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Integrating indigenous and modern water supply systems in rural South Africa

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Water is essential for human survival, economic growth, and environmental sustainability. However, rural South Africa faces ongoing challenges in delivering reliable and clean water due to infrastructural inadequacies, climate variability, and historical disparities. Addressing these water supply issues is critical for reducing poverty, improving health outcomes, and fostering sustainable development in rural areas. This study utilises a mixed-methods approach within a positivist framework, collecting data through document analysis, self-administered surveys, and structured interviews with various stakeholders across four rural settlements in the Joe Gqabi and Gert Sibande District Municipalities. The primary aims are to evaluate water accessibility and reliability, examine the impact of water scarcity on poverty, investigate the availability of water infrastructure, and assess the effects of water supply on health and education. Findings indicate that deficient water infrastructure and intermittent supply significantly disrupt daily life, educational access, and healthcare services. Health risks due to contaminated water were prevalent, leading to waterborne diseases. Socio-economic impacts included exacerbated poverty, with particular challenges for female students in maintaining menstrual hygiene due to inconsistent water availability. The study proposes a sustainability model that integrates indigenous practices, such as rainwater harvesting and groundwater recharge, with modern water management technologies. This model, customised to local needs, underscores the importance of increased investment, integrated planning, and enhanced capacity-building in rural water management. By combining traditional and modern approaches, this model aims to improve water reliability, promote health, and support economic resilience in rural settlements.

KEYWORDS

water supply, rural settlements, indigenous knowledge, modern water management, sustainable development

1 Introduction

The inadequacy of water resource systems to meet diverse water-related needs often reflects shortcomings in planning, management, and decision-making processes (Loucks and Beek, 2017, p. 7). Over 40% of the global population faces water scarcity challenges, and water-related incidents account for roughly 70% of all fatalities among various types of natural disasters (The World Bank, 2022). The provisioning of safe drinking water, adequate sanitation facilities, and proper hygiene practices collectively referred to as WASH, assumes a foundational role in improving the quality of life for individuals (World Health Organization, 2023). Proper sanitation, hygiene practices, and access to safe drinking water significantly contribute to disease prevention and the reduction of waterborne illnesses (World Health Organization and United Nations Children's Fund, 2015). Water stands at the nexus of sustainable development and is indispensable for socio-economic progress, food and energy production, the health of ecosystems, and human survival itself (Connor, 2015, p. 3; Hutton et al., 2014).

A significant quarter of the global population residing in 17 countries faces extremely high-water stress, leading to intense competition over water resources (Food and Agriculture Organisation of the UN, 2013, p. 17). Urban areas exhibit a higher level of water service, particularly in terms of piped water supply. In 2015, four out of five urban residents enjoyed access to piped water, while this proportion dropped to two out of three in rural areas (Onda et al., 2012, p. 884). Rural settlements in South Africa suffer from a lack of water infrastructure, with 74 percent of rural inhabitants relying entirely on groundwater from local wells and pumps (Colvin et al., 2016; Van Der Mescht and Van Jaarsveld, 2016). Presently, 19 percent of the rural population lacks access to a dependable water supply, and 33 percent lack basic sanitation services. Additionally, more than 26 percent of all schools in both urban and rural areas, as well as 45 percent of clinics, lack access to a water supply (Massachusetts Institution of Technology, 2017).

1.1 Background

In numerous nations, pollution is contaminating dependable water sources. Water scarcity disproportionately affects women and girls, as they often serve as the primary custodians of natural resources, particularly for household needs and small-scale agriculture. This situation not only impacts their health and safety but also restricts their opportunities for engaging in economic activities (Government of Canada, 2017).

In rural communities worldwide, the shortage of safe water and sanitation represents a significant contributor to preventable diseases and fatalities (Kapwata et al., 2018, p. 1668). Over the decade between 1994 and 2004, the government allocated 15 billion ZAR (equivalent to US$3 billion) for infrastructure development (van Koppen and Schreiner, 2014, p. 545). From 1990 to 2015, access to water supply improved by 98 to 100% in urban areas and 66 to 81% in rural regions, respectively (StatsSA, 2015). In 2003 and 2006, the responsibility for service delivery and water supply was decentralised to local governments and municipalities (van Koppen and Schreiner, 2014, p. 551).

2 Literature review

The persistent challenges in the realm of water and sanitation persist due to the intricate nature of community structures and the diversity of customary practices across different regions. Various traditional water technologies and management methods have been employed for generations in different parts of the world. These practices are inherently tied to local conditions and requirements, with some relying on surface water sources while others are centred around the extraction and management of groundwater (Singapore's National Water Agency, 2022). Traditional water systems are typically connected to readily accessible water sources such as springs, rainwater, shallow wells, and even deep wells. The fundamental driving force behind traditional water management is the pressing need for water in the face of scarcity, driven by the necessity for survival (Behailu et al., 2016, p. 3).

2.1 Current global WASH trends

The advancements facilitated by WASH encompass a range of benefits, including enhanced physical health, preservation of the environment, improved educational achievements, time efficiency gains, assurance of dignified living, and equitable treatment for individuals regardless of gender (Elebeke, 2023). On a global scale, the utilisation of enhanced drinking water sources witnessed a significant rise, increasing from 76 percent in 1990 to 91 percent in 2015 (UNCTAD, 2016).

The United Nations, in its 2012 report featuring estimates from 2010, indicated that the Millennium Development Goal (MDG) target of reducing by half the proportion of the population without access to safe drinking water had been achieved (United Nations Children's Fund (UNICEF), 2019). However, it is important to note that these global estimates conceal regional disparities and inequities in access, particularly between urban and rural populations (Hutton and Chase, 2016).

Several countries have witnessed significant enhancements in the availability of safe drinking water. Notable examples include Myanmar, where the proportion of the population with access to potable water increased from 58% in 1990 to 80% in 2014. Mali has also seen substantial improvements, with 75% of the population now enjoying access to clean water, compared to just 27% in 1990. The most remarkable progress is observed in Afghanistan, where over half the population (55%) now has access to safe water, a substantial increase from the mere 20% two decades ago (UNCTAD, 2016, p. 45). While there appears to be a correlation between GDP *per capita* and access to safe water, it is important to note that many countries have made more substantial gains in improving their access to drinking water than this correlation would imply.

In several sub-Saharan African nations, including Angola, Chad, the Democratic Republic of Congo, Madagascar, and Mozambique, approximately every other individual lacks access to safe drinking water. Notably, in various other countries, such as Burundi, Cameroon, Congo, Guinea, Liberia, Mali, Rwanda, and Zimbabwe, one out of every four people faces a scarcity of safe drinking water. For several additional countries, data on this matter are unavailable. Equatorial Guinea, despite witnessing significant income improvements, finds itself in a situation where only half of its population can access clean water, and there has been no appreciable progress in increasing availability. Similar challenges persist in Afghanistan, Haiti, Mongolia, and the State of Palestine (UNCTAD, 2016, p. 46).

While urban areas have made significant strides in addressing the challenges of ensuring access to safe water, the issue of securing improved drinking water sources continues to be a pressing concern for numerous rural regions across the globe. This challenge is especially pronounced in the regions of Oceania and sub-Saharan Africa. The analysis reveals that, on average, compliance with safety standards was nearly 90 percent for piped water sources and ranged from 40 to 70 percent for other improved sources. When these findings are extrapolated to a global scale, it is estimated that in 2010, approximately 1.8 billion individuals, accounting for 28 percent of the world's population, relied on unsafe water sources. This figure is more than twice the 783 million people, or 11 percent, who relied on unimproved water supplies (Hutton and Chase, 2016, p. 237).

2.2 Water storage and resource management in South Africa

South Africa heavily relies on the use of storage reservoirs to ensure a consistent supply of water during periods of water scarcity. Dams and rivers serve as critical water storage sources, with a significant proportion of large dams in Africa situated in South Africa and Zimbabwe, accounting for 60% of the total. South Africa boasts more than 500 large dams, of which 50 have a storage capacity

exceeding 100 million m^3. These dams primarily serve the purposes of irrigation, as well as supplying water for urban and industrial use (Department of Water Affairs, 2015, p. 13).

The challenges related to water scarcity are exacerbated by pollution affecting both surface and groundwater resources. The condition of rivers and dams is a source of concern, given that certain rivers exhibit alarming levels of pollution (Ali, 2011, p. 196). Groundwater plays a substantial role in South Africa, particularly in rural and arid regions. Presently, South Africa's groundwater resources contribute approximately 13% of the total volume of water consumed nationwide (Pietersen et al., 2011, p. 26).

Types of modern water resources:

- Terminating or Tree-Like Distribution System
- Gridiron Distribution System
- Circular or Ring Distribution System
- Radial Distribution System

Examples of indigenous practices for water harvesting and management:

- Rainwater Harvesting (Figure 1)
- Proposed water harvesting for South Africa.
- In-Field Rainwater Harvesting Technique
- Gelesha
- Stone Terracing
- Homestead Ponds
- Contouring
- Saaidamme
- 'Klipplaate en Vanggate'

2.3 The current state of South Africa's reservoirs in January 2023

The Department of Water and Sanitation (DWS) has issued a call for South Africans to embrace water conservation practices and adhere to water restrictions imposed in specific municipalities. This advisory remains in place despite the fact that the nation's reservoirs currently hold 94.2% of their total capacity, representing a marginal 0.1% increase compared to the same period in the preceding year (Fraser, 2023).

The Eastern Cape province stands out as a major area of concern for the Department of Water and Sanitation (DWS), as certain regions within the province continue to contend with persistent drought conditions (Department of Water and Sanitation, 2023). As of January 5, 2023, the department reported that despite facing drought conditions in certain areas, the Eastern Cape has seen a slight uptick in water storage, rising from 76.9% the previous week to 77.3% in the current week. However, the DWS has cautioned that water supply in the Nelson Mandela Bay Municipality remains under significant strain (South African Goverment News Agency, 2023).

2.4 The effect of water scarcity on the economy, women, and education

Water is a fundamental resource for agricultural, industrial, and domestic use (Oweis et al.,2012). When water becomes scarce, it can have a profound economic impact. Reduced access to water affects agricultural productivity, leading to crop failures and reduced food security (Kaur, 2019). This, in turn, can lead to increased food prices and reduced income for both rural and urban populations. Industries reliant

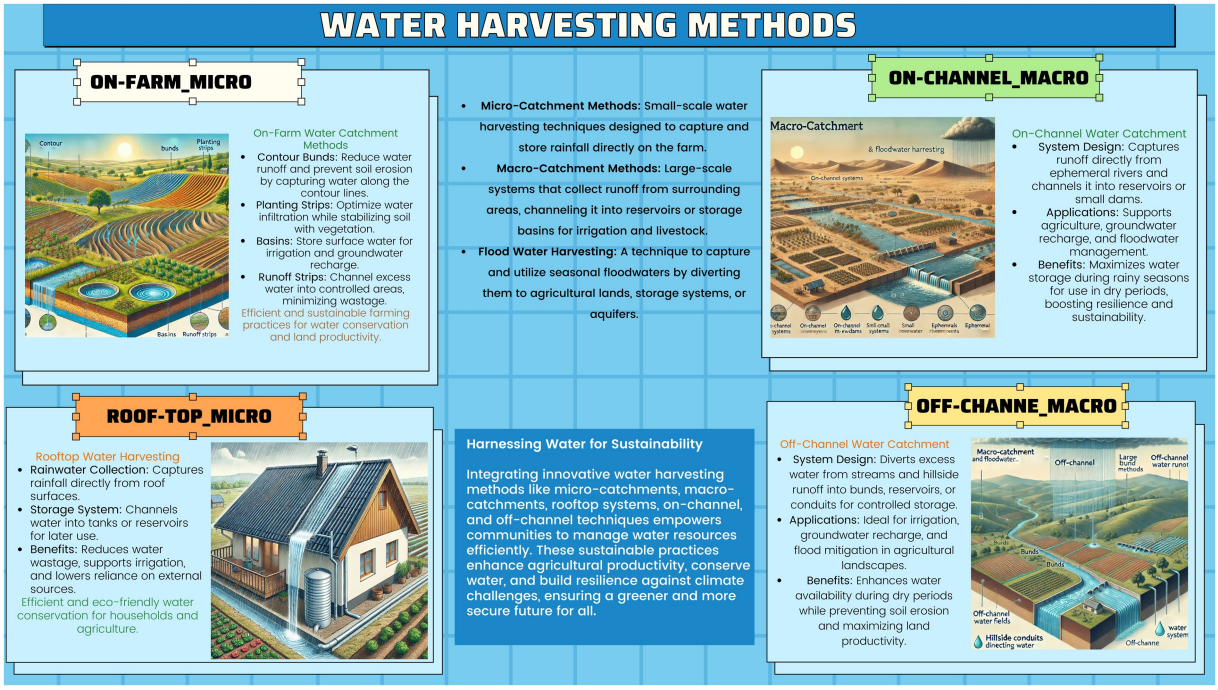

FIGURE 1
Sustainable water harvesting techniques for conservation and resilience.

on water, such as manufacturing and energy production, may face higher operational costs. The consequent economic strain can result in reduced job opportunities and increased poverty rates (World Bank, 2019).

Women, particularly in developing countries, are disproportionately affected by water scarcity. The responsibility of collecting water often falls on women and girls. The time spent fetching water can prevent them from pursuing education or engaging in income-generating activities. Moreover, the burden of water scarcity exacerbates gender inequalities by limiting women's participation in decision-making processes regarding water management (United Nations, 2020). Addressing gender disparities in water access and management is crucial to mitigating the effects of water scarcity on women.

Water scarcity can disrupt educational systems in various ways. In areas where water is scarce, schools may not have access to clean water for drinking, sanitation, and hygiene (World Health Organization and United Nations Children's Fund, 2015). This can lead to increased absenteeism among students, particularly girls, who may stay home to help fetch water. Additionally, the time spent collecting water or dealing with water-related illnesses can impact students' ability to focus on their studies, leading to reduced educational attainment (He and Vilain, 2014).

2.5 The sustainable development goal on water

In spite of global advancements, a significant portion of the world's population continues to lack access to safe water, sanitation, and proper handwashing facilities. Statistics indicate that achieving universal access to basic sanitation services by 2030 would require doubling the current annual rate of progress. Efficient water utilisation and management are crucial to addressing the growing demand for water (Charlesworth and Booth, 2016), ensuring water security, and mitigating the increasing frequency and severity of droughts and floods resulting from climate change (United Nations Publications, 2018, p. 7).

The Sustainable Development Goals (SDGs), adopted by the United Nations in 2015, aim to progress toward a sustainable and poverty-free world by 2030. Goal 6 of the SDGs seeks to ensure global access to clean water and adequate sanitation services. The SDGs consist of 17 goals intended to unite nations in the shared mission of ensuring the well-being of all humans by 2030. These goals encompass efforts to eradicate poverty, combat climate change, and maintain high standards of resources (OECD, 2018, p. 23).

Approximately 40 percent of the world's population faces water scarcity, and this number is expected to increase as global temperatures rise. Drought affects some of the poorest countries, leading to famine and malnutrition. Across the globe, about 1.7 billion people reside in watersheds where water is used faster than the watershed can be replenished. According to some estimates, if current trends continue, one in four people, or more, may face regular water shortages by 2050 (WWAP, 2019, p. 36).

United Nations SDG 6 strives to make adequate sanitation and water services accessible to all individuals by 2030. To achieve these goals, as many as 800 million people or more would require the construction of facilities to provide reliable clean water and waste disposal (Katila et al., 2019, p. 178).

3 Research methodology

This study adopted a mixed-methods approach, combining both quantitative and qualitative techniques to thoroughly investigate the research objectives. Quantitative methods, including survey was employed to measure and predict variables, while qualitative data was gathered through semi-structured interviews. This dual approach enabled a detailed exploration of the research phenomena, providing both numerical data and in-depth insights.

The primary data collection tool was a structured questionnaire, designed for efficient, large-scale data gathering. To minimize bias and encourage open responses, the questionnaires were administered both in person and remotely, with anonymity assured. However, recognizing the limitations of questionnaires in capturing qualitative nuances, semi-structured interviews were conducted to provide richer, more detailed data. Open-ended questions and thematic analysis further enhanced the depth of understanding.

3.1 Targeted population

The study targeted a diverse population, including households from four selected rural settlements, agriculture officers, local business owners, healthcare and school executives, ward councillors, and officials from various administrative levels. This diversity was essential to capturing a wide range of perspectives on water supply challenges.

3.2 Sampling method

A total of 335 households were selected using multi-stage sampling from the four settlements (Hlankomo, Mndeni, Dundonald, and Betty's Goed). Additionally, 37 stakeholders including local authorities, business owners, and water management officials were purposively selected. The sample size was calculated using the Cochran formula, with a target range of 360–372 participants, ensuring data robustness. The convenience sampling method was employed for household selection based on the availability of adults during site visits, while purposive sampling was used for selecting key stakeholders involved in water management.

3.3 Data analysis methods

Both quantitative and qualitative data were analysed. For quantitative data, statistical tools such as descriptive and inferential statistics were applied. Qualitative data from interviews were analysed using thematic analysis with the help of NVivo® software, providing a structured interpretation of patterns and themes in the data.

Ethical considerations and inclusivity were prioritized, with door-to-door data collection ensuring participation despite digital access limitations in rural areas. Questionnaires were translated into local languages. Triangulation through interviews, observations, and document analysis strengthened the study's validity.

Reliability and validity were carefully maintained through measures like Cronbach's alpha, used to assess internal consistency,

and structured data collection protocols. Validity was further ensured by an extensive literature review, robust sampling strategies, and a pilot study to refine the research instruments. This comprehensive approach ensured the study's findings were reliable, credible, and generalizable to similar contexts.

3.4 Geographical location of the study

The Joe Gqabi District Municipality, previously known as the Ukhahlamba District Municipality, is a Category C municipality located in the Eastern Cape. Within this district, the Elundini Local Municipality, classified as a Category B municipality, is a primary area of focus. In Mpumalanga Province, the Gert Sibande District Municipality is also classified as a Category C municipality, with special attention in this study given to the Chief Albert Luthuli Municipality.

4 Study findings and discussion

4.1 Water resources

The identified rural areas in Eastern Cape and Mpumalanga, both are aware of and have access to both groundwater and surface water resources (see Figure 2).

The perceived reliability of the water sources was analysed through a rating scale, and the results showed that in the case of Groundwater Resources, 8 respondents (2.4%) found them to be "Extremely reliable," while the majority of 225 respondents (67.2%) rated them as "Reliable." An additional 102 respondents (approximately 30.4%) held a "Neutral" stance regarding groundwater reliability, with no respondents considering them "Unreliable" or "Extremely unreliable."

For Surface Water Resources, none of the respondents rated them as "Extremely reliable." However, 110 respondents (32.8%) found them "Reliable." A larger group of 133 respondents (39.7%) held a "Neutral" opinion about surface water reliability. On the other hand, 82 respondents (24.5%) rated surface water as "Unreliable," and 10 respondents (3%) considered them "Extremely unreliable."

Overall, the data suggests that a significant proportion of respondents in these regions consider both Groundwater Resources and Surface Water Resources to be reliable or have a neutral perception. Nevertheless, there are concerns regarding the reliability of surface water resources, as nearly one-fourth of the respondents found them unreliable or extremely unreliable (refer to Figure 3).

4.2 Accessibility of water infrastructure in rural communities of the Eastern Cape and Mpumalanga

In the combined analysis of the Eastern Cape and Mpumalanga regions, it is evident that access to various water infrastructure types is notably shared between these areas. Household taps, a critical source of water supply, are readily accessible to approximately 73% of respondents, underscoring the significance of this water supply mode across both regions. Communal taps, though less prevalent, are still an essential source, with about 23% of respondents reporting access.

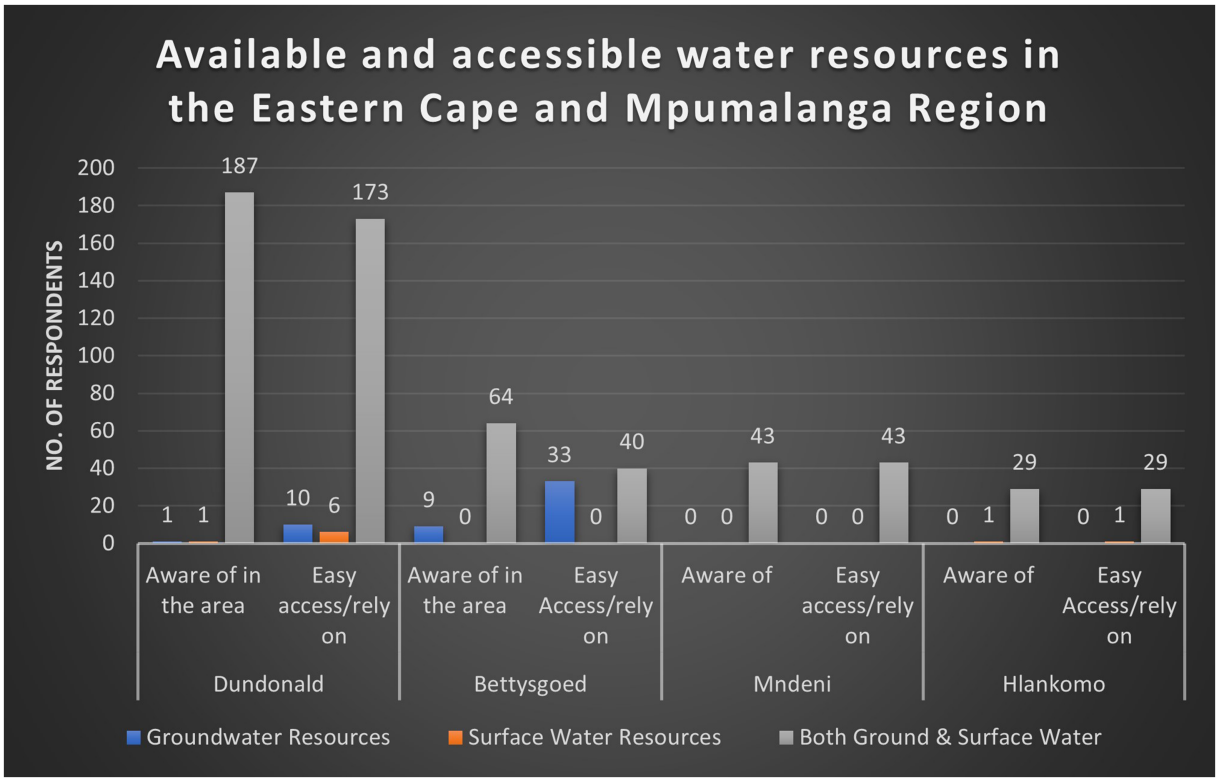

FIGURE 2
Available and accessible water resource in the Eastern Cape and Mpumalanga Region.

Boreholes and water tanks each provide accessible water sources for roughly a quarter of the respondents, highlighting their importance in addressing water needs. Truck water tankers play a substantial role in water supply, with approximately 39% of respondents relying on this mode of delivery. The accessibility of dams and rivers stands out as a major feature in both regions, with over 90% of respondents having easy access to these natural water sources.

Springs and wells, while slightly less prevalent, remain significant water sources, with around 68 and 69% of respondents having access, respectively. This combined analysis suggests that both the Eastern Cape and Mpumalanga regions exhibit relatively equitable access to various water infrastructure types, ensuring a broad range of options for securing this essential resource. These findings underscore the importance of diverse and accessible water sources in meeting the water needs of the population in these regions (refer to Table 1 and Figure 4).

The Consumer Satisfaction Index (CSI) measures the level of satisfaction or access to various water infrastructure sources in different settlements and provinces. In Hlankomo, Eastern Cape, the highest CSI is for communal taps and water tanks both at 50%. This indicates that communal taps and water tanks are the most satisfactory water source in Hlankomo. In Mndeni, Eastern Cape, the highest CSI is for communal taps at 53.50%. This suggests that communal taps are the most satisfactory water source in Mndeni.

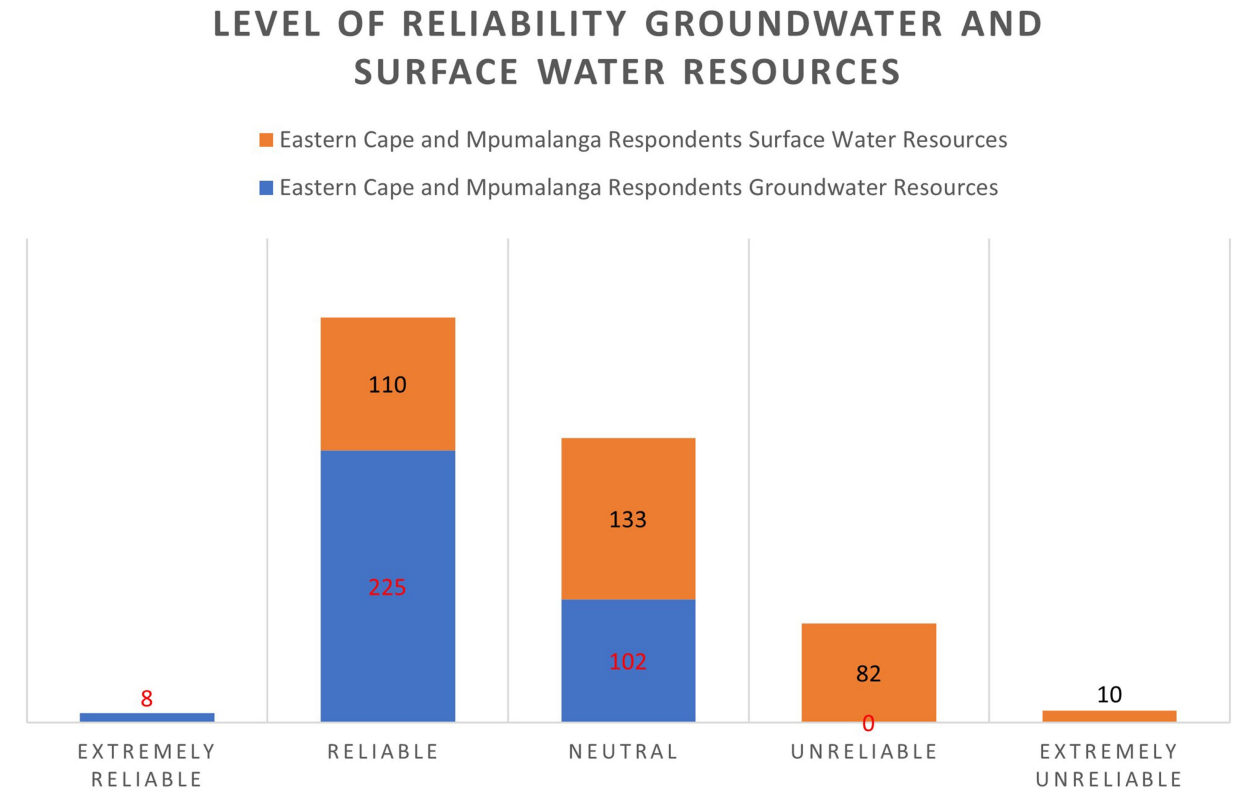

FIGURE 3
Level of reliability of groundwater and surface water resources.

TABLE 1 Easily accessible water sources in the rural areas of the Easten Cape and Mpumalanga Region.

Water infrastructure that you can easily access	Mpumalanga	Eastern Cape	Eastern Cape and Mpumalanga respondents (combined)	% combined
Households taps	231	14	245	73%
Communal taps	4	72	76	23%
Boreholes	84	0	84	25%
Water tanks	87	25	112	33%
Truck water tankers	131	1	132	39%
Dams/rivers	237	66	303	90%
Springs	228	0	228	68%
Wells	232	0	232	69%
Total Number of Respondents	262	73	335	

In Dundonald, Mpumalanga, the highest CSI is for household tap at 83.10%. This means that household taps are the most satisfactory water source in Dundonald. In Betty's Goed, Mpumalanga, the highest CSI is for wells at 73.9%. This indicates that wells are the most satisfactory water source in Betty's Goed.

These findings indicate that the type of water infrastructure with the highest CSI varies by settlement and province. These disparities highlight the differences in access to clean and reliable water sources, which can significantly impact the quality of life and well-being of the residents in these areas (Table 2).

Figure 5 provides information about the availability of running water (tap water) in households in the Eastern Cape and Mpumalanga provinces.

Only 2 households, representing a mere 0.6% of the total respondents, reported that they always have tap water in their area. This indicates an extremely low percentage of households with continuous access to tap water. The majority of households, constituting a significant 98.5% of the total respondents, reported that they do not always have tap water in their area. This reflects the prevailing issue of intermittent or unreliable access to tap water in these provinces. A small percentage, 0.9% of the total respondents, did not specify whether they always have tap water or not.

the data suggests that the vast majority of households in the Eastern Cape and Mpumalanga do not have continuous access to tap water. The low percentage of households reporting constant access to tap water emphasises the challenges related to reliable water supply in these regions. This highlights the need for improved water infrastructure and management to ensure more consistent access to clean water for these communities.

4.3 Purification status of utilised water supply

Figure 6 presents data regarding the purification of water in households in both the Mpumalanga and Eastern Cape provinces. The data indicates that a significant majority of households in the

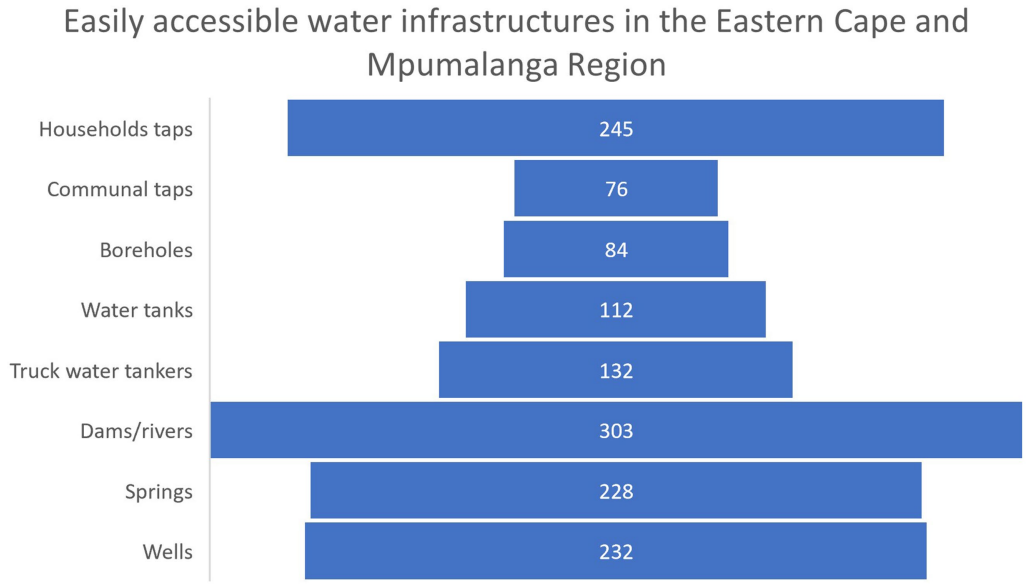

FIGURE 4
Easily accessible water sources in the rural areas of the Easten Cape and Mpumalanga Region.

TABLE 2 Consumer Satisfaction Index (CSI) for various water infrastructure types.

	Eastern Cape		Mpumalanga	
Water infrastructure	CSI-Hlankomo	CSI-Mndeni	CSI-Dundonald	CSI-Betty's Goed
Households taps	13%	39.60%	83.10%	57.5%
Communal taps	50%	53.50%	7.40%	6.9%
Boreholes	0%	0%	7.40%	23.3%
Water tanks	50%	25.60%	34.40%	30.1%
Truck water tankers	0%	0%	36.50%	19.2%
Dams/Rivers	0%	7.00%	79.40%	63%
Springs	0%	0%	72.00%	63%
Wells	0%	0%	70.90%	73.9%
Other (specify)				

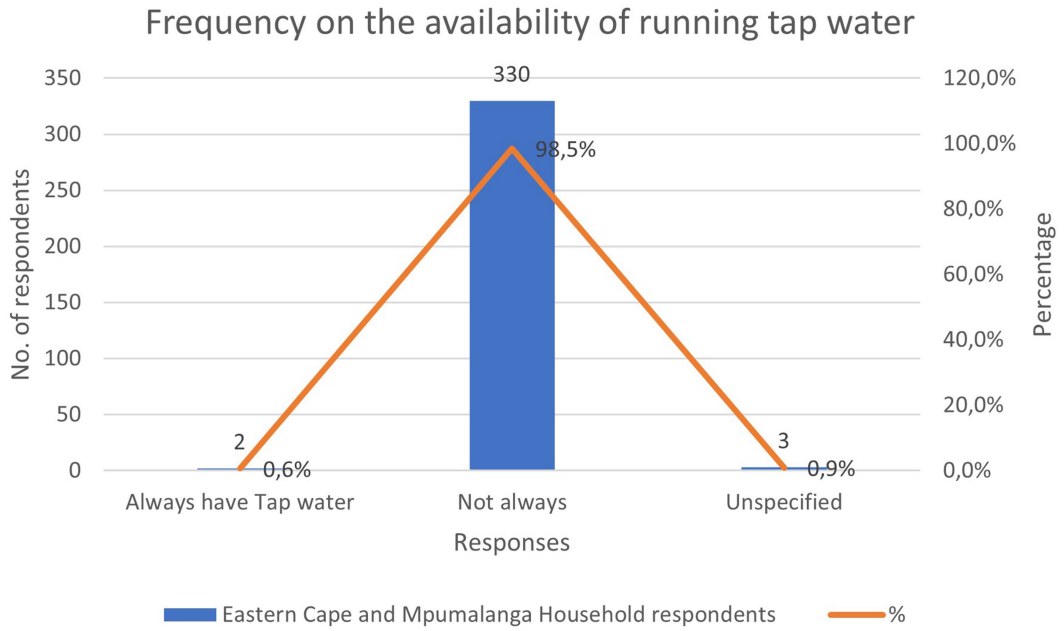

FIGURE 5
Frequency on the availability of tap water in the rural settlements.

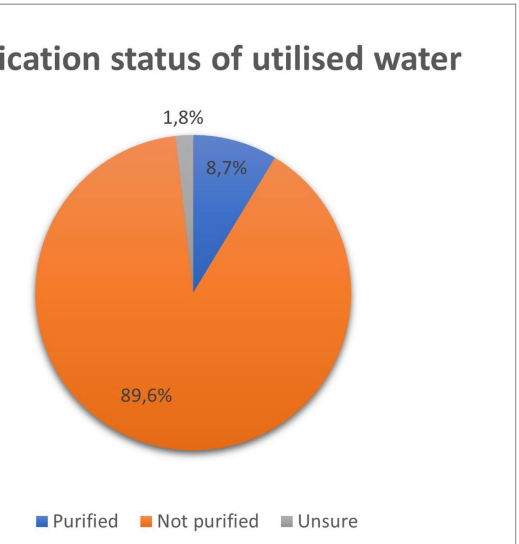

FIGURE 6
Purification status of utilised water.

Mpumalanga and Eastern Cape provinces do not have access to purified water. The low percentage of households reporting purified water highlights the challenges related to ensuring clean and safe drinking water in these regions. This underscores the importance of improving water treatment and purification infrastructure to enhance the quality of water sources for these communities.

A relatively small proportion of households, approximately 8.7% of the total respondents, reported that their water is purified. This suggests that a minority of households in these provinces have access to treated or purified water. The majority of households, comprising a substantial 89.6% of the total respondents, indicated that their water is not purified. This reflects a prevalent issue of untreated or non-purified water sources in these areas. The majority of households, comprising a substantial 89.6% of the total respondents, indicated that their water is not purified. This reflects a prevalent issue of untreated or non-purified water sources in these areas (refer to Figure 6).

4.4 Impact of water challenges on income generation and business/employment opportunities in rural settlements

Figure 7 provides a descriptive analysis of responses regarding the impact of water challenges on income-generating resources across four settlements. In Dundonald, 9.52% of respondents reported being affected by unreliable water supply, while 90.48% were unaffected. Similarly, in Betty's Goed, 8.22% of respondents were affected, with 91.78% unaffected. In contrast, no respondents in Mndeni and Hlankomo reported being affected, with all (100%) indicating no impact from water supply issues. These results suggest that in Dundonald and Betty's Goed, a small but notable portion of the population faces water-related challenges affecting income generation, potentially contributing to poverty, while in Mndeni and Hlankomo, water supply issues appear either non-existent or not linked to income generation.

4.5 Impact of water accessibility on employment and business opportunities

Figure 8 provides a descriptive analysis of responses to whether respondents have ever missed employment or business opportunities due to unreliable water access. A significant majority, 95.22% (319 respondents), reported that they had never missed such opportunities,

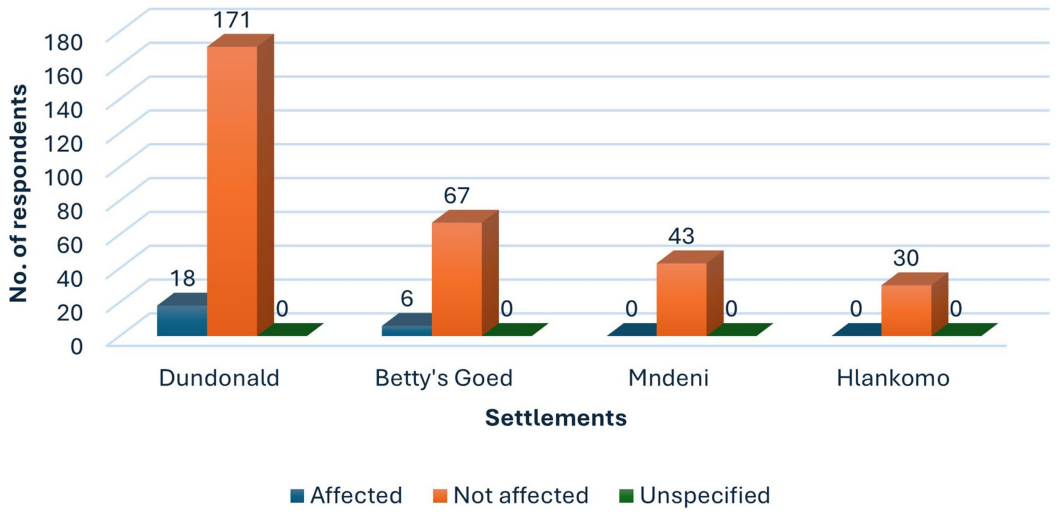

FIGURE 7
Impact of unreliable water supply on income generating resources.

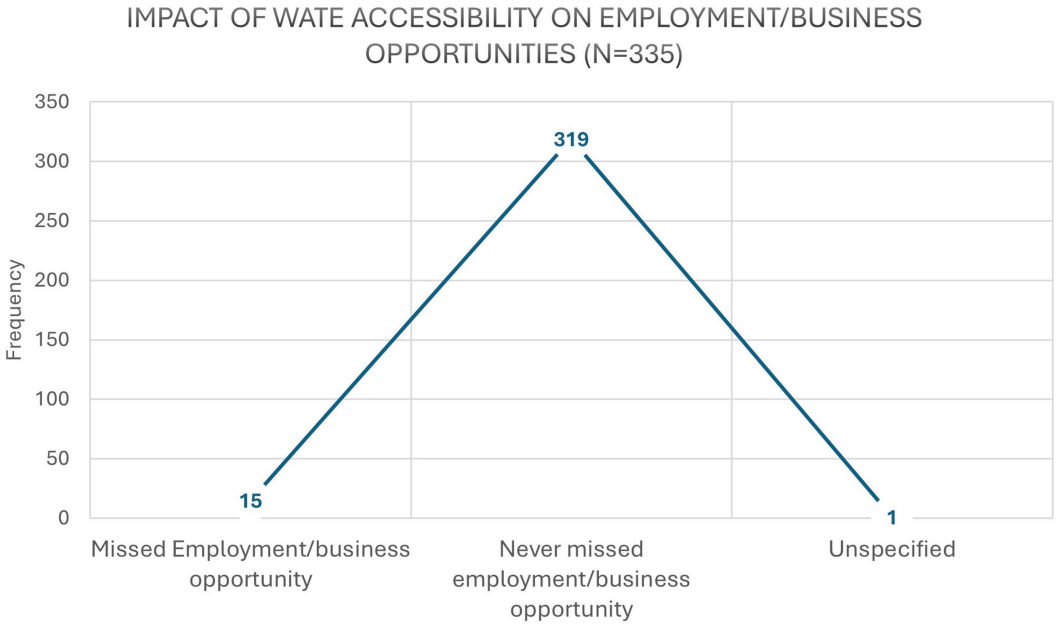

FIGURE 8
Impact of water accessibility on employment/business opportunities.

while 4.48% (15 respondents) indicated that they had. These findings offer valuable insights into the role of water accessibility in shaping economic opportunities, which is critical for poverty alleviation and enhancing livelihoods.

> *Z069: "I missed an interview because of water management (Water collection)."*

> *P048: "It was a business partnership opportunity but due to unreliability of water and my business the partnership did not last even for 6 months."*

> *P065: "I was late for an interview because I first had to fetch water from the dam, but it was too dirty, so I had to go to a stream which took bit of my time, and I was red flagged."*

While the data shows that water challenges are present and can impact rural life, they do not uniformly lead to missed opportunities or direct economic losses across all surveyed areas. However, where these challenges do have an impact, they can be significant, potentially contributing to the persistence of poverty.

4.6 Perceptions of water supply reliability across rural settlements

The provided data furnishes insights into the perceived reliability of water supply among household respondents. Figure 9 presents an analysis of water supply reliability in rural areas. In Dundonald, 13.2% (25 respondents) believe their water supply is reliable, while 71.9% (136 respondents) express doubts, and 14.8% (28 respondents) are uncertain, providing insights from 189 households. In Betty's Goed, 16.4% (12 respondents) find the water supply reliable, 53.4% (39 respondents) view it as unreliable, and 30.1% (22 respondents) are uncertain, based on 73 households. In Mndeni, 7.0% (3 respondents) reported reliable water, while 93.0% (40 respondents) found it unreliable, with no uncertainty. In Hlankomo, 6.7% (2 respondents) found their water reliable, 90.0% (27 respondents) found it unreliable, and 3.3% (1 respondent) expressed uncertainty. These figures provide a comprehensive view of household perceptions across the four settlements.

Across all areas, 42 responses found the water supply reliable. A substantial majority, 242 responses, perceive the water supply as unreliable. A total of 51 respondents were unsure about the reliability.

4.7 The effects of water supply on health and education

The qualitative data from officials reveals that reliable water supply plays a pivotal role in healthcare delivery and education.

4.8 Impact of water scarcity on healthcare operations and staff performance

Water scarcity directly affects hygiene practices, infection control, patient care, and sanitation, leading to significant operational challenges. Without adequate water, clinics struggle to maintain basic hygiene protocols, such as handwashing and sterilization, which increases the risk of infection transmission. One respondent emphasized, *"We cannot wash hands properly between patients, which is risky for spreading infections."* Essential procedures like wound cleaning and medication preparation are compromised, negatively impacting patient care. Another respondent added, *"Sometimes we have to delay treatments because there's no clean water for procedures like wound irrigation."* Water scarcity also hinders sanitation efforts, making it difficult to maintain clean restrooms and manage waste disposal, further contributing to potential health risks within the clinic environment.

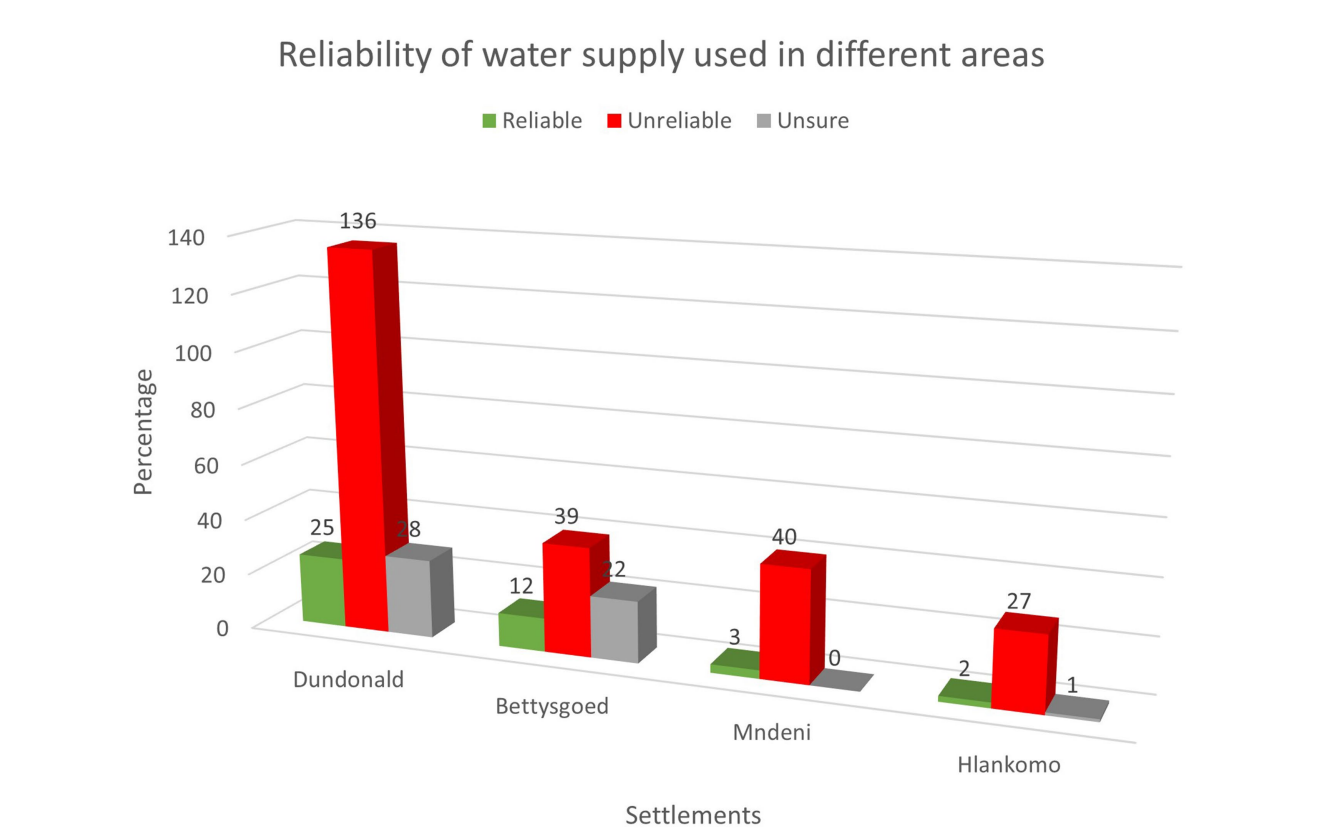

FIGURE 9
Reliability of utilised water supply in rural areas.

In addition to compromising healthcare quality, water scarcity in clinics leads to financial and operational strains. The lack of reliable water increases operational costs, as clinics must invest in alternative water sources such as boreholes or water storage systems, and often face higher energy costs to maintain functionality. As one respondent shared, "*We have to rely on water tankers, which adds to our costs and disrupts services when the tankers are late.*" This diverts resources from other critical healthcare needs and strains the clinic's budget. The impact on staff morale is also considerable, with one clinic worker noting, *"It's frustrating for staff when we cannot do our jobs properly due to the lack of water, and this definitely affects our morale and productivity."* Ultimately, water scarcity not only affects the health and well-being of patients but also compromises the overall effectiveness and sustainability of rural healthcare services.

4.9 Impact of water scarcity on school health, hygiene, and educational outcomes

The qualitative data emphasizes that access to reliable water is crucial for creating a supportive learning environment, impacting both student health and academic performance. One respondent explained, "*Without clean drinking water, students get dehydrated, and it becomes hard for them to focus in class, which directly affects their learning.*" Additionally, water is fundamental for hygiene and sanitation, as another respondent noted, "*We need water for food preparation and to keep the school clean, especially to prevent the spread of diseases.*" The gendered impact of water scarcity is also significant, particularly for female students. One teacher highlighted, "*Girls miss school during their periods because there is not enough water for proper hygiene, which affects their attendance and learning.*" This underscores how unreliable water access exacerbates absenteeism, especially for girls, and disrupts the overall learning experience.

Financial strain is another critical consequence of water scarcity. One respondent remarked, "*The school has to spend extra money on water deliveries or paying people to fetch water, which takes away from the budget for books and other learning materials.*" This redirection of resources negatively affects the quality of education, as less funding is available for essential educational tools and facility upgrades. Additionally, water scarcity complicates efforts to maintain health and safety protocols during the COVID-19 pandemic. A respondent explained, "*We struggle to keep up with proper hand hygiene because there is not always enough water, putting both students and staff at risk.*" These challenges highlight the financial and operational burdens schools face in managing water shortages, which directly affect the students' learning environment and overall well-being.

5 Conclusion and recommendations

5.1 Conclusion

The study highlights the critical role of reliable water supply in both the Eastern Cape and Mpumalanga provinces, revealing the profound effects of water availability on livelihoods, health, and education in rural areas. The findings show that groundwater is generally perceived as reliable by a majority of respondents, while surface water sources face more skepticism regarding their reliability. Despite access to various water infrastructure types, including household taps, communal taps, boreholes, and natural sources like rivers and dams, challenges persist in ensuring consistent and clean water supply across these regions. The Consumer Satisfaction Index (CSI) analysis further emphasizes disparities in water satisfaction levels between settlements, with some communities more reliant on less satisfactory water sources, which impacts their quality of life.

Water scarcity significantly affects both healthcare and educational outcomes in these rural communities. In healthcare, the lack of reliable water compromises hygiene, infection control, and patient care, forcing clinics to rely on costly alternative water sources, which strains their budgets and reduces operational efficiency. Similarly, schools face major challenges due to inadequate water access, which negatively impacts student health, academic performance, and sanitation, especially for female students who face additional difficulties related to menstrual hygiene. Financial strain is a common theme, as both clinics and schools must divert critical resources to address water shortages, thereby affecting their capacity to deliver essential services.

The study underscores the urgent need for improved water infrastructure and management to ensure that both rural healthcare facilities and educational institutions can function effectively and provide high-quality services. Addressing water challenges is paramount for alleviating poverty, promoting public health, and ensuring equitable access to education, thereby improving the overall well-being and sustainability of these communities.

5.2 Recommendations

Implementation of Integrated Water Supply Systems: A combination of indigenous and modern water management techniques, such as rainwater harvesting and boreholes, can be effectively employed in rural areas. Local springs, which are perceived as reliable, should be developed further, alongside modern water infrastructure like household taps and communal water points. The integration of these systems ensures a continuous and reliable water supply, especially during periods of drought.

Rainwater Harvesting: Promoting rainwater harvesting systems is critical, particularly in areas like the Eastern Cape and Mpumalanga, which experience variable rainfall patterns. Roof-based collection systems and homestead ponds can be introduced at the household level, allowing communities to capture and store water for both domestic use and small-scale agriculture. Government and municipal authorities should provide incentives, training, and resources to facilitate the installation and maintenance of these systems.

Improved Water Infrastructure Development: Investment in infrastructure is necessary to ensure equitable access to clean water. Initiatives should include building water treatment plants, expanding the distribution network of household and communal taps, and improving the efficiency of water tankers in areas with limited access. In addition, upgrading existing boreholes and installing purification systems will be critical in providing safe drinking water to underserved communities.

Community Awareness and Training: Raising awareness about the benefits and techniques of rainwater harvesting and water conservation is essential for the successful implementation of sustainable water supply solutions. Educational campaigns should be conducted,

focusing on how communities can efficiently manage and maintain water resources. Collaboration with local schools and community leaders can further enhance the effectiveness of these efforts.

Strategic Water Resource Management and Maintenance: The ongoing maintenance and management of water infrastructure must be prioritized. Local municipalities, in partnership with community-based organizations, should establish routine checks and ensure that existing water systems are well-maintained. This approach will help to prevent disruptions and ensure the long-term sustainability of water supply systems.

Addressing Water Quality and Health Impacts: The provision of safe drinking water should be a priority. Improving water quality through treatment facilities will help reduce waterborne diseases and improve overall public health. Investments in purification systems, such as low-cost filtration methods, can play a crucial role in preventing contamination.

Comparative Analysis with Other Regions in South Africa: Comparing the water access and infrastructure challenges in the Eastern Cape and Mpumalanga to other rural regions in South Africa could help identify best practices. For example, regions that have successfully implemented rainwater harvesting and groundwater recharge systems should serve as models for replication in Mpumalanga and the Eastern Cape. This comparative study could also highlight areas where investments and strategies have been more effective.

Consumer Satisfaction Index Improvement Strategies: To improve consumer satisfaction with water infrastructure, the focus should be on enhancing the reliability of household taps and springs, which have the highest satisfaction levels in Mpumalanga. Expanding access to these water sources and ensuring their regular maintenance will likely lead to higher satisfaction rates. Similarly, addressing gaps in water access and quality for less satisfactory sources, such as communal taps and truck water tankers, should be a priority.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

NN: Writing – original draft, Writing – review & editing. SM: Writing – review & editing. AA: Writing – review & editing. EK: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2024.1468973/full#supplementary-material

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