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AUTHORS:
Surina Esterhuyse[1]
Danita Hohne[1]
Fanus Fourie[2]
Craig Sheridan[3]

AFFILIATIONS:
[1]Centre for Environmental Management, University of the Free State, Bloemfontein, South Africa
[2]Institute for Groundwater Studies, University of the Free State, Bloemfontein, South Africa
[3]Wits: H_2O, School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

CORRESPONDENCE TO:
Surina Esterhuyse

EMAIL:
esterhuyses@ufs.ac.za

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Climate-resilient water supply in South Africa: Bridging science and policy in arid regions

Significance:

In this Commentary, we consider water supply challenges in South Africa's rural arid regions in the face of climate change. Water supply failures stem from both hydrological variability and governance challenges. Climate change and weakness at the science–policy interface increasingly exacerbate these failures. By improving data collection and groundwater governance, institutional coordination and capacity development can be enhanced. To ensure future water security, South Africa must move beyond reactive water management approaches to proactive, adaptive strategies. These strategies include water resource monitoring, scenario planning, investing in resilient infrastructure, climate-informed decision-making and incorporating uncertainty into policy design, especially at the municipal level.

Introduction

South Africa is water-scarce, especially in the western parts of the country. It has a mean annual precipitation of ~460 mm,[1] less than the African average of ~680 mm.[2] The precipitation is widely varied – it ranges from less than 200 mm in the west to more than 1200 mm per annum in the east.[3] This variability is a consequence of its geographical location, complex topography and the contrasting influence of the warm Agulhas Current along the eastern coastline and the cold Benguela Current along the western coastline.[3] Consequently, the west is characterised by dry conditions and the east by much wetter conditions.

A trend of reduced rainfall over the western parts of South Africa has also been observed over a 50-year period.[3] Reduced rainfall may cause prolonged drought conditions, such as the one that caused the 2017–2018 Cape Town water crisis.[4] Global climate cycles may also influence future rainfall patterns. The South African Weather Service has warned that the 2026–2027 El Niño cycle[5] could result in below-normal rainfall and above-normal temperatures, with the potential to become one of the strongest climate events experienced in recent decades[6]. In the semi-arid western parts of the country, which include the Karoo, the profound spatial and temporal rainfall variability exacerbates water scarcity. In the Karoo, the rainfall can be as low as 20 mm per annum. In Williston in the Northern Cape, which had an average annual rainfall of 167 mm until 2015[7], rainfall has since dropped to a low of 50 mm, even during strong La Niña events[8]. In comparison, the eastern half of the country has had an increase in rainfall intensity over the past 50 years, with some of these areas estimated to receive above 400 mm for the 1:50 and 1:100 return period values.[3] Not only is rainfall becoming more intense, but these high-intensity events increase surface runoff and flash-flood risk, placing additional stress on fragile water service infrastructure.

Additionally, population growth and development activities intensify water management and supply challenges across South Africa. South Africa's population has grown from 40.6 million in 1996 to 62 million in 2022, driven by an average annual growth rate of about 1.7%.[9] Development activities that may strain water resources include agriculture, industrial development and mining. The potential water demand for hydraulic fracturing during regional-scale unconventional oil and gas development in the Karoo could also significantly strain scarce water resources.[10] Communities in South Africa (and across Africa) face hydrological, institutional and socio-economic challenges, all of which undermine adaptive capacity. These challenges are not primarily technical; they reflect systemic gaps at the science–policy interface, where knowledge production, governance and implementation remain insufficiently aligned. We argue that strengthening this interface is central towards achieving climate-resilient water management.

Climate change and hydrological variability

Climate change is expected to increase the frequency and severity of droughts in southern Africa, while also intensifying rainfall events.[11,12] Some extreme climate events have been observed in the Karoo: drought followed by flash floods damaged wellfields (Loeriesfontein in 2023) and damaged managed aquifer recharge related infrastructure (Sutherland and Calvinia in 2025). High-intensity rainfall has also reduced aquifer recharge.[8] Additionally, the scarcity of vegetation exacerbates flood-related damage. Vegetation slows overland flow, enhances groundwater recharge and reduces run off volumes. Growing climate variability challenges conventional water resource planning approaches, which rely on assumptions of stationarity. In South Africa's arid and semi-arid environments, such assumptions may no longer apply.

Research across the Karoo has demonstrated that rainfall is often a poor proxy for water availability.[4,12] Surface water systems (including dams and rivers) are over-allocated, while non-perennial rivers are an unreliable water source during drought conditions.[11] Additionally, groundwater, the main water resource during drought conditions in the Karoo, relies on complex recharge processes for its replenishment, including episodic precipitation and preferential flow through fractures. These processes are often associated with substantial lag times between rainfall events and observable groundwater responses.[13,14] These complexities amplify the critical disconnect between climate data, water resources and water resource decision-making at both the local and national government levels.

The South African Department of Water and Sanitation, together with private enterprise, has thus started to explore new methods to manage and safeguard groundwater in water-stressed regions such as the Northern Cape.[8,15] For example, managed aquifer recharge is being used to assist with natural groundwater recharge and thereby augment groundwater resources. We successfully used managed aquifer recharge to enhance groundwater recharge in the rural Karoo towns of Carnarvon, Vanwyksvlei, Williston, Sutherland and Calvinia, where they rely

on groundwater supply, but where natural recharge from rain did not provide sufficient water supply to optimally recharge the aquifer.[8] In a region as dry as the Karoo, a false impression can be created by the weekly reporting of dam storage levels. While the weekly dam levels in the Northern Cape were above 84% capacity as reported in August 2026[16], groundwater-dependent towns such as Williston were running dry. As most Karoo towns depend primarily on groundwater because surface water supplies are unreliable[15,17], provincial dam level statistics can create a misleading impression of water security. Unfortunately, groundwater availability and use data are incomplete. Many boreholes are not registered and abstraction from these boreholes is also often not reported, meaning that the actual volumes of groundwater used could be much higher than the reported volumes.[18] The hidden groundwater crisis usually only becomes visible when the water supply in towns like Beaufort West becomes strained.[19]

Monitoring groundwater use at the municipal level and accurate reporting of groundwater levels need urgent attention to ensure groundwater security. From a policy perspective, this highlights the need to obtain accurate hydrogeological data and effectively integrate these data into water allocation and infrastructure planning frameworks.[18] Without this integration, adaptation strategies risk being based on misleading indicators, potentially further exacerbating water insecurity.

Groundwater dependence and governance

Groundwater is a critical resource for rural water supply in South Africa; it supports domestic use, livestock production and small-scale agriculture. Well over half the population of South Africa relies on groundwater, with 79% of all communities (or about 34.1 million people) in South Africa using groundwater as domestic supply.[10,20,21] This dependence is particularly pronounced in the country's semi-arid regions. Unfortunately, groundwater governance remains a challenge in most rural areas. While the *National Water Act* recognises water as a national resource and promotes integrated water resource management, implementation of the Act remains inconsistent, with significant gaps in groundwater monitoring, data availability and the enforcement of applicable legislation.[20,21]

Several concurrent groundwater governance challenges exist, especially with data collection, transparency and the regulation of subsurface activities. In the context of shale gas development, baseline data collection, well location disclosure and long-term monitoring to safeguard aquifers are necessary and emphasised.[22] For groundwater abstraction, data on the location and abstraction from boreholes are under-reported and poorly recorded. The proposed regulations for governing groundwater[23] aim to address these data gaps. To protect water resources during oil and gas extraction, regulations governing hydraulic fracturing for gas (fracking) are being developed.[24–26] Global geopolitics and the consequent energy supply shocks may result in renewed interest in fracking in South Africa.[27]

At municipal level, groundwater is governed by water bylaws. Bylaws have also been used by smaller municipalities to govern water use in dry areas (e.g. Calvinia and Beaufort West) through, for example, the implementation of tiered structure tariffs for higher water use volumes.[28] Fragmented governance, weak institutional coordination, limited technical capacity, inadequate monitoring and poor integration of scientific evidence into planning and regulatory decision-making constrain the implementation of groundwater policy.[20] Addressing these challenges is essential for sustainable groundwater management.

Infrastructure, service delivery and institutional capacity

Ageing infrastructure, financial constraints and capacity deficits at the municipal level constrain water service delivery in rural South Africa.[28,29] Many municipal water supply systems experience high levels of non-revenue water, intermittent supply and inadequate maintenance; 38% of municipalities are rated as high risk or critical in terms of the No Drop assessment for 2026.[30] While climate change exacerbates these challenges in the Karoo by increasing water demand (due to rising temperatures) and reducing water supply reliability[4], the core issue is not only physical infrastructure but also includes institutional capacity[31]. Municipalities often lack the technical expertise required to manage complex water supply systems under conditions of uncertainty.[32] In contrast, municipalities with dedicated groundwater management staff are better able to meet water demand.[33]

To address groundwater supply challenges in municipalities with limited skills and funding, such as in the Karoo, small-scale managed aquifer recharge systems that enhance groundwater recharge have been implemented. They have specifically been designed as low-cost and low-maintenance systems.[8] In several Karoo towns, gabions and check dams are used to slow run off and enhance natural groundwater recharge. Where low-permeability clay layers restrict infiltration, boreholes have been drilled through these layers to improve recharge using only natural rainfall, supported by monitoring boreholes to assess system performance. As no wastewater infiltration or artificial injection is used, these systems require minimal treatment and engineering. Ideally, these schemes should be developed before droughts occur to ensure aquifers are optimally recharged. Other low-cost interventions suitable for municipalities with limited technical capacity include basic groundwater level monitoring, routine borehole maintenance, wellfield protection from contamination and sustainable groundwater abstraction to reduce borehole failure and improve long-term water security.[33] Protecting existing wellfields from over-abstraction and contamination is far cheaper than developing new wellfields.

Climate change and associated flooding during intense rainfall events also damage physical infrastructure.[34] This places financial stress on municipalities and also poses serious risks to surface and groundwater quality as untreated sewage can enter the water resource, often for long periods whilst repairs are conducted.[35] Water quality is also of increasing concern in South Africa, especially in rural areas. Pollution from poor sanitation practices caused by inadequate or overloaded infrastructure and poor service delivery in rural municipalities is a regular occurrence and, for example, has caused typhoid and diphtheria outbreaks in Beaufort-West.[36] The 2025 Green Drop report[37] indicates that 47% of audited systems are in a critical state, while only 14 systems nationally achieved Green Drop certification. Agricultural run off and mining activities pose additional risks to rural water resources.

The municipal infrastructure and service delivery challenges have important implications for climate adaptation. While national policies emphasise resilience and sustainability, local implementation is frequently constrained by skills shortages and governance weaknesses, including limited institutional capacity, insufficient financial resources, weak planning, limited monitoring data, and ageing and poorly maintained infrastructure. Bridging this gap requires targeted investment in capacity building, as well as stronger linkages between research institutions and local government. From a policy perspective, these implementation challenges underscore the importance of precautionary approaches and robust regulatory frameworks, andhighlight the need for transparent data sharing and public participation in decision-making processes.

Improving data to strengthen the science–policy interface

A central argument of this paper is that many of the challenges outlined above are rooted in poor monitoring and the limited availability of accurate data, which cause weaknesses at the science–policy interface. While South Africa has a strong scientific community and a progressive policy framework, accurate groundwater use data[18] and the translation of knowledge into practice are often limited.

Key aspects that must be addressed to improve knowledge and strengthen governance include[38,39:]

- improving the availability of accurate data to make informed decisions;
- using the best available groundwater and climate data to improve water supply resilience in cases where accurate data are limited;
- reducing fragmentation across data systems and increasing access to information;
- improving institutional coordination across sectors (government, NGOs and private sector) and scales (between government departments at local and national levels);

- improving engagement between researchers and policymakers; and
- addressing capacity constraints at local government level.

Addressing these barriers within South African municipalities requires a deliberate focus on monitoring, data archiving and knowledge co-production, where scientists, policymakers and communities collaborate to develop context-specific solutions that strengthen hydrological outcomes and improve water security. South Africa must move beyond reactive approaches to water management towards proactive, adaptive water governance. This includes incorporating climate projections into water resource planning, applying scenario-based decision-making, accounting for hydrological uncertainty and adopting flexible management approaches that enhance the resilience of water supply systems, groundwater resources and aquatic ecosystems. For example, the long-term adaptation scenarios research programme developed water resource management adaptation scenarios for South Africa under plausible climate conditions for the short, medium and long term.[40] This project recommends specific governance, development and management actions to buffer against projected climate change outcomes.

Towards climate-resilient rural water systems

Building climate-resilient water resource systems in rural South Africa requires an approach integrating science, policy and practice. Key priorities for ensuring this integration include:

- **improving groundwater governance**, including monitoring, data transparency and regulation;
- **investing in resilient infrastructure**, focusing on maintenance and life-cycle management;
- **strengthening institutional capacity**, particularly at municipal level;
- **enhancing water quality monitoring** and establishing baseline data sets;
- **promoting community-based adaptation**, including local water management initiatives; and
- **integrating climate information** into water planning and decision-making, especially at local municipal level.

Stronger linkages between research and policy must support these actions. These linkages include mechanisms for translating scientific findings into policy-relevant formats, as well as platforms for ongoing stakeholder dialogue.

Conclusion

Water resource management in South Africa has reached a critical juncture. Climate change, population growth and development are exacerbating existing water supply challenges, particularly in vulnerable arid regions such as the Karoo. Despite a robust policy framework, South Africa continues to face challenges related to data gaps, the effective translation of scientific evidence into policy, and weak institutional coordination and implementation.

The Department of Water and Sanitation should establish a climate-resilient water governance model that prioritises the collection of critical data, integrates scientific evidence into decision-making and strengthens municipal capacity. A practical opportunity to achieve this is through the newly established National Water Action Plan, which must assist in the implementation of the National Water Resource Strategy (NWRS-3). The National Water Action Plan aims to develop a focused, programmatic series of actions to ensure a reliable supply of good quality water to all South Africans, and to address the root causes of the water supply challenges in many municipalities. Achieving this would shift South Africa's water sector from sound policy development to effective implementation, thereby strengthening long-term water security under a changing climate.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. All authors read and approved the final version.

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