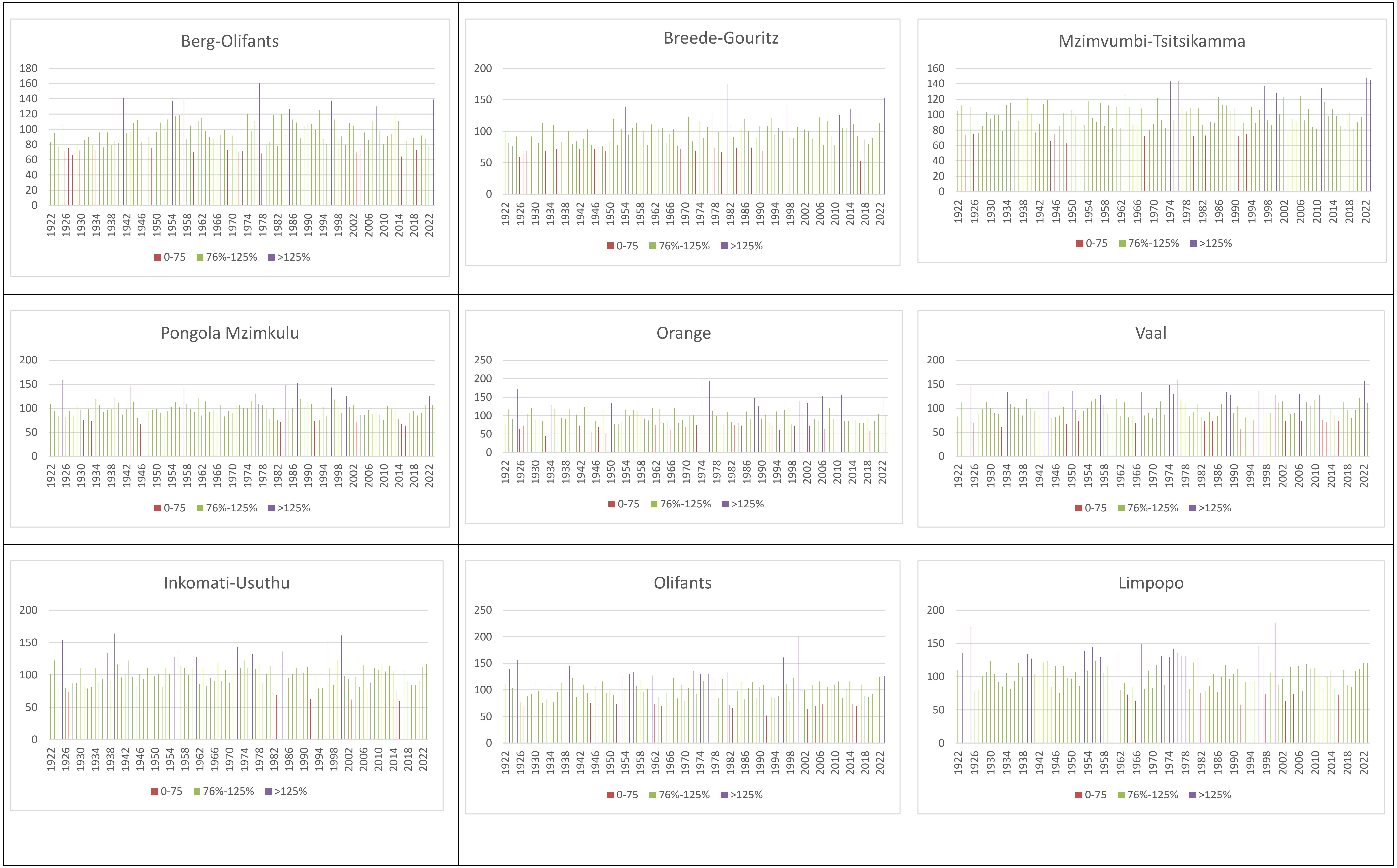

Figure 3.15: Hydrological year long-term trends of Rainfall Anomalies: > 125% (wet) & < 75% (dry) (Data Source: SAWS)

3.3 Potential Evapotranspiration

Figure 3.16 shows the total Potential Evapotranspiration (PET) calculated from observed weather data for the 2023/24 hydrological year. The PET for the hydrological year follows the typical distribution with the highest totals over the warmer, drier northwestern parts of the country, exceeding 1 700 mm and lowest values over the coastal areas in the south and south-east, including the Garden Route, where the total PET for the 12-month period was lower than 1000 mm in general and in isolated areas lower than 900 mm.

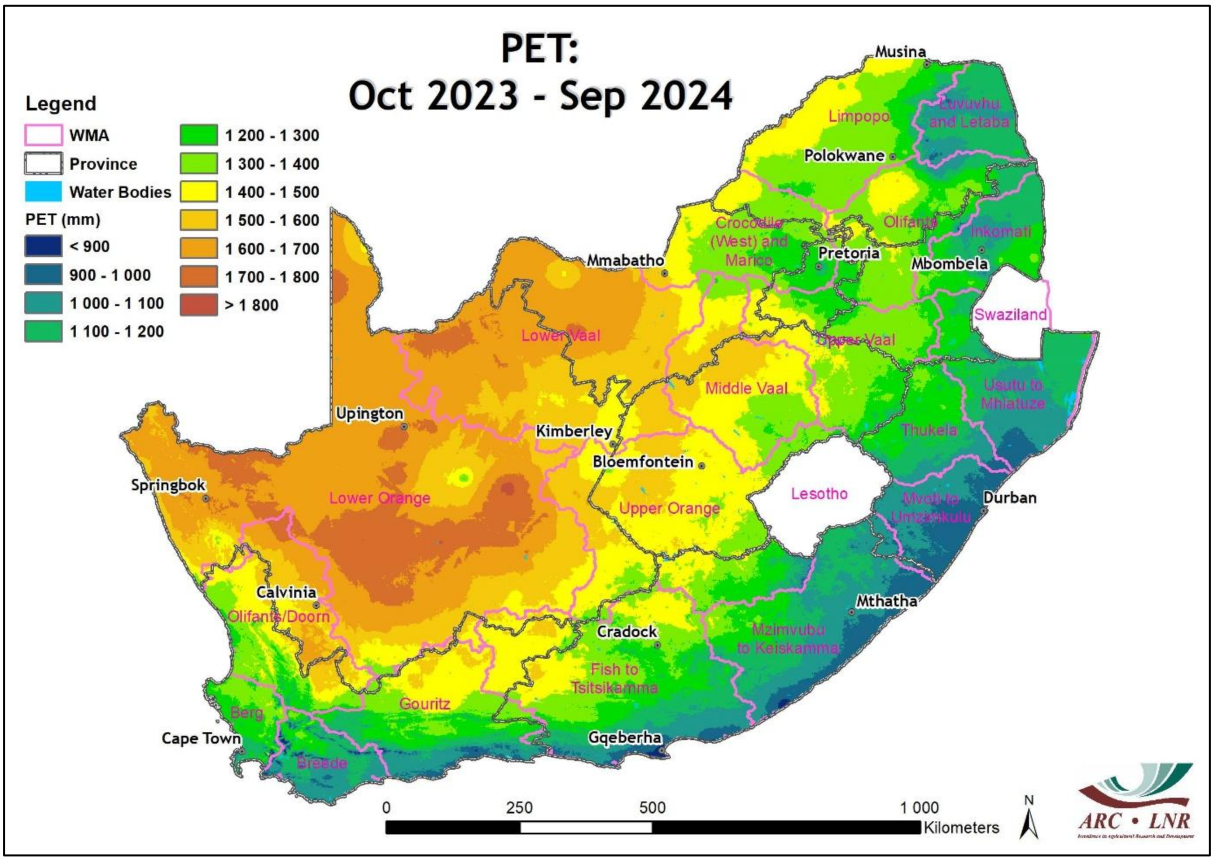

Figure 3.16: Potential Evapotranspiration (PET - mm) for the 2022/23 hydrological year.

In total, PET values were higher than the long-term average only over parts of the Northern Cape as well as along the south-eastern to eastern escarpment and Eastern Highveld (Figure 3.17). PET was lower than the long-term average, especially in the central interior and extreme northeast.

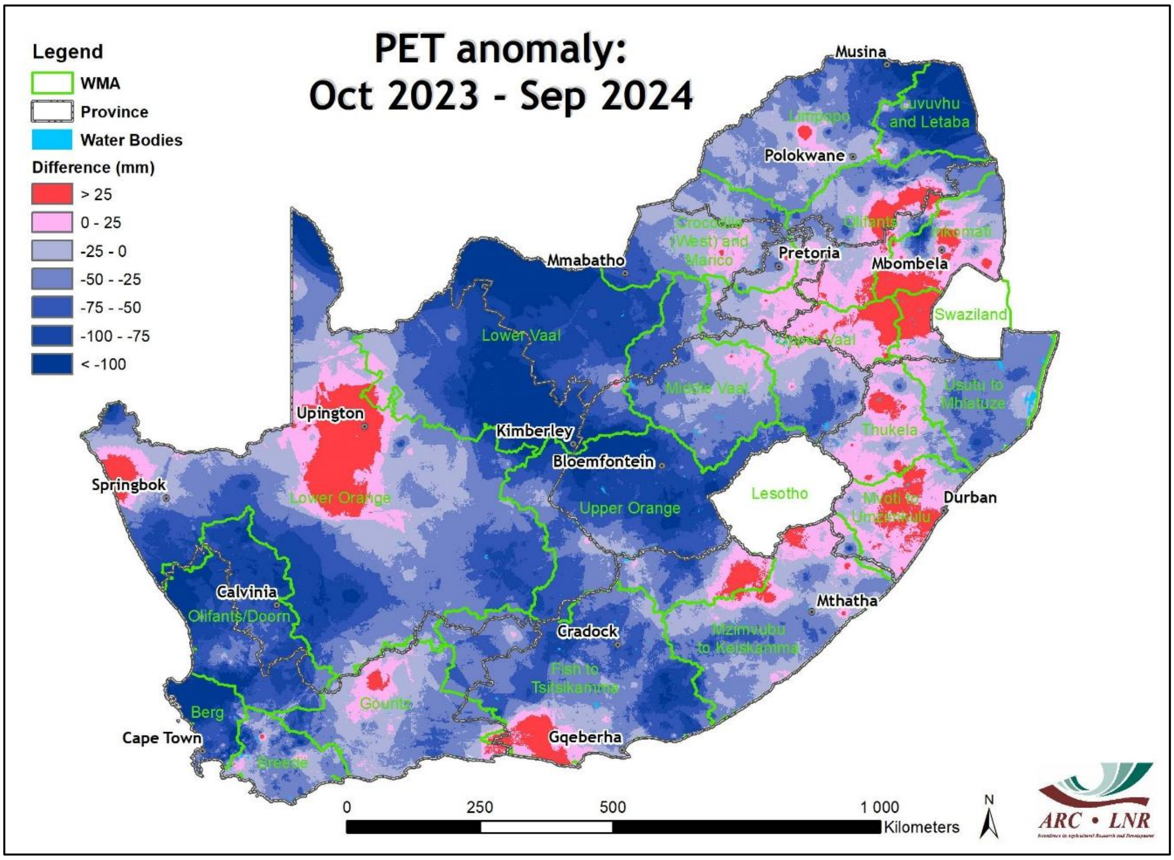

Figure 3.17: Difference (mm) in total Potential Evapotranspiration (PET) for the 2022/23 hydrological year with the long-term average (2022/23 total minus the long-term average value).

3.4 Indicators of Drought

The classification of meteorological drought is based on precipitation's departure from normal (long-term average) over time. Hydrological drought refers to deficiencies in surface and subsurface water supplies due to prolonged meteorological drought. It is measured using indicators derived from streamflow, dam storage levels, and groundwater levels. When precipitation (mostly rainfall in the context of South Africa) is low for a long time, it is reflected in a decline in surface flow and storage and subsurface water levels (soil moisture and groundwater).

3.4.1 Standardised Precipitation Index

The Standardised Precipitation Index (SPI) is an index based on the probability of rainfall for any time scale and can assist in assessing the severity of any drought. The 12- and 24-month SPI maps indicate areas where prolonged droughts exist, in other words, where below-normal rainfall occurred over one year or longer.

The Standardized Precipitation Index (SPI) for the 2-year period ending by September 2024 (Figure 3.18) shows that drought over this longer time scale was virtually absent, with limited areas over the interior experiencing moderate drought. Over the interior, this is linked to the protracted La Niña period, of which the October 2022 – September 2023 period was still a part of and during which widespread above-normal rain still occurred. An area in Lower Orange experienced moderate to severe drought, while moderate drought also occurred in isolated areas over the north-eastern parts of South Africa. Most of the winter rainfall region was moderately to severely wet during this 2-year period, with moderately wet conditions also dominating along the southern escarpment from the winter rainfall region up to Lesotho.

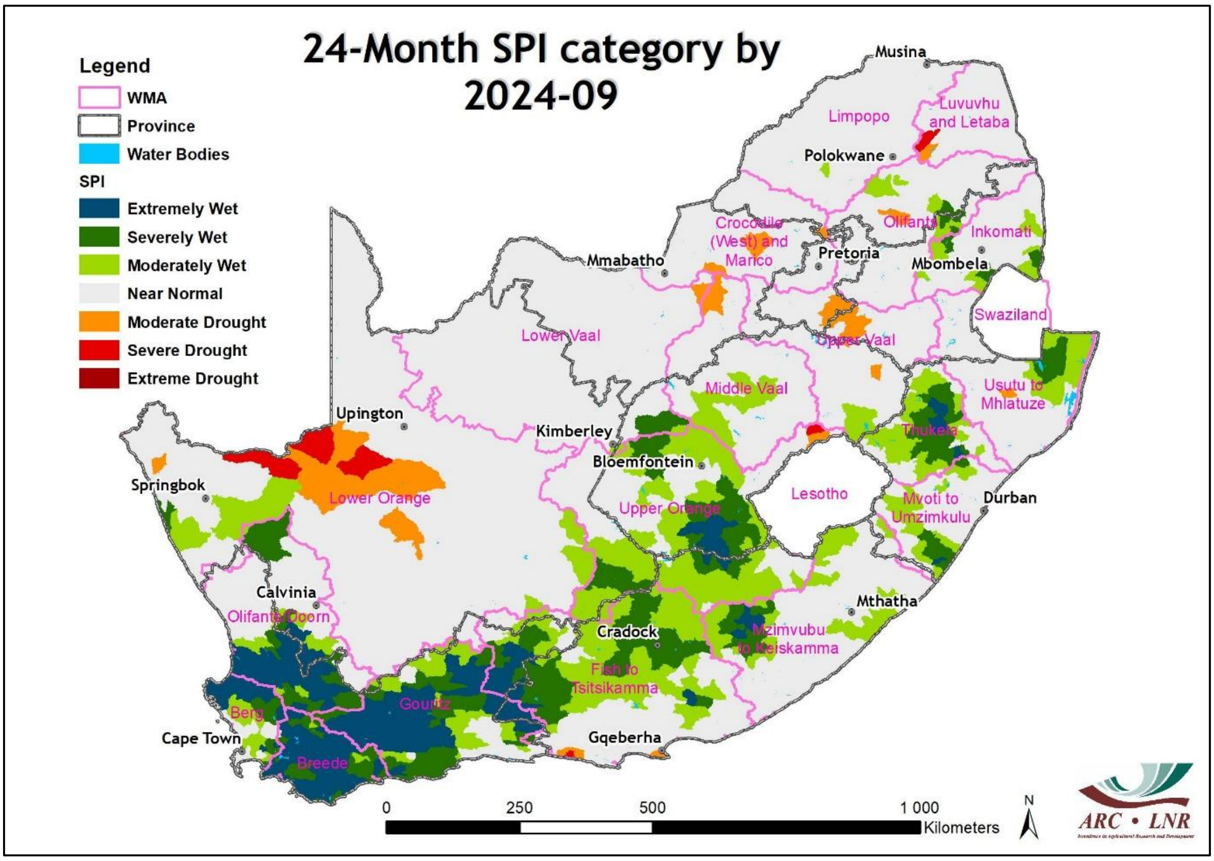

Figure 3.18: 24-Month Standardized Precipitation Index (SPI) by September 2024.

The 12-month SPI (Figure 3.19), which covers the 2023-2024 hydrological year only, shows substantially drier conditions over the interior at this shorter time scale. With the El Niño-associated below-normal rainfall over the interior, large areas in the north-east experienced moderate to severe drought. Water Management Areas where a majority of quaternary catchments experience moderate to severe drought include the Upper Vaal and Crocodile Management Areas.

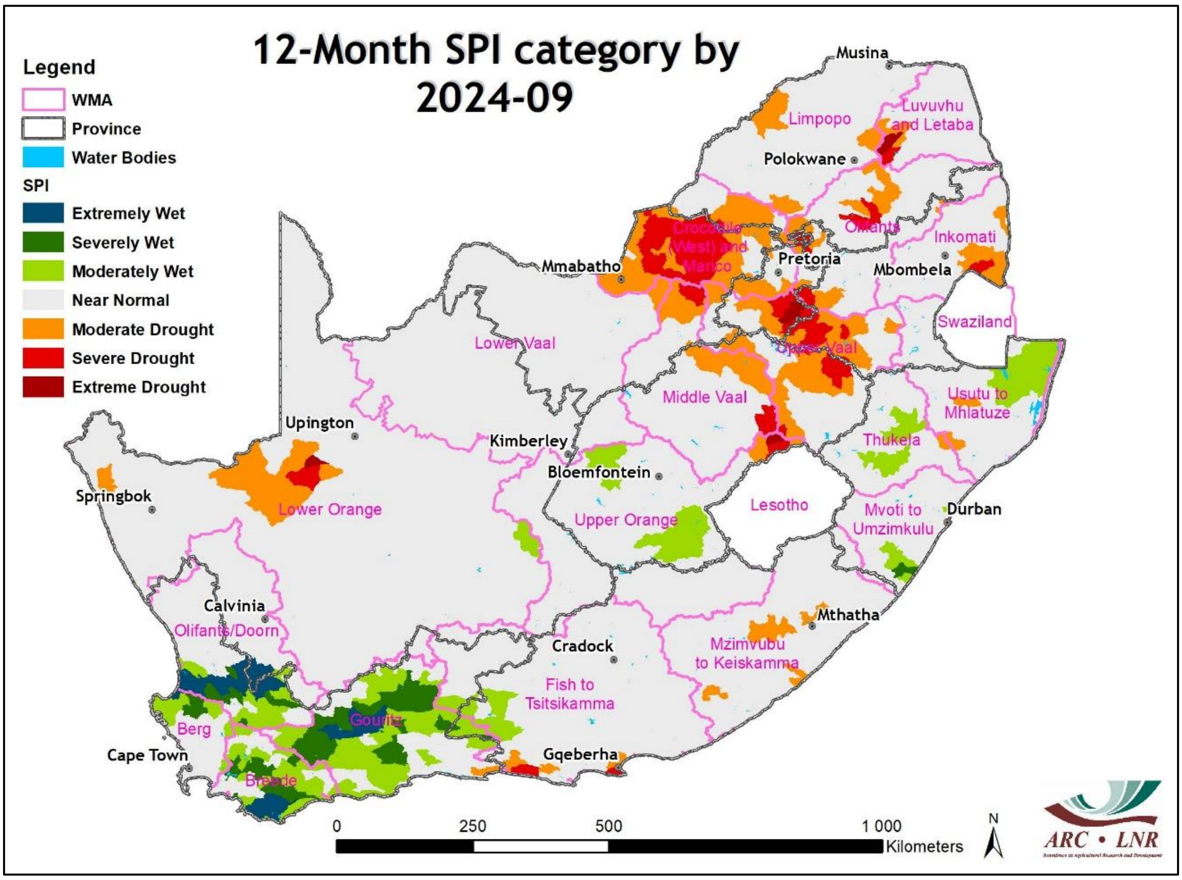

Figure 3.19: 12-Month Standardized Precipitation Index (SPI) by September 2024.

The time series of the 12-month SPI, summarised by WMA, is given in Figure 3.20 for the period 2015–2024. Drier and wetter multi-year periods are shown in the time series. The general trend in all catchments during the 2023/24 hydrological year was downward.

Regional patterns during the last decade include the following:

- Most of the country (north-eastern catchments, central to western and eastern to south-eastern catchments) experienced wetter periods around 2017 and then again during the 2021-2023 period. Drier periods, with widespread drought, occurred during the 2015-2016 period as well as the 2018 – 2020 and, more recently, during the second half of the latest hydrological year (2024).
- The south-eastern, southern and south-western catchments, including the winter rainfall region, experienced regular drought conditions from 2015 to 2020 (Berg WMA, Olifants WMA). Further east, the drought period only started in 2017. This entire region has been relatively wet since 2022.
- The 12-month SPI over the southern catchments has been on a downward trajectory throughout the 2023/24 hydrological year. This followed a peak over the winter rainfall region and in the south by late 2023 and a peak over the south-eastern parts by late 2022/early 2023.

- The El-Niño-related drought over the interior resulted in a downward trend in the 12-month SPI over much of the central to northern interior also following a peak in late 2022/early 2023.

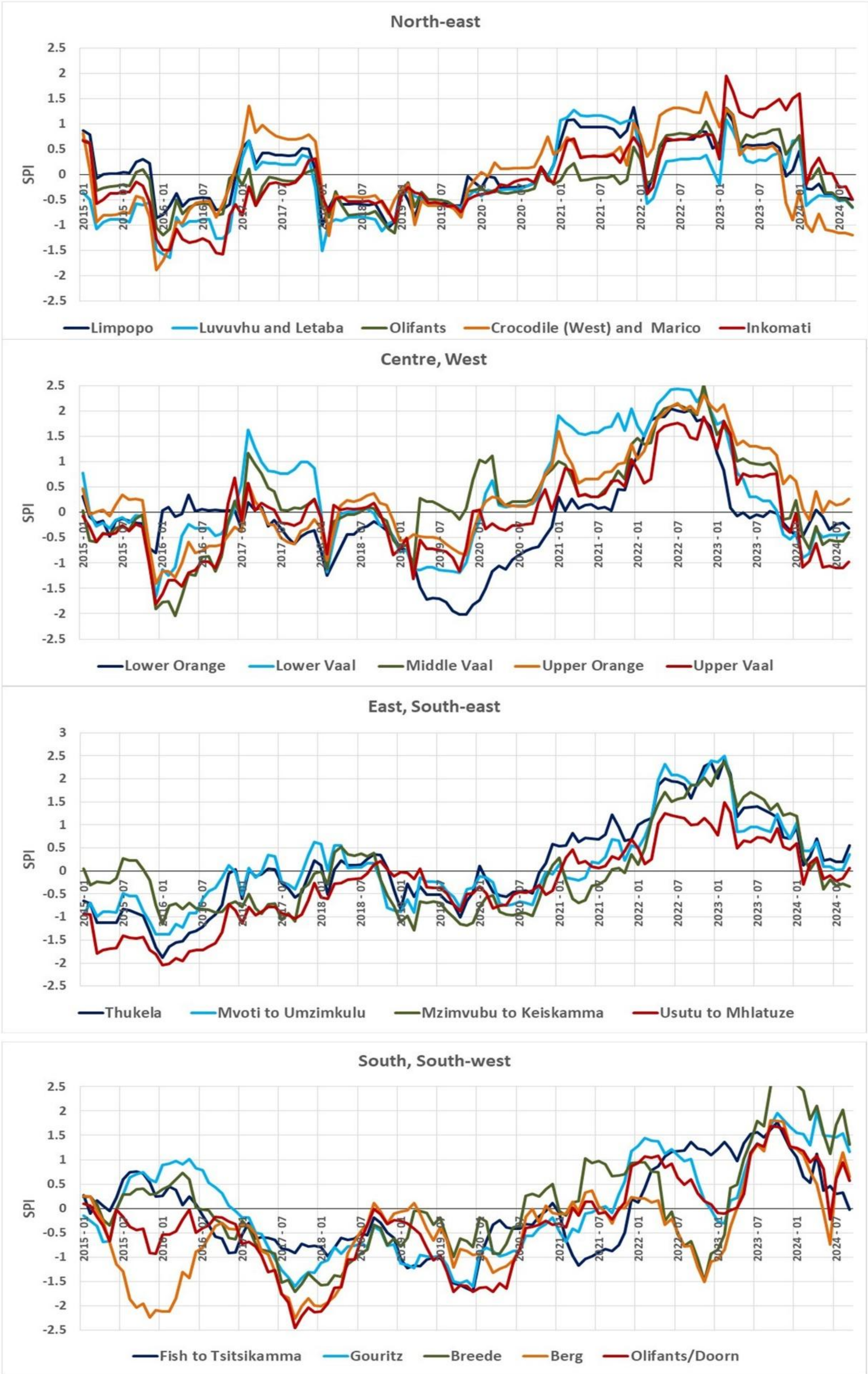

Figure 3.20: 12-Month SPI, per WMA as indicated, for the North-east (top), central to western parts (upper-middle), eastern to south-eastern parts (lower-middle) and

southern to south-western parts (bottom) of South Africa, for the period 2015 – 2024.

3.4.2 Vegetation activity

Figure 3.21 shows the cumulative vegetation activity, as represented by the cumulative Normalized Difference Vegetation Index (NDVI), expressed as a percentage of the long-term average (Percentage of Average Seasonal Greenness – PASG) calculated over the entire 2023/24 hydrological year.

Cumulative vegetation activity, as represented by the PASG, was above average during the 2023/24 hydrological year over the southern to southwestern parts of the country, including the winter rainfall region where above-normal rain occurred during both the 2023 and the 2024 winter. Cumulative vegetation activity was near normal over most of the rest of the country, linked partially to the heterogeneous nature of the summer rainy season that formed part of the 2023/24 hydrological year with alternating wet and dry periods. The northern half of the Lower Orange Water Management Area is an extensive region with below-average cumulative vegetation activity.

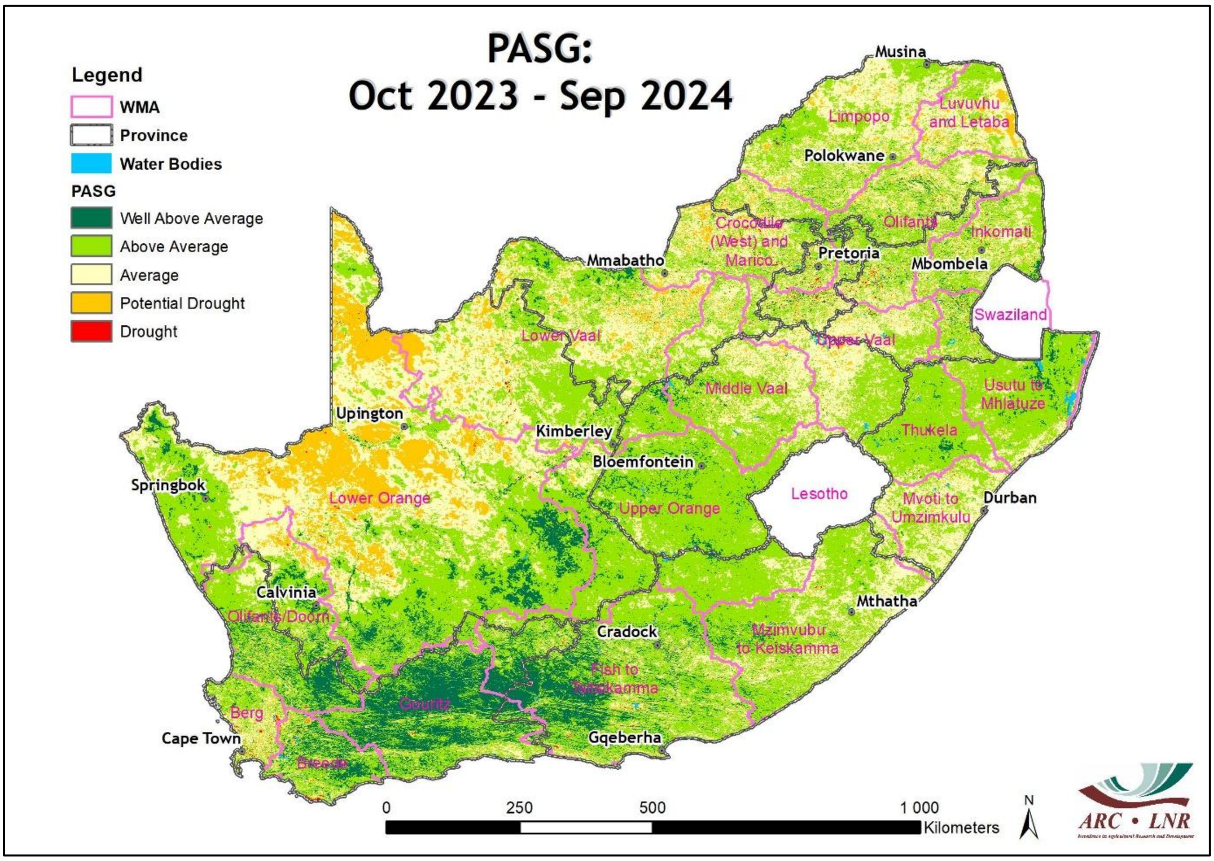

Figure 3.21: Percentage of Average Seasonal Greenness (PASG) for the 2022/23 hydrological year.

3.5 Extreme Weather Events

March also falls within the tropical cyclone season, with the forecast for the season projecting below-normal cyclone activity. However, there was still a chance for a tropical cyclone system to affect the sub-continent. This materialised when severe Tropical Storm Filipo affected South Africa in mid-March 2024. Tropical Storm Filipo made landfall north of Vilanculos, Mozambique, on the evening of 11 March, with average wind speeds of 100 km/h (Figure 3.22). After that, Filipo moved across the southern parts of Mozambique as a post-tropical depression and caused widespread heavy rainfall and flooding. The extreme north-eastern parts of South Africa, particularly the extreme southern Lowveld (Komatipoort) and the extreme north-eastern parts of KwaZulu-Natal, received more than 100 mm of heavy rainfall.

Figure 3.22: Tropical Storm Filipo's position 12 March 2024. Source: Eumetsat, 2024

3.5.1 Extreme Rainfall and Temperature Events from October 2023 to September 2024: Implications for Water Resources

From October 2023 to September 2024, the South African region experienced numerous extreme weather events, with hazardous impacts. Some of these are discussed as examples below, including a heatwave from 19-28 November 2023, a heavy rainfall event from 1-5 June 2024), and a mid-summer drought event from 15 January to 25 March 2024 (Figure 3.23). These events placed significant pressure on water resources, with cascading effects on agriculture, infrastructure and other resources, highlighting the South African region's vulnerability to extreme weather events. Given these challenges, this section draws on ARC weather station observations and reported impacts to examine these events and their effects, particularly for regional water resources, considering water availability, quality, and management.

3.5.2 19-28 November 2023 heatwave event

During the warmest November globally since 1850, a prolonged 10-day heatwave (19–28 November 2023) influenced all regions of South Africa. In the media (Omarjee, 2023), the South African Weather Service (SAWS) reported that this event was associated with record-breaking maximum temperatures, which were observed at roughly 21 weather stations, spread in the Northern Cape, Eastern Cape, Free State, North West, Limpopo and KwaZulu-Natal provinces. On 27 November, which was the hottest day of the heatwave and the day when most temperature records were broken, the SAWS reported that the Northern Cape Augrabies region recorded the highest observed daily maximum temperature during the heatwave, which was the location's highest ever observed daily maximum November temperature Figure 3.23.

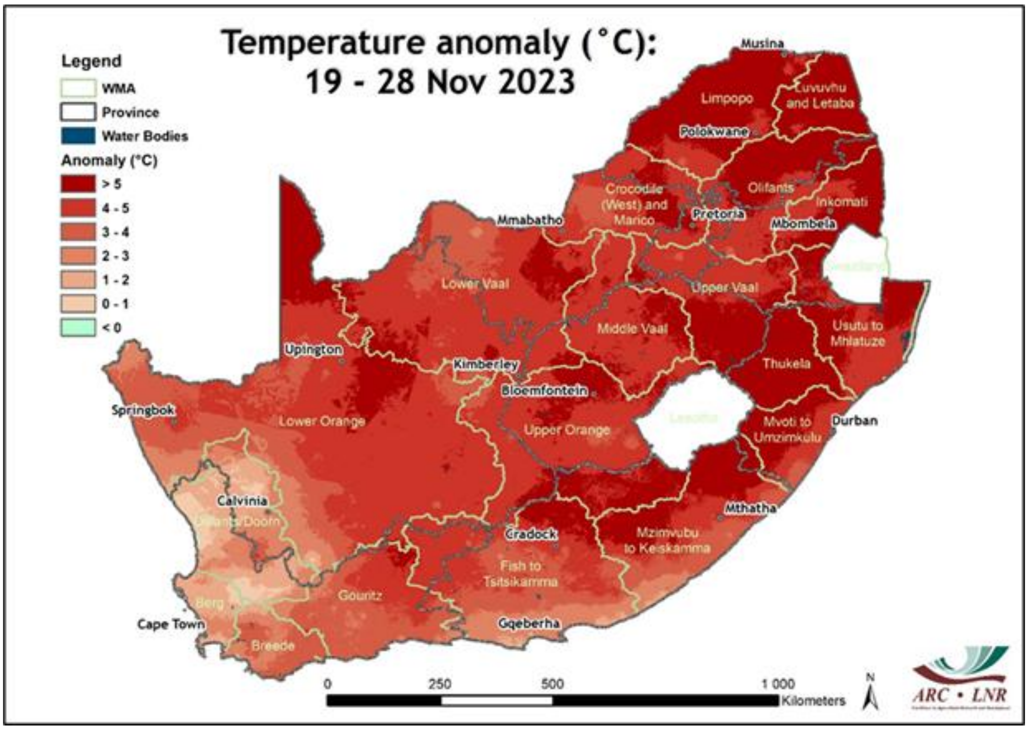

Figure 3.23: Map of average daily maximum temperature anomalies recorded for 19-28 November 2023.

In addition to these very warm temperatures, the long-lasting nature of this event contributed to its severity and extreme nature. This event occurred during a strong El Niño event, which, coupled with ongoing warming, likely contributed to the intense and long-lasting nature of this event, given that heatwaves across South Africa tend to be longer-lasting and more intense during El Niño events.

Although this heatwave notably impacted all regions of South Africa, the ARC weather station network observations reflect that anomalous above-normal temperatures were at varying degrees over South Africa. The highest anomalies reached approximately 5°C above normal, occurring over parts of central, northern and eastern South Africa, whereas, over far western regions of the country, above-normal temperature anomalies were below 4°C. These above-normal temperatures were likely driven by a stronger-than-normal mid-level high-pressure system causing air to warm and subside, coupled with a near-normal strength near-surface level trough, which pulled warm air from higher latitudes to South Africa. Such conditions typically cause intense, long-lasting heat waves over South Africa.

According to the December 2023 ARC Umlindi newsletter issue (ARC, 2023), drier-than-normal conditions were observed for November 2023 – this, coupled with the hot temperatures that occurred throughout the heatwave duration, would have notably influenced water resources over SA. Therefore, despite the level of above-normal temperatures, all regions of the country likely experienced water challenges in terms of water availability for drinking, household, industrial and agricultural use. For instance, in the key water management area of the Upper Vaal, temperature anomalies of roughly 4-5°C likely accelerated evaporation and evapotranspiration, reducing water availability in the Vaal dam surface water reservoir, which was 13% lower than during November 2023 (Mafenya et al., 2023) – water availability in many other key reservoirs would have also been notably impacted. This likely also reduced the quantity of available water that could be used for drinking, household, agricultural, and industrial use.

The heatwave also contributed to a surge in water consumption, which placed considerable strain on water supply systems. In an area such as Johannesburg, residents were urged to use water sparingly to prevent system overloads (Sithole, 2023). Even the City of Ekurhuleni, for example, noted a strain on its water supply system due to the high temperatures – officials had urged residents to use water sparingly to reduce pressure on the municipality water system (City of Ekurhuleni, 2023). Moreover, even soil water availability would have been compromised by the prolonged period of above-normal temperatures, negatively impacting water availability for farming activities. Hence, from a reduction in water availability to increases in water demand and stresses on water infrastructure, this November 2023 heatwave had notable impacts on South Africa's water resources, underscoring the current broader challenges to South Africa's water security posed partly by increasing temperatures.

3.5.3 1-5 June 2024 Heavy precipitation event

From 1-5 June 2024, many southwestern, southern and southeastern regions of South Africa experienced heavy precipitation, with up to roughly 50-300 mm of rainfall accumulating (Figure 3.24). Above this, conditions were also cold, with an intense cold snap having occurred – this caused widespread frost over interior regions, while snowfall also occurred over some high-lying regions. Over many of the regions influenced by this event, winds were also reportedly quite strong. Having first persisted over southwestern regions, this event was caused by a deep, intense cold-cored cut-off low-pressure system, which extended to the surface as a low-pressure system – on 2 June, a cold front along with this surface low also contributed to some rainfall over southwestern regions. On 3 June, as the cut-off low (and surface low) persisted eastward, a band of thunderstorms developed. Some of these storms became so intense that they produced two tornadoes, which influenced and caused widespread damage to the Newcastle, Tongaat, and Utrecht areas in the KwaZulu-Natal province.

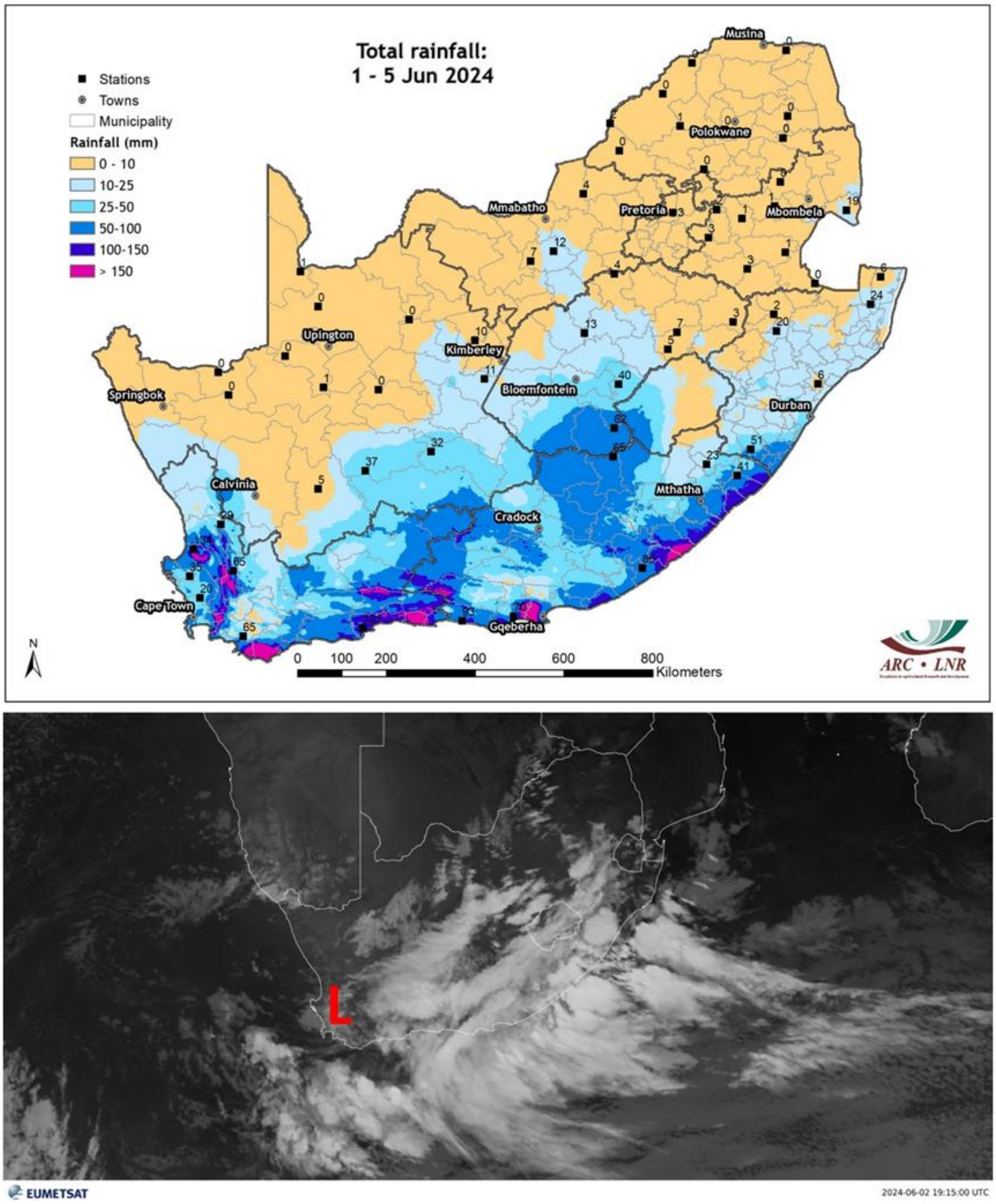

Figure 3.24 Map of the total daily rainfall amount recorded from 1-5 June 2024 (top) along with an EUMETSAT Meteosat black and white satellite image at 15:00 UTC on 2 June 2024 (bottom).

In the context of water resources in South Africa, this event brought both relief and new challenges. In terms of the former, the event contributed to providing relief and replenishment in soil moisture/water and surface water levels following the 2024 mid-summer drought as well as the generally dry conditions that persisted thereafter during April-May (as per the May and June 2024 ARC Umlindi newsletters; ARC, 2024e, f). However, in terms of new challenges and damage, the storm caused widespread infrastructure (housing, roads, bridges and irrigation, among other infrastructure) damage via wind and flood damage, which was mainly concentrated over the Eastern Cape province. The flooding caused at least six deaths, while several thousands of people were displaced and had to evacuate their houses due to the flood damage. This was particularly true in low-lying and informal settlements, where poor drainage systems exacerbated the crisis. In many of the Eastern Cape municipalities, the flooding led to dam level breaches (for dams including the Loerie, Wriggleswade and Nahoon dams), overflowing rivers and saturated soils. The flooding above caused extensive infrastructure damage, leading to a significant risk of potentially contaminated water, causing waterborne diseases, such as cholera. Additionally, the heavy runoff from the flooding also likely resulted in increased sedimentation in dams, reducing storage capacity and affecting water quality. This, in turn, complicated efforts to manage water resources effectively in regions still recovering from prolonged dry conditions.

This event underscored the increasing variability of rainfall patterns, with periods of extreme dryness followed by intense, short-lived downpours, making long-term water resource planning even more complex. As with the November 2023 heatwave and the 2024 mid-summer drought, the impacts of the June 2024 rainfall highlighted the urgent need for adaptive infrastructure, improved early warning systems, and more resilient water management strategies to mitigate both drought and flood risks in a rapidly changing climate.

Case study: Monitoring the January to March 2024 mid-summer drought

Drought is a significant climate-related hazard that poses substantial risks to agricultural productivity, water resources, and livelihoods on a global scale, including in South Africa. The Agricultural Research Council – Natural Resources and Engineering (ARC-NRE) developed the Agricultural Drought Early Warning System (ADEWS) to address these challenges. This web-based platform (https://www.drought.agric.za/) integrates multi-disciplinary datasets and indices specific to agricultural commodities, providing free access to real-time and forecasted drought data (Figure 3-25). The ADEWS enables users to monitor drought conditions, visualise and analyse spatial and temporal trends, and receive daily email updates about drought developments tailored to specific regions.

Figure 3.25 The user-interface of the Agricultural Drought Early Warning System (ADEWS).

The effectiveness of ADEWS was clearly demonstrated in monitoring the mid-summer drought event from 15 January 15 to 25 March 2024 (Figure 3.26). The ADEWS was utilised to track and assess the drought conditions during this period, which followed a heatwave in November 2023 and a period of near-normal to normal rainfall levels in December 2023, as noted in the January 2024 issue of the Umlindi newsletter (ARC, 2024a). The system allowed for detailed tracking of rainfall anomalies, with data showing widespread rainfall deficits across South Africa. Central, northwestern, southern, and northeastern regions, in particular, received less than 75% of the long-term average rainfall, with some areas facing deficits of less than 50% (Figure 3.26). According to the February-April 2024 issues of the Umlindi newsletter (ARC, 2024b, c, d), the February period was especially dry. This resulted in extended dry spells, with many regions experiencing little to no rainfall for consecutive weeks. These conditions led to a substantial reduction in soil moisture, severely impacting agricultural production.

The occurrence of this mid-summer drought was driven by large-scale atmospheric circulation patterns, including higher-than-normal geopotential heights at the 850 hPa level, which contributed to suppressing convection and reducing moisture availability. Moreover, a stronger-than-normal mid-level high-pressure system further inhibited cloud development and rainfall, reinforcing dry conditions. Typically, such patterns are associated with subsidence, warming, and drying, creating an environment unfavourable for rainfall events. These atmospheric anomalies co-occurred with a moderate to strong strength El Niño event, which is typically lined to drier-than-normal mid-summer conditions over much of South Africa – together, these conditions contributed to the occurrence of this drought while also intensifying the severity of the drought. A report by the World Weather Attribution group highlighted that this El Niño event was a particularly strong driver of this mid-summer drought (Kimutai et al., 2024), and it also highlighted that such El Niño induced droughts are becoming increasingly likely as the planet warms. Additionally, the persistence of heatwave conditions during most of February and March 2024 further compounded the drought's severity, exacerbating the soil moisture deficits and extending the dry spell (Evans, 2024).

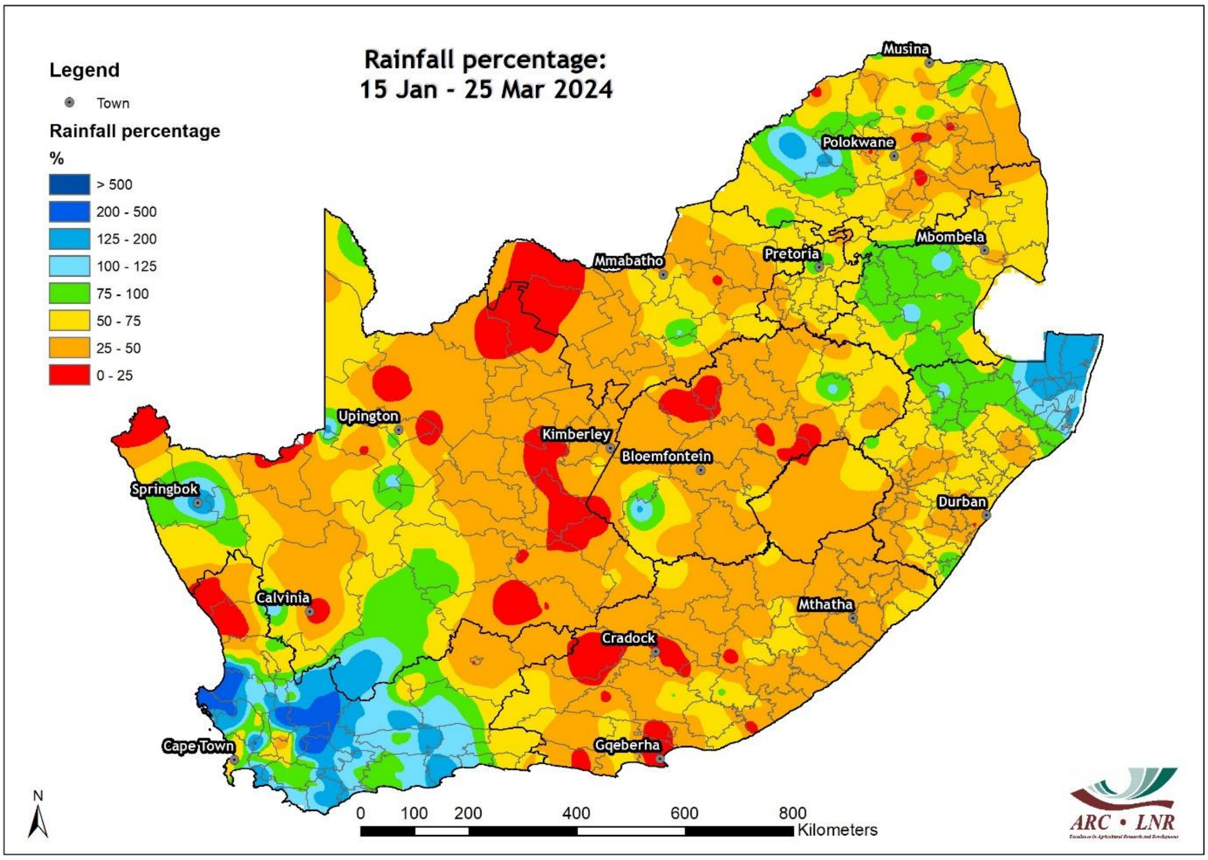

Figure 3.26: Map of the daily rainfall anomalies, represented as a rainfall percentage with respect to the long-term mean rainfall, for 15 January to 25 March 2024.

For dryland farmers, the drought posed significant challenges, especially during critical growth stages for crops. Preliminary reports indicated a 20% decrease in grain and oilseed yields compared to the previous season, underscoring the extent of the losses caused by the drought (Sihlobo, 2024). The lack of rainfall, combined with persistently warm temperatures, exacerbated the moisture deficits, further straining crops already vulnerable to water scarcity. In addition to dryland farming challenges, irrigation-dependent farmers also faced difficulties as surface water resources became increasingly scarce. The reduction in surface water availability due to below-normal rainfall levels and the depletion of reservoirs raised concerns about the availability of water for irrigation and other uses. Considering the DWS monthly state of water bulletin reports for March and April 2024 (Mafenya et al., 2024a, b), surface water reservoir levels in most South African provinces were reported to be up to 7.4% lower than the normal levels observed in March 2023 and previous months. This significant decrease was attributed to higher evaporation rates resulting from above-average temperatures, compounded by the reduced rainfall during the drought period. As a result, many farmers were forced to adapt by seeking alternative water sources, implementing water-saving irrigation techniques, or reducing the areas planted in order to conserve water. However, these adaptations often led to further declines in crop yields, contributing to significant financial strain on farming communities.

Overall, the mid-summer drought of early 2024 underscores the growing vulnerability of South Africa's agricultural and water systems to climate variability. The combination of heatwaves, reduced rainfall, and prolonged dry spells places increasing pressure on water resources, agricultural production, and livelihoods. Addressing these challenges requires enhanced resilience through improved water resource management, climate-informed agricultural practices, and adaptive measures to mitigate the impacts of future droughts and heat waves. The importance of early warning systems and proactive response strategies will only continue to grow as South Africa navigates an increasingly uncertain climate future.

3.6 Floods

In December 2023, most parts of the country received rainfall, which was sufficient to improve surface water storage in some areas. However, the rainfall caused widespread havoc in KwaZulu-Natal, resulting in flooding. On 22 December 2023, the South African Weather Service (SAWS) issued a warning of an upper-air system that was expected to cause scattered to widespread showers and thundershowers in the Free State, North-West, KwaZulu-Natal, Gauteng, Mpumalanga, and Limpopo from Sunday (24 December) onwards, with the possibility of local heavy rainfall and cooler conditions.

According to the report, while isolated severe thunderstorms were expected over the central and south-eastern interior on Sunday (24 December 2023) and possibly into Monday (25 December 2023), the atmosphere was expected to eventually become tropical, allowing for locally heavier and widespread rainfall (SAWS, 2023). SAWS numerical weather models predicted 15-30 mm of rainfall across much of the eastern country from Sunday to Monday (Figure 3.27).

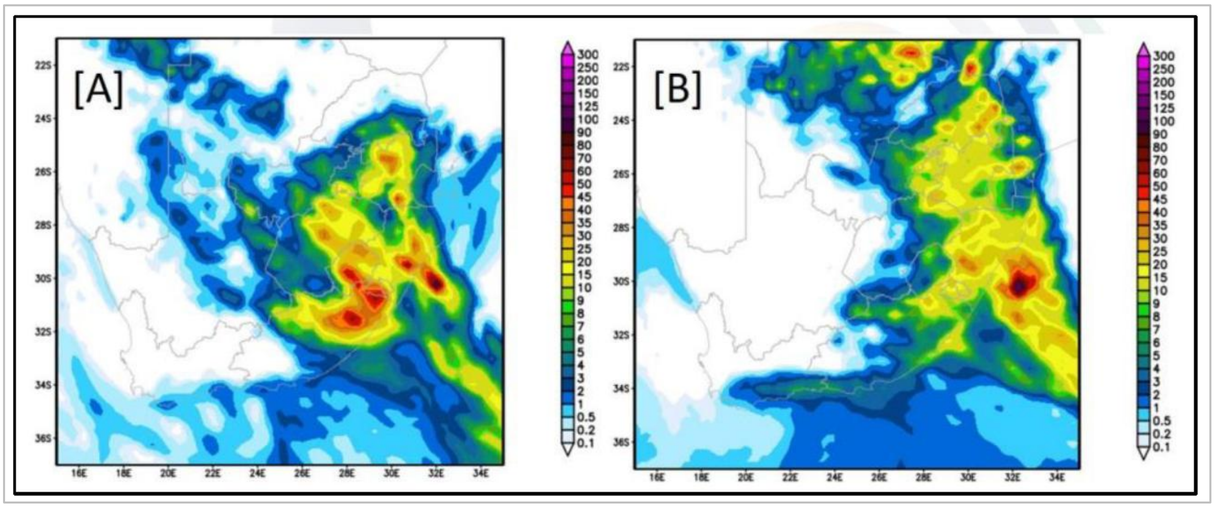

Figure 3.27 24-hour rainfall accumulation (mm) for Sunday, 24 December 2023 (A), Monday, 25 December 2023, as predicted by the Global Forecast System (GFS) (Source, SAWS).

SAWS later issued a yellow level 2 warning for severe thunderstorms and disruptive rain for the province on the 24th and 26th of December 2023, respectively (Figure 3.27). On Christmas Eve (24 December 2023), heavy rains and severe thunderstorms intensified, causing flash floods in the northwestern parts of the province. Figure 3.28 shows that the province received accumulated rainfall ranging from 100 to 200mm in most areas, with the northwestern parts receiving 200 to 500mm in December 2023.

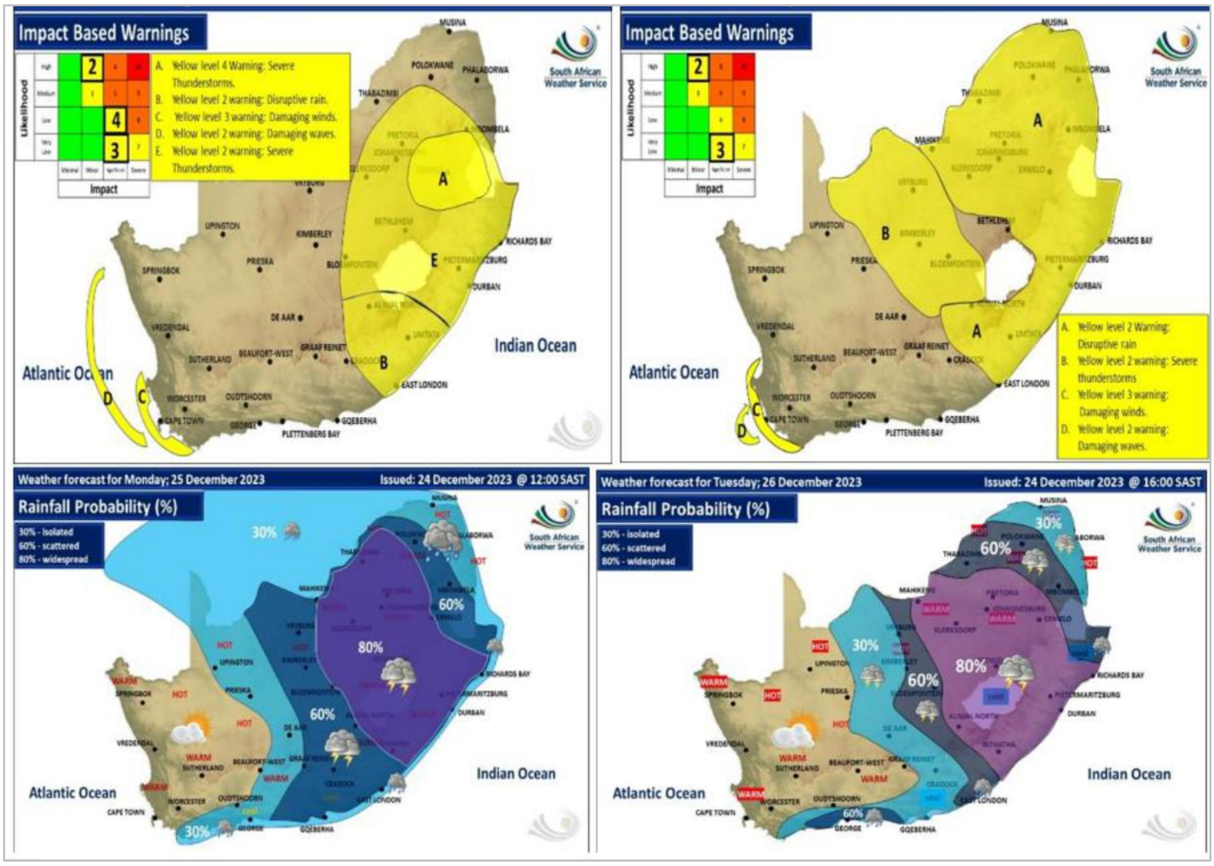

Figure 3.28 Severe weather warnings and rainfall predictions for 25 and 26 December 2023.

These heavy rains caused widespread destruction, affecting households, businesses, and public infrastructure such as schools, roads, and bridges (Figure 3.29). The UThukela District was severely affected, with 23 deaths reported during floods that hit Ladysmith on 24 December 2023 and more than 100 houses damaged.

On 24 December 2023, weather stations in the Ladysmith area reported approximately 60mm of rain within an hour, with approximately 80mm of rain falling over three hours. Strong winds also damaged over 40 homes in King Cetshwayo District, destroying several businesses in the Eshowe industrial area. By 31 December 2023, the number of fatalities from extreme weather conditions in KZN had risen to 31, with three people still missing. COGTA reported that over 600 households and over 140 dwellings were destroyed (COGTA, 2023).

Figure 3.29 Destruction caused by floods in Ladysmith, KZN.

On 7 January 2024, SAWS issued a Yellow Level 2 Warning of an upper-air system that was expected to cause disruptive rain in the province's western and southern areas on 8 January 2024 (Figure 3.30). SAWS numerical weather models had predicted a 24-hour rainfall accumulation of 50mm. The Alfred Duma Local Municipality was severely affected by the heavy rainfall, resulting in flash floods in some of its municipal areas. The floods caused damage to several roads, business properties in the Central Business District (CBD), and homes in its thirteen municipal wards. According to the municipality's assessment, thirty-nine (39) households were affected, with five (5) structures destroyed and eleven (11) partially damaged, affecting one hundred and ninety-nine (199) people. Figure 3.31 depicts a few flooded low-water bridges within the ADLM.

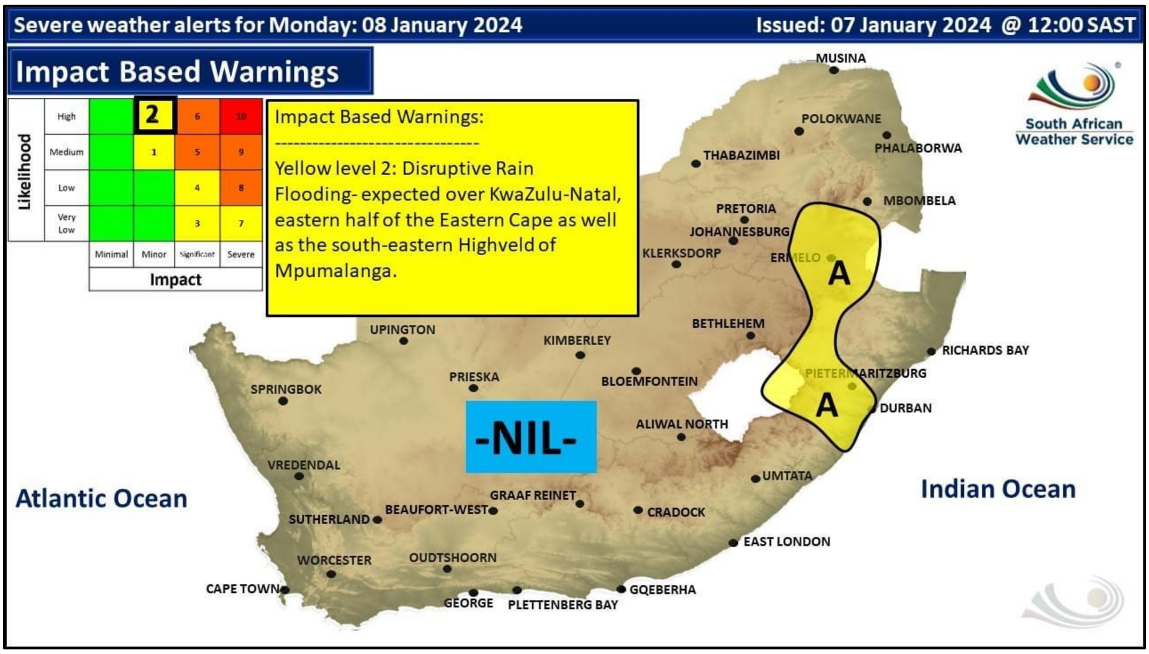

Figure 3.30: Severe weather warning for 08 January 2024 in KZN (Source:SAWS)

Figure 3.31: Damages on road infrastructure in the Alfred Duma Local Municipality (Source: Alfed Duma Local Municipality).

3.6.1 Floods in the eThekwini Metropolitan Municipality

On 12 January 2024, SAWS issued a Yellow Level 2 Warning for Disruptive Rain, which was expected to cause flooding and isolated structural damage in central KwaZulu-Natal (Figure 3.32). On 13 January 2024, heavy rainfall, severe thunderstorms, and strong winds wreaked havoc across KwaZulu-Natal, leaving a trail of destruction. The most severe damage and fatalities were reported in parts of the eThekwini Metropolitan Municipality (EMM) and the north coast of KZN. Hundreds of homes, roads, and bridges were damaged, six people died, and two people were reported missing.

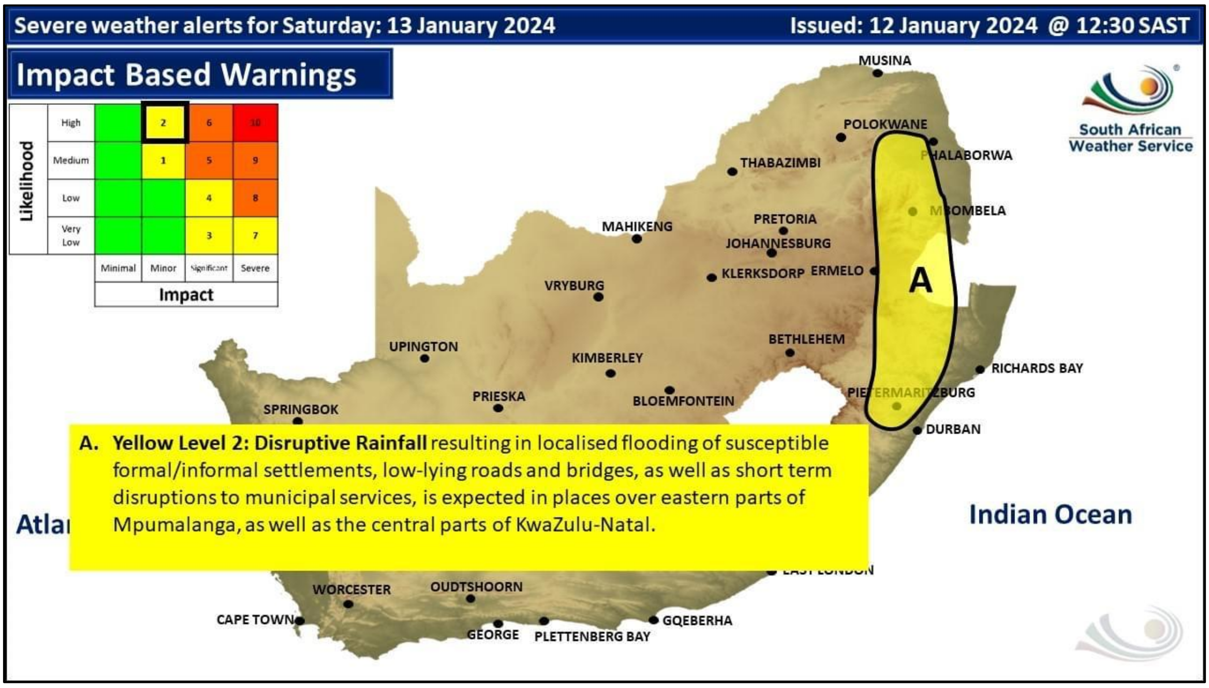

Figure 3.32 Severe weather warning for 13 January 2024 in KZN (Source: SAWS)

Floods also damaged water and electricity infrastructure, leaving some communities in eThekwini and Stanger without access to water and electricity (EMM, 2024a). The Verulam area, located North of Durban, experienced widespread road closures, mudslides, and power outages. According to eThekwini Disaster Management, 250 households and 1,000 people were directly affected in the eThekwini Metro area. Furthermore, on 14 January 2024, the eThekwini Metro issued a statement informing the public of the beach closures due to heavy rains that impacted water quality at some of its beaches (EMM, 2024b).

Most provinces received heavy rainfall in April; in some provinces, the heavy rainfall caused floods, leaving a trail of destruction and fatalities. The rainfall was caused by a cut-off low weather system, which occurs most frequently during this period. Cut-off lows are large weather systems that are known to cause widespread flooding, such as the KwaZulu-Natal flooding in 2022 and the Laingsburg flooding in 1981 (SAWS, 2024*a*). In the first week of April, the cut-off low-pressure system was positioned over the country's western interior. Figure 3.33 shows a widespread showers and thundershowers predicted by the Global Forecast System across most parts of the country, with heavy rainfall and severe thunderstorms predicted in some areas for 7 and 8 April 2024.

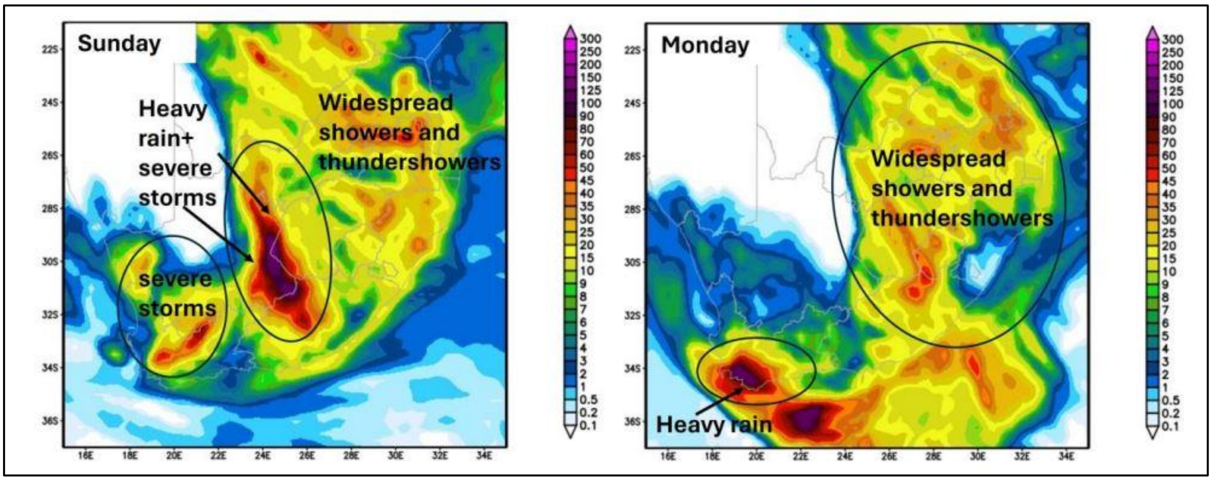

Figure 3.33 24-hour rainfall accumulation for Sunday, 7 April (left) and Monday, 8 April (right) according to the Global Forecast System (GFS) (Source: SAWS

3.6.2 Western Cape: Strong Winds and Floods

On 4 April 2024, SAWS issued an early warning for the Western Cape for disruptive rain and strong winds from 7 April to 9 April (Figure 3.34). The statement described an intense cut-off low that was expected to develop along the country's west coast from 4 April 2024. The statement also predicted heavy rainfall over parts of the Overberg and the south-west coast of the Western Cape on the 8th and 9th as the cut-off low exited along the southern coast of the Western Cape, as well as a strong to gale-force south-easterly wind, which could disrupt coastal marine routines and operations (SAWS, 2024*a*).

On 9 April, the Western Cape Government reported that George had accumulated more than 100mm of rain within 24 hours. Furthermore, dam levels in the Karoo and Garden Route districts rose rapidly, with some dams reportedly overflowing, particularly those along coastal areas.

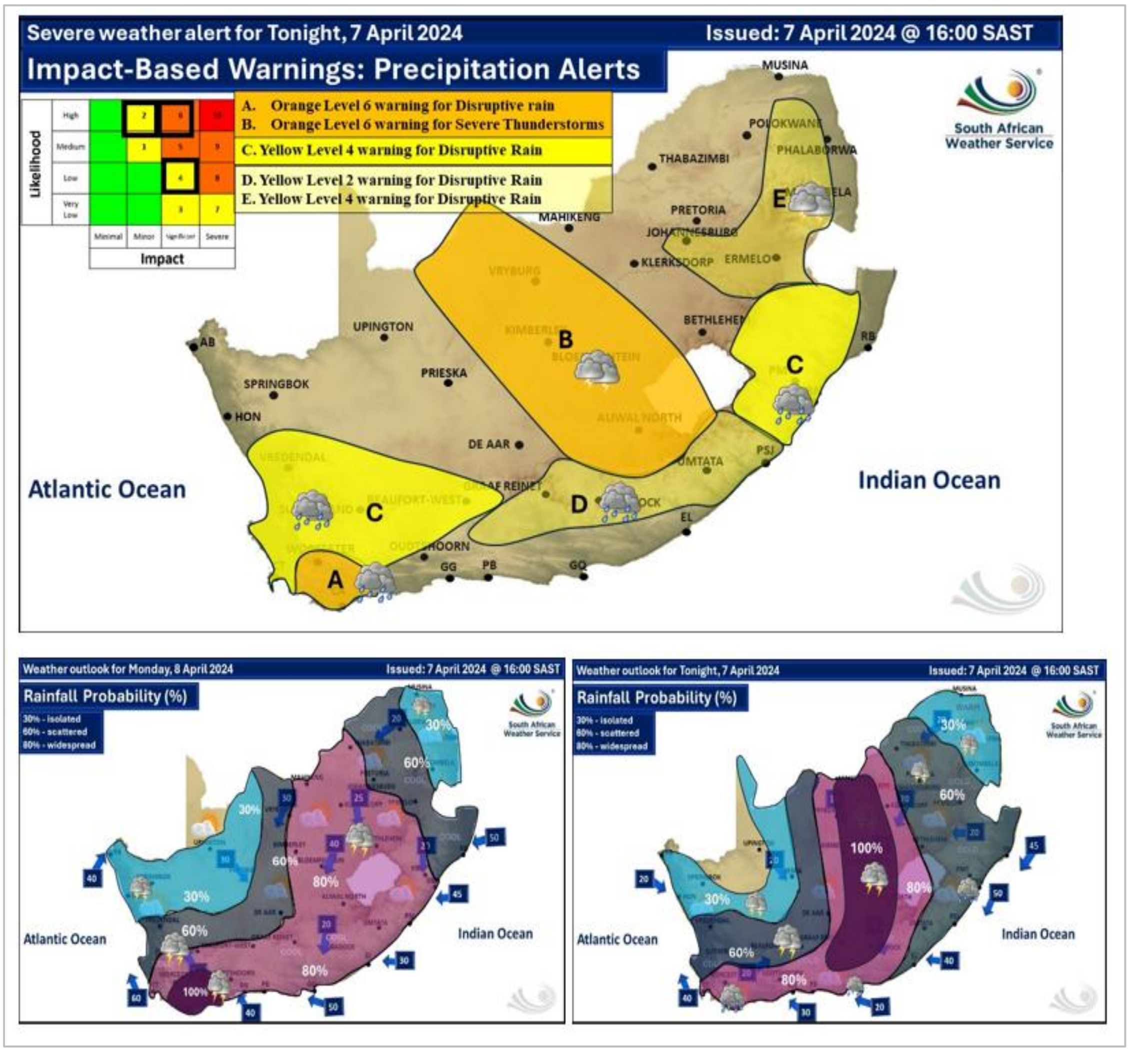

Figure 3.34 Extreme weather warning indicating heavy rainfall for the Western Cape Province

By 10 April, one fatality had been reported, with 2,779 buildings affected, at least 26 schools damaged, and several highways closed across the Cape Winelands, Overberg, and West Coast regions, as well as several power outages.

3.6.3 Kwa-Zulu Natal: Floods

On 14 April, SAWS issued an orange level 5 warning for KwaZulu-Natal's South Coast, predicting heavy rainfall and thunderstorms (Figure 3.35). A severe storm hit the Margate- Uvongo -Shelly Beach - Port Edward areas from the 14 to 15 April, as per rainfall probability, and a warning was issued, as displayed in Figure 3.35. A total rainfall of 250mm was recorded in Margate, with 225 mm recorded between 16h00 and 22h00 on 14 April (SAWS, 2024*b*).

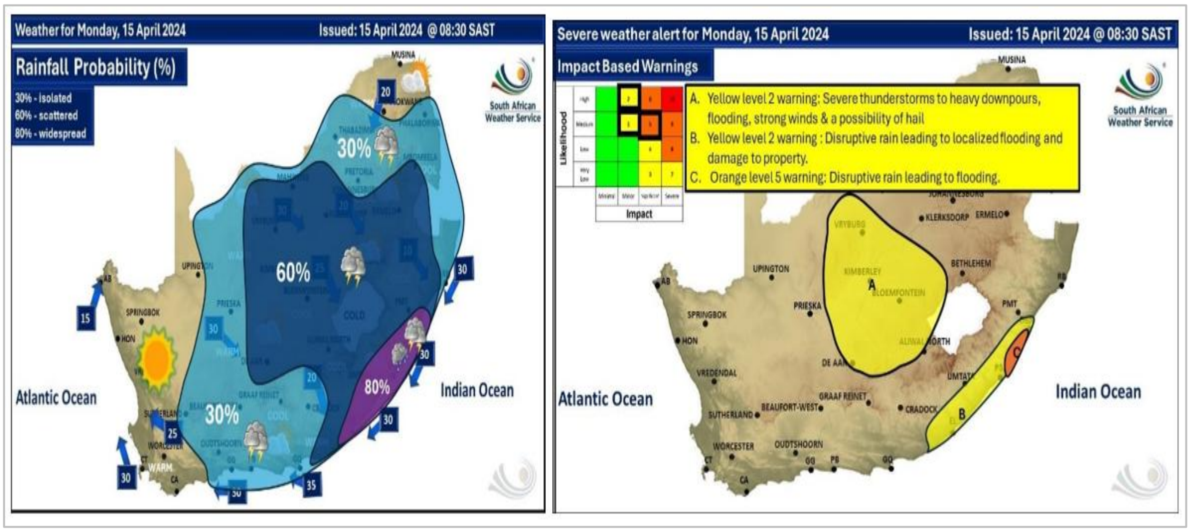

Figure 3.35 Rainfall probability and severe weather warning for 15 April 2024, affecting KZN's south coast.

The two most severely affected districts were uGu District (Margate area) and eThekwini District. Floods caused damage to infrastructure such as shelters, roads, schools, clinics, water, businesses, and electricity supply. Over 249 people were estimated to have been affected, more than 110 households were destroyed, and five fatalities were confirmed. Figure 3.36 depicts the trail of destruction left by floods in Margate.

Figure 3.36 Images showing the destruction caused by floods in KZN's South Coast (Margate 15 April 2024). (Source: Social media).

The range of extreme events which occurred from October 2023 to September 2024 underscores the growing vulnerability of South Africa’s water resources to climate variability and change. Such events' increasing frequency and intensity highlight the urgent need for improved forecasting, early warning systems, and adaptive water management strategies. Strengthening resilience requires a deeper understanding of how these events affect water supply, quality, and distribution, ensuring better preparedness for future climate challenges.

3.7 State of El Niño-Southern Oscillation (ENSO)

The El Niño-Southern Oscillation (ENSO) has recently crossed the La Niña threshold and is predicted to remain on the boundary of this threshold for the next few months (March, April and May). Current predictions are still uncertain, with multiple global models predicting different directions (either strengthening the La Niña state or moving back to a Neutral state). For South Africa, caution is still advised when using the ENSO in any important planning decisions as it seems to be currently very volatile and unpredictable. For South Africa, time is running out as well for a potential La Niña to affect us as summer is coming to an end.

Current predictions indicate above-normal rainfall for most of the north-eastern parts of the country during autumn; however, this is expected to change to only above-normal rainfall for the interior and eastern coastal areas during late autumn and eventually mostly below-normal during early winter (Figure 3.37). However, due to a significant reduction in rainfall over the central and northeastern parts of the country during late autumn and early winter climatologically, the most important forecast is for the southwestern parts of the country, where below-normal rainfall is expected during these seasons.

Minimum (Figure 3.38) and maximum (Figure 3.39) temperatures are expected to be mostly above normal countrywide for the forecast period. However, the southern coastal areas indicate that below-normal temperatures are more likely throughout the summer period.

The SAWS will continue to monitor the weather and climate conditions and provide updates on any future assessments that may provide more clarity on the current expectations for the coming season.

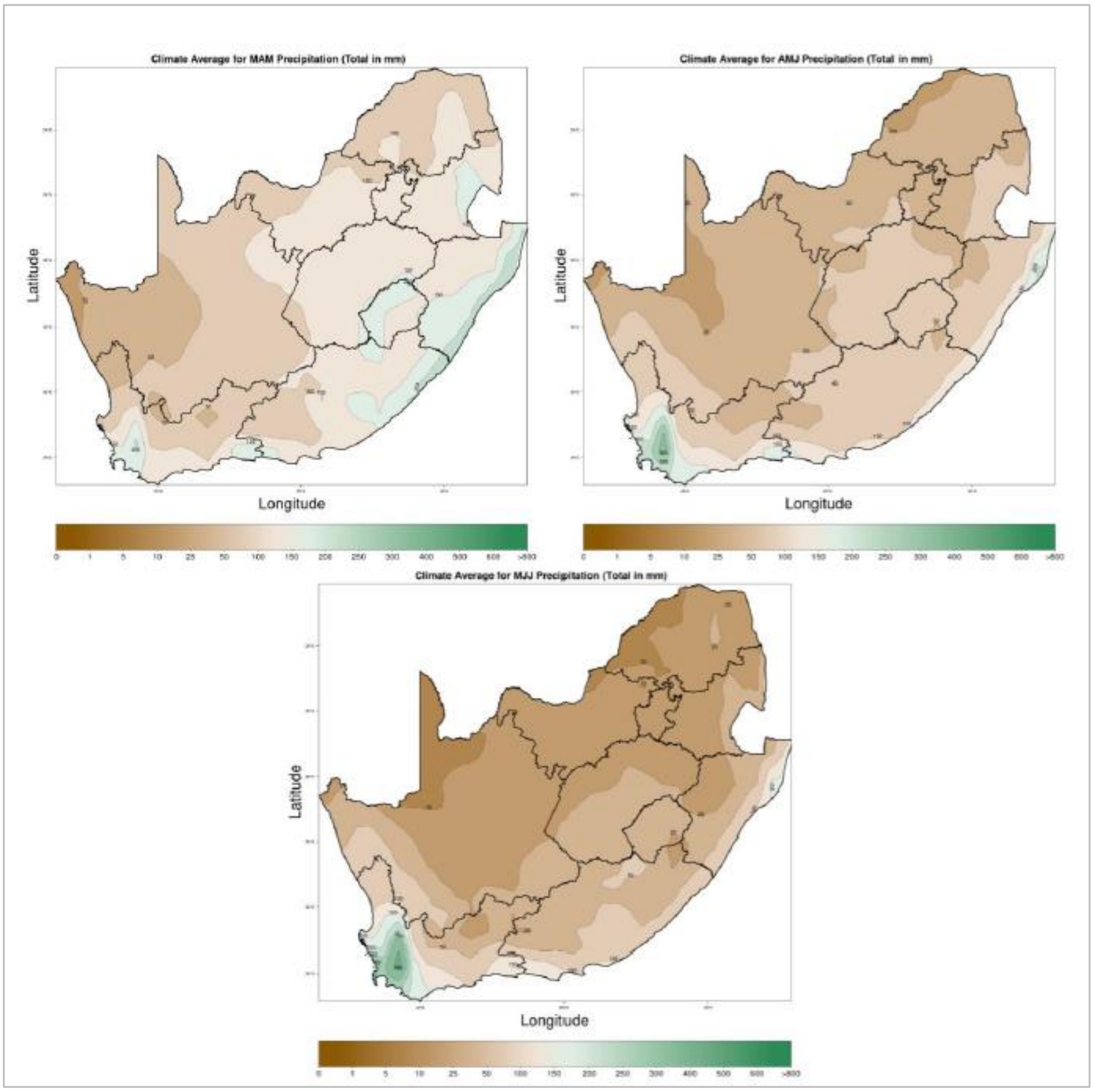

Figure 3.37 Climatological seasonal totals for precipitation during March-April-May (MAM; left), April-May-June (AMJ; right) and May-June-July (MJJ; bottom).

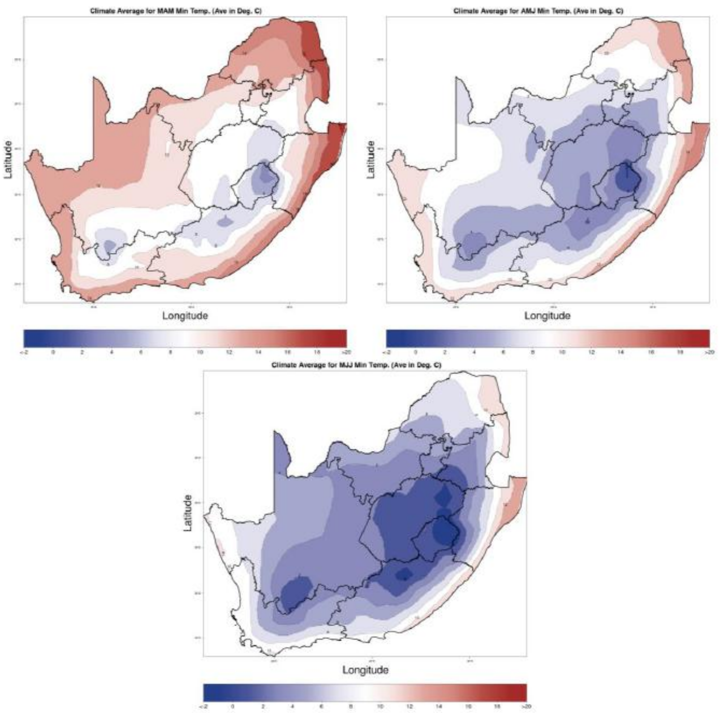

Figure 3.38 Climatological seasonal averages for minimum temperature during March-April-May (MAM; left), April-May-June (AMJ; right) and May-June-July (MJJ; bottom).

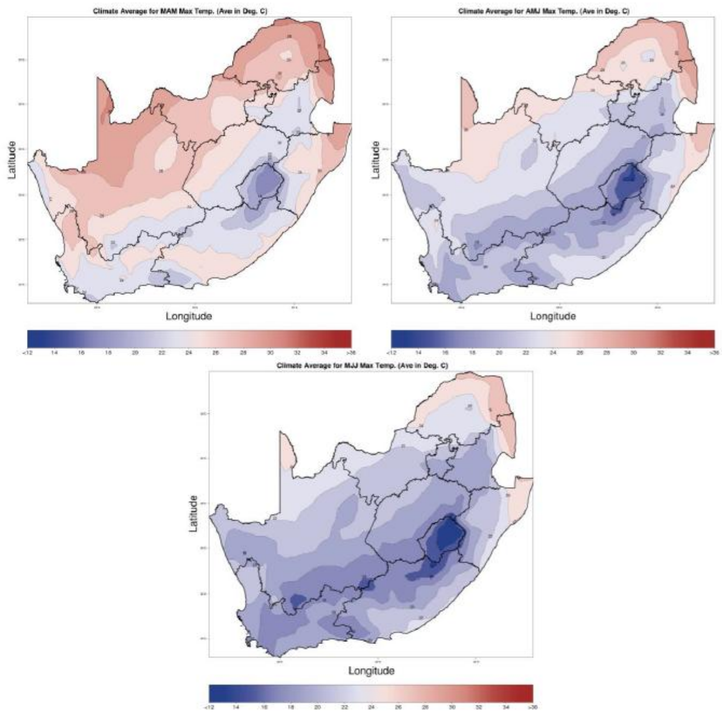

Figure 3.39 Climatological seasonal averages for maximum temperature during March-April-May (MAM; left), April-May-June (AMJ; right) and May-June-July (MJJ; bottom).

3.8 Climate Change

The phenomenon known as climate change refers to an ongoing trend of changes in the earth's general weather conditions due to an average rise in the earth's surface temperature, often referred to as global warming. This rise in the average global temperature is primarily due to the increased atmospheric concentration of greenhouse gases (GHGs). These gases intensify a natural phenomenon called the greenhouse effect by forming an insulating layer in the atmosphere that reduces the amount of the sun's heat that radiates back into space, making the earth warmer.

In South Africa, future climate scenarios suggest significant temperature increases and variability in rainfall. Overall, the western half of the country is expected to see significant drying, while the eastern half could see increased wetting, on average, but with greater variability contributing to an increased frequency of both floods and droughts. In the long term (i.e. up to 2100), South Africa will likely experience drying. This, combined with increasing demands for water, requires immediate response so as not to negatively impact individual livelihoods, communities, companies, and the economy. In addition to the direct impact on water availability, higher temperatures and reduced streamflow might also contribute to increasing water quality risks, which is already a national crisis. Increased rainfall intensity will also contribute to more flooding and threaten critical water-related infrastructure.

The National Climate Change Response White Paper (2011) and, more recently, the National Climate Change Act (2024) indicate that all sectors are required to develop climate change response strategies (CCRS) and plans. In response to this, the Department went through a process of reviewing its National Climate Change Response Strategy for the Water and Sanitation Sector, developed in 2014, that involved a review of the state-of-the-art science on climate change and water resources and sanitation, which culminated in the updating of the 2013 Climate Change Status Quo for the Water and Sanitation Sector. The outcomes of this assessment then informed the review and update of the 2014 National Climate Change Response Strategy for Water and Sanitation.

The CCRS includes an updated vision, key strategic objectives (KSOs), and priority response actions (RAs). These KSOs and RAs are unpacked as part of the Strategy and include proposed next steps for implementation. The Strategy also includes a summary of the updated status quo assessment and proposed adaptation and mitigation actions that can inform the next steps in moving towards achieving the vision of a low-carbon, climate-resilient, equitable and sustainable water and sanitation sector by 2050.

Priority actions, potential partners, proposed timeframes, and indicators for each of the five Key Strategic Objectives (KSO) of the updated strategy are identified in Figure 3.40.

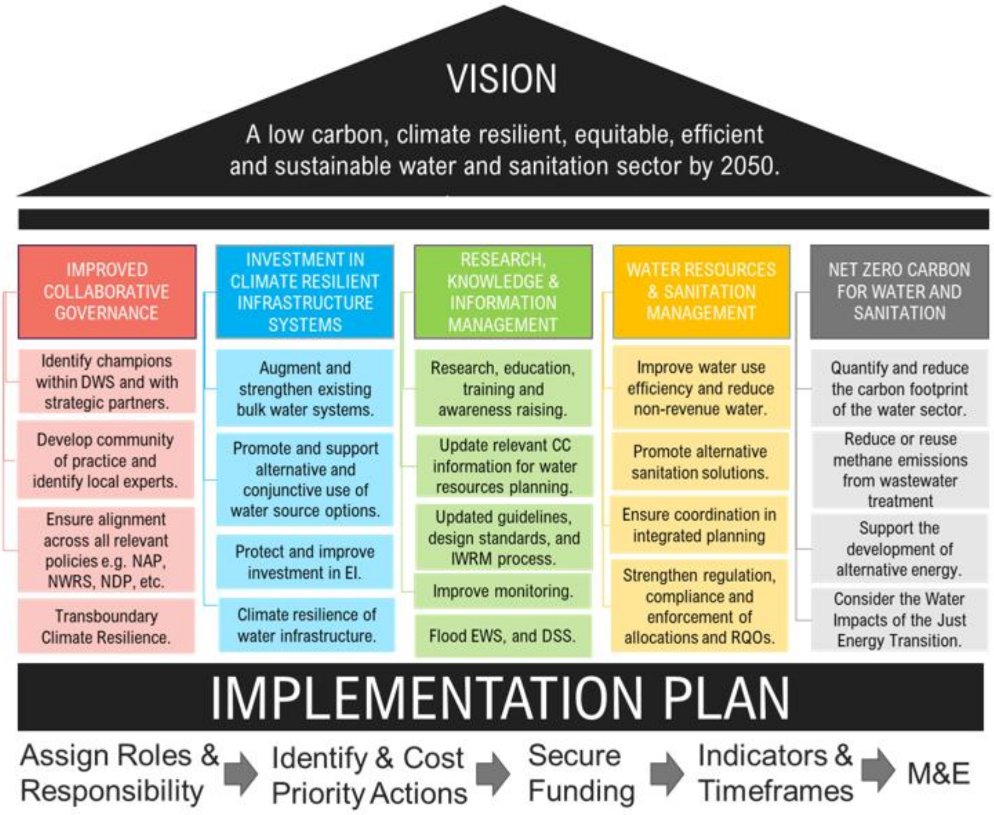

Figure 3.40 Strategic framework for achieving the vision of low carbon, climate resilient water and sanitation sector

To achieve the vision of a low-carbon, climate-resilient, equitable, efficient, and sustainable water and sanitation sector by 2050, one of the most critical priorities for South Africa is to implement critical water and sanitation infrastructure that has already been identified through the various planning processes at both national and local level. Several of these critical infrastructure projects have been delayed and are contributing to the current level of water and sanitation security risks impacting the economy and individual livelihoods. As a result, the priority of KSO is to implement KSO2, which includes the implementation of critical (and, in many cases, delayed) infrastructure as well as increased investments in protecting and rehabilitating natural systems and ecological infrastructure (EI).

Improving operations and maintenance of existing water and sanitation infrastructure is even more critical than investing in new climate-resilient infrastructure (i.e. KSO 3). This will not only have a direct impact on achieving the overall vision but is also necessary to support the investment in climate-resilient infrastructure systems (KSO 2) and also to achieve the objective of reducing the overall carbon footprint of the water and sanitation systems (i.e. KSO 5).

Underlying improved operations and maintenance (KSO 3), investing in climate-resilient infrastructure systems (KSO 2) and reducing the carbon footprint of the water and sanitation sector (KSO 5) is improved collaboration and cooperative governance, which includes training and capacity building for key stakeholders and decision-makers.

Finally, the provision of knowledge and information through training, research, and capacity building is critical in supporting all aspects of improved climate resilience for water and sanitation in South Africa and science-based decision-making for water security.

It is clear that climate change is already starting to have a major impact on water security and infrastructure in South Africa, and any delays in responding to these increasing risks will make it increasingly difficult to adapt in future and result in further damage and economic impacts.

In terms of the Way Forward, the immediate priority actions for DWS (i.e. the **FIVE BOLD STEPS**) that need to be taken to advance the updated climate change strategy are as follows:

- Implement critical (and delayed) water supply and sanitation infrastructure.
- Integrated climate change response actions into a revised NWRS and WSMP
- Raise awareness of climate change risks within DWS and alignment with the JET.
- Identify critical areas of research and updating of IWRM guidelines and practices.
- Help develop guidance on securing climate finance for water security and sanitation.

The development of the updated CCRS for water and sanitation has undergone extensive stakeholder engagement to try to accommodate all voices. It has also been developed in the specific context of promoting Gender, Equity and Social Inclusion (GESI). In addition to updating the CCRS, the DWS is also currently revising the latest version of the National Water Resources Strategy (NWRS) and the Water and Sanitation Master Plan (WSMP). These documents together form a comprehensive approach to improved water security in the

DWS also developed the water and sanitation sector policy (2017) to set out the policy position for the water and sanitation sector. This Water and Sanitation Policy on Climate Change will provide a framework for the implementation of the Climate Change Response Strategy for the water and sanitation sector, not forgetting that the policy will also strengthen the development.

3.8.1 Climate Change Act of 2024

The South African Climate Change Act (Act No. 22 of 2024), signed into law on July 18, 2024, establishes a legal framework for the nation's response to anthropogenic climate change. The Act recognises the urgency of addressing greenhouse gas (GHG) emissions and adapting to the impacts of climate change, with the goal of transitioning to a low-carbon and climate-resilient economy. Of particular relevance to the Water and Sanitation sector are several key aspects:

National Adaptation Strategy and Plan & Sector Adaptation Strategy and Plan (Sections 21 & 22): The Act mandates the development of a National Adaptation Strategy and Plan, which will outline a coordinated approach to reducing vulnerability to climate change impacts across various sectors. Critically, each sector (including water and sanitation) must develop its own sector adaptation strategy and plan. This necessitates a comprehensive scientific assessment of climate change risks to water resources, water infrastructure, and sanitation services.

It will require detailed modelling of potential changes in precipitation patterns (including increased drought and flood frequencies), temperature increases, and their impacts on water availability, water quality, and the functioning of wastewater treatment systems. Adaptation measures must be evidence-based, incorporating the best available climate science and hydrological data. These strategies need to consider factors such as rainfall intensity and seasonality changes. Increased evaporation rates due to higher temperatures, Sea-level rise and its impact on coastal water infrastructure, The effects of altered water temperatures on aquatic ecosystems and water quality, The potential for increased frequency and intensity of extreme weather events (floods, droughts) to damage water and sanitation infrastructure.

Greenhouse Gas Emissions: While the Water and Sanitation sector may not be a primary GHG emitter compared to energy or industry, the Act's provisions related to GHG emissions are still relevant. Wastewater treatment plants, for instance, can be sources of methane (CH_4) and nitrous oxide (N_2O), both potent GHGs. The Act’s emphasis on developing sectoral emissions targets (Section 25) and potentially carbon budgets (Section 27) will likely require the sector to quantify its GHG emissions, identify mitigation opportunities (e.g., improved energy efficiency in treatment processes, biogas capture from anaerobic digestion), and implement strategies to reduce its carbon footprint. The Act also establishes a National Greenhouse Gas Inventory (Section 29), which will require the sector to contribute data on its emissions.

Intergovernmental Coordination: The Act acknowledges that climate change transcends traditional sectoral governance and necessitates a coordinated, cooperative response across national, provincial, and municipal levels. This is particularly important for the Water and Sanitation sector, where responsibilities are often shared between different levels of government. The Act calls for a collaborative approach, requiring effective communication and data sharing to ensure that climate change considerations are integrated into water resource management, infrastructure planning, and service delivery.

3.8.2 Climate Change Response Strategy

The Department of Water and Sanitation (DWS) has developed a Climate Change Response Strategy for the Water and Sanitation Sector, recognising that "Water Security is Climate Security." The strategy acknowledges South Africa's vulnerability to climate change impacts, which exacerbate existing water security challenges, including increased risks of floods and droughts and declining water quality. The strategy aims for a "low-carbon, climate-resilient, equitable, efficient, and sustainable water and sanitation sector by 2050."

The strategy emphasises improved collaborative governance across sectors and spheres of government, partnerships between state, civil society, the private sector, and multilateral nations (Figure 3.40). The strategy focuses on reducing vulnerability and improving resilience through adaptation and mitigation actions. Adaptation measures aim to provide multiple benefits, including increased agricultural productivity, food security, and biodiversity conservation.

The Climate Change Response Strategy operates within the existing framework of integrated water resources management in South Africa, recognising that climate change impacts are superimposed upon existing climate variability and water security challenges. Key stakeholders and strategic partners such as municipalities are identified as playing a crucial role in climate change mitigation, adaptation, and resilience, as they are responsible for providing water services.

Implementation of the strategy requires significant investment from both the public and private sectors, aligned with South Africa's Just Energy Transition (JET). Cross-sectoral partnerships and collaboration are essential. The strategy emphasises the use of knowledge and information generated from partnerships to inform actions and steps taken by municipalities to ensure resilience. Improved monitoring of climatic variables and citizen science are crucial for data availability and knowledge generation.

The strategy strongly encourages transdisciplinary collaboration and knowledge exchange among government agencies, research institutions, municipalities, and local communities to address climate change impacts on rivers. Data sharing, collaborative monitoring programs, and the integration of local ecological knowledge are crucial. Finally, the report can inform evidence-based policy and investment decisions that promote climate-resilient water resources management and safeguard the ecological integrity of South Africa's rivers. This should include recommendations for optimised water allocation strategies, investments in green infrastructure, and the implementation of policies that reduce pollution and protect riparian habitats.

3.8.3 Climate Change Scenarios for Water and Sanitation

- *Increasing Climate Change Risk and Vulnerability in Africa*

Much of Africa, including Southern Africa, will be impacted by climate change (Figure 3.41) and is vulnerable to the impacts of climate change largely due to limited financial capacity to adapt to the impacts of climate change, according to the Notre Dame Global Adaption Initiative (ND-GAIN) index. South Africa is currently ranked 96 out of 182 countries in terms of their vulnerability to climate change, preparedness for adaptation, and enhanced resilience. The worst-performing indicators for South Africa are the projected change in cereal yields, agriculture capacity, and dam capacity in terms of the low average storage capacity per capita, despite South Africa having several large dams.

This vulnerability is reflective of South Africa having one of the lowest rates of per capita runoff and without the large rivers that can provide significant storage, including in countries such as Zimbabwe and Zambia, which have fewer dams but a few very large dams on the Zambezi.

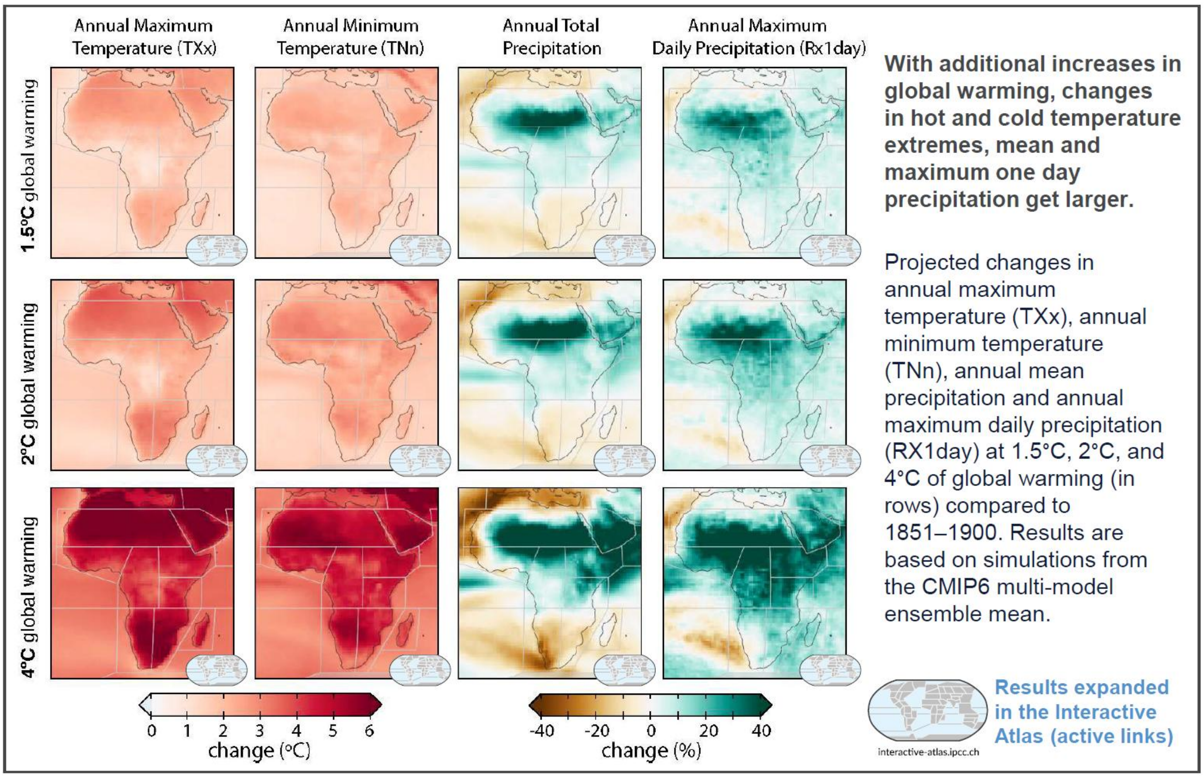

Figure 3.41 Increasing Climate Change Risks for Africa (IPCC, 2022)

- *<u>Latest Global Climate Change Scenarios for South Africa</u>*

The latest climate change scenarios from the IPCC 6th Assessment Report (Figure 3.42) indicate an increase in average temperature from around 18.54 °C to a median value of between 18.89 °C and 23.37 °C for South Africa by 2100, depending on the resulting global emission scenarios, but with much hotter temperatures expected in the north and inland areas and cooler by the coast. There is a similar significant increase in the number of very hot days.

Overall, there is an expected small decrease in precipitation nationally, but with significant spatial variability, as shown in Figure 3.43. The country's eastern half is expected to see an overall increase in mean annual precipitation, while the western half, and in particularly the southwest, is expected to experience drying. It is also expected that the number of very hot days and the maximum daily rainfall will increase across almost all of the country, which suggests an increased risk of flooding, and there will be increased variability in precipitation, contributing to more droughts. In contrast, there is an expected significant increase in the maximum daily rainfall over most of the country, particularly over the eastern half.

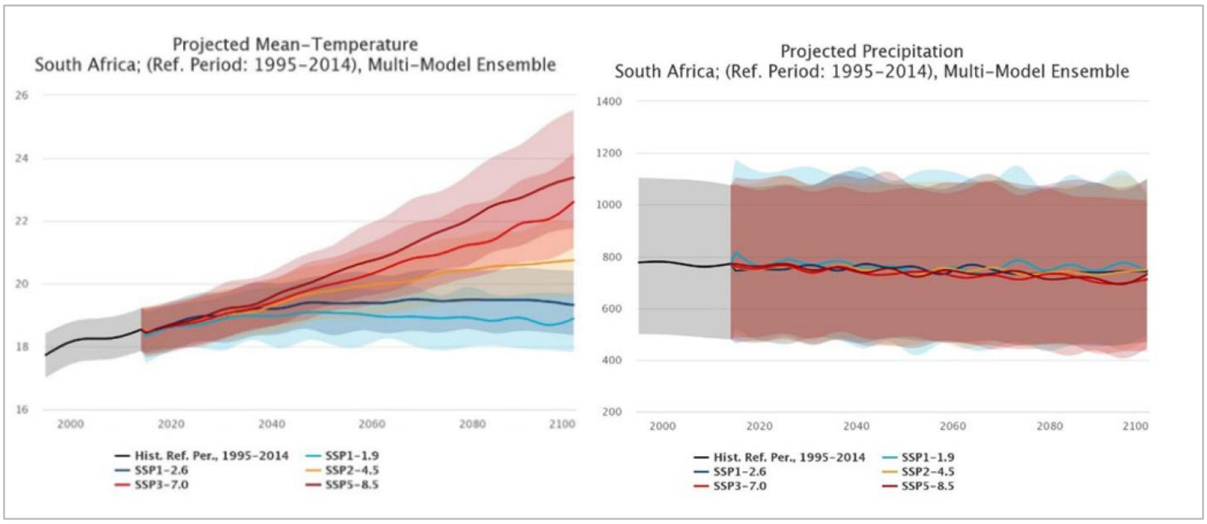

Figure 3.42 CIMP6 projected changes in mean temperature and mean annual precipitation for South Africa.

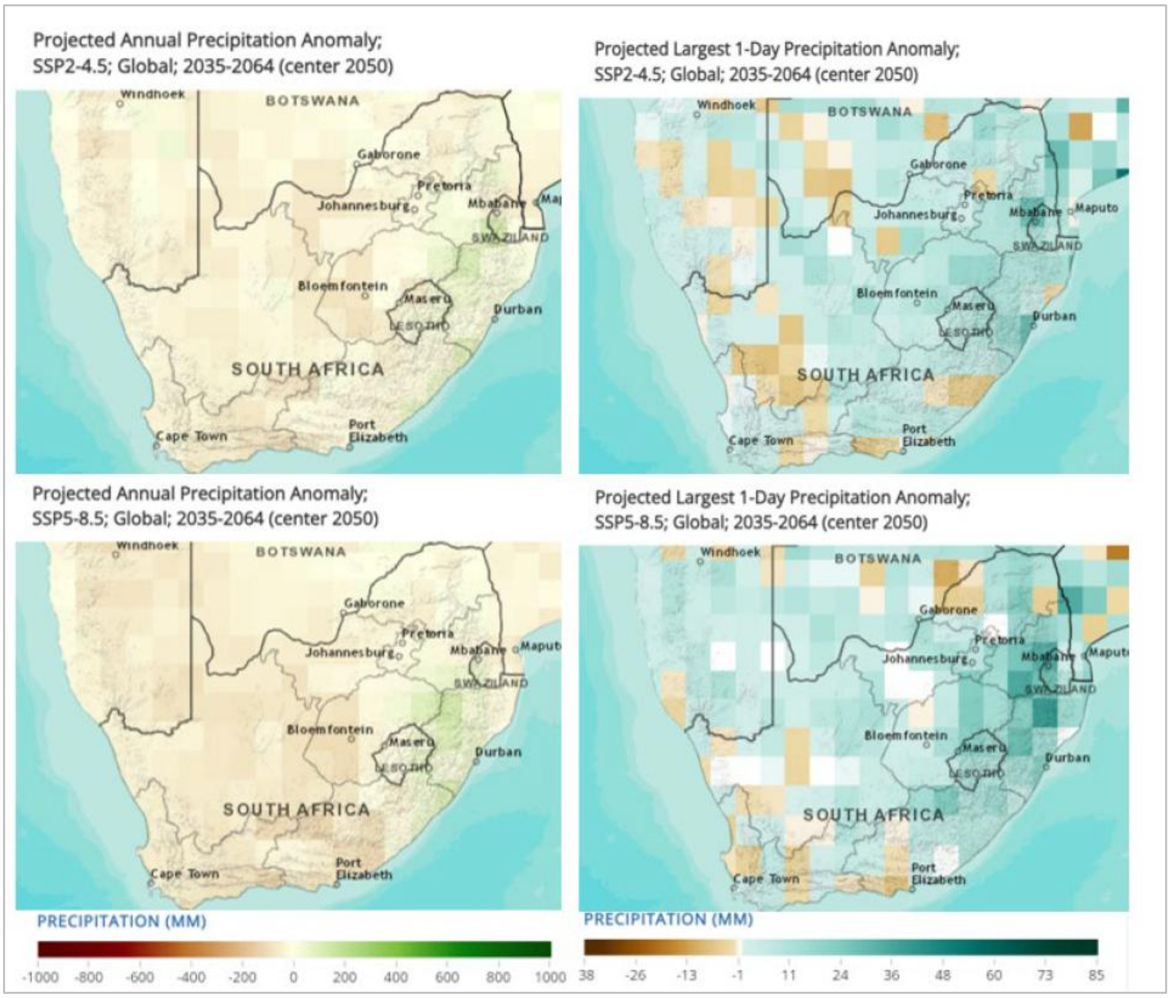

Figure 3.43 Projected change in average annual precipitation (left) and largest 1-day rainfall (right) under two different global emission scenarios for the period 2035-2064 across South Africa (Source: CCKP).

- <u>*Downscaled Climate Change Scenarios for South Africa*</u>

To date, there has been no work on downscaling the latest CIMP 6 data, and the currently available downscaled climate scenarios, such as those used in the CSIR Greenbook and described below, are based here to see how these compared to the available downscaled climate scenarios and analysis relevant for each of the different hydro-climatic zones. High-resolution (8km x 8km) downscaled climate scenarios have been produced for South Africa and are presented in the CSIR Greenbook (**www.greenbook.co.za**) for the CMIP5 RCP4.5 and RCP8.5 climate scenarios (Figure 3.44).

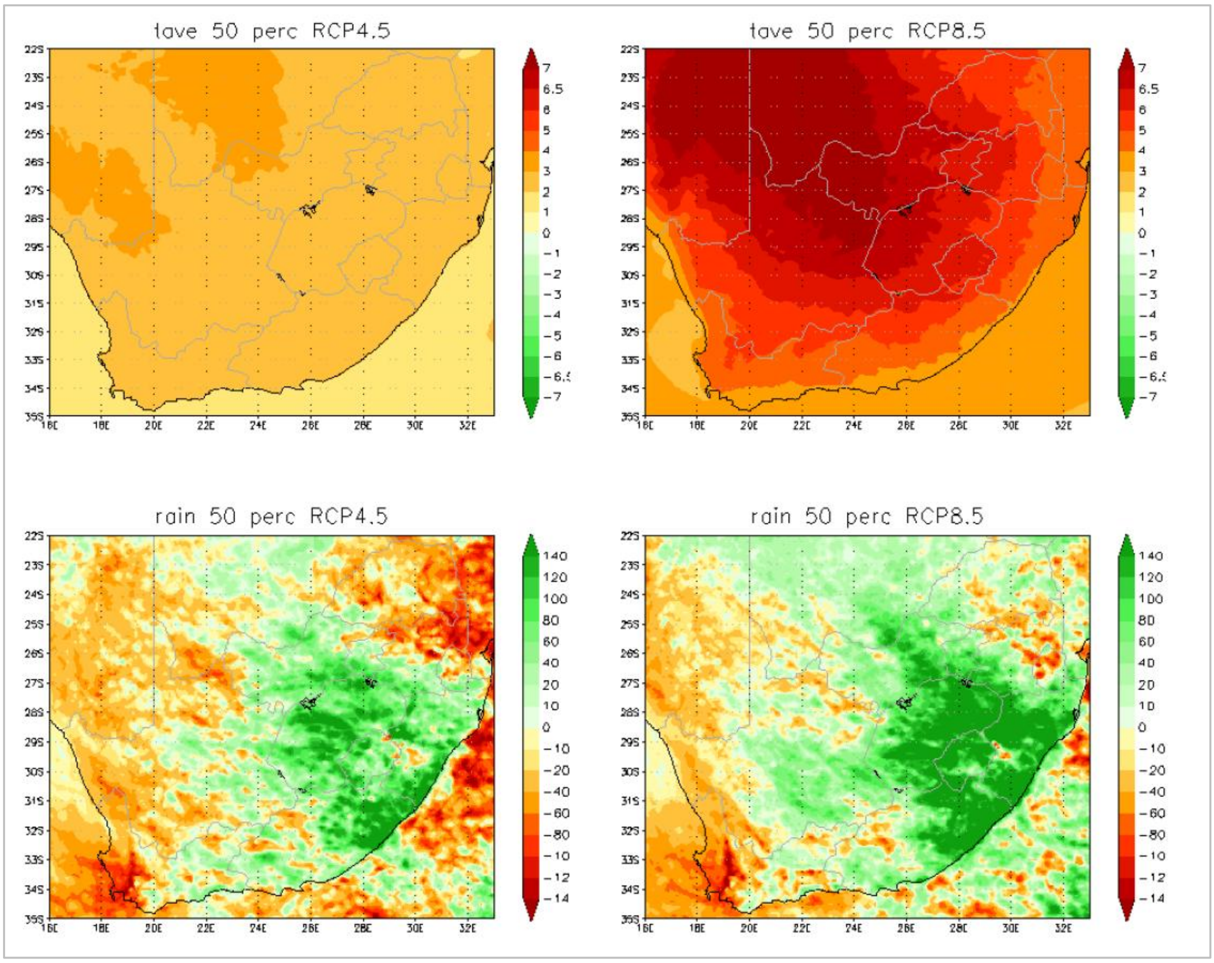

Figure 3.44: Summary of downscaled climate change scenarios for South Africa (Source: CSIR Greenbook)

- <u>*Hybrid Frequency Distribution Climate Scenarios and Impacts*</u>

As an alternative to producing selected individual global climate models to be downscaled, a study undertaken in support of determining the economic impacts of climate change in South Africa (Cullis *et al.,* 2015) and the Long Term Adaptation Scenarios (DEA, 2015) consider a hybrid frequency distribution (HFD) approach to evaluating climate change risk across a wide range of possible climate scenarios that was also then modelled in terms of the potential impact on surface water runoff as well as reliability of water supply taking into account the ability to manage and move water across the country with the integrated bulk water supply system (Cullis *et al.,* 2015). The results of this study were used to assess the overall economic impacts of climate change and highlighted the critical importance of the integrated bulk water system.

The HFD approach considers global emission scenarios, namely an unconstrained emission scenario (UCE), which is equivalent to a low mitigation scenario such as SSP5-RCP8.5 and a Level 1 stabilisation (L1S) scenario, which is representative of a lower emission scenario equivalent to SSP2-RCP2.5.

Figure 3.45 shows the range of possible impact (i.e., relative change) on MAP across each secondary catchment under the UCE scenario.

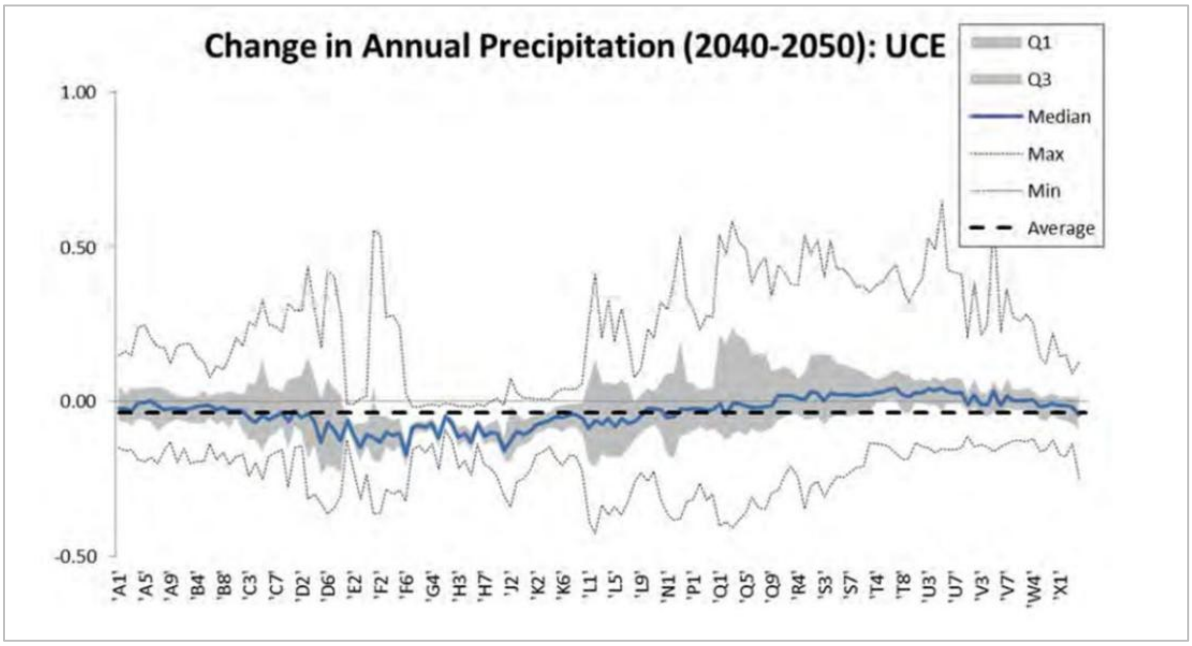

Figure 3.45 Range of possible impact of climate change on mean annual precipitation across all secondary catchments in South Africa under the UCE scenario for the period 2040-2050 relative to the base period. The solid blue line indicates the median value in each section.

The impact of the different climate change scenarios on surface water runoff was determined using the Pitman model (Pitman, 1973) at quaternary catchment scale across South Africa using existing calibrated Pitman parameters contained in Water Resources 2012 (WR2012) and used to generate monthly streamflow impacts at quaternary catchment scale for the two global emission scenarios (UCE and LS1). The Pitman model is a monthly rainfall-runoff model that is the standard for water resources simulations to enable planning in South Africa (Pitman, 2006; DWA, 2012) and is widely used for hydrological modelling across Southern Africa (Hughes *et al.,* 2006).

The variation in the impact on the mean annual rainfall (MAR) across the country is shown in Figure 3.46 for the UCE scenario. These results show a reduction in streamflow for the western half of the country (D to K), particularly the Western Cape (F, G and H), where all the climate models show a reduction in streamflow. In contrast, some very large potential increases in runoff for the east coast (Q to W) could result in increased flooding risks.

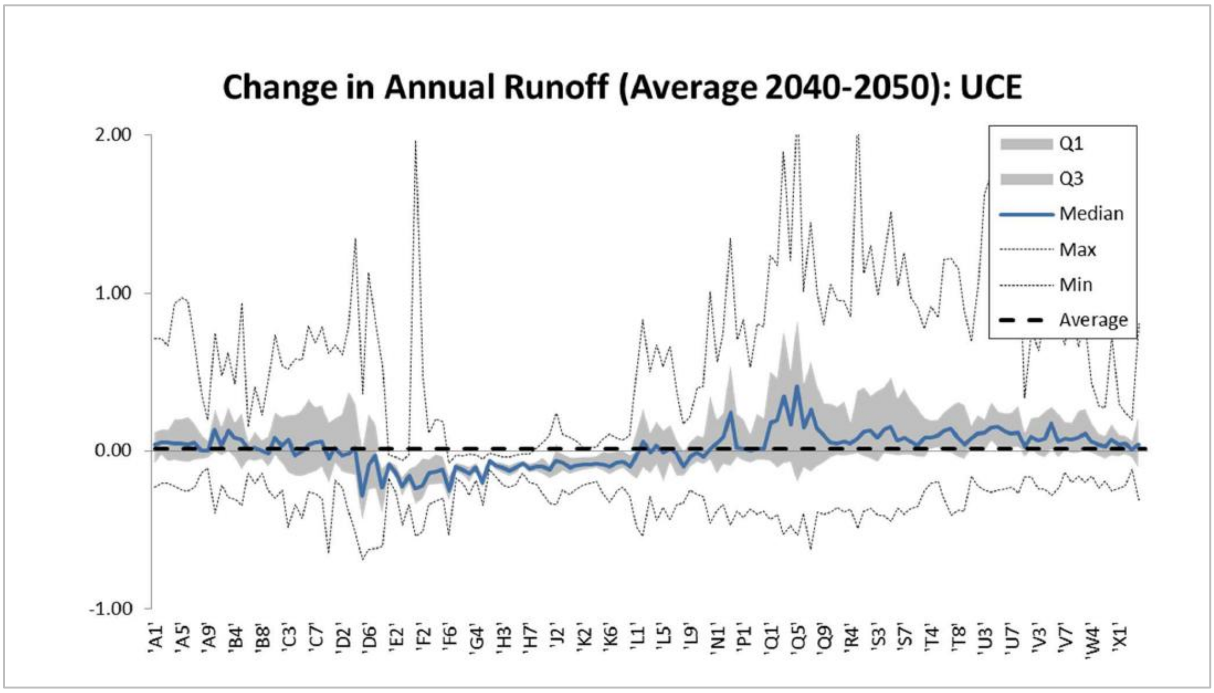

Figure 3.46 Range (i.e., mean, Q1, Q3, max and min) of potential impacts of climate change on the mean annual catchment runoff for all secondary catchments from 2040 to 2050 under the UCE scenario.

The impact of the L1S scenario in terms of reducing the potential risk for both large increases in catchment runoff and large reductions in catchment runoff becomes more obvious at the secondary catchment scale (Figure 3.47). While some models were showing the potential doubling in annual MAR in selected secondary catchments in the eastern half of the country, under the L1S scenario, the additional risk is only half but still shows possible increases up to 100% of the base scenario under some of the more extreme (but less likely) model results. The spatial variations are projected to change in the median, 5th and 95th percentile of MAR by 2050 relative to the base period at the secondary catchment scale. Results show that drying is still likely to occur in the Western Cape, even under a very wet scenario.

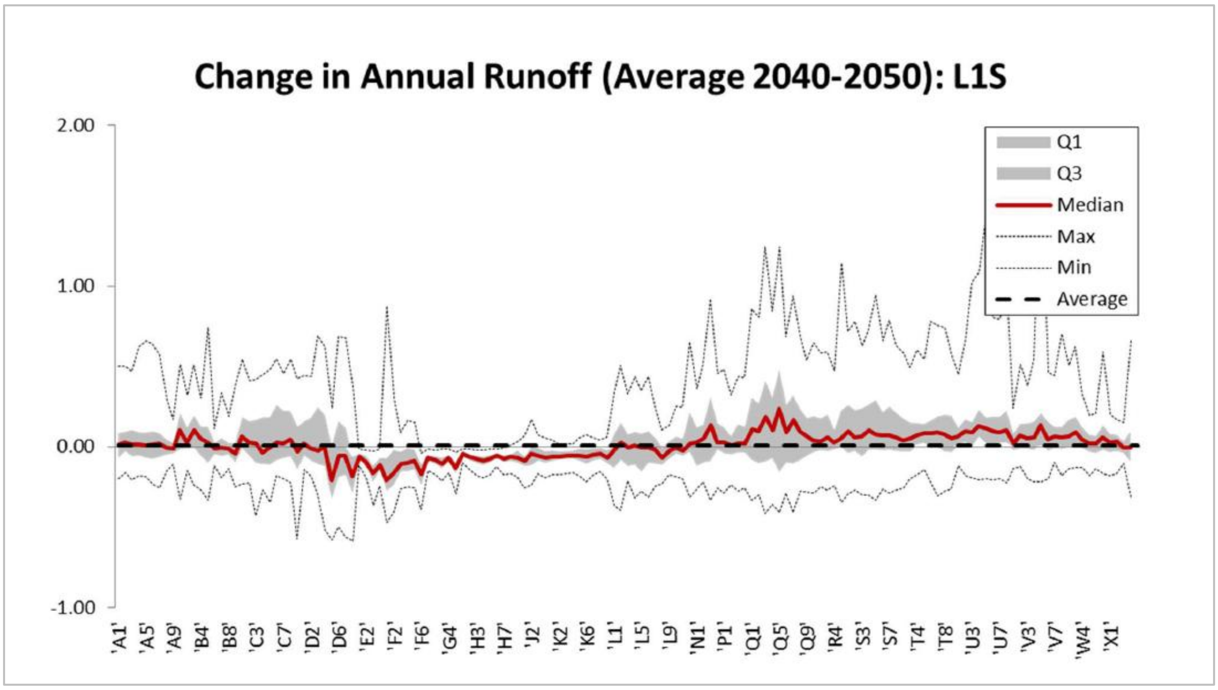

Figure 3.47 Range of potential impacts of climate change on the average annual catchment runoff for all secondary catchments for the period 2040 to 2050 due to the L1S scenario relative to the base scenario

A comparison of HFD results for the change in the national average annual catchment runoff for the whole of South Africa resulting from the UCE and L1S scenarios relative to the base scenario for 2040 to 2050 is present in Figure 3.48. The results show that the median impact of the UCE scenario is an annual catchment runoff over the whole country of around 4.4% over the baseline, while the median impact of the L1S scenario is an increase in the total catchment runoff of only 2.6%. For both scenarios, there is a wide range of potential impacts. The risk of extreme impacts at both ends of the spectrum (wet and dry) is significantly reduced under the L1S climate scenario. For the UCE scenarios, the potential impacts on total catchment runoff range from a 13% reduction to a 48% increase, while under the L1S scenario, the range is markedly smaller, from a 10% reduction to a 30% increase.

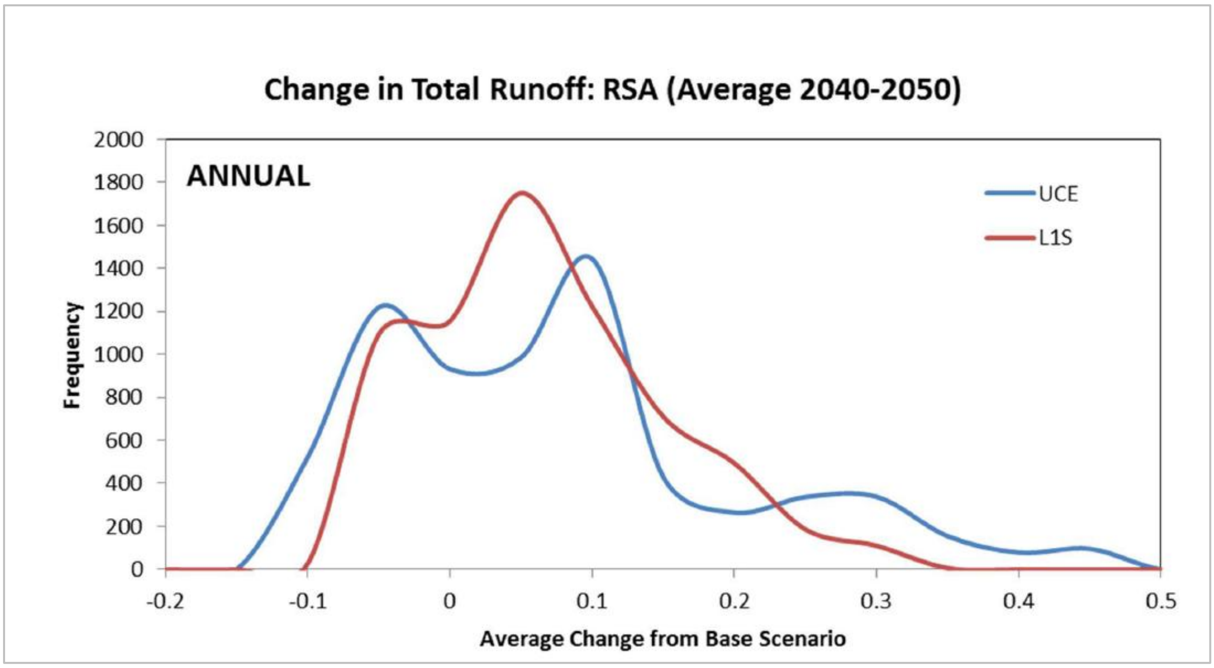

Figure 3.48 Hybrid frequency distributions (HFDs) of the impacts of the UCE and L1S climate scenarios on the national average annual catchment runoff for the period 2040-2050 relative to the base scenario

The following general observations can be made based on these results for different catchments across South Africa that represent the different hydro-climatic zones:

Mokholo River: Even a chance of increases and decreases in annual precipitation, with the impact being most significant in the early part of the wet season (December and January).

Modder River: A general drying with only a few scenarios showing the potential for increases in annual runoff with the potential impacts relatively evenly spread during the year.

Berg River: All models show drying. The likely impacts are relatively consistent for each month, but the magnitude of the impact is greatest during the winter rainy season.

Koega River: A roughly equal chance of either wetting or drying with the median close to zero change in the MAR. The wettest scenarios show the greatest impact in April.

Mfolozi River: A greater possibility of wetting than drying, but still some dry scenarios are possible. The greatest impact is likely to occur in January showing a potential shift in the early period of the high flow season. There is a significant risk of increased flooding.

Sabi River: Possibility for increased runoff outside of current variability with the greatest impact being during the wetter months (December and January). As a result, there is an expected increase in the risk of flooding and greater variability in mean annual runoff (MAR).

3.8.4 Climate Change Adaptation and Mitigation Options

Climate Change adaptation options for water and sanitation should be implemented through reducing vulnerability and improving resilience. In addition, adaptation can result in various benefits, including increased agricultural productivity, innovation, health and well-being, food security, livelihood security, biodiversity conservation, and risk and damage reduction (IPCC, 2022). A provisional list of adaptation possibilities based on an examination of observed climate adaptation responses in the literature and in applied practice include:

- Integrated Water Resources Management and Planning
- Implementing critical water and sanitation infrastructure
- Improved monitoring and decision support systems
- Diversification of water supply options
- Climate-resilient water and sanitation systems
- Reducing Unaccounted and Non-Revenue Water
- Improved Water Use Efficiency in All Sectors
- Climate Smart Agriculture
- Innovative Sanitation Technologies and Solutions
- Ecosystem-based Adaptation
- Water-Sensitive Cities and Urban Water Resilience

In addition to the list of general adaptation response options described below, individuals or institutions can implement several individual adaptation response actions to reduce water security risks in the context of climate change. These are presented in various documents, including the CSIR Greenbook and a recent WRC Report (Schulze et al., 2023).

All adaptation response actions for water and sanitation in South Africa need to be considered in the context of the existing approaches to integrated water resources management practised in South Africa, recognising that any impacts of climate change are “superimposed” upon existing climate variability and water security challenges (Schultze *et al.,* 2023). Identifying and implementing adaptation responses for water and sanitation must also be developed and operate within the overarching guiding principles of South Africa’s National Climate Change Adaptation Strategy (NCCAS).