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Water security and livelihoods in the arid zones of South Africa: a human geography approach to rural education and curriculum development

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Water insecurity poses a critical threat to livelihoods in South Africa's arid zones, where rural communities are increasingly vulnerable to hydrological stress, ecological degradation, and socio-economic marginalization. Despite the urgency of the issue, scholarly engagement that bridges water security with rural development education through a human geography perspective remains underexplored. Also, inadequate integration of local ecological knowledge and community-driven water management strategies into formal education systems undermines both resilience and innovation in rural development initiatives. This study conducts a systematic literature review of policy papers and peer-reviewed articles drawn from Scopus and Web of Science databases to investigate the nexus between water security and livelihoods in South Africa's arid regions, with a focus on its pedagogical relevance to rural education development. Guided by the Sustainable Livelihoods Framework (SLF), the findings reveal that water scarcity is a deeply social and spatial condition shaped by historical land dispossession, poor infrastructure, climate variability, and fragmented governance, hence, the urgent need to recalibrate rural education curricula to incorporate interdisciplinary, context-specific knowledge on water governance, environmental justice, and sustainable livelihoods. This study recommends a transformative educational model that embeds water security into human geography, environmental science, and rural development programs, which prioritizes experiential learning, participatory research, and transdisciplinary partnerships to foster water-literate graduates and empowered rural citizens. Hence, this study reimagines education as a tool for adaptation, equity, and charts a new course for integrating water justice into the heart of rural transformation in South Africa's arid landscapes.

KEYWORDS

arid regions, water security, sustainable livelihoods, rural education, human geography

1 Introduction

In the arid landscapes of South Africa, water is more than a physical resource, it is a powerful determinant of life, livelihoods, and local development (Mabhaudhi et al., 2019). For the rural communities inhabiting these drylands, access to water shapes every aspect of existence, from the productivity of smallholder farms and the viability of local economies to the health and education of the population (Masunungure and Shackleton, 2018). Yet, water insecurity remains a persistent and multi-dimensional challenge, exacerbated by climate

change, historical inequalities, mismanagement, and environmental degradation (Adeyeye et al., 2020). These dynamics, in turn, perpetuate rural poverty, hinder socio-economic advancement, and weaken the resilience of communities that are already on the margins of development (Strauch et al., 2021). Against this backdrop, there is a growing imperative to understand and address water security not simply as a technical or environmental issue, but as a deeply human and geographical concern, one that is intimately tied to rural transformation and the broader goals of sustainable education and empowerment. Despite the abundance of global discourse on water scarcity and rural vulnerability, there remains a striking disconnect between academic knowledge production, policy implementation, and community-based practices. Even more concerning is the minimal integration of water literacy, environmental justice, and local ecological knowledge into rural education systems, especially within historically disadvantaged areas (Dile et al., 2013). This disconnect has created a knowledge gap that hinders effective, participatory responses to water insecurity (Leal Filho et al., 2022), and limits the transformative power of education in rural spaces (Adeyeye et al., 2020). It is on this premise that this study explores the complex interplay between water security and livelihoods in South Africa's arid zones through the perspective of human geography, with a particular focus on its implications for rural development education. By conducting a systematic literature review (SLR), this study interrogates the extent to which water-related research in South Africa's arid zones speaks to the educational needs and lived realities of rural populations. Rooted in the theoretical frameworks of human-environment interaction and the Sustainable Livelihoods Framework (SLF) and the Place-Based Education Theory (PBET), this work draws on insights from geography, environmental science, rural sociology, and education studies. It seeks to highlight how place-based knowledge and human agency are central to the co-production of water resilience strategies, and how these can be harnessed to reimagine rural education as a driver of social change. At its core, this research champions the notion that education in rural South Africa must evolve beyond abstract theory and urban-centric models. Instead, it must embrace the rich complexity of rural life, foregrounding the real challenges and opportunities that water security presents. Education that is grounded in environmental justice, local context, and interdisciplinary inquiry can empower rural learners (Dimick, 2012), elevate community voices, and catalyze development that is not only sustainable, but also inclusive and just (Wu et al., 2022). In responding to the urgent call for rural transformation, this study underscores the vital role of Higher Education Institutions in shaping the next generation of water-literate citizens, researchers, and policymakers. It argues for a radical rethinking of how knowledge about water and livelihoods is produced, shared, and embedded into curricula that are attuned to the spatial realities of South Africa's arid zones. In doing so, this study not only contributes to the discourse on rural development and water governance but also offers a blueprint for educational reform that places human geography at the heart of rural sustainability.

1.1 Statement of the research problem

According to Goswami and Bisht (2017) and Kosolapova et al. (2017), water is one of the most vital resources for human survival and socio-economic development, yet in South Africa's arid zones, its

scarcity has evolved from an environmental issue into a multidimensional crisis with far-reaching implications (O'Connell, 2017). These regions, characterized by low rainfall, fragile ecosystems, and limited infrastructure are home to some of the country's most vulnerable rural populations (Mwendera and Atyosi, 2018). Here, the struggle for water is not just about quenching thirst or irrigating fields; it is about sustaining livelihoods (Bortolini et al., 2018), preventing migration, maintaining dignity (Priyan, 2021), and fostering long-term development (El-Rawy et al., 2023). Despite decades of interventions, the communities in these drylands continue to grapple with unreliable access to clean water, fluctuating agricultural productivity, and limited institutional support (Mabhaudhi et al., 2019). This persistent water insecurity has deepened existing inequalities and stalled the progress of rural transformation initiatives (Xia et al., 2017; Nhamo et al., 2022), making it increasingly urgent to revisit the problem through a more human-centered and geography-informed perspective. What complicates this crisis further is the evident disconnect between knowledge production, policy design, and the lived realities of rural communities (Schwabe et al., 2015). Much of the existing research on water security in South Africa is dominated by technical, engineering, or environmental science paradigms (Meissner, 2016; Steyn et al., 2019) that often overlook the social, spatial, and educational dimensions of the problem (Workman and Ureksoy, 2017). As a result, local voices are underrepresented, indigenous knowledge systems are sidelined, and rural learners are frequently excluded from meaningful engagement with water governance issues (Nhemachena et al., 2020). This has serious consequences for rural education development (Hosea and Khalema, 2020). In many rural schools and higher education institutions, curricula remain detached from the pressing environmental and livelihood challenges faced by the communities they are meant to serve (Geere and Cortobius, 2017; Nhemachena et al., 2020). As opined by Mwendera and Atyosi (2018); McLoughlin et al. (2021), opportunities to empower learners with relevant, context-based knowledge about water security, sustainability, and local resilience strategies are missed, thus stalling not only education but also the broader goals of rural transformation. The central problem, therefore, lies in the failure to integrate human geography, water security, and education into a cohesive framework that can inform both policy and pedagogy (Walshe, 2017; Anthonj, 2021). There is a need to critically examine how research and education systems can bridge the gap between environmental realities and developmental aspirations in South Africa's arid zones (Shackleton et al., 2015; Angelstam et al., 2017). Without addressing the spatial injustices and educational disparities that underpin water insecurity, efforts toward rural transformation will remain fragmented and ineffective (Truelove, 2019). This study responds to that need by interrogating the literature through a human geography perspective and advocating for an educational paradigm that connects water security directly to rural development, community empowerment, and social justice.

1.2 Theoretical framework

This study is grounded in interdisciplinary theoretical frameworks that draw primarily from human geography, the Sustainable Livelihoods Framework (SLF), and Place-Based Education Theory. These frameworks collectively conceptualize an understanding of the

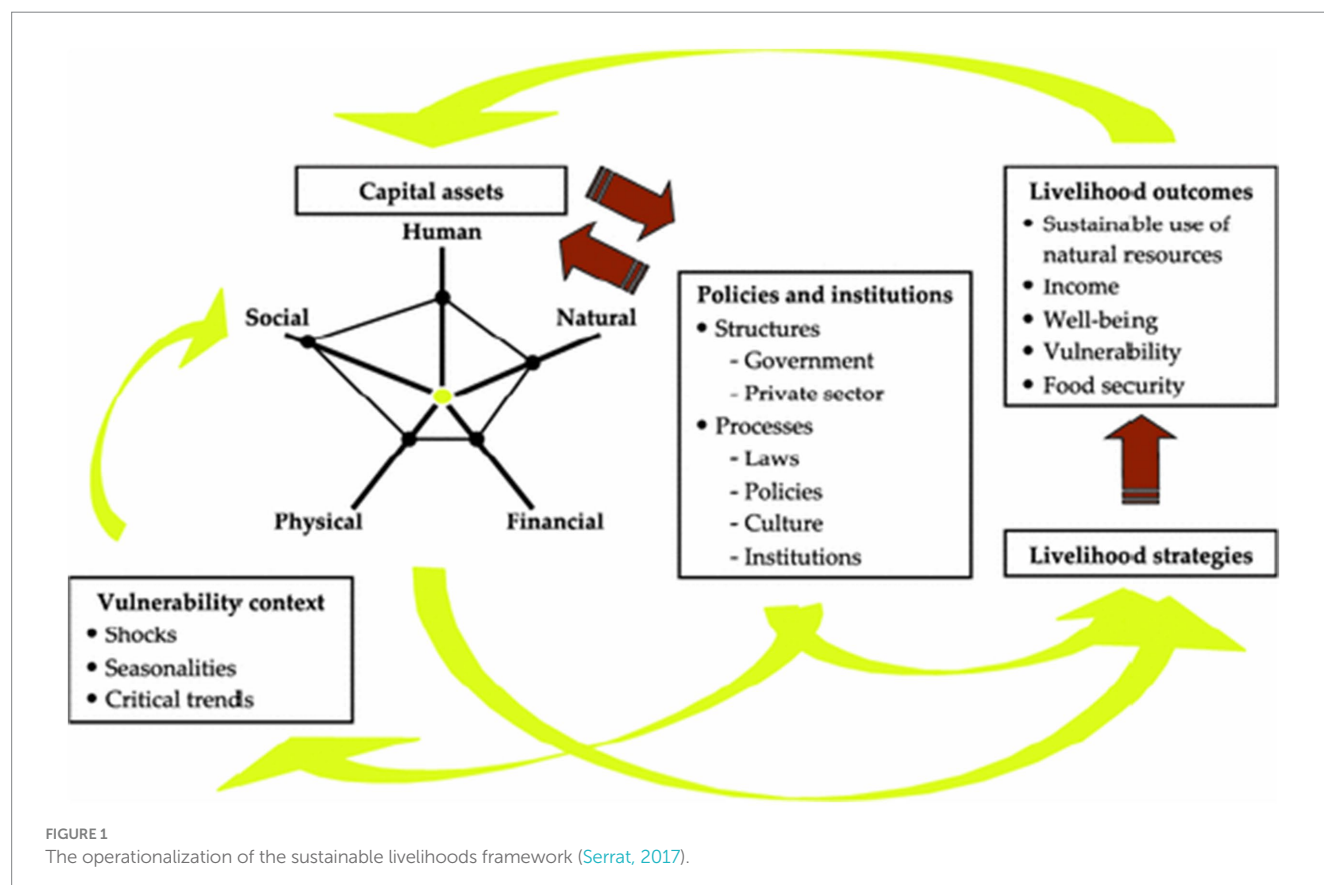
spatial, social, and educational dynamics of water security and rural livelihoods in South Africa's arid zones. They also support a critical interrogation of how education systems and curricula can be reoriented to empower rural learners and drive sustainable development. SLF is a framework for understanding and improving people's lives, particularly those experiencing poverty and vulnerability. It focuses on how people build and maintain their livelihoods by utilizing various assets and strategies, and it emphasizes the importance of considering the broader context of vulnerability, policies, and institutions.

1.2.1 Sustainable livelihoods framework

According to Pandey et al. (2017), Natarajan et al. (2022) and Serrat (2017) the SLF aims to promote sustainable and equitable development by empowering individuals and communities to build on their strengths and resources. In the context of this study, human geography offers a valuable platform for analyzing how environmental stressors like water scarcity are not only shaped by natural processes but also by political, historical, and educational forces. As opined by Saxena et al. (2016), SLF emphasizes the role of space and place in shaping human experiences, an essential insight when considering how rural communities perceive, respond to, and are impacted by water insecurity. This spatial perspective highlights how rural arid zones are often excluded from mainstream development narratives and educational priorities (Bizikova et al., 2015; Rao et al., 2019), reinforcing structural marginalization (Davis, 2016). The SLF complements this by focusing on the assets, strategies, and institutions that rural households draw upon to sustain their livelihoods.

Furthermore, Jackson (2021) and Dube and Chatterjee (2022) narrated that the SLF acknowledges that access to water, land, knowledge, and social capital are crucial for building resilience and reducing vulnerability. In the South African arid zone context, water is both a livelihood asset and a stressor (Connolly-Boutin and Smit, 2016; Mabhaudhi et al., 2019). The SLF underscores the importance of participatory and context-specific interventions, suggesting that solutions to water insecurity must be co-created with local communities (Dube and Chatterjee, 2022; Natarajan et al., 2022). This aligns with educational goals that prioritize critical thinking, community engagement, and empowerment. Thus, the SLF reinforces the need for a curriculum that teaches rural learners not just about environmental challenges, but how to navigate and transform them using locally relevant strategies. Figure 1 depicts the SLF.

As presented in Figure 1, The SLF is composed of five interrelated components namely Vulnerability Context, and this includes external factors such as Shocks (e.g., droughts, floods), Seasonal variations (e.g., rainfall patterns), Critical trends (e.g., climate change, population growth), These affect the livelihoods of rural communities, especially in arid regions where water is scarce. Capital Assets are the resources people use to build their livelihoods, and they include Human Capital—skills, knowledge, education, health, Social Capital—networks, relationships, social claims, Natural Capital—land, water, biodiversity, Physical Capital—infrastructure, tools, shelter, Financial Capital such as savings, income, access to credit. The central pentagon visually emphasizes the interconnectedness and relative strength/weakness of each asset. Policies, Institutions, and Processes (PIPs) influence how assets can be accessed, used, and converted into



outcomes. They include Structures—government, private sector, NGOs, Processes—laws, policies, social norms, institutions. These are the decisions and activities that households undertake to survive and improve their lives, e.g., farming, trading, migration, water conservation, or community water-sharing practices. Livelihood Outcomes include both positive and negative outcomes such as increased income, improved wellbeing, Sustainable natural resource use, reduced vulnerability, enhanced food security, while the yellow arrows show the dynamic, iterative relationships among these components.

1.2.1.1 Application of SLF to the study

In South Africa's arid rural zones, the vulnerability context is shaped by persistent droughts, erratic rainfall, and the broader effects of climate change (Nyam et al., 2020). These shocks severely impact natural capital, particularly water, which in turn affects agricultural productivity, food security, and overall wellbeing (Gibbens and Schoeman, 2020). Households with weak human capital (e.g., limited education on water conservation or sustainable agriculture) and low financial capital are less able to respond to these shocks (Connolly-Boutin and Smit, 2016). In many of these areas, inadequate infrastructure (physical capital) and weak institutional support further constrain sustainable livelihood strategies (Rao et al., 2019). The policy and institutional environment, especially the integration (or lack thereof) of water issues into development planning and rural education plays a crucial role (Steyn et al., 2019). When policies are disconnected from the real spatial challenges people face, such as water scarcity, they fail to support adaptive strategies (Nhamo et al., 2022). Moreover, the absence of water-related knowledge in school and university curricula undermines the ability of rural learners to engage meaningfully in community resilience efforts (Mwendera and Atyosi, 2018). According to Scoones (2015), Rieckmann (2018) and Natarajan et al. (2022), the applications of SLF in rural education and curriculum development can be transformed by focusing on:

Human Capital Enhancement: Incorporating place-based education that teaches students about local water systems, indigenous water management practices, and environmental stewardship.

Natural Capital Awareness: Encouraging water literacy and sustainability education that empowers learners to contribute to community water solutions.

Policy Literacy: Educating students about laws and institutions that affect water governance, enabling them to participate actively in civic life and local planning.

Livelihood Strategy Training: Equipping learners with practical, adaptable livelihood skills, such as permaculture, rainwater harvesting, and entrepreneurship—that directly respond to water-related challenges. In this way, the SLF supports a vision of education as a tool for rural transformation, where schools and Higher Education Institutions (HEIs) in arid zones become centers for local innovation, resilience, and empowerment.

1.2.2 Place-based education theory

According to Deringer (2017), Semken et al. (2017) and Smith (2017), PBET is an educational approach that focuses on connecting learners to their local environments, cultures, and communities. Rooted in the belief that knowledge is most meaningful when it is anchored in real-world experiences, PBE emphasizes the importance of local contexts in shaping both learning and community

development (Thornton et al., 2021). In study, the application of the PBET offers a transformative strategy to address water insecurity, promote sustainable livelihoods, and empower rural communities through a deeper understanding of their immediate surroundings.

1.2.2.1 Application of the PBET to the study

Integrating Water Security into Local Contexts: In the arid zones of South Africa, the physical and environmental context plays a central role in shaping the daily lives of residents. Water scarcity is not an abstract, global issue but a local challenge that directly affects food production, health, and social stability. Place-Based Education enables students, whether they are schoolchildren or adult learners, to engage directly with the water systems around them (Cincera et al., 2019). Instead of learning about water conservation in distant, hypothetical scenarios, learners can explore the local rivers, boreholes, and water sources that sustain their communities. This hands-on approach allows them to observe firsthand the impacts of water scarcity and to understand the dynamics of their local ecosystems. For example, learners can participate in field studies to monitor the quality and quantity of local water resources, work alongside local water managers to understand the infrastructure challenges, or collaborate with environmental NGOs to assess the sustainability of water usage. By tying education to their local environment, learners not only gain critical knowledge about water systems but also develop a deep sense of ownership and responsibility toward those resources. The practical experience of working with water resources fosters problem-solving skills, enhances their understanding of the socio-economic factors influencing water security, and equips them with tangible skills to manage and protect these resources.

Empowering Communities through Collaborative Learning: PBET also emphasizes community engagement and collaboration, making it an ideal framework for addressing water security in rural arid zones. In these areas, communities often face challenges such as insufficient infrastructure, limited access to clean water, and a lack of representation in policy decisions. PBE recognizes that sustainable solutions to complex problems like water insecurity must involve the active participation of the local community. By bringing together learners, local leaders, water experts, and educators, PBE encourages collective problem-solving and decision-making. One practical application could involve organizing local workshops or community forums where students and community members come together to discuss water management strategies. These events could focus on exploring traditional water practices, sharing knowledge on water conservation techniques, or brainstorming innovative approaches to local water challenges. For example, a community in an arid zone might develop a water recycling initiative or a rainwater harvesting system that is tailored to the unique needs and capabilities of the area. By engaging learners directly in these processes, PBE not only addresses immediate water security concerns but also builds a strong sense of community ownership and responsibility for local environmental issues.

Building Local Knowledge Systems: PBET also aligns with the concept of recognizing and valuing local knowledge systems. In the arid zones of South Africa, rural communities often possess rich, place-based knowledge about water management, drawn from generations of experience in living with water scarcity. However, this traditional knowledge is frequently underappreciated or overlooked in formal education and policymaking. Hence, PBET helps in

integrating this indigenous knowledge into the curriculum, thereby bridging the gap between modern scientific approaches to water management and traditional, community-based practices. Learners can be encouraged to research and document local water-related traditions, such as indigenous irrigation methods, natural filtration techniques, or culturally significant water sources. Through collaborative projects, students can compare these traditional methods with contemporary, scientific water management strategies, fostering a more holistic understanding of water security that draws from both local wisdom and global knowledge.

Promoting Sustainability and Social Justice: PBET's emphasis on sustainability and social justice aligns directly with the core values of rural development education, particularly in addressing water security in South Africa's arid zones. Water insecurity disproportionately affects marginalized groups, including women, children, and the elderly, who often bear the brunt of water collection duties and face the greatest risks from waterborne diseases. PBET provides a platform for learners to explore these issues of equity and justice, challenging them to think critically about the socio-political dynamics that shape water access and management in their communities. In a nutshell, incorporating these themes into educational initiatives can foster a generation of learners who are not only informed about the challenges of water insecurity but are also motivated to advocate for more equitable solutions. For example, students could work with local governments and non-governmental organizations to create educational campaigns that raise awareness about gender inequalities in water access or advocate for more inclusive water policies that address the needs of vulnerable populations. Through such initiatives, PBE can play a pivotal role in driving social change and promoting greater inclusivity in the management of natural resources.

Fostering Innovation and Adaptive Solutions: PBET also encourages innovation by challenging learners to think creatively about solving local challenges. In the context of water security, learners can explore cutting-edge water management technologies that are

adaptable to arid environments, such as solar-powered desalination systems, drought-resistant crops, or low-cost water filtration methods. By encouraging students to design, test, and implement these solutions in their local context, PBET empowers them to become agents of change, equipped with both the knowledge and the practical skills needed to address water security. For instance, students could be tasked with developing a sustainable water use plan for their community that includes both modern technologies and traditional water-saving methods. This approach not only teaches students about the science of water management but also encourages them to think critically about how to apply these concepts in ways that are culturally and environmentally appropriate for their specific community. Hence, PBET creates a foundation for sustainable water management that is both practical and innovative. In doing so, it ensures that learners not only acquire knowledge but also develop the skills, attitudes, and sense of responsibility needed to contribute to the long-term well-being of their communities and the protection of their natural resources. Through this holistic approach, Place-Based Education can play a pivotal role in addressing water security challenges and promoting rural development in South Africa's arid regions. [Figure 2](#) depicts the PBET.

2 Methods

This study adopted a systematic literature review (SLR) methodology, which is particularly well-suited for synthesizing existing knowledge, identifying research gaps, and drawing evidence-based conclusions in complex, interdisciplinary fields such as water security, rural livelihoods, and geography-informed education. The SLR approach allowed for a structured and replicable process of gathering, evaluating, and synthesizing peer-reviewed literature relevant to the relationship between water security and rural development in the arid zones of South Africa. It also facilitated a critical analysis of the intersection

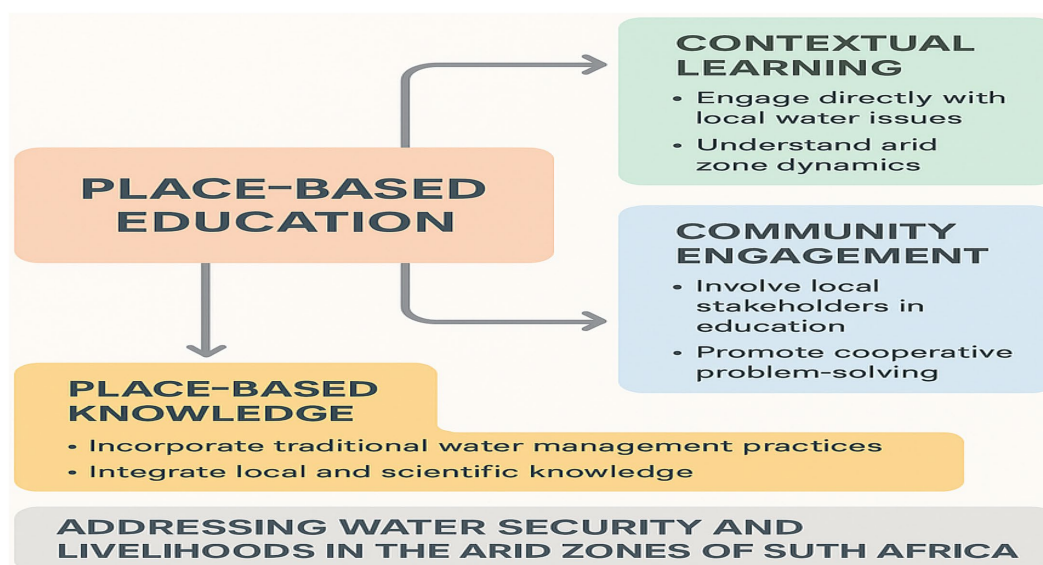


FIGURE 2

Empowering rural resilience: how place-based education bridges learning and water security in South Africa's arid zones.

between environmental geography, livelihood strategies, and educational practices in rural contexts that were derived from academic databases including Scopus, Web of Science, JSTOR, ScienceDirect, and African Journals Online (AJOL) were systematically searched using a combination of key terms such as “water security,” “arid zones,” “South Africa,” “rural livelihoods,” “human geography,” “environmental education,” and “rural development.” The search was limited to studies published in English between 2010 and 2024 to capture contemporary debates and the most recent policy-relevant insights. Data extraction was performed using a thematic analysis approach, identifying recurring themes, theoretical framings, and policy recommendations across the selected studies. The analysis was both descriptive and interpretive, emphasizing the spatial dimensions of water insecurity and the role of knowledge systems in shaping rural responses to environmental stressors. This methodology draws from a rich and diverse pool of interdisciplinary literature, thus offering a comprehensive and human-centered account of how water, geography, and education intersect to influence the pathways of rural development and community resilience.

2.1 The study area: South Africa’s arid zones in focus

South Africa, a dynamic and rapidly developing nation, lies between latitudes 30.5595° S and longitudes 22.9375° E. Soaring to a maximum elevation of 3,370 meters (11,0450 feet) above sea level, the country is home to an estimated population of 60.6 million people (StatsSA, 2021). Spanning an impressive 1,221,037 km² (471,445 square miles), it boasts a coastline stretching 2,798 km along the captivating shores of the South Atlantic and Indian Oceans (SANBI, 2020). Geopolitically, South Africa shares its borders with six neighboring nations: Zimbabwe, Botswana, Lesotho, Namibia, Mozambique, and Eswatini. Administratively, the country is divided into nine distinctive provinces, Northern Cape, Free State, Western Cape, Limpopo, KwaZulu-Natal, Northwest, Eastern Cape, Mpumalanga, and Gauteng, with each province contributing uniquely to the nation’s cultural mosaic and geographical diversity (Forssman, 2022). Climatically, South Africa is a land of contrasts. The country encompasses three primary climate zones: arid deserts, humid subtropical regions with seasonal dry winters, and dry subtropical zones characterized by sweltering summers. Temperatures typically range from a monthly average of 11–22°C, while the nation’s annual rainfall averages around 469.9 mm. The rainy season peaks from November to March, while the driest months fall between June and August (Mbokodo et al., 2023).

Regional climatic differences are particularly pronounced: the eastern corridors experience a subtropical wet climate marked by lush vegetation, high humidity, and temperate winters. In contrast, the northern interior regions endure a subtropical dry climate defined by intense summer heat and sporadic rainfall (Mahlalela et al., 2020). These diverse environmental conditions not only shape South Africa’s agricultural and ecological dynamics but also frame the complex realities of water availability and rural livelihoods, central concerns in addressing sustainable development and rural education transformation in the country’s most vulnerable zones.

South Africa presents a unique and complex geographical landscape characterized by stark environmental contrasts, from lush subtropical coasts to semi-arid and arid interior regions. Approximately two-thirds of South Africa’s land surface is classified as arid or semi-arid, receiving

less than 500 mm of rainfall per year. These areas, including significant parts of the Northern Cape, Western Cape interior, Eastern Cape Karoo, and parts of Limpopo and Northwest Provinces, are among the most vulnerable to water scarcity, climate variability, and ecological degradation. The arid zones are not only ecologically sensitive but also socially and economically marginalized, with high poverty rates, limited infrastructure, and constrained access to quality education and basic services. In these regions, water security is both a developmental imperative and a daily struggle. The scarcity of reliable water sources, compounded by over-reliance on rain-fed agriculture, puts immense pressure on rural livelihoods. The effects of climate change, such as more frequent droughts and unpredictable rainfall patterns further exacerbate the vulnerability of communities whose livelihoods depend directly on natural resources. Many rural households engage in subsistence farming, livestock rearing, and informal economic activities, all of which are deeply intertwined with the availability and accessibility of water. As such, the geography of water scarcity in South Africa’s arid regions is not merely a natural phenomenon, it is a deeply human and developmental concern. From a human geography perspective, these arid landscapes are not voids or peripheries, but dynamic spaces of cultural heritage, traditional knowledge, and potential innovation. However, the structural exclusion of arid rural communities from mainstream development discourse and national curriculum planning remains a critical issue. Rural schools in these regions often operate with limited resources, outdated learning materials, and curricula that do not reflect the lived realities of learners. This mismatch between environmental context and educational content undermines the capacity of young people to respond to pressing local challenges, such as water scarcity and ecological fragility. Positioning South Africa’s arid zones as the study area is therefore not incidental but intentional. These regions symbolize the intersection of ecological stress, socio-economic marginalization, and educational neglect, yet they also embody the potential for transformative rural education. By reimagining curriculum development through environmental geography and rural livelihoods, schools can become platforms for climate resilience, water literacy, and sustainable local development. Hence, the arid zones are fertile grounds for rethinking how education can serve as a strategic tool for adaptive rural development in the face of water insecurity. Figure 3 depicts the Map of the Study Area.

3 Literature review

3.1 The arid and semi-arid regions in South Africa

South Africa’s arid regions cover vast, rugged landscapes where rainfall is scarce, temperatures are extreme, and water is a precious, life-defining resource. These areas, though often overlooked in mainstream development conversations, are home to resilient rural communities whose survival depends on navigating environmental hardships daily. The key arid and semi-arid regions of South Africa are described with geographical precision and practical relevance for rural development and livelihood studies:

3.1.1 The Northern Cape (Karoo and Namaqualand)

The Northern Cape is the driest province in South Africa, with vast parts classified as hyper-arid to arid. Here, the Great Karoo and



FIGURE 3
Map of South Africa showing the nine provinces (source: www.exploresouthafrica.net).

the Richtersveld/Namaqualand landscapes dominate a mixture of semi-desert plains, salt pans, and rocky outcrops. Rainfall is extremely low, often less than 200 mm per year, and is highly unpredictable. These areas are livestock-rearing zones and depend on boreholes and ephemeral rivers. Rural communities face constant drought, grazing limitations, and deteriorating water infrastructure, making it a critical site for water security research. In terms of the region's human geography relevance, the dispersed settlements, limited infrastructure, and fragile ecosystems pose significant challenges to rural livelihoods and basic education delivery.

3.1.2 Western and Eastern Karoo

The Karoo region, which stretches across three provinces (namely the Northern, Western, and Eastern Cape Provinces), is characterized by vast plateaus, open skies, and dry shrubland. It is classified as semi-arid to arid, depending on the subregion. The Karoo is a key

agricultural zone (wool and mutton production) but declining rainfall and changing weather patterns are undermining productivity. Local farmers are forced to adapt or abandon their ancestral livelihoods. Schools in these sparsely populated areas struggle with water shortages and long travel distances for learners. This creates a compelling case for integrating water-focused, land-based learning into rural curricula.

3.1.3 Bushmanland (Northern Cape interior)

This remote, ultra-arid region lies between Calvinia, Pofadder, and Upington. It is one of the harshest environments in the country, with wide temperature fluctuations and minimal vegetation. Bushmanland's isolated settlements highlight the extreme ends of water insecurity, where communities rely on water trucking or unreliable boreholes. A particular human geography insight of this region stems from the socio-spatial marginality of the Bushmanland,

which is a stark reminder of the persistent inequalities born from South Africa's colonial and apartheid spatial planning.

3.1.4 Kalahari region (Northern Cape and parts of Northwest)

The Kalahari Desert, which extends into Botswana and Namibia, covers the northern edges of South Africa. Though technically a semi-desert due to some rainfall, it remains an ecologically fragile and water scarce region. Communities in this region are highly dependent on ecosystem services and natural resource gathering. Water scarcity limits not only agriculture but also wildlife-based tourism and other alternative livelihoods. There is growing interest in developing dryland agriculture, solar energy, and water harvesting technologies in this region, offering educational opportunities in STEM and vocational training.

3.1.5 Parts of Limpopo and Free State (western fringes)

Some western areas of Limpopo and the Free State are also classified as semi-arid, particularly near the Lephalale and Zastron regions. Though not as dry as the Karoo or Namaqualand, they are prone to seasonal drought and water stress. These areas are critical agricultural zones (maize and cattle) but are increasingly at risk due to rainfall variability. Inadequate water governance further compounds water security in the region. Rural learners in these regions are disconnected from land-based education, missing opportunities to engage in water conservation and agro-ecological practices that could future-proof their communities. It is also expedient at this juncture to state that South Africa's arid regions are not barren wastelands, they are spaces of resilience, adaptation, and human ingenuity. They form a complex geography where natural scarcity meets socio-political exclusion, making them urgent sites for research, policy, and education reform. Addressing water insecurity in these areas is not just an environmental challenge, it is a moral imperative for advancing equitable rural development, sustainable livelihoods, and transformative education.

3.2 Water security and its socio-economic impacts on rural livelihoods in South Africa's arid regions: a human geography perspective

In South Africa's arid and semi-arid regions, where rainfall is erratic, groundwater is scarce, and climate change continues to accelerate environmental stress, the concept of water security takes on a profoundly urgent and multidimensional meaning. These areas, which include vast expanses of the Northern Cape, Eastern Cape Karoo, and parts of Limpopo and the Free State, face persistent droughts, depleted water tables, and underdeveloped infrastructure. From a human geography standpoint, water is not merely a natural resource; it is a social lifeline, an economic catalyst, and a political issue, deeply embedded in the spatial realities and lived experiences of rural communities. For many rural households in these regions, water scarcity is both a daily challenge and a barrier to development. Agriculture, the primary livelihood activity for many, is predominantly rain-fed. Without consistent water access, smallholder farmers experience crop

failures, reduced yields, and livestock losses, which in turn lead to food insecurity, income instability, and deepening poverty. This creates a cycle of economic vulnerability, where communities are increasingly dependent on government grants, food aid, or seasonal migration for survival. Women and children often tasked with collecting water from distant or unreliable sources bear the brunt of this burden, losing valuable time that could otherwise be spent in school, vocational training, or income-generating activities. The human geography of water insecurity in South Africa's arid zones also reveals stark inequalities in access and opportunity. Spatial disparities are exacerbated by historical patterns of land dispossession, underinvestment in rural infrastructure, and limited representation in water governance structures. While urban centers benefit from relatively stable water systems, many rural settlements lack piped water, reliable boreholes, or sustainable irrigation schemes. This geographic marginalization perpetuates social exclusion and hinders the ability of rural communities to achieve meaningful socio-economic progress. Critically, water insecurity undermines the transformative power of education in these regions. Schools without clean water struggle to maintain hygiene and sanitation, leading to health challenges that affect attendance and learning outcomes. Curriculum content often remains detached from the environmental realities students face, offering little in the way of practical skills or local problem-solving strategies. This disconnect reinforces a cycle where rural learners are not equipped to address the water-related challenges in their communities, nor are they empowered to contribute to local development through sustainable innovations.

From a human geography perspective, addressing water security in arid regions must go beyond technical fixes or short-term relief. It requires a place-based, socially informed approach—one that understands how water scarcity intersects with gender, education, class, mobility, and local knowledge systems. It also demands the integration of water literacy and environmental stewardship into rural education curricula, preparing the next generation not only to cope with ecological uncertainty but to lead transformative change in their communities. In essence, water security is not simply a matter of supply and demand, it is a powerful lens through which we can understand the spatial injustices, livelihood vulnerabilities, and educational gaps that persist in South Africa's rural heartlands. [Figure 4](#) depicts the interplay between water insecurity, rural livelihoods, spatial inequality, and educational barriers in South Africa's arid regions. [Figure 4](#) further elucidates how Water Insecurity Shapes Rural Livelihoods.

[Figure 4](#) visually maps out the intertwined relationship between water security, socio-economic vulnerabilities, human geography dynamics, and educational challenges in South Africa's arid and semi-arid regions. At the heart of this representation is the map of South Africa, shading the arid zones that are at the epicenter of these cascading crises. With reference to human geography, it highlights how water scarcity cascades into socio-economic vulnerabilities, disrupts rural development, and demands a radical rethinking of curriculum and education strategies to foster resilience, empowerment, and transformation in marginalized communities. In the top left quadrant, Water Security is highlighted as being “characterized by limited and

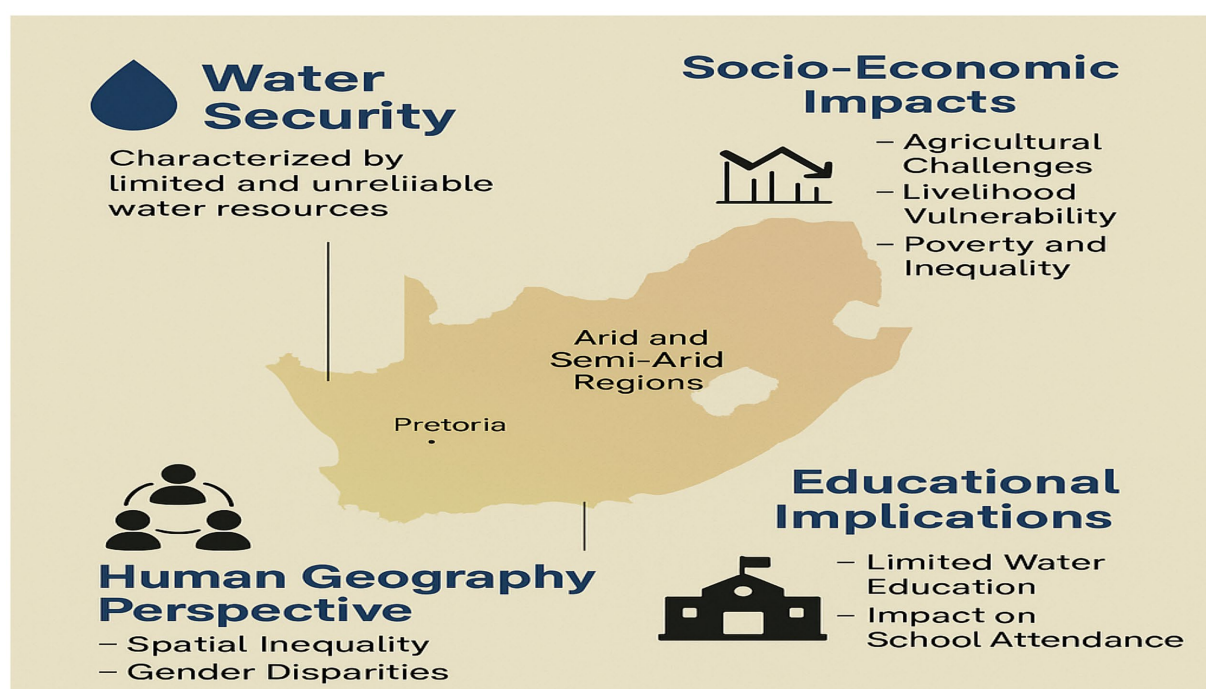


FIGURE 4

How water insecurity shapes rural livelihoods, deepens inequalities, and calls for education reforms to drive resilience and transformation in South Africa's arid regions.

unreliable water resources.” In South Africa’s arid regions, the natural environment is defined by minimal and unpredictable rainfall, drying rivers, and overburdened groundwater reserves. From a human geography lens, water insecurity is not just a physical issue it is spatial, social, and economic. It determines where people can live, how they sustain their livelihoods, and their very prospects for survival. In these communities, water is both a source of daily struggle and a driver of social inequality, making it the foundation on which other socio-economic challenges are built. Further, the diagram points to Socio-Economic Impacts, a domino effect triggered by water insecurity. Farmers, whose survival hinges on rainfall and irrigation, face agricultural challenges: withering crops, dying livestock, and failed harvests. This weakens rural economies, intensifies livelihood vulnerability, and entrenches cycles of poverty and inequality. Families are forced to make heart-wrenching choices—selling off assets, withdrawing children from school to work, or migrating in search of opportunities. Human geography teaches us that these are not isolated incidents, but spatial patterns born from unequal access to natural and infrastructural resources over decades. At the bottom left, the Human Geography Perspective connects spatial inequality and gender disparities to the broader theme. Rural women and girls are disproportionately affected—often walking long distances to fetch water, sacrificing education, and bearing the brunt of household water management. The arid geography is not neutral; it privileges some spaces over others, determines resource allocation, and affects the rhythms of everyday life. By understanding these spatial dynamics, we can appreciate how environmental conditions become deeply woven into the social fabric, perpetuating marginalization if left unaddressed. The

bottom right section exposes the Educational Implications. Schools in water-scarce areas struggle to provide basic sanitation, hygiene, and even drinking water—leading to absenteeism, health crises, and learning disruptions. Moreover, rural curricula often fail to equip students with practical, place-based knowledge about water conservation, sustainable agriculture, or climate adaptation. Without intentional curriculum reform, rural education risks remaining irrelevant to the lived realities of learners, leaving communities trapped in vulnerability. Education must not just deliver knowledge; it must foster resilience, innovation, and agency among rural youth. Hence, this diagram illustrates that water security in South Africa’s arid zones is a deeply human issue, intertwined with livelihoods, justice, gender, and opportunity. A purely technical response such as building more boreholes, is not enough. We must transform how water, development, and education are imagined and implemented. Policies must be spatially sensitive, socially inclusive, and educational systems must teach for adaptation and resilience. Rural communities are not passive victims; they are potential innovators and leaders, if empowered with the right tools and knowledge. In essence, the diagram challenges us to see water insecurity not just as a crisis, but as a call to reimagine rural development, redraw the geography of opportunity, and reinvent rural education for a more equitable future. This section is summarized in [Table 1](#).

The systematic literature review revealed a profound and consistent narrative across academic and policy literature: water security in South Africa’s arid regions is a deeply entrenched challenge with far-reaching implications for rural livelihoods and educational advancement. Across the Northern Cape, Western Karoo, Bushmanland, and fringes of Limpopo and Free State,

TABLE 1 The socio-economic features of arid zones and their impact on rural education & curriculum development.

Region	Geographic coverage	Water security challenges	Socio-economic features	Impact on rural education and curriculum development
Northern Cape (Karoo and Namaqualand)	Western interior of South Africa, near Namibian border	Extremely low rainfall (<150 mm/year), salinized boreholes, prolonged droughts	Extensive livestock farming, low population density, mineral dependency	Schools lack water infrastructure; curriculum must include desert ecology and dryland farming education
Western and Eastern Karoo	Spanning parts of the Northern, Eastern, and Western Cape	Rainfall variability, drying rivers, overgrazed land	Sheep farming, heritage tourism, aging populations	Emphasize sustainable grazing, local water harvesting techniques, and land rehabilitation in school syllabi
Bushmanland	Northern fringes of Northern Cape, bordering Namibia	Sparse groundwater, reliance on seasonal rainfall	Subsistence farming, marginalization of indigenous communities (e.g., San)	Integrate indigenous knowledge systems and climate adaptation strategies into rural education
Kalahari (NC and NW Provinces)	Shared by Northern Cape and Northwest Provinces	High evapotranspiration, ephemeral rivers, poor aquifer recharge	Nomadic cattle rearing, rural poverty, poor infrastructure	Use community-based water management and climate resilience modules in school projects
Western Limpopo and Free State Fringes	Transition zones near the Limpopo River and Free State drylands	Groundwater depletion, erratic rainfall, limited irrigation infrastructure	Informal farming, labor migration, low literacy in remote areas	Introduce agro-ecological education, emphasize sustainable rural livelihoods, and improve water-tech training in schools

studies highlight a recurring pattern of deteriorating access to potable water (Du Plessis, 2023), coupled with increased exposure to climate extremes (Connolly-Boutin and Smit, 2016), erratic rainfall patterns (Mararakanye et al., 2022), and diminishing groundwater yields (Pamla et al., 2021). These environmental stressors are not isolated events but symptoms of a broader structural water vulnerability that is both ecological and socio-economic in nature (El Kenawy, 2024). One of the most striking findings is the multidimensional impact of water insecurity on rural households. It does not merely disrupt daily living, it fractures the economic backbone of communities dependent on agriculture, pastoralism, and informal water-based economies (Bortolini et al., 2018). Livestock losses, reduced crop yields, and the abandonment of arable land due to desiccation are now commonplace in several surveyed regions (Jackson, 2021). This has triggered an alarming rise in rural poverty (Bizikova et al., 2015), food insecurity (Mabhaudhi and Modi, 2015), and out-migration (Masunungure and Shackleton, 2018), particularly among the youth, who perceive urban centers as offering greater stability and opportunity (Fox et al., 2016; Driskell, 2017). These shifts have further compounded the fragility of local knowledge systems and traditional water stewardship practices, which once thrived under communal governance (Aswani et al., 2018; Zarei et al., 2020; Ghorbani et al., 2021).

The findings also draw attention to the neglected role of education in addressing water and livelihood resilience (Biggs et al., 2015; Salleh, 2016). Schools in arid regions are routinely affected by water shortages, leading to reduced attendance, poor hygiene conditions, and weakened learning outcomes (Hutton and Chase, 2016; McMichael, 2019), and as noted by Hanna and Oliva (2016), the current curriculum remains largely detached from the

immediate environmental realities of learners. According to Sibanda and Manik (2023), less than 20% of reviewed educational interventions across rural provinces include contextualized modules on water conservation, climate adaptation, or land use planning. Where such content exists, it is often superficial, theoretical, or urban-centric in perspective (de Bruin et al., 2015). Furthermore, the review identified a critical disjuncture between national climate change policies and local education strategies. While South Africa's National Water Resource Strategy (NWRS) and National Climate Change Adaptation Strategy (NCCAS) make broad commitments to sustainability and community resilience, they rarely translate into tangible curriculum reforms or localized educational content (Ngcamphalala, 2021). This policy-practice gap was evident in the lack of integration between departments of water, education, and rural development at provincial levels, hindering cohesive responses to rural transformation (Pandy, 2019). In contrast, a smaller subset of innovative case studies emerged, offering models of integration. In parts of the Eastern Karoo and Namaqualand, for example, community schools partnered with NGOs to implement school-based rainwater harvesting projects, ecological garden programs, and climate education clubs (Makokotlela, 2016). These localized initiatives demonstrated measurable improvements in learner engagement, environmental awareness, and community participation, proving that place-based education can indeed yield transformative outcomes when aligned with the lived experiences of rural youth (Ngcamphalala, 2021). In essence, the findings illuminate the urgent need for a recalibrated educational framework that positions human geography, environmental literacy, and water resilience as central pillars of rural curriculum development. As elucidated by Morris (2016), education, when embedded in the

socio-ecological fabric of place, has the power to convert water-insecure, economically vulnerable regions into incubators of innovation, stewardship, and resilience. This shift is not only desirable, it is imperative for the future sustainability of South Africa's arid zones (Samantara, 2023).

4 Discussion

4.1 Water security, rural livelihoods, and the imperative of curriculum transformation

Water insecurity in South Africa's arid and semi-arid regions is not merely an ecological concern but a complex developmental issue with far-reaching socio-economic and educational implications. As delineated in the preceding table, areas such as the Northern Cape (particularly the Karoo and Namaqualand), Bushmanland, and the fringes of Limpopo and the Free State experience prolonged droughts, minimal and erratic rainfall, and groundwater salinization. These environmental stressors severely constrain rural livelihoods, which are predominantly dependent on small-scale agriculture, livestock farming, and subsistence economies. Within this context, schools are not immune to the cascading effects of water scarcity. Learners are disproportionately affected by the absence of adequate water and sanitation infrastructure, leading to reduced attendance, compromised health, and weakened academic performance. This situation underscores the urgent need for curriculum transformation that is context-responsive and geographically grounded. Traditional educational frameworks often overlook the environmental realities that rural learners encounter daily. There is, therefore, a critical need to recalibrate rural education curricula to incorporate local geographical knowledge, sustainable agriculture, climate resilience, and rainwater harvesting techniques. For example, learners in the Kalahari or Karoo regions must be equipped with practical knowledge of water conservation methods and land stewardship strategies that are suitable for arid environments. Integrating these elements into the curriculum can foster a sense of relevance, ownership, and applicability among learners. Furthermore, a human geography approach offers a powerful lens through which rural youth can understand the spatial inequalities that perpetuate their socio-economic marginalization. By exploring the intersections of environment, demography, infrastructure, and social policy, learners gain a holistic understanding of why certain regions face chronic underdevelopment and what structural interventions are required. In doing so, education transcends its traditional role and becomes a vital instrument of empowerment, enabling young people to envision and participate in the sustainable transformation of their communities. Ultimately, the intersection of water security, livelihoods, and education in South Africa's arid regions calls for an integrated approach that combines curriculum development, community engagement, and policy advocacy. Embedding human geography perspectives within rural education does not only enhance pedagogical relevance—it prepares a generation of learners to become active agents of resilience and change in the face of mounting environmental and socio-economic challenges.

5 Conclusion

Water security plays a major role in sustaining rural livelihoods in South Africa's arid zones. Water scarcity, exacerbated by climate change, population pressures, and poor infrastructure, severely limits agricultural productivity, which is the primary source of income and sustenance for these communities. The study reveals that communities living in the arid zones face significant challenges in accessing sufficient and clean water, which in turn affects their ability to maintain food security, health, and socio-economic stability. In terms of livelihoods, the research underscores that water scarcity is not just a matter of limited access to water but is also intertwined with social, political, and economic dimensions. Rural communities in these areas are often marginalized, and their voices are underrepresented in water management policies, which compounds the difficulties they face in securing water for both domestic and agricultural use. Furthermore, the research highlights the critical role of gender in water access and usage, with women and children being disproportionately affected by the water insecurity that characterizes these regions. The study also reveals that rural development education is an underutilized tool in addressing water security issues. Hence, it is germane to integrate water security education into rural development curricula, in a bid to empower communities with the knowledge and skills needed to manage water resources effectively, adopt water-saving technologies, and engage in policy advocacy. This approach can also foster a culture of environmental stewardship, which is vital for sustainable water use and rural development.

5.1 Practical implications for policy and practice

Considering the findings, this study proposes several practical strategies for addressing water security and improving livelihoods in South Africa's arid zones. First, there is a critical need for robust water management policies that are inclusive and sensitive to the unique challenges faced by rural communities. Policymakers must prioritize equitable water distribution, ensure the repair and maintenance of water infrastructure, and promote water-saving technologies. Public-private partnerships could also play a role in financing water infrastructure projects, particularly in underserved rural areas. Second, enhancing rural development education is key to building local capacity for water resource management. Educational programs should not only focus on the technical aspects of water management but also on fostering community-led initiatives that encourage collaboration, knowledge sharing, and advocacy for water rights. By incorporating water security into school curricula and vocational training programs, young people in these regions can be equipped with the skills to adapt to changing environmental conditions and to advocate for their communities' needs. Furthermore, gender-sensitive policies are essential for ensuring that women and marginalized groups have equal access to water and the opportunity to contribute to water governance. Empowering women through education and leadership roles in water management could help address the gender disparities that currently hinder effective water resource management.

Author contributions

TO: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. RF: Funding acquisition, Project administration, Supervision, Visualization, Writing – review & editing.

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