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The Threats of Climate Change on Water and Food Security in South Africa

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ABSTRACT

Globally, water and food crises are exacerbated by climate change, population growth and changing lifestyles. These phenomena have resulted in escalating cycles of civil unrest and conflicts. In South Africa, climate change has led to increased temperatures resulting in numerous deadly heat waves and varying rainfall patterns contributing to deadly flooding in most provinces and droughts in others. These extreme climatic conditions significantly impact agricultural production and water insecurity nationally. Despite the strong impact of climate change on water and food resources in the country, there is less education and inadequate data to address the impacts of climate change, especially at local levels; information is seldom used in planning and decision-making while there is a lack of actionable planning to mitigate the impacts of climate change. This paper explored the weaknesses in the current climate change mitigation programmes in South Africa in the context of water and food security using a mixed method approach of data collection and related literatures. The finding established that while multiple policies, regulations, and programmes are designed to minimise climate change's impact on water and food resources, the policies lack coherency at the formulation and implementation stages and are fragmented across various departments and institutions. This paper recommends a coordinated approach to tackling climate change and investment in research that will better understand the country's climate programmes in addressing water and food security.

INTRODUCTION

Over the past two centuries, the human population and the world's economic wealth have multiplied three folds (Peterson, 2017). These two factors have increased resource consumption significantly, evident in agriculture and food production, industrial development, international commerce, energy production, urbanisation and recreational activities (Bruin *et al.*, 2021). With a global population in excess of six billion all sharing the basic human needs: water and food Boretti *et al.*, (2019), these developments have significantly impacted the functioning of the earth system and climate globally. The critical determinant of climate consequences is how these are met at all scales. In the developed world, affluence, and more importantly, the demand for consumer goods for entertainment, mobility, communication and a broad range of goods and services is placing significant demand on global resources and equally emitting dangerous gases into the atmosphere impacting climate and other earth systems European Commission (EU 2018).

Different climatic conditions characterise the African continent, ranging from high aridity in the Northern and Southern regions to very humid conditions in the Central and Western regions. Notably, these climatic conditions are highly variable and unpredictable with regards to their characteristics and impacts (Nicholson, 2017; Helbling *et al.*, 2021). The cyclical periods of droughts and unpredictability of precipitation patterns have contributed to the corresponding environment and social systems. This has threatened the continent's livelihoods and economic development as it is whelming linked to agriculture. Biteye (2016) and Oluwatoyo *et al.* (2016) disclosed that over 70% of Africans depend on agriculture for their livelihood. Prolonged drought linked to climate change has adversely impacted farming and water provision in many key agricultural regions in the West, East and Southern regions on the continent and has contributed negatively to human livelihoods and economic prosperity, causing millions of rural population to migrate to cities (Zwane, 2019). Furthermore, climate change has contributed to water and food insecurity in many developing countries and threatens international and peace stability worldwide (Nhemachena *et al.*, 2020, UNFCCC, 2017). For instance, consistent prolonged drought in the West African Sahel, Kenya, Ethiopia, Somalia and the Darfur region have witnessed numerous instabilities to livelihoods due to lack of water resources and drought-induced famines, loss of livestock and pasture fields, as well as enduring farmer-herder conflicts. While some countries such as Morocco, Rwanda, and Ethiopia have made significant food production gains, the intensification of agriculture across Sub-Saharan Africa still lags behind much of the world (van Wijk *et al.*, 2020).

South Africa is not immune to the threat of climate change on water and food security. Sustainable food production is critical in sustaining human health, economic prosperity and overall peace and security (Myers *et al.*, 2017). Currently, the country's freshwater resources are under severe pressure due to rising population, overuse, mismanagement, intersectional competition, pollution, and declining precipitation. The largest freshwater

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consumption comes from the agricultural sector, accounting for over 70% of all the use in South Africa (du Plessis, 2017). As the country's population peaks at around 65 million by 2025, more than 80% of water resources will be required to increase food production to feed the growing population (Boretti *et al.*, 2019). This would include other strained water resources like groundwater. Current statistics reveal that more than 50% of the country's groundwater is under tremendous stress (Maddock *et al.*, 2016). Various sectors have exploited water resources including groundwater, diminishing its availability, whilst others have heavily contaminated it, leaving it unusable. Sobowale *et al.* (2021) supports this view and indicated that groundwater reserves have been key to Eskom coal power generation for decades; however, the over-reliance on Eskom for power generation has resulted in overexploitation of groundwater resources. Akhta *et al.*, (2020) adds on by disclosing that urban and municipal waste, chemical contamination from mining, agriculture, and livestock contribute to a decrease in surface and groundwater resources. These losses in water quality are exacerbated by climate change reducing the availability of water resources in all sectors.

Climate change has already altered the distribution, timing, intensity of both rainfall and temperature and snow events in the country. For many provinces, earlier snowpack and thawing means less water is available during the growing season (Chersich *et al.*, 2019). Atanga *et al.* (2019) highlight that over 80% of small-scale farmers are largely relying on rain-fed agriculture and are already being hit substantially by regular and persistent droughts and floods, both destroying crops and reducing productivity.

As temperatures are projected to rise by up to 1.50C globally in the 21st century, South Africa is expected to experience shorter wet spells (prolonged droughts) or heavier rains (causing floods), all of which will contribute to reduced yield and water shortages (USAID, 2022; Hosea *et al.*, 2021). By 2030, national crop yields are expected to decrease depending on the province (Mapisa, 2017). For instance, Eastern Cape, Free State and Gauteng are expected to experience a 30% decrease in rainfall (Ncoyini *et al.*, 2022).A reduction or change in long-term precipitation patterns subsequently leads to insufficient soil moisture, that cannot meet the needs of crops and livestock at a particular time. In most cases, farmers are becoming increasingly water insecure, creating food and water insecurity (Ncoyini *et al.*, 2022).

With the threat of climate change on the country's food and water resources, the government has implemented a range of national and sectoral policies, programmes, and strategies to mitigate climate change's impact on these resources over the past three decades. Avenchenkova *et al.* (2019) alluded that the 2004 and 2013 National Water Resource Strategy incorporated climate variability in the short-medium-long-term planning across all the critical sectors of the economy: agriculture, industry, energy, science and technology. It also incorporated into the policies 'state-of-the-art' water-related research and capacity development in all aspects of planning to guarantee the accessibility of constant high quality, comprehensive and current data, together with an instrument that will assist in examining the information collected (Carter *et al.*, 2015). With these policies, the government has the tools to implement the best water resource management practices, that guarantee high levels of water safety and asset protection under fluctuating climatic conditions and, in particular, funding for water preservation and water demand management (Adom *et al.*, 2022). While these policies have achieved some level of success, they have failed to address the challenges related to climatic extremes.

Researchers, policymakers and managers engaging in the complex issues around climate change's threat to water and food security have proposed different and diverse models to address constraints experienced in attaining water and food security. For example, Pilato *et al.* (2018) suggest that climate change should be integrated into planning, implementation and decision making and provide easy access to climate information, especially at the community level. However, their study did not offer any concrete strategies or adaption mechanism to anticipate any future impact on the resources. Based on these gaps, this paper explored the weaknesses of the current policies and programmes designed to address the climate change impact on water and food security under the following sub-headings: (a) climate literacy among the population in the country (b) trend of climate change and its impact on water and food security in the country (c) climate change mitigation strategies to meet water and food security. Other topics covered by this paper include literature on climate change and food security in global and African contexts, contextualizing the relationship between climate change and food and water security.

The Impacts of climate change on Water and Food Security in Africa

In combination with other global drivers of change, climate change presents a significant threat to Africa's socio-economic development, human health, water, and food security. It is impacted significantly more than any other continent by climate change challenges and host to the majority of the global developing countries and communities globally. This is regardless of it making only 14% of the world's population and contributing to only 3.8% of total Greenhouse Gas (GHG) emissions (just 1.59% from Sub-Saharan Africa (UNFCCC, 2020). Regional climate models have indicated that Africa's Northern and Southern regions are predicted to have the worst impacts to climate change impacts associated with rising temperatures, changes in rainfall patterns and freshwater runoff, in regions that are already considerably warm and largely dry most parts of the year (Lawal *et al.*, 2019). In addition, the Sahara and the Kalahari deserts are also in these regions, and these desert environments predominantly dictate weather patterns (Nsengiyumva, 2019). Rainfall occurs in small areas within these two sub-regions, primarily along with narrow coastal shorelines in South Africa and the land locked regions in Mozambique, Zimbabwe, Lesotho and Malawi (du Plessis *et al.*, 2017). In contrast, the different situations exist in Libya, Tunisia, Algeria, and Egypt. Brief seasonal snow cover is confined to a few major mountain chains in both regions (Nsengiyumva, 2019). However, Africa's Central, Eastern, and Western regions have different climatic characteristics. These regions are endowed with significant waterways, huge lakes, enormous swamps, and pervasive underground waters (Dallas, 2014). Most of these resources are situated in the Central African sub-region and the island countries. Moreover, the regions have average precipitations of more than 670 mm per annum and moderately slight levels of water extraction for their three primary consumption – farming, households and manufacturing, which were projected to be approximately 4% of overall annual extraction (Ahmed *et al.*, 2014).

Recent projections of climate change's impact indicate that a temperature increase of 20 C could equate to a loss of 4.7% of GDP across the continent by 2025 (Scott, 2005). Most of this will lead to losses in agricultural production and water security, with a further rise in temperature of 2.50 C worsening conditions. More than 128 million would starve while 108 million will be affected by flooding and a rise in sea-level of between 15 cm and 95 cm (Mimura, 2013).

Many scholars, including Connolly-Boutin *et al.* (2016), Mekou *et al.* (2013), have used more advanced scientific models, including the Milankovitch model, the two-dimension climate models as well as the general circulation climate models, to argue that there are more threats of climate change on water and food security in Africa than predicted. Mekou *et al.* (2013) argued that climate change would affect development directly through changes in precipitation, evaporation and hydrology, sea-level rise, and changes in the occurrence of extreme weather events (floods, droughts, storms), which will directly impact primary production, ecological systems, public health and poverty. This argument was supported by Mpandeli *et al.* (2019) that increased intensity of droughts, floods and changes to growing seasons may have significant implications on soil productivity, water supply, food security, and in turn, human welfare and poverty, as well as biological diversity.

Many regions in Africa are already experiencing water and food scarcity as a result of extreme weather conditions. These sentiments were shared by Thurlow *et al.* (2012) and UNECA (2019), who concurred that climate change is one of the significant contributors to prevailing poverty, food insecurity, and weak economic growth in Africa today. Misra (2014) opined that climate change had increased variability in global hydrology and weather parameters, and increased weather extremities, largely in Southern Africa, whilst Mazibuko *et al.*, (2021) agrees and adds on, stating that the severity and frequency of droughts, floods and storms have increased in every region in Africa, straining water resources and food production. More than 28 million people in the Horn of Africa, Kenya, Ethiopia, and Somalia are currently experiencing severe food insecurity due to severe drought, which is the worst in the history of those countries (Cervigni *et al.*, 2016). Ironically in the Southern region countries such as Mozambique, Zimbabwe, and Madagascar, have experienced one of the worst floods in the recent history of the continent "Cyclone Idai and Cyclone Kenneth" (Charrua *et al.*, 2021). These cyclones displaced tens of thousands of families, leaving many food and water scarce. The two storms brought widespread flooding and destruction of almost 780,000 hectares of crops (Tavera *et al.*, 2021).

Renewable freshwater resource constraints constitute one of Africa's most critical challenges to sustainable development and human security. More than 60% of the continent's population is projected to face the rising scarcity of freshwater resources, exacerbated by climate change. Increased temperatures have been projected throughout the continent, leading to rising evaporation rates that will reduce surface and ground water runoff and freshwater availability. Subsequently, changes in food production, livestock and fisheries and water accessibility are projected to worsen (Dallas *et al.*, 2021). This assertion is supported by Zwane (2019) that climate variability will impact the productivity of irrigated and rain fed agriculture across the continent. The author goes on further to state that climate change will significantly affect food production by increasing water demand and reducing water availability in households' consumption and other sectors of the economy in most countries on the continent.

Reductions in river runoff and aquifer recharge are expected in most basins and semi-arid areas of the southern region, northern and western parts of Africa, affecting water availability in already water-stressed regions (Hamed *et al.*, 2018). In the Southern and Northern regions, the large contiguous areas of irrigated land that rely on snowmelt and high mountain glaciers for water will be affected by changes in runoff patterns. At the same time, highly populated deltas are at risk from reduced inflows, increased salinity and rising sea levels (Bjornlund *et al.*, 2020). Inherently, food and water security across the continent will be seriously affected (Appiah *et al.*,2021). Current maize and beans yields are projected to decrease by between 40%-45% by 2050 with the climate suitability of most major crops is also projected to shift as climate warms (Rosenstock *et al.*, 2018; Thornton; 2015). Increasing atmospheric levels of carbon dioxide are likely to affect the nutrient content of plants, resulting in severe protein and micro-nutrient cold spots in parts of sub-Saharan Africa (Medek *et al.*, 2017).

Climate Change Concept in the South African Context

South Africa's evidence of climate change is substantial, with weather trends appearing to shift away from 'normal' over the past fifty years and reflecting similar changes seen in other parts of the world (van Bronkhorst, 2021). Since the 1950s, the country's average temperature has climbed by about half a degree, with weather stations recording fewer cold days and more warms days. Sea temperatures have warmed slightly, and wind speed along the Cape's west coast appears to be picking up. (van Bronkhorst, 2021). According to Godsman *et al.* (2019), South Africa will be between three to four degrees warmer, on average, along the coastal region and six to seven degrees in the interior regions.

Data obtained from World Bank Group's Climate Change Knowledge Portal (CCKP, 2021) cited from van Bronkhorst (2021: 5) disclosed that "the current climatic conditions, climate data between 1991 to 2020 and projections of between up to 2099. The Figures and Tables below summarise the average annual precipitation as well as average temperature and climate projections in South Africa, stated by the National Meteorological Service of South Africa

Many authors including Kusangaya *et al.* (2013), Davis *et al.* (2020) and Chersich *et al.* (2019), have applied different climate change models such as Integrated Assessment Models (IAM), and Intercomparison Radiation Codes for Climatic Models (ICRCCM) to project that rising temperatures are expected to continue in South Africa, with average monthly temperatures projected to rise to

Table 1: Summary of current climate statistics in South Africa

Climate Variables	**1991–2020**
Mean Annual Temperature (°C)	20.3°C
Mean Annual Precipitation (mm)	450.0 mm
Mean Maximum Annual Temperature (°C)	22.0°C
Mean Minimum Annual Temperature (°C)	15.0°C

Source: National Meteorological Service of South Africa, 2018

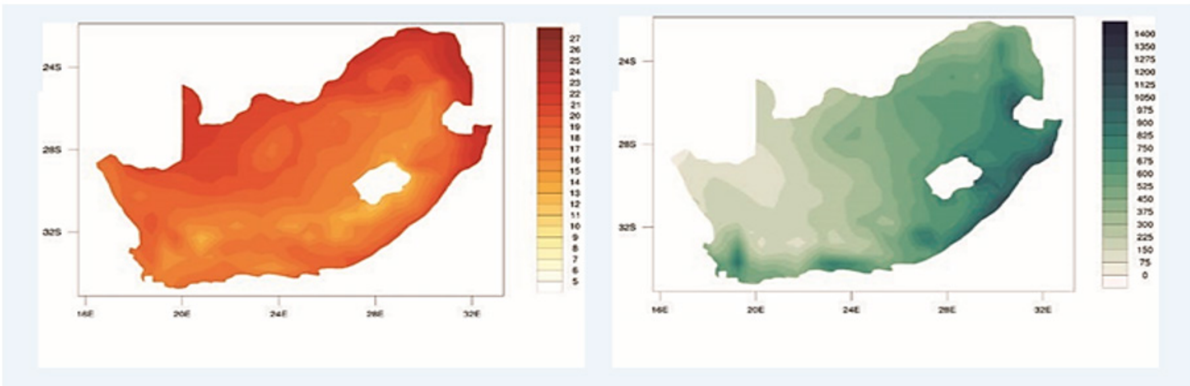
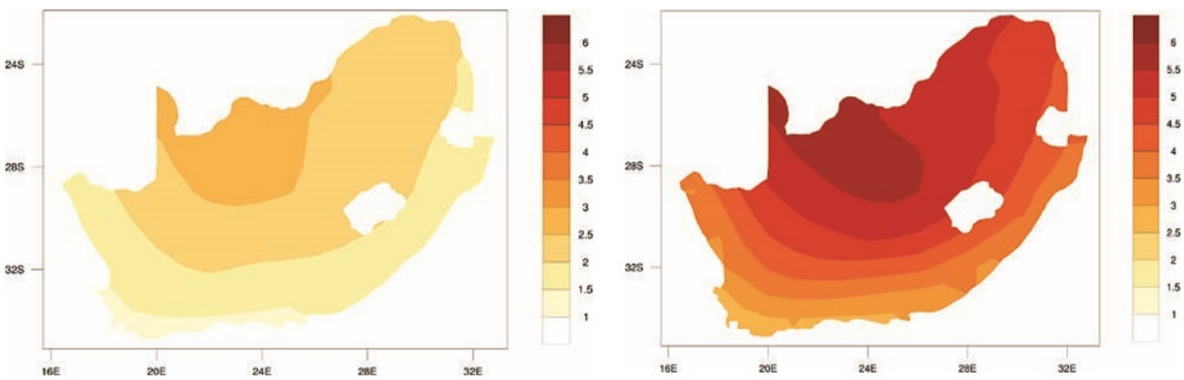


Figure 1: Average monthly temperature and precipitation in South Africa between 1999-2020
Source: Centre for Scientific and Industrial Research

Table 1: Summary of current climate statistics in South Africa

CMIP5 Ensemble Projection	**2020–2039**	**2040–2059**	**2060–2079**	**2080–2099**
Annual Temperature Anomaly 0C	+0.5 to +1.7 (+1.20C)	+1.4 to +2.9 (+2.00C)	+2.4 to +4.4 (3.20C)	+3.3 to +6.0 (4.20C)
Annual Precipitation Anomaly (mm)	-16.2 to +14.0 (-1.6mm)	-21 to +11.9 (-3.7mm)	-22 to +13.2 (-4.3mm)	-26.1 to + 12.4 (-5.9mm)

Source: Meteorological Service of South Africa, 2018



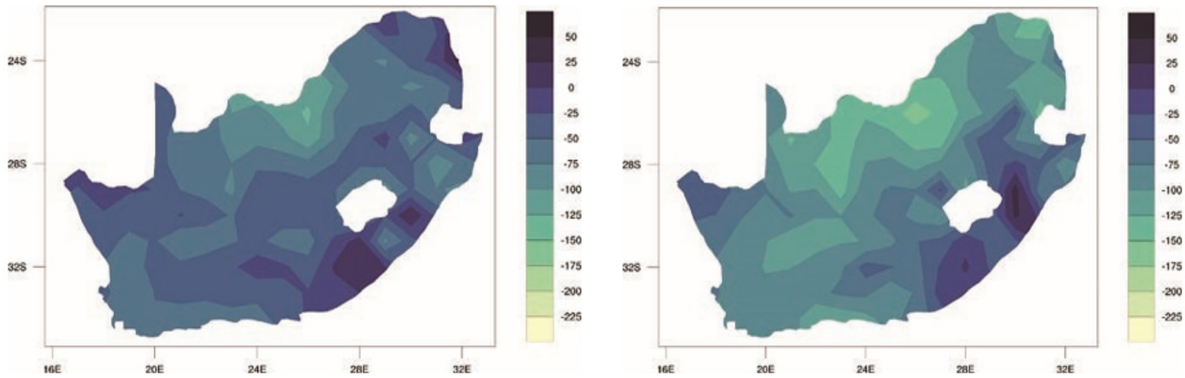


Figure 2: Projected Climate Change in South Africa: Annual temperature and precipitation from 2040-2059 and by 2080-2099: *Source: World Bank Open Data*

2.0°C by the 2050s and 4.2°C by the 2090s, if the current emissions persist. van Bronkhorst (2019) indicated that the most pronounced increases in temperature are projected for the summer months, between November to March. As temperatures rise, more intense heat waves and higher evapotranspiration rates will follow, impacting multiple aspects of local economic development and agricultural productivity (van Bronkhurst, 2019). Higher temperatures are projected to be more pronounced in the country's western, central, and eastern regions. These increases are expected to impact most in Northern Cape, Northwest, Eastern Cape and Limpopo provinces (Godsmark *et al.*, 2019).

Climate change and variability have also significantly impacted precipitation trends (Chersich *et al.*, 2019). Since the 1960s, there has been a marginal reduction in precipitation across South Africa. While annual rainfall trends are low overall, observations suggest that a significant decline has occurred in the Free State, Eastern Cape, Limpopo and Northern Cape provinces. High inter-annual rainfall variability is evident in the historical record. Above-average rainfall was received in the 1970s, late 1980s and mid-to-late 1990s, with below-average rainfall values were observed in the early 2000s (Ziervogel *et al.*, 2014).

This pattern is expected to continue, as suggested by Mpandeli *et al.* (2013) and Davis *et al.* (2021), who stated that South Africa is likely to become hotter and drier in the future. They go one to mention that the country will experience continued rainfall variability and temperatures rising, accompanied by extreme events like droughts, floods, and other climate-related hazards. This will likely result in adverse environmental impacts, including soil erosion, deforestation, recurrent droughts, desertification, land degradation, and biodiversity loss, including the country's unique wildlife populations (van der Bank *et al.*, 2020). Verschuur *et al.* (2021) further mentioned that climatic induced changes will lead to an intensification of the country's hydrological cycle and could have major impacts on the country's water resources. Furthermore, Scholes *et al.* (2021) alluded that climate change will lead to shifts in the geographical distribution of wetlands and an increase in the severity and extent of coral reef bleaching and mortality. Further, sea-level rise and increases in storm surges associated with climate change could result in the erosion of shores and habitat, increased salinity of estuaries and freshwater aquifers, altered tidal ranges in rivers and bays, changes in sediment and nutrient transport, increased coastal flooding, and in turn, increase the vulnerability of some coastal populations (Verschuur, 2021).

The Impacts of Climate Change on Water and Food Security in South Africa

Many scientific pieces of literature, including Chersieh *et al.* (2019), der Bank *et al.* (2020) and Masipa (2017), concurred that water and food are the resources that are impacted the most by the climate change globally, including in South Africa. Myers *et al.* (2017) alluded that climate change is already a measurable reality, posing a significant threat to water and food security in many South African households. Scholes *et al.* (2021) opined that South Africa generally is a water-scarce country. The country ranks as one of the 30 driest countries globally, with an average rainfall of about 40% less than the annual world average rainfall (Winter, 2018). The country has an average annual rainfall of less than 500 mm, while that of the world is about 850 mm (Mahlalela *et al.*, 2020). Rainfall varies considerably from west to east. In the northwest, annual rainfall often remains below 200mm (van de Walt *et al.*, 2020). In contrast, most parts of the eastern Highveld receive 500mm to 900mm of rainfall per year. A large area of the country's centre receives about 400mm of rain, on average, with wide variations closer to the coast (Botai *et al.*, 2018). Rainfall mainly occurs during summer (November through March), although rainfall occurs in winter from June to August in the Western Cape (Botai *et al.*, 2018). Variations in elevation, terrain, and ocean currents influence temperatures more than latitude. South Africa's climatic conditions range from Mediterranean in the south-western corner to temperate in the interior plateau and subtropical in the country's northeast (Botai *et al.*, 2018). A small area in the northwest has a desert climate. A large part of the country has warm, sunny days and cool nights (van der Walt, 2020).

Surface and groundwater resources are already declining in the summer rainfall region due to less and more variable rainfall (van der Walt *et al*., 2020). The winter rainfall regions are also on downward trends as rainfall period have reduced significantly (Asfaw *et al*., 2017). There is also strong evidence that the risk of multi-year droughts has increased substantially (Pascale *et al*., 2020). Lower rainfall and the high temperature that will increase evaporative demand (driven by increasing temperatures) are projected to increase and contribute to reducing soil moisture, translating to reduced runoff in rivers. Reduced groundwater recharge in semi-arid areas render these communities vulnerable to food insecurity and unstable livelihoods, promoting unsustainable agroecological systems, which experience crop failures and reduce the productivity of rangelands (Pascale *et al*., 2020). Similarly, Adom *et al*. (2021) disclosed that climate change impacts on the most vulnerable population the hardest, contributing to food insecurity, population displacement and stress on water resources.

South Africa is highly vulnerable to climate variability and changes due to the country's extreme dependence on rain-feed agriculture and natural resources, high levels of poverty, particularly in rural areas and low adaptive capacity (Nhemachena *et al*., 2020). Currently, South Africa is facing severe pressure concerning water and food security, especially in the Free State, Eastern Cape, Limpopo and Western Cape provinces (StatsSA, 2018). While droughts are prevalent in South Africa, nevertheless, in recent years, their occurrence has increased, with more multi-year droughts. Summertime rainfall series in most provinces in the country have declined significantly, with Eastern Cape, Limpopo and Free State being the worst affected provinces (Amoah, 2021). Agriculture is the backbone of South Africa's economy and accounts for most livelihoods across the country.

The sector employs more than 860,000 people and contributes significantly to food security and export revenues. Maize dominates the sector, followed by wheat and sugar cane and sunflower seed (Grote *et al*., 2021). Livestock production is a significant part of the sector. While the country's agriculture sector is diverse, it includes commercial and subsistence farming systems. Only 14% of the country is considered arable, with just one-fifth of this land characterised as having high agricultural potential. The climate is a critical driver of agricultural activities and suitability across the country (Agbugba *et al*., 2021).

The projected impacts of changing climate on food production, agricultural livelihoods, and food security in South Africa are significant and warrant national policy concerns (StatsSA, 2018). They are crucially linked to prolonged droughts and poverty. For instance, the 2017 statistics South Africa report revealed an increase in poverty and inequality trends in South Africa between 2006 and 2017 due to climate variability and change (StatsSA, 2018). The report revealed that more than 28,2% of the population live below the food poverty line (R441 per person per month in 2015 prices) compared to almost a third (20,4%) in 2006. Between 2006 and 2009, South Africa experienced an increase in the proportion of people living below the food poverty line rising from 28,4% to 33,5% (StatsSA, 2014). This increase was followed by a notable decline of 12,1 percentage points in 2011 to 21,4%, followed by an increase of 3,8 percentage points to 28,2% in 2017 (Leibbrandt *et al*., 2017). The significant increase in food poverty noted in 2009 coincided with global warming, affecting South Africa (StatsSA, 2018). Gornall *et al*. (2010), Zwane (2017) and Uddin *et al*. (2020) expand on the issue and state that climate change has impacted cereal crop production significantly.

In addition, export of agricultural products and intensive animal husbandry practices in South Africa in last three decades have also been affected (Zwane, 2017). These impacts are witnessed in the pastoral industry and increased pest damage and disease, directly impacting food security and livelihoods of individual households. The adverse effects on food security and livelihoods in the drought-prone provinces have increased by 36% since 2012 according to the Department of Agriculture Food and Fisheries (DAFF, 2015). Crop scientists project a reduction in mean yield of 13% in Free Sate, 11% in North Cape, and 18% in Eastern Cape (Nalley *et al*., 2018). Nevertheless, maize and wheat will experience a higher yield by 2050 of up to 5% and 8%, respectively, due to their greater resilience to heat-stress conditions, while maize and wheat are expected to be the most affected crops with a yield loss by 2050 of 15% and 11%, respectively (Estes *et al*., 2013). De Wit (2010) disclosed that households in the lowest income categories tend to be significantly more affected by lower yields than higher-income households. This is likely due to their low adaptive capacity to shocks and stresses. Hence, climate change and food security in the country (Chen *et al*., 2021).

In addition to food insecurity, water scarcity is another significant threat facing South Africa (Misra, 2014). Currently, more than ten million households (25%) do not have access to safe and reliable drinking water (Schreiner *et al*., 2018). While every projection suggests that if the current demand persists without effective interventions, the water deficit in the country could be between 2.7 and 3.8 billion cubic meters, a gap of approximately 45% of available water sources by 2030 (Donnenfeld *et al*., 2017). A f study on Climate change in South Africa by the Department of Environmental Affairs DEA (2013) revealed that climate change would significantly impact water supply nationally, but more impacts will be felt particularly drier provinces such as Eastern Cape, Free State Western Cape and Limpopo.

These provinces are prone to the extreme water scarcity, with a significant number of communities in these provinces are facing dire water shortages (Viljoen *et al*., (2018). The amount of water available in their water reserves is already limited, while the demand continues to rise as the population grows (NW&SMP, 2018). Many provinces in the country have experienced less rain over the past 50 years and increases in the severity and length of droughts (Viljoen, 2018). Additionally, most provinces have isolated drainage systems with limited or single sources or small geographical areas with limited hydrological variability, including small farm dams in headwater catchments and water supply schemes for rural towns (Cilliers *et al*., 2014). For instance, the Western Cape water supply depends on limited drainage and generally from the western part of the province, mainly from the Riviersonderend-Berg River Water Scheme. This scheme captures the flow of three rivers – the Sonderend River, Berg River and Eerste Rivers. Unfortunately, these rivers are highly exposed to climate change variability and change (Jeffes *et al*., 2017). In Free State, there is less annual rainfall, less snowpack on the mountains, and earlier snowmelt resulting in less water available during the summer months when demand is highest (Ratikane, 2013). These natural cycles of water supply have made it difficult to effectively manage water to satisfy water demands throughout the year (Botai *et al*., 2016).

Climate change is not only exacerbating the existing water-related challenges, but it is creating new impacts directly linked to economic development, sustainable livelihoods, and infrastructure development, including water quality-related issues. Projected impacts are due to changes in rainfall and evaporation rates, wind speed, air temperature, soil texture, geology, land cover, and topology of water catchments across South Africa (Oduniyi, 2018). A critical impact of climate change on water resources is the changes in runoff across the country (Ncube *et al*., 2016). Under a wetter future climate scenario, significant increases in runoff would result in increased flooding, human health risks, ecosystem disturbance and aesthetic impacts (Kusangaya *et al*., 2013). Drier future climate scenarios would reduce surface water availability but would not exclude the risk of extreme flooding events (Dennis *et al*., 2012). Projections for the national runoff will range from a 20% decrease to a 60% increase based on an unmitigated emissions pathway, which reflects substantial uncertainty in rainfall projections (Dennis *et al*., 2012). The range increases along the eastern coastline and central interior to decreases towards the Western and Northern Cape (du Plessis *et al*., 2017). Provinces with the highest risk from extreme runoff include Kwazulu-Natal, parts of southern Mpumalanga and the Eastern Cape, other show neutral to reduced risk from runoff, except for the central and lower Orange River region (du Plessis *et al*., 2017).

Other risks directly impacted by climate change are the livelihoods of people. These range from the prospect of increasingly poor health that will result from air pollution (the projected increase in the number of inversions will trap pollutants in the atmosphere close to the ground), heat stress) and the possibility of increased flooding (Bein *et al*., 2020). The combination of water scarcity and rising temperatures will impact sectors of the economy that are mainly linked to ecosystem goods and services agriculture, manufacturing, commerce and trade, transport and communication infrastructure (Mancosu *et al*., 2015; Furukawa *et al*., 2021).). The livelihoods of people who may be most severely affected are those whose asset bases, may be damaged or destroyed (Demekas *et al*., 2021). Hallegatte *et al*., (2020) concurred that the first people to suffer most of the climate change consequences are the poor, who are usually constrained to living in risk-prone areas.

Legislation and Policies Governing Climate Change in South Africa

Climate change is a global threat, complex, and unavoidable (Berlie, 2021). Comprehensive studies on the effect of climate variability and change on natural resources, including water and food, remain a serious risk to many countries globally, including South Africa (Affoh *et al*., 2022). South Africa is among the countries at the forefront globally to tackle climate change challenges. The country agreed to the "United Framework Convention on Climate Change (UNFCCC) in 1997 and ratified the Kyoto Protocol in 2002 (Avenchenkova *et al*., 2019). Over the past twenty years, South Africa has implemented a range of national and sectoral policies, programmes, and strategies to mitigate climate change effects on water and food resources (See Figure 3). Similarly, Corfee-Morlot *et al*. (2009) alluded that South Africa has put one of the most elaborate and consultative climate governance systems observable among developing and emerging economies. Furthermore, van der Bank *et al*. (2020) opined that South Africa, post-independent in 1994, has formulated and implemented diverse national climate programmes and policies to meet the Paris Agreement of minimising emissions.

The National Water Resource Strategy NWRS of 2004 and 2013 played a critical role in the government's IWRP procedure, which promotes the contemporary preservation of the "water balance reconciliation strategies" for water management areas which have been developed recently for water provision 224 schemes for up to 75 per cent of the country's population, and the areas which, together, generate well over 80 per cent of the national GDP. Avenchenkova *et al*. (2019) alluded that the current policy, for instance, the NWRS of both 2004 and 2013, have integrated climate variability contemplations in the short, medium and long terms water developments across all the critical sectors of the economy, "agriculture, industry, energy, science and technology". It has also promoted the sustenance of "state-of-the-art water-related research and capacity development in all aspects of climate change" to guarantee the accessibility of constantly high quality, comprehensive and current data, as well as an instrument that will assist in examining the information (Mthembu *et al*., 2021).

Through the policies, they have implemented the best watersheds and water resource management practices that guarantee a greater level of water safety, and the asset protection under fluctuating climatic conditions and, in particular, funding in water preservation and water demand management (Lukey, 2020)

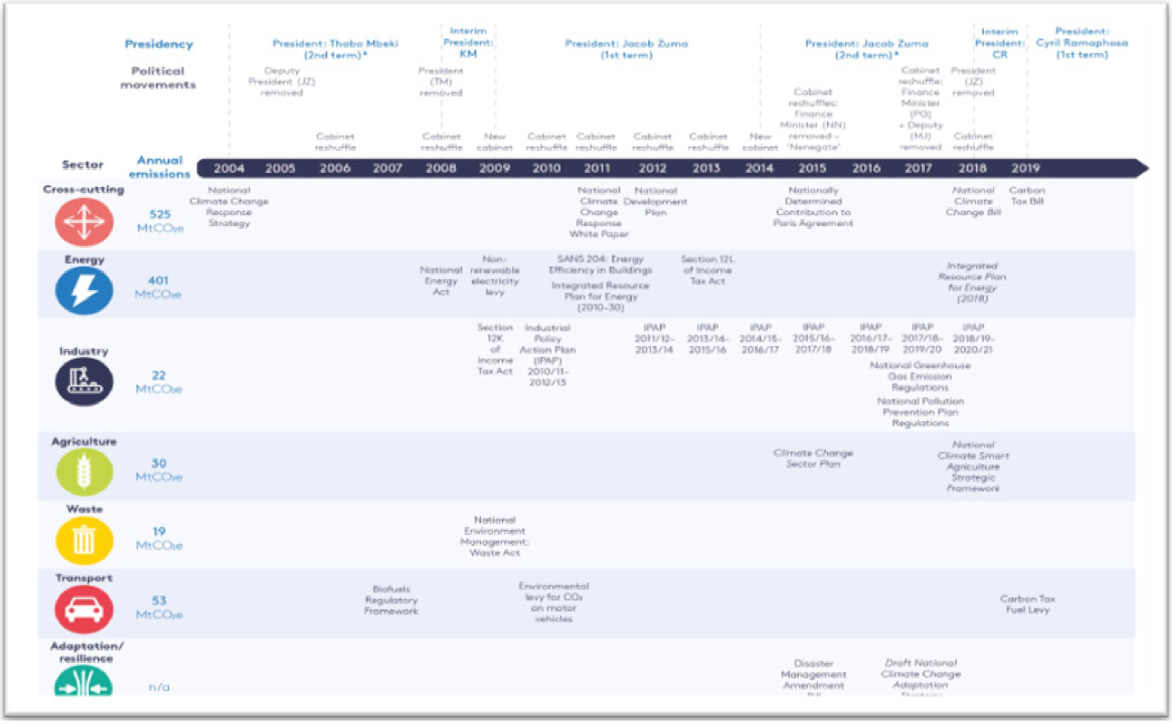


Figure 3: Timeline of climate-related policies and programmes from 2004-19
Source: White Paper on National Climate Change Report

While multiple policies, regulations and programmes have been designed to minimise climate change's impact on water and food security, ensuring a coherent policy formulation and implementation both vertically and horizontally remained a severe challenge due to the fragmentation nature of responsibility of climate policy. Moreover, the country's general climate plan trajectory is not on a sustainable platform (Avenchenkova *et al.*, 2019). This highlights that there a lack of clarity among government structures.

This has led to poor coordination on how the policies should be aligned and implemented in most cases. The lack of alignment and clarity has impacted the effectiveness of the policies, especially at the implementation level. The common consensus among many scholarly works of literature, such as Avenchenkova *et al.* (2019) and Zhuwakinyu (2019), is that the existing policies and strategies are silent on building capacity to deal with climate change and other related challenges. For instance, one of the critical factors is limited human and financial resources, an absence of right and suitable expertise and skills, inadequate research, and under-resourced institutions to implement policies to address the climate change debacle effectively.

These constraints are aggravated by the growing complexities of the task involved in formulating and implementing sectoral and multisector decentralisation and resilience policies. It was indicated that these constraints are more severe at provincial and municipal levels (Zhuwakinyu, 2020). The country's leadership should evaluate the numerous policy solutions to combat these threats.

METHODOLOGY

This paper aims to investigate the impact of climate change on water and food resources in South Africa. It was carried out through a comprehensive study of the relevant literature and empirical research based on the mixed research approach of quantitative and quantitative data.

Study Area

While this study covers the whole of South Africa, data collection for this study was limited to some selected communities in (Bloemfontein, Fickburg, Winburg, Bethlehem, Welkom and Harrismith) in the Free State Province. This province was chosen due to its strategic location in the country. The province is centrally located in the country and is dominated by agricultural production (Puukka *et al.*, 2012). Agriculture in the province is highly dependent on rainfall. Only 10% or less of the arable land is under irrigation (Botai *et al.*, 2016). The province contributes about 40% of the total national white maize production, mainly used for human consumption, and 38% of yellow maize, mainly used for animal feed (Agbugba *et al.*, 2020). The climatic condition of the province is characterised by warm to hot summers and cool to cold winters (Moeletsi *et al.*, 2012). This semi-desert area also experiences fluctuations in temperature from day to night. Areas in the east experience frequent snowfalls, some the high precipitation, whilst the west can be extremely hot in summer (Ndlovu *et al.*, 2021). Almost all precipitation falls as brief afternoon thunderstorms during the summer, with aridity increasing towards the west. Frost occurs throughout the region, usually from May to early September in the west and up to early October in the east (Botai *et al.*, 2016).

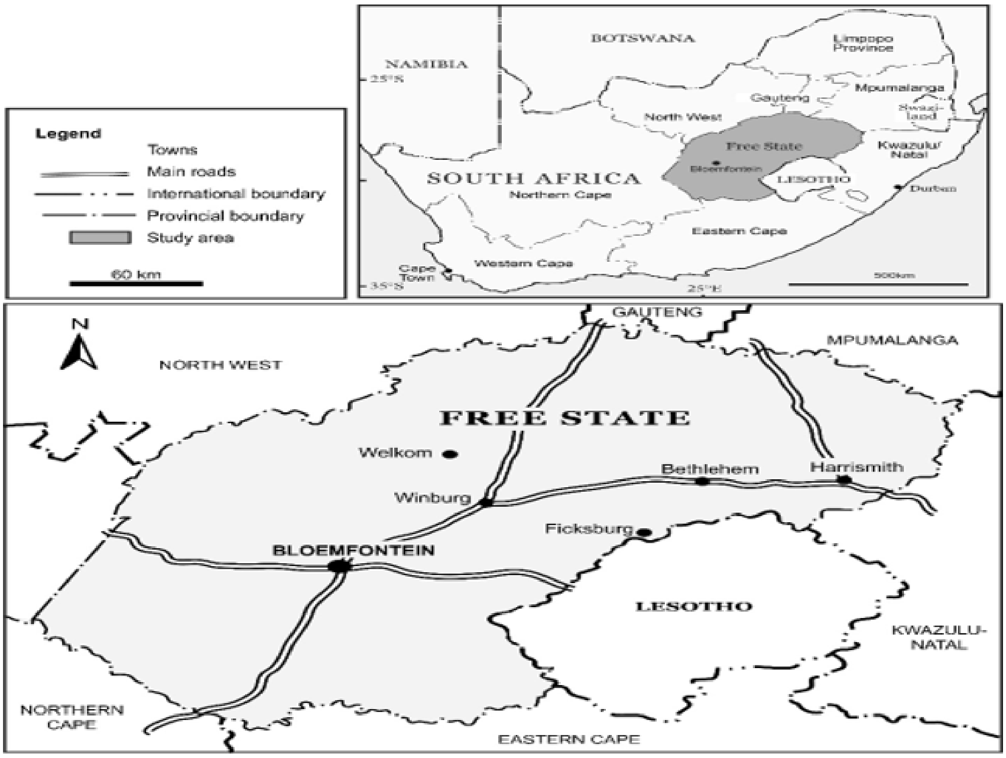


Figure 4: A map of the study site Free State Province. *Source: Free State Provincial wall map. Mapstudio.co.za*

Research Design

This study employed both qualitative and quantitative methodologies to explore the impact of climate change on water and food security in South Africa. The qualitative approach includes participatory rural appraisal (PRA), such as the historical trend analysis and face-to-face and in-depth interviews. This method was used to establish the general perceptions of climate change and variability on water and food production, historical climate changes, and adaptation strategies to address climate change. The quantitative method employed the use of a household questionnaire survey. The approach was used to assess the literacy levels of climate changes and weather pattern variation and adaptability over the past ten years, the impact of climate on water accessibilities and agricultural activities among the population. The content in documents from journals, book chapters, government gazettes, and minutes was used to obtain data on legislation, policies, regulations, and strategies designed to address climate change and its associated impact on water and food production in South Africa.

Sample Population and Size

A total of ten in-depth interviews were conducted with respondents from the Department of Water and Sanitation (DWS), Department of Food Agriculture and Fisheries (DAFF), and the lecturers and students within the Department of Environment and Geography of the University of Free State. Owing to the sheer size of the population, a stratified and proportional sampling method was applied. The number of respondents picked from an institution was based on the total number of employees within the department. Based on this approach, three interviewees were picked from the DWS, two from DAFF and five from the Department of Environment and Geography from the University of Free State.

A total of 150 questionnaires were distributed to municipal officials in management positions, farmers and community members. Due to the massive target population, a stratified, proportional probability sample was also applied. According to Howell *et al.*, (2020), an appropriate sampling fraction for a homogenous population is 10%.

This paper's sample fraction was 30% (150 of 500 target population). This sample can thus be regarded as the target population. Out of the 150 questionnaires distributed, 100 were returned, resulting in a response rate of 67%. According to Perneger *et al.* (2020), a response rate of at least 50% can be regarded as satisfactory for analysis, while 60% and 70% are 'good' and 'very good', respectively. The biographical details of the respondents were assessed using a series of questions on their post, age, experience and educational attainment. These variables were deemed relevant because the researchers were looking for levels of understanding of climate change among the general population, the impact of climate change on water security and food production and adaptation and coping strategies

Data Analysis

Both the qualitative and quantitative data obtained were analysed concurrently. The quantitative data was analysed using descriptive statistics of SPSS Windows Version 21. This technique enabled data to be captured, analysed and produced frequency tables and diagrams that ensured quick interpretations of the data obtained. The qualitative data obtained from interviews were analysed using the thematic analysis technique. Thematic analysis technique was used to classify data into themes for interpretation and discussions.

RESULTS AND DISCUSSION

Assessment of Climate Change Literacy

Although most of the population is aware of climate change and agree that some intervention is required, the ordinary person appears incompetent to rise to the challenge. The magnitude of this challenge was captured

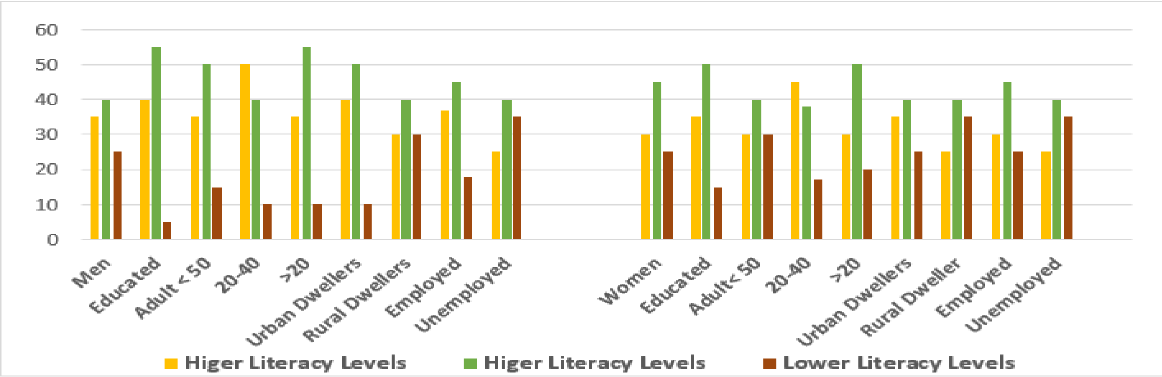


Figure 5: Literacy levels of Respondents on climate Change. *Source: Field survey 2021*

in this paper. The results on climate change literacy are presented in Figure 5.

The survey evaluated climate change literacy among the respondents using socio-economic and demographic factors these include; gender, age, education, educational attainment, place of location and income status. These variables were used to establish a holistic picture of climate change literacy and its determination across the country. The statistical breakdown revealed that the strongest predictor of climate change literacy is education by far. Additionally, employed and wealthier individuals and those living in urban areas are more aware of climate change related issues. The results further established that they differ according to gender, with men being more climate change literate than men. The changing environment determines climate change literacy. For instance, a respondent who was engaged in an in-depth interview disclosed that:

"When we speak of climate, we refer to the long-term average of the individual weather conditions that we experience every day. He further disclosed that our climate is important because it determines how and where we live, which foods we can grow, our sources of water for irrigation and drinking, and how we organise our societies and our economic activity."

The views of these respondents confirmed the observation of (Helbling *et al.*, 2021) that climate literacy will assist the population to translate cognitive judgement (perception of temperature changes) to evaluative judgement (understanding the long-term consequences) of the climate change to livelihoods and the environment.

Climate Change Projection and its Impact on Water and Food Security in Free State

This paper obtained data on climate change projections and their impacts on water and food production in the Office Centre for Scientific and Industrial Research (CSIR). Figure 6 shows projected changes in annual average temperatures in Free State Province. The data revealed increasing temperatures throughout the province between 2021-2050.

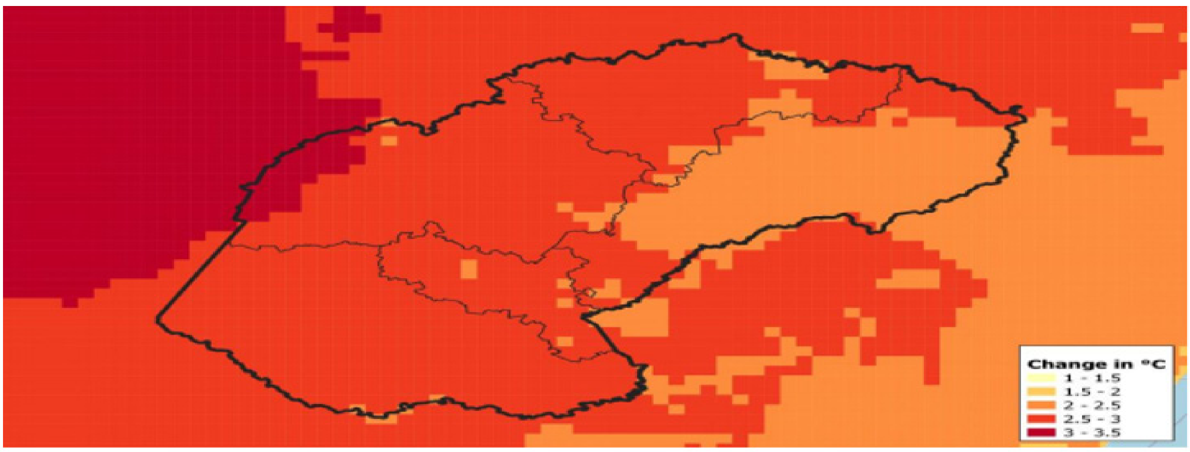


Figure 6: Projected changes in annual average temperatures throughout Free State between the periods of 2021-2050. *Source: Centre for Scientific and Industrial Research, 2019s*

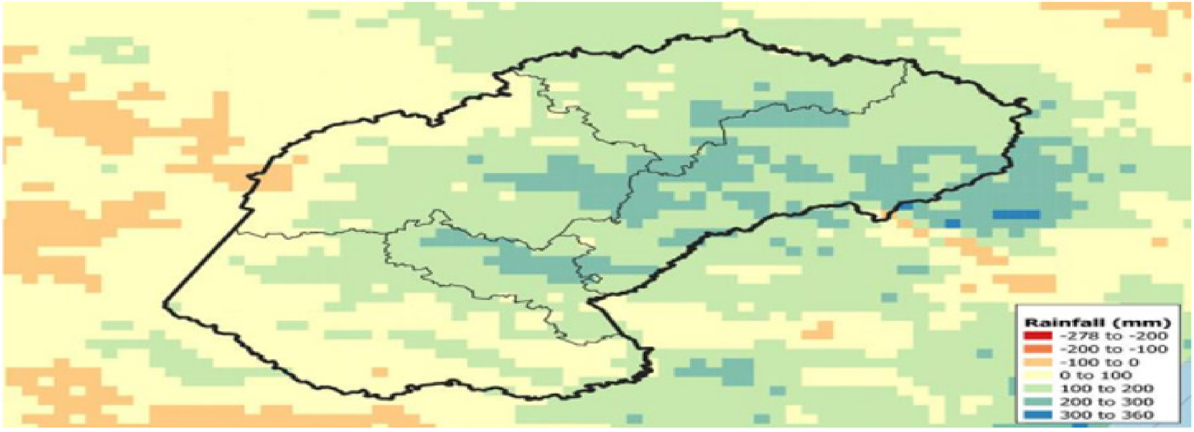


Figure 7: Projection of annual average rainfall the province between 2021-2050.
Source: Centre for Scientific and Industrial Research, 2019

Both Figures 7 and 8 project increases in the number of rainfall days and increase intense storms and flooding events across the province. Climate model projections summarised both indicate that the Free State's surface temperature and precipitation, both minimum and maximum are likely to fluctuate during the 21st century (superimposed on the existing observed climate). Further, regional climate modelling suggests that mid-summer rainfall over the province may become more extreme (see Figures 7 and 8).

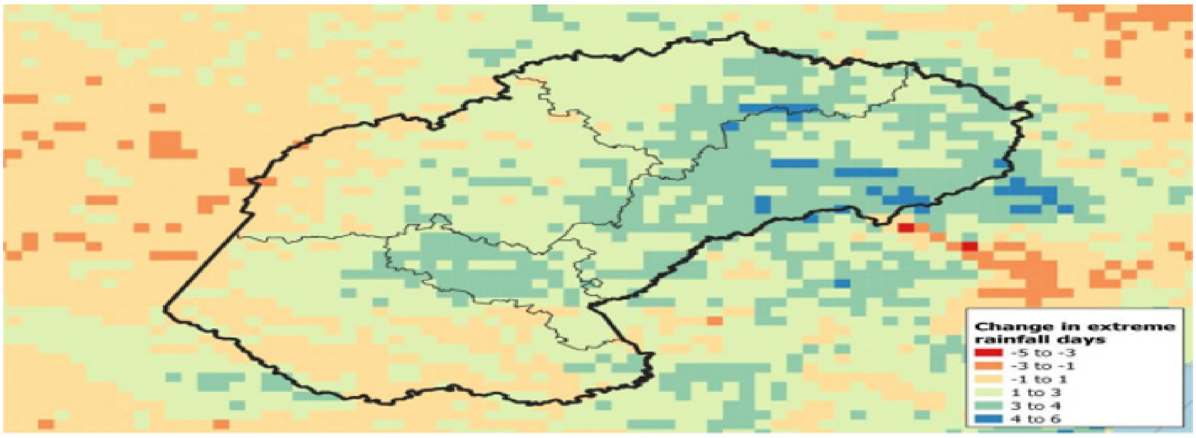


Figure 8: Projected changes in annual average number of rainfall Free State between 2021-2050.
Source: Centre for Scientific and Industrial Research

Climate Change Impacts on Water and Food Security
Based on projections illustrated in Figures 6, 7 and 8, this paper analysed the levels of impact of climate change on water and food security in their community. Table 2 portrays the answers of respondents
Table 2 revealed that of the eighteen variables assessed under 'not vulnerable', 'fairly vulnerable' ', very vulnerable' and extremely vulnerable' on water and food security, 16 of them, representing 89%, are regarded as either 'very

Table 3: Levels of climate change impacts on water and food security

	{∑fx/n)}	Not Vulnerable	Fairly Vulnerable	Very Vulnerable	Extremely Vulnerable
Reduction in crop yield, food availability and increase in food inflation	Respondents(100)	0	5	10	85
	%	0.0%	5.%	10%	85%
Higher cost of agricultural production due to high cost of water	Respondents (100)	0	12	20	68
	%	0.0%	12%	20%	68%
The intensity of drought frequency, duration and lengthen of abstraction	Respondents (100)	2	20	55	23
	%	2%	10%	55%	23%
Impacts on the stability of food Supplies and food utilisation	Respondents (100)	12	20	55	25
	%	12%	10%	55%	267%

Reduction in availability of water for human consumption and livestock	Respondents (100)	0	5	40	55
	%	0.0%	5%	40%.	55%
Reduction of underground storage, increase of melting snow leading to increase in runoffs and flooding	Respondents (100)	10	15	55	20
	%	10%	15%	55%	20%
Induration and increased damage in low-lying coastal areas affected by sea-level use with storms surges	Respondents (100)	5	20	45	30
	%	5%	20%	45%	30%
Rising temperature increases agricultural pests and impacts crop's survival	Respondents (100)	20	45	30	5
	%	20%	45%	30%	5%
Increased evaporative demand from crops as a result of higher temperature.	Respondents (100)	20	35	30	15
	%	20%	35%	30%	15%
Cultivated become unsuitable for cropping, and tropical grassland becomes increasingly arid	Respondents (100)	10	18	29	50
	%	10%	18%	29%	50%
Rising of sea levels and coastal erosion	Respondents (100)	15	18	45	22
	%	15%	18%	45%	22%
Impact on freshwater accessibility and quality and prices of water	Respondents (100)	0	5	25	70s
	%	0.0%	5%	25%	70%
Intensification and duration of heat waves lead to crop failures and diseases in livestock and farmers					
	Respondents(100)	5	16	40	34
	%	5%	17%	42%	36%
The risk of severe storms, including intense tropical cyclones and intense thunderstorms, leading to loss of life, injury and damage to infrastructure also increases	Respondents (100)	5	8	40	47
	%	5%	8%	40%	47.%
Climate change worsens existing vulnerabilities and adds to the pressures on the environment and natural resources	Respondents (100)	5	10	32	53
	%	5%	10%	32%	53%

Source: Field survey 2021

or extremely vulnerable'. These answers suggest that climate change significantly impacts their communities' food production and water accessibility. For instance, a commercial farmer who was engaged in an interview said that:

"Climate change alters the frequency and intensity of rainfall, floods and droughts, causing significant impacts on agriculture and food production. While food shocks and stressors affect all people, women, indigenous populations, subsistence farmers, pastoralists and fishers are disproportionately affected."

This view was supported by another interviewee in the Department of Environment at the University of Free State who was engaged in an in-depth interview. He mentioned that:

"Climate change negatively affects freshwater ecosystems by altering streamflow and water quality, posing risks to drinking water even with conventional treatment. The risks are increased temperature, increases in sediment, nutrient and pollutant loadings due to heavy rainfall, reduced dilution of pollutants during droughts and disruption of treatment facilities during floods.

More floods and severe droughts are predicted. Changes in water availability will also impact socio-economic livelihoods, health and food security in the province as it has already proven to trigger much civil instability in the country.

Mitigation strategies of Climate Change

Based on the outcomes of respondents towards impacts of climate change on water and food production, respondents were asked to suggest mitigations strategies based on marked out variables. Table 4 depicts the views of the respondents

The breakdown of the table suggests the majority of the respondents regarded mitigation strategies enlisted as either 'a priority' or 'high priority'. Some of the outcomes in Table 3 revealed that 60% of the respondents agreed that indigenous knowledge and local coping strategies should be used as a baseline and starting point for any

Table 4: Perspectives of respondents on the levels of priorities of mitigation strategies

	{∑fx/n)}	Not a Priority	Fairly Priority	Priority	High Priority
Encourage sound management and protection of freshwater resources	Respondents (100)	3	10	35	52
	%	3%	10%	35%	52%
Promote cooperation on shared water resources and encourage low-cost strategies with multiple benefits.	Respondents (100)	5	12	30	53
	%	5%	12%	30%	53%
Strengthen water-sector governance, finance and institutions	Respondents (100)	2	10	40	58
	%	2%	10%	40%	58%
Improve adaptation planning among the population, encourage research in climate change development	Respondents (100)	10	15	45	30
	%	10%	15%	45%	30%
Develop awareness of flood risk and identification of adaptation measures	Respondents (100)	18	15	40	27
	%	18%	15%	40%	27%
Co-exploration of climate data and information needs	Respondents (100)	10	15	45	35
	%	10%	15%	45%	35%
Use climate information to improve and plan adaptation measures	Respondents (100)	20	35	25	20
	%	20%	35%	25%	20%
Use climate information in future planning and develop low-cost strategies with multiple benefits.	Respondents (100)	20	45	30	5
	%	20%	45%	30%	5%
Factor in weather-driven mitigation into the design and construction of development projects	Respondents (100)	10	15	35	40
	%	10%	15%	35%	40%
Promote sustainable growth, especially in rural communities	Respondents (100)	5	10	35	50
	%	5%	10%	35%	50%
Promote climate-friendly agriculture such as efficient, clean energy and micro-irrigation	Respondents (100)	0	5	25	70
	%	0.0%	5%	25%	70%
Provide easy access to weather and climate information, especially to women who make up a large percentage of the agriculture workforce and are the most vulnerable	Respondents (100)	5	15	25	65
	%	5%	15%	25%	65%
Promote multi-disciplinary and multisectoral institutions and processes.	Respondents(100)	5	16	40	39
	%	5%	17%	40%	34%
Use of indigenous knowledge and local coping strategies as a baseline and starting point of adaptation planning	Respondents (100)	0	8	32	60
		0.0%	8%	32%	60%
Apply climate forecasts to manage water resource operations, provide more versatile inter-basin transfer schemes and more flexible operating rules for water systems	Respondents (100)	5	10	44	41
		5%	10%	44%	53%

Source: Field survey 2021

planning programme on climate change adaptation. In comparison, 70% of the concurred that climate-friendly agricultural practices such as efficient, clean energy and micro-irrigation should be promoted. For instance, an expert in the Department of Environment and Economic Planning who was engaged in an interview disclosed that: "Although there is a large body of knowledge within local communities on coping with climatic variability and extreme weather events, rapidly changing climate conditions will require upgrading local knowledge with more scientific observations and establishing collaboration among neighbours and neighbouring countries to transfer knowledge from areas already experiencing these changes"

This view was buttressed by an expert in the Department of Geography and Environmental Science at the University of Free State disclosed that:

"There is an urgent need to strengthen the capacity of grassroots organisations to make efficient use of available data. Provision of data to end-users' entails power dynamics between the providers and end-users and among end-users (e.g. men and women). Local communities need access to global information and analyses specifically tailored to their needs that support their specific adaptation and planning requirements. This needs to cover markets and weather and climate and requires invigorated extension services".

There was agreement amongst most participants that that investment is required in enhancing hydrological data, institutions and governance, education and capacity enrichment, risk assessment and knowledge sharing. Policies are needed to ensure all stakeholders' representation, participation, behavioural change, and accountability, including the private and private sectors. Mitigation strategies need to integrate targeted strategies that help vulnerable populations disproportionately affected by climate change impacts.

ANALYSIS AND DISCUSSIONS

This paper explores the impact of climate change on water and food security in South Africa under the themes; of climate literacy, climate change projections and its impacts on water and food production and the mitigation strategies. Our findings revealed that although a significant number of the population in South Africa are cognisant of climate change and its impacts on livelihood. However only 33% of the population are climate literate, suggesting that they understand causes, impacts and adaptation strategies. Furthermore, it was established that the socio-economic and demographic factors significantly influence the literacy and interest population towards climate change. For instance, it was established that educated individuals with high income and access to information and urban dwellers are more informed of climate change dynamics than rural, poor and rural dwellers. Moreover, adult young men are more abreast of climate change than women. These findings confirmed the views of (Simpson *et al.*, 2021) that climate change awareness and risk perceptions are unevenly distributed across population groups, countries, and regions. The highest levels of climate literacy or awareness are mostly within educated and high incomes households and developed economies. By contrast, most lower-income, less educated households and developing countries from Africa to the Middle East and Asia are less climate literate and less interested in on issues pertaining to climate change.

This assertion was confirmed by Lee *et al.* (2015), who stated that geographic location (urban/rural) determines climate literacy. In developed countries such as the USA, the most important predictors of climate change awareness are civic engagement, communication access and education. Residents with higher levels of civic engagement are almost always aware of climate change, whereas those with lower levels of civic engagement and communication access tend to be unaware (Lee *et al.*, 2015). Lower-income residents who are poorly educated and rural dwellers or on farms are the least aware of climate change. In terms of gender relations, the findings established that resources, attitudes and strategies to respond to weather-related hazards often differ between women and men. For instance, it was established that women tend to limited access to critical information on weather alerts and cropping patterns, affecting their capacity to respond effectively to climate variability and education. This view confirmed the observation of Lambrous *et al.* (2016) that gender norms, roles, and relations contribute significantly to gender inequalities in climate literacy

In terms of climate change past variations future projections and its impact on water and food security in the country, our findings established that climate change has contributed significantly to the rising of temperatures in South Africa in past century, but a notable increase has been recorded in the last two decades. This is reinforced in Figure 6 of our findings and buttressed by numerous scholarly works of literature including Engelbrecht *et al.* (2015); Nyoni *et al.* (2021); Carcel *et al.* (2015). Consistent with our findings confirmed that South Africa's annual surface mean temperature has increased by 02°C to 0.06°C per annum in the past two decades. This is buttressed by statistical evidence from Centre for Scientific and Industrial Research (CSIR) 2021 report which disclosed an average increase of about 10C temperature has occurred across the entire country in the past five decades. Buttressing our findings and data from South Africa's Second National Climate Change Report (NCCRWP, 2020) revealed that the country's interior regions have experienced more intense warming than the coastal areas. The Spring seasons have experienced the greatest increased and prolonged temperature in the past two decades, while the country's precipitation and hydrological zones have decreased significantly in the same period.

In relation to future projections our findings shown in Figure 6 supported by pieces of scientific literature including Mbokodo *et al.* (2020); CSIR (2019) projects a rapid increase in the annual average temperature of between 1.50C to 2 times the global rate of temperature increases in South Africa in the 21st century. Confirming our findings Maure *et al.* (2018); Mbokodo *et al.* (2020) concludes that for a period 2021-2050 temperature increases of 10C to 2.50C will plausibly occur over the southern coastal regions, while the interior provinces such as Free State and, Northern Cape and Northwest are likely to experience temperature increases exceeding 30C in the same period. A projected annual rainfall pattern is displayed in both Figure 7 and 8. Critical analysis of the Figures Project a general reduction in mean annual rainfall in the country. Our findings supported by climatic studies such as Zengeni *et al.* (2014); du Plessis *et al.* (2017) modelled declined precipitation to around -5%, -2%, and 0% by 2035. Augmenting these findings Mackellar *et al.* (2014) project that by 2050 the interior provinces such as Free State, Northern Cape, North-West and Limpopo will experience an average declined of up to 30% of their annual rainfall between 2025 to 2050. Consistent with these findings Jury (2019) and Archer *et al.* (2019) further project a declining rainfall trends during the austral spring months, implying a delay in the onset of seasonal rains over a large part of the summer rainfall region in the country. Interestling, as Shown in Figure 8 of our findings and supported by some scholarly literature such as Mackellar *et al.* (2014); Chersich *et al.* (2019) concludes that the rainfall patterns are expected to increase in both intensity and frequency in certain coastal provinces such as Eastern Cape, KwaZulu Natal and Western Cape. The extreme and less predictable weather conditions in these provinces are projected to affect availability and distribution of rainfall, snowmelt, river flows and groundwater, and further deteriorate water quality.

Regarding the impact of climate change on water and food security our findings portrayed in Table 3 concludes that climate variations have contributed tremendously to water and food insecurity across households in South Africa, particularly the vulnerable and poor communities who cannot meet their food requirements through market access. Numerous pieces of literature such as Masipa (2017); Nhemachena *et al.* (2020) augmented our findings that climate change has contributed to livelihoods, economies, and the environmental woes, and have exacerbated existing vulnerabilities in the country. More worryingly, our study findings supported by many climatic studies including Fawzy *et al.* (2020); Chersich *et al.* (2019) strongly believed that the worst impact of climate change is yet to be felt in the water and food sector in the South Africa if adequate adaptation measures are not put in place as soon as possible.

Based on our findings climate change will alter the hydrological cycle, temperature balance, and rainfall patterns across South Africa which will impact severely on of water provision, food production and other sustainable livelihoods. The breakdown of Table 3 supported by numerous scholarly literature including Kusangaya *et al.* (2013); Ngcamu *et al.* (2020) confirmed that climate change will affect food and livestock production therefore, food availability through several different pathways, will be negatively affected by rising temperatures, floods, drought, or other extreme weather events; that have potential to reduced crop yields, risk to food safety due to aflatoxins, declined nutritional quality of foods due to increased CO2 levels in the atmosphere and increased risk of diseases. A combination of all the above means that climate change will lead to water and food insecurity through increased shocks and stressors resulting in food and water insecurity, undernourishment, increased environmental degradation combined with natural resource scarcity.

The phenomenon of climate change will disrupt livelihoods, increase poverty, marginalise the poor, and escalate inequality (Kusangaya *et al.*, 2013). It was proved that water is an essential and central resource in the country because most of the population derives their livelihood from cultivation and livestock production, dependent on the availability of rainfall and water. The evidence increases the potential risks to water posed by climate change. There are multiple risks derived from changes in precipitation and increases in temperature, which relate to damage to infrastructure leading to the loss of services and environmental contamination and to deterioration in water quality, impacts that will increase risks to health. These risks are widespread, affecting both poor and wealthy households.

Regarding mitigation strategies, as shown in Table 4, our finding established most effective strategies that could minimise the risks from extreme weather events on water and food production must be promoted. These include adapting basic agronomic techniques must be implemented to reduce losses from droughts, floods and other extreme weather events. Findings pointed out that efficient irrigation methods that conserve water and mulching and contouring to retain and increase soil moisture ought to be promoted. Additionally, it was established that planning and implementing adaptation strategies must be transparent and well-documented in a manner that is open to public scrutiny and discourse. Ensure the representation of key stakeholders, especially representatives of vulnerable communities, marginalised groups, women, and indigenous peoples, at every stage of the process, including the governance and disbursement of adaptation finance, planning, implementation, monitoring, and reporting. These findings confirmed the views of Fawzy *et al.* (2020) that effective strategies for combating climate change must prioritise the adaptation needs of and ensure that resources reach the most vulnerable, including marginalised groups, women and children, indigenous peoples, local communities and those disproportionately impacted, as well as vulnerable ecosystems, through enhancing adaptive capacity and reducing vulnerability.

Furthermore, Mfitumukiza *et al.* (2020) concurred that it is appropriate to maximise regional, national, provincial and community level ownership over adaptation planning and implementation processes and disbursement of adaptation finance to enable and encourage participatory local level planning and implementation. Furthermore, appropriate transboundary cooperation should be emphasised in all steps of the climate change adaptation process: from collecting and sharing information (which form the basis of robust decision-support systems), developing joint vulnerability assessment, managing water with flexible and adaptive institutions, and developing basin-wide adaptation strategies, to planning and operation of different adaptation measures such as infrastructure on shared waters. Joint data and knowledge-sharing arrangements and joint monitoring of basin conditions are prerequisites for successful transboundary cooperation in an era of climate change (Schmeier *et al.*, 2018).

CONCLUSION

This paper established that climate change is irrefutable and significantly impacts water and food security in South Africa. There is all indication that climate change has altered the hydrological cycle, temperature balance and rainfall patterns across South Africa over the past fifty years. Higher temperatures, changes in precipitation trends and increased variability will be key physical challenges to the population's well-being. The amalgamation of climate change, population growth, and consumption vicissitudes are projected to significantly impact agriculture production and the hydrological cycle in the next fifty years. Consequently, the pressure will increase on the water and food security across the country if unrestrained the adverse effect of climate change on water resources across the country is likely to translate into food and nutritional deficits, health and economic deterioration, and poverty exacerbation. Furthermore, climate change is projected to contribute negatively to water and food availability, stability, access, utilisation, and demand in most provinces. This will lead to immense disruption of livelihoods, increase poverty, marginalise the poor and escalate inequality.

In light of these foreseeable challenges, this paper recommends a multi-disciplinary and comprehensive approach that must incorporate policymakers, researchers, practitioners and public and private sectors to devise realistic and practical adaptation and mitigation strategies in South Africa. Such strategies must be tailored to each province's specific biophysical and socio-economic conditions. Furthermore, South Africa and the rest of the continent should strengthen their leadership responsibilities in programmes of climate-water-food agenda, and combat climate change together using global mitigation strategies that seek to minimise greenhouse gas emissions to prevent long-term negative impact on the region the country. As part of the mitigation strategies, this paper recommends an increase in investments in access to cleaner energy, water infrastructure and an agro-friendly environment, especially in rural communities, to enable them to build economic and social resilience to respond to climate and water disasters and to convert climate and water and food-related constraints into an opportunity for human development and economic growth in the country.

Conflict of Interest

The authors of this paper declared that there is no conflict of interest in writing this manuscript.

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