Projected Impacts of Climate Change on Water Resource Availability in South Africa's Major River Basins: A Multi-Model Assessment

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Abstract**—**South Africa ranks among the driest countries in the world, receiving an average of only 464 millimetres of rainfall per year, which is less than half the global average. Climate change is deepening this structural water deficit. Temperatures across the country are climbing, and rainfall has become increasingly unpredictable. Three of the country's most important river systems, namely the Orange, the Limpopo, and the Vaal, are now under measurable and growing stress. This article draws on existing multi-model climate projections and peer-reviewed empirical studies to assess the likely trajectory of water availability across these basins. The evidence consistently points toward reduced streamflow, more prolonged droughts, and a widening gap between water supply and the growing demands of agriculture and urban populations. Without immediate policy intervention, infrastructure investment, and the diversification of water sources, South Africa faces a severe and worsening water crisis by 2030 and beyond.

Index Terms**—***Climate change, water security, South Africa, Orange River, Limpopo Basin, Vaal River, drought, streamflow, water scarcity.*

I. INTRODUCTION

Water underpins every dimension of human and ecological life. It feeds crops, sustains cities, drives industries, and supports ecosystems. Yet across the world, freshwater is increasingly difficult to secure, and South Africa sits at the sharp end of this global challenge. The country is formally classified as water-scarce. Less than 9% of its annual rainfall flows into rivers, and less than 5% percolates into groundwater reserves [25]. These figures leave virtually no buffer when rainfall declines or temperatures rise.

Climate change is not a projected threat for South Africa; it is an unfolding reality. Average temperatures have already risen across all major regions. Rainfall has grown more erratic and, in several areas, more infrequent. Droughts that once occurred once a decade are now arriving with greater regularity. These shifts are placing acute pressure on the three river systems that matter most to the country's water future: the Orange River, which runs across the south and west; the Limpopo River, which defines the northern boundary; and the Vaal River system, which lies at the heart of South Africa's economic and industrial core.

This article examines how rising temperatures and changing rainfall patterns are affecting, and are projected to affect, water availability across these three basins. It draws on peer-reviewed studies and multi-model climate projections to evaluate the consequences for agriculture and urban water supply, and considers what adaptation options are currently being pursued or proposed.

II. SOUTH AFRICA'S CLIMATE: CURRENT TRENDS AND FUTURE PROJECTIONS

A. Temperature

South Africa's temperatures are rising at a pace that exceeds the global average. Under a high-emissions pathway, scientific models project a temperature increase of as much as 2.1°C by 2050, while a low-carbon pathway could limit this to 1.2°C [6]. Warming is not uniform across the country. Inland areas are expected to warm more sharply than coastal zones, with projections suggesting increases of 1.5°C along the coast and between 2°C and 3°C further inland by mid-century. Under the most optimistic scenario, the likely temperature increase still falls in the range of 1.5°C to 2.0°C by 2050 [22].

These temperature increases carry direct hydrological consequences. Higher ambient temperatures accelerate evaporation from soils, open reservoirs, and vegetation. A study examining extreme temperature events in major South African cities confirmed the relationship clearly: elevated temperatures intensify both evaporation from water bodies and transpiration from plants, together reducing the moisture available in soils and diminishing flows in rivers [11].

B. Rainfall

Across the western and south-western parts of the country, the signal is clear: rainfall is declining. The south-western region could experience annual rainfall reductions exceeding 40 millimetres per year (South African National Climate Change Information System [4]. The Western Cape in particular faces an extended dry season and warmer conditions, while some areas in the north-east may see marginal increases in rainfall.

These projections are not merely modelled futures. Observed data from the Olifants River catchment already show declining rainfall and rising temperatures between 1976 and 2019, with the Standardised Precipitation Index (SPI) confirming persistent drought conditions across the period [13]. In Johannesburg, mean annual rainfall is estimated to have declined from 821 millimetres in 1981 to approximately 626 millimetres by 2023, a reduction of close to 200 millimetres over four decades [20].

III. THE THREE MAJOR RIVER BASINS: CONDITIONS AND PROJECTED STRESS

A. The Orange River Basin

The Orange River is the longest in South Africa, rising in the Drakensberg Mountains in the east and flowing westward to the Atlantic Ocean. It is essential to the country's agricultural sector, supports hydropower generation, and provides municipal water to several cities and towns. Despite its importance, there have been long-standing concerns that water in the Orange River Basin has not been managed sustainably, with unsustainable usage patterns traceable at least 25 years back [9].

Climate modelling confirms that the basin faces growing threats. Risks include prolonged droughts, episodes of intense flooding, persistent water stress, and high inter-annual variability in flows [9]. Particularly worrying is the non-linear relationship between rainfall and streamflow that characterises semi-arid basins such as the Orange. A rainfall decreases of 10%, for instance, can produce a streamflow decline of 20% or more [5].

Research on catchments with characteristics similar to the orange basin found that under the higher emissions scenario (RCP8.5), temperatures could rise by 1°C to 4°C and precipitation could fall by 5% to 30% relative to baseline conditions. The resulting decline in streamflow would increase unmet water demand by 58% by mid-century and by as much as 80% by the end of the century [10].

B. The Limpopo River Basin

The Limpopo River Basin spans approximately 416,000 square kilometres across South Africa, Botswana, Mozambique, and Zimbabwe. South Africa accounts for roughly 45% of the basin by area and draws approximately 3,000 million cubic metres of water from it annually, the majority going to irrigation [15]. The basin is already classified as one of the most water-stressed in Africa [15].

Rainfall within the basin is both highly variable and spatially uneven, ranging from as low as 250 millimetres in the dry western and central areas to over 1,050 millimetres in the wetter eastern escarpment zones [7]. Critically, around 95% of this rainfall falls between October and April, concentrated in isolated rain events rather than spread evenly across the season. This makes agricultural planning and water management inherently difficult.

Climate change projections for the basin point toward more frequent droughts and a greater incidence of flooding [15]. Irrigation, which already accounts for 60% of allocated water resources in the South African portion of the basin, faces growing uncertainty as modelled streamflow projections show consistent declines for both the near future (2036 to 2065) and the end of the century (2070 to 2099) [15].

Rural communities in Limpopo Province bear a disproportionate share of these risks. The province has one of the highest proportions of rural inhabitants in South Africa, many of whom rely directly on rain-fed water sources for domestic use and subsistence farming [19]. The 2022 IPCC Sixth Assessment Report confirmed that Southern Africa is likely to experience a sustained decline in water availability as a result of both reduced rainfall and accelerated evapotranspiration driven by warming temperatures [19].

C. The Vaal River System

The Vaal River is the primary water source for Gauteng Province, home to nearly 15 million people and the economic engine of South Africa [25]. The Integrated Vaal River System draws on the Vaal Dam and is supplemented by transfers from Lesotho through the Lesotho Highlands Water Project. This complex supply infrastructure exists because local water resources alone are insufficient for the demand generated by the region’s population and industry.

Recent data illustrate how vulnerable this system has become. In 2024, water levels in the Vaal Reservoir dropped to approximately 35% of total capacity, compared to around 75% in preceding years [26]. During the 2015 to 2016 drought, the dam had already fallen to just 26% of its capacity [12]. By late 2024, levels had again slipped to 34.8% [26]. These fluctuations reflect the increasing frequency and severity of droughts affecting the region as a result of climate change.

Compounding the supply problem is the demand side. Johannesburg residents use approximately 275 litres of water per person per day, a figure roughly 60% above the global average [26]. With demand rising, population growing, and river flows becoming less reliable, the conditions that precipitated Cape Town’s near-crisis in 2018 are increasingly present in Gauteng.

IV. THE CAPE TOWN DAY ZERO CRISIS: A WARNING SIGN

The most extensively documented example of climate-induced urban water failure on the African continent occurred in Cape Town between 2017 and 2018. Three consecutive dry winters from 2015 to 2017 progressively drained the city’s reservoir system. By early 2018, Cape Town, a metropolitan area of approximately 3.7 million people, had come dangerously close to running entirely out of municipal water [3]. Dam storage supplying the city fell to around 20% of total capacity by May 2018 [23].

Research published in the *Proceedings of the National Academy of Sciences* established that human-induced climate change made the 2015 to 2017 rainfall deficit between five and six times more likely to have occurred than it would have been in a pre-industrial climate [23]. Projections from the same study indicate that under a high-emissions scenario, the probability of a similar multi-year rainfall deficit occurring rises to approximately 80% by the end of the 21st century [23].

During the drought, monthly average rainfall across the six major supply dams fell to 45.11 millimetres, representing a 34.5% decline from the pre-drought monthly average recorded between 2008 and 2014 [1]. Residents were restricted to 50 litres per person per day. Through a combination of tariff increases, public information campaigns, and pressure reductions in the network, the city achieved a nearly 54% reduction in per capita water use relative to pre-drought levels [24].

The Day Zero crisis demonstrated unambiguously that climate change is not a future risk to be managed over decades. It is a present and material threat to urban water supply, and the conditions that created Cape Town’s crisis are increasingly visible elsewhere in the country.

V. IMPLICATIONS FOR AGRICULTURE

Agriculture is the dominant user of water in South Africa, accounting for more than 60% of total water consumption nationally [18]. As climate change reduces available surface water and drives up evaporation rates, farmers will require more water to achieve the same crop yields, at precisely the time when less water is available.

Research from UNU-WIDER found that irrigation demand across South Africa is very likely to increase as a direct consequence of rising temperatures and evaporation [18]. Rain-fed agriculture is expected to experience yield declines across many crops, with the most severe projected losses for maize and wheat [18]. Under an unconstrained emissions scenario, median maize yields could decline by roughly 4% to 5% by 2050. A study published in *Environmental Research Letters* confirmed that total national irrigation demand could increase by between 6.5% and 32% by 2090, depending on the emissions pathway.

Smallholder farmers face the steepest risks. They typically lack access to irrigation infrastructure, climate-resilient seed varieties, or the financial resources needed to adapt rapidly to shifting growing conditions [5]. In the Limpopo basin specifically, where agriculture already claims 60% of available water and shares that resource with domestic, mining, and energy users, the prospect of declining streamflow under future climate scenarios raises serious questions about the long-term viability of food production.

VI. URBAN WATER SUPPLY UNDER PRESSURE

South Africa is a rapidly urbanising country. Approximately 68% of its population of 58.8 million people now lives in urban areas [25], and that share is expected to grow. The water systems servicing those urban populations depend overwhelmingly on surface water, primarily rivers and dams, and those systems are showing increasing signs of strain.

South Africa's National Water and Sanitation Master Plan has projected a water supply-demand gap of approximately 17% by 2030 [8]. When the additional impacts of climate change are incorporated, this gap is expected to widen to around 30% [27]. In volumetric terms, this translates to a potential annual water shortfall of between 1.6 billion and 2.7 billion cubic metres by 2030 [21]. Seven out of 13 major water supply systems are projected to be in deficit by 2040, and six out of eight major cities had already imposed water restrictions as of 2022 [21].

The city of Gqeberha, formerly known as Port Elizabeth, is particularly exposed. It has been experiencing severe drought conditions since 2015. In March 2023, total storage in its supply dams was recorded at just 12.7% of capacity, the lowest level at that time of year since 1979 [25]. Without significant investment in alternative water sources and demand management, Gqeberha is at serious risk of becoming the first South African city to experience a full Day Zero shutdown of municipal water supply [25].

VII. ADAPTATION: WHAT IS BEING DONE?

South Africa has begun responding to its water crisis through a combination of demand management, infrastructure investment, and the development of alternative water sources, though the scale of response remains insufficient relative to the scale of the challenge.

Demand management has demonstrated real results. During the Day Zero crisis, Cape Town achieved a reduction in per capita water use of approximately 54% through a combination of restrictions, tariff escalation, and sustained public information campaigns [24]. That achievement is now referenced internationally as a model of urban demand management under extreme conditions. However, it represents an emergency response, not a sustainable management model.

Water reuse is gaining growing policy attention. The Green Climate Fund is supporting the development of a national water reuse programme in South Africa, which aims to transform wastewater into a dependable supplementary water source [8]. Despite this progress, South Africa currently lacks a unified, delivery-focused national water resilience strategy that embeds reuse systematically within long-term planning [17].

Desalination, rainwater harvesting, and managed groundwater extraction are also being explored as supplementary supply options, particularly for coastal cities and regions where surface water is chronically insufficient [16]. These approaches carry higher unit costs than surface water treatment but offer climate-independent supply sources that are not subject to rainfall variability.

Nature-based solutions are playing an emerging role as well. The Greater Cape Town Water Fund funds the removal of invasive alien plants from key catchment areas, increasing the volume of water that reaches rivers and dams at a lower cost than desalination or wastewater recycling [26]. Johannesburg is being encouraged to adopt comparable catchment management strategies for the Vaal basin [26].

Financing remains the central constraint. Meeting South Africa's water security needs through 2050 is estimated to require approximately R7.2 trillion in total investment, equivalent to roughly R256 billion per year [27]. This level of investment requires coordinated commitment from government, the private sector, and international climate finance institutions.

VIII. DISCUSSION

The cumulative picture drawn by this review is one of systemic and growing water insecurity in South Africa, driven by climate change but compounded by structural weaknesses that have little to do with rainfall. Ageing infrastructure, poor local governance, unequal access to water services, population growth, and the absence of a unified national water resilience strategy all amplify the risks that climate change creates.

The three basins examined here illustrate different but interconnected dimensions of this problem. The Orange River faces declining runoff and growing agricultural pressure in an already over-allocated system. The Limpopo basin, one of the most water-stressed transboundary basins in Africa, will face more frequent droughts and declining streamflow at the same time that demand from irrigation, domestic use, and industry is rising. The Vaal system, which supplies the largest concentration of economic activity and population in South Africa, is showing year-on-year deterioration in reservoir levels that makes a major urban water crisis increasingly plausible.

These challenges fall most heavily on the most vulnerable populations. Around 42% of rural households in South Africa lack consistent access to safely managed water and rely on unprotected surface water sources [12]. Climate change will intensify this inequality unless water policy is explicitly designed to reach and protect the communities that are already most exposed. Equity must be a core organising principle of adaptation planning, not an afterthought.

At the same time, the Cape Town experience demonstrates that South Africa has the capacity to respond effectively under pressure. The city's crisis response has attracted international attention and study. The task now is to institutionalise those lessons at a national scale, before the next crisis arrives, rather than in the middle of it.

IX. CONCLUSION

Climate change is not a future risk for South Africa's water sector. It is an active and measurable pressure on the systems that millions of people depend on every day. Temperatures across the country are rising. Rainfall in the western, southern, and central regions is declining. River flows are becoming less predictable and, in many basins, less reliable. The evidence from the Orange, Limpopo, and Vaal basins, taken together, points to a consistent and serious trajectory: water availability is diminishing precisely as demand continues to grow.

South Africa's own National Water and Sanitation Master Plan projects a 17% supply-demand gap by 2030. With climate change factored in, that gap could reach 30%. Agriculture, which uses more than 60% of the country's water and underpins the food security and livelihoods of millions, faces declining yields and rising irrigation costs. Cities, already constrained by ageing infrastructure and high per capita consumption, are approaching conditions that make a Johannesburg or Gqeberha equivalent of Day Zero a realistic rather than theoretical prospect.

Addressing this requires more than technical fixes. It requires sustained investment in infrastructure, serious diversification of water sources, reform of water governance at local and provincial level, and a deliberate focus on protecting the communities most exposed to water insecurity. Climate change is a structural challenge to South Africa's water future, but it is not an insurmountable one. With the right policy priorities, adequate financing, and genuine institutional commitment, adaptation is possible.

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