The Utilisation of Solar-Powered Boreholes for Groundwater Supply: Addressing Water Scarcity in the Polokwane Municipality, Mankweng Cluster

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MEISIE ALPHINAH RASAKANYA
Department of Anthropology,
Archaeology and Development Studies
University of Pretoria
alphymeisie1@gmail.com

Abstract

In many African countries, including South Africa, groundwater remains vital for rural communities, yet sustainable methods of its supply still require improvement. The purpose of this study is to enhance groundwater supply through an innovative and sustainable borehole system that improves reliability and ensures a consistent water supply. This study was motivated by the need to provide sustainable water access in rural communities by addressing critical gaps in existing groundwater supply systems, thereby enhancing community resilience. This study identified a problem of water scarcity in the Polokwane Municipality, Mankweng Cluster, where the existing borehole systems are inadequate to supply groundwater. Handpumps demand significant physical effort, grid-powered boreholes cease to operate during frequent power cuts, and the inconsistent diesel supply further limits borehole operation. The study was conducted using a qualitative approach, involving data collection through interviews that were analysed using content analysis. Findings indicate several challenges, including power cuts, diesel supply shortages, poor infrastructure maintenance, vandalism, and theft of equipment, which affect the proper operation of boreholes. The study concludes that water scarcity in the Mankweng Cluster stems from inadequate water infrastructure. The study recommends implementing a solar-powered borehole system that uses photovoltaic energy to pump water from underground aquifers.

Keywords: Borehole, Groundwater, Rural development, Water infrastructure, Water supply

Introduction

In many African countries, like South Africa, groundwater remains vital for rural communities, yet sustainable methods of its supply still require improvement. Furthermore, the availability of groundwater resources is affected by climate change and population growth, which pose major challenges to water supply in rural communities across Africa. Africa is vulnerable to extreme climate change, which poses a significant risk to the availability, quantity, and accessibility of water resources (Rankoana, 2020). The continent is likely to warm during this century, and the warming is predicted to be larger than the global annual mean warming, with drier subtropical regions warming more than the moist regions (Rankoana, 2020). Many countries in the Sub-Saharan region are severely affected by water stress due to drought, low rainfall, and minimal water storage resolutions (Nephawe, 2021). South Africa is particularly vulnerable to water stress, considered the 30th country globally, with 40% less rainfall than the global average (Patrick, 2021). Climate change intensifies these challenges, as reduced rainfall and higher temperatures threaten groundwater and surface water levels, while more frequent extreme weather events risk damaging critical water storage facilities and infrastructure, ultimately impacting water quality and availability (Patrick, 2021).

The Limpopo province, the study's location, is already facing shifts in climate, with warmer, wet winters and increasingly hot, dry summers that are projected to intensify in the future (Rankoana, 2020). Beyond the existing challenges of poverty and limited access to services, changing climate conditions could further strain Limpopo's natural resources and impact community livelihoods (Limpopo Climate Change Response Strategy, 2016-2020). Due to climate variability and various socio-economic factors, groundwater has become an essential source of freshwater for domestic use (Lalumbe et al., 2022). Groundwater is widely available throughout the landscape, providing natural inter-annual and inter-seasonal storage with much higher water quality than surface water sources (Vitale et al., 2022). Groundwater is increasingly essential in rural Africa, particularly in Sub-Saharan regions, where surface water supplies are often insufficient or unreliable due to seasonal variations, climate change, and infrastructure challenges (Crookes et al., 2018). The reliance on groundwater resources has grown as rural populations expand, agricultural demands increase, and climate variability disrupts traditional water sources (Ohenhen et al., 2023). As rural communities are often the most vulnerable to water scarcity, especially where access to municipal supply infrastructure is limited, groundwater plays a crucial role in supporting household needs, farming, and small-scale industry (Nkuna et al., 2014; Ohenhen et al., 2023).

The South African Department of Water and Sanitation (DWS) estimates that nearly 85% of the country's groundwater aquifers are under-allocated, and at least 4.8 km3 is worth of exploitable groundwater (DWS, 2004). However, Jovanović et al. (2023) suggest that the sustainable use of groundwater resources can be achieved if it is carefully managed and regularly monitored. Tleane & Ndambuki (2020) also support that, to ensure such groundwater supplies are sustainable, accurate prediction of recharge to the groundwater aquifers must be done. In the Mankweng Cluster, communities rely primarily on municipal surface water supplied by Lepelle Northern Water to Polokwane Municipality, with groundwater being less utilised due to unreliable and inefficient pumping methods (Polokwane Municipality Integrated Development Plan, 2020–2021). Research across Africa highlights that solar energy is gaining global recognition as an efficient, readily available, and environmentally friendly option for sustainable groundwater abstraction and supply, offering clear advantages over fossil fuels (Odesola & Bright, 2020). Tleane & Ndambuki (2020) also emphasise the importance of identifying the appropriate type of solar system for effective water abstraction and sustainable groundwater supply.

This study aims to introduce an innovative and sustainable method for groundwater abstraction through a rotating solar-powered borehole system, offering a solution that enhances the reliability and consistency of groundwater supply. In particular, it examines how solar-powered borehole systems could alleviate the limitations of existing infrastructure, which relies primarily on handpumps, grid-powered boreholes, and diesel-powered generators. This study thus addresses the urgent need for a sustainable, cost-effective solution to improve groundwater access and aims to contribute meaningfully to rural water supply infrastructure. This study was guided by the following research questions: 1) How does inadequate water supply infrastructure affect water availability and community development in rural areas? 2) To what extent can a solar-powered borehole system improve the sustainability and reliability of groundwater supply in the Mankweng Cluster? This study identified a problem of water scarcity in the Polokwane Municipality, Mankweng Cluster, where inadequate borehole systems fail to supply enough groundwater to meet the community's needs. The boreholes in the study area face several challenges: handpumps require significant physical effort, grid-powered boreholes stop working during frequent power outages, and diesel-powered boreholes are hindered by an unreliable fuel supply.

The structure of this study begins with an introduction that outlines the main focus and justification. The introduction is followed by a literature review that examines water supply infrastructure and its role in community development. The review highlights how inadequate infrastructure affects livelihoods and identifies the need for sustainable solutions in rural water management. The study also includes the methodology section, which provides an overview of the study area, data collection methods, and data analysis techniques used. The results and discussion sections present findings on the current state of boreholes in the Mankweng Cluster, addressing several themes derived from the data. Subsequently, the study explores the characteristics and operational requirements of a solar-powered borehole system, outlining considerations for its effective implementation.

The final section offers conclusions and recommendations, emphasising the potential of solar-powered boreholes as a sustainable strategy for reliable groundwater supply in rural areas.

Literature Review

Water Supply Systems (WSS), often referred to as Water Distribution Systems (WDS) or Water Infrastructures (WI), are a form of water conveyance consisting of pumps, pipelines, valves, meters, storage tanks, and reservoirs, connecting treatment plants to consumer taps (National Research Council [NRC], 2005, p. 1). Since ancient times, water as a scarce resource has been imperative to the functioning of communities (Mays, 2010). Many ancient civilisations, such as Mesopotamia and the Indus Valley, sprang up along riverbanks and implemented various water technologies to manage and supply water to their communities (Mays, 2010). However, water supply has consistently been a primary challenge since the beginning of civilisation, and balancing water demand and supply has remained a major concern throughout history (Obeta & Nwankwo, 2015). Today, studies such as Salom & Khumalo (2022) show that inadequate water infrastructure disrupts many aspects of rural life by limiting access to a consistent water source, which directly affects crop irrigation, household needs, and sanitation practices.

Rural communities in South Africa, such as those in the Mankweng Cluster, heavily depend on groundwater sources (Loza et al, 2024). However, the inefficiencies of the current water supply systems underscore the need for sustainable and innovative solutions. Studies by Piliso et al. (2021) and Jovanović et al. (2023) illustrate how these challenges result in a decreased reliability of water access, often pushing rural residents to depend on unsafe or distant sources. This lack of a stable water supply and the mismanagement “perpetuate poverty, tremendous human health costs, as well as gender and other social inequalities,” resulting in weak local development (Salom & Khumalo, 2022, p. 29).

Inadequate water supply systems are not limited to South Africa but are also prevalent in other developing countries such as Malawi, where Phiri et al. (2020) similarly found that electric-powered water systems frequently fail due to power-outage, leaving communities vulnerable to water shortages. The consequences of inadequate water infrastructure are profound, impacting not only health but also economic productivity and educational outcomes. Research by Oskam et al. (2021) shows that women and children, who are often responsible for collecting water in rural communities, are disproportionately affected by infrastructure failures, spending hours searching for alternative sources This time-consuming task detracts from opportunities for education and economic activities, reinforcing cycles of poverty and limiting community progress (Oskam et al., 2021).

Amid these challenges, this study aims to bridge the gap in groundwater supply and management through a renewable energy solution, particularly a solar-powered borehole system, which offers a promising pathway for sustainable water supply. Solar-powered water infrastructure has also been suggested as a solution for supplying water to communities by (Chandel et al., 2015); (Longwe et al., 2019); (Piliso et al., 2021) & (Jovanović et al., 2023). Solar energy has the potential to bridge gaps in the existing boreholes by providing a reliable, renewable power source that mitigates the disruptions caused by load shedding and fuel shortages. Other researchers, such as Ashokkumar et al. (2020), also highlighted the importance of solar-powered systems. However, their focus was primarily on irrigation systems, leaving a gap in understanding the implications for potable water supply, which is more urgent in regions like the Mankweng Cluster. This study aims to address this gap by prioritising the application of solar-powered boreholes for drinking water, meeting the critical need for a reliable and sustainable water supply in rural communities.

Although solar-powered boreholes are widely considered an effective and suitable method for groundwater supply, the literature highlights high failure rates caused by issues with design, implementation, and maintenance.For example, Rilwanu (2016), who generated data through field observation, interviews, and focus groups, reported that 58% of solar boreholes in Kumbotso Local Government Area, Nigeria, were non-functional due to issues such as lack of finance, poor design, vandalism, and the exclusion of key stakeholders during the planning and implementation phases. Further, Longwe et al. (2019) reported that out of ten solar-powered boreholes implemented, three borehole projects were unsuccessful due to poor financial planning. Findings point out the importance of financial consideration when implementing innovative projects for rural communities. Addressing these barriers is crucial for advancing solar-powered water infrastructure as a viable solution to water scarcity. This study addresses a gap in the literature by proposing a sustainable, solar-powered borehole system designed specifically for the needs of rural South African communities. The goal is to present a model that not only enhances the reliability of water supply but also aligns with the socio-economic and environmental contexts of these communities, ultimately contributing to sustainable development. By addressing these gaps, the study contributes to the broader discourse on sustainable water supply solutions in rural communities, particularly in regions with limited access to grid electricity and vulnerability to water scarcity.

Materials and Methods

Description of the Study Area

The study area, known as the Mankweng Cluster, is located within the Polokwane Municipality in the Limpopo Province of northern South Africa. It is situated approximately 27 km east of Polokwane city along the R71 road. The Mankweng Cluster is one of the most prominent and densely populated clusters within the municipality (see Figure 1). It is also the second-largest cluster in the Polokwane Municipality, as noted in the Polokwane

Municipality Integrated Development Plan (2020–2021). According to the United Nations World Urbanisation Prospects (2018), the Mankweng area has an estimated population of 85,104. The region experiences a warm climate, characteristic of the summer rainfall zone. According to the Polokwane Municipality Integrated Development Plan (2020/2021), the highest temperatures typically occur in December and January, with an average high of 28.1°C in January and a recorded maximum of 36.8°C. The mean annual temperature variation is 15 °C with an average annual precipitation of around 478 mm. Rainfall is particularly low between May and September, with the June to August period receiving an average of just 4.6 mm of precipitation (Tleane & Dambuki, 2020). Geologically, the Mankweng Cluster is underlain by medium-grained, yellowish, laminated sandstone of the Makgabeng Formation within the Waterberg Group. The region is also characterised by various rock types, including granite, biotite granite-gneiss, pegmatite, lava, and pyroclastic materials (Tleane & Ndambuki, 2020).

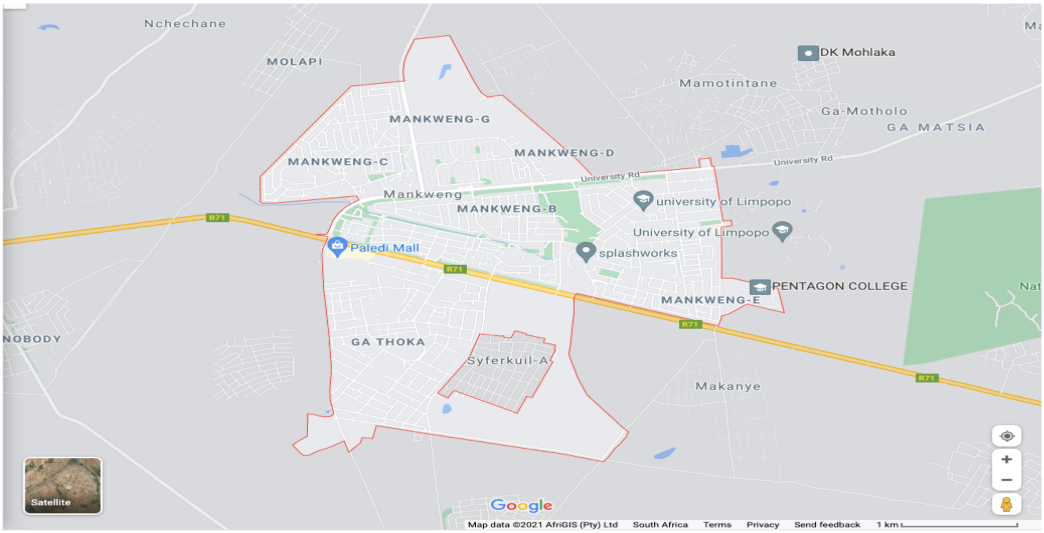

Figure 1: The map of the Mankweng Cluster in the Polokwane Municipality (Municipalities of South Africa, 2024).

Water supply to the Mankweng Cluster is primarily provided by the Ebenezer Regional Water Scheme (ERWS), which relies on surface water. However, the ERWS often runs dry during the dry season, leading to significant water shortages. The municipality's water supply infrastructure includes dams, reservoirs, reticulation networks, street taps, and borehole pumps. Despite these facilities, the current infrastructure is inadequate, largely due to the dispersed nature of the villages, which makes it challenging and costly to implement an effective reticulation system.

Data Collection

This study involved 117 participants under seven ward areas of the Mankweng Cluster, namely: ward six (06), ward seven (07), ward twenty-five (25), ward twenty-six (26), ward twenty-seven (27), ward twenty-eight (28) and ward thirty-four (34). In each ward area, 15 participants were selected, making a total of 105 household participants. Furthermore, the study also selected two (2) municipal officials (including the municipal manager responsible for water supply and sanitation in the Mankweng Cluster and a water infrastructure technician), seven (7) ward councillors, and three (3) headmen representing the entire area of study.

Households' participants were selected through systematic random sampling, while the municipal officials, Ward Councillors, and headmen were selected purposefully for their relevant knowledge about the status of the borehole systems and water supply in the community.

Data for the study was gathered through face-to-face interviews and focus group discussions to determine responses based on the challenges associated with existing boreholes and the responses to the solar borehole proposed in the study. The study also conducted field observation of existing boreholes to determine their functionality.

The proposed solar-powered borehole system was explained to community members, emphasising its potential impact on water security in the Mankweng Cluster. Although the system has not yet been implemented, it has already been showcased at several notable events, such as the Young African Leadership Initiative in 2022, the National Institute of Humanities and Social Sciences in 2022, the Young Leadership Initiative in 2023, and Entrepreneurship Development in Higher Education in 2023. These presentations highlighted the system's approval and its potential to address water scarcity in rural South Africa. While the proposed borehole system is still in the planning phase, the study identified key stakeholders for the implementation phase. These include renewable energy engineers specialising in solar systems, hydrogeologists for assessing groundwater resources and determining optimal drilling sites, and water resource engineers for designing efficient water distribution systems. Comprehensive consultation with these stakeholders will be essential for the successful deployment of the borehole system..

Data Analysis

The data analysis process began with transcribing the audio recordings into an Excel spreadsheet. The transcripts were then read multiple times to identify key themes and patterns. This step ensured that all relevant information was captured and aligned with the aims of the study. The identified themes were categorised and analysed to understand the participants' experiences. Next, the study employed coding, as described by Creswell

(2014), which involved assigning labels or symbols to different text segments to organise and interpret the data effectively.

Results and Discussion

In Mankweng Cluster, there are 62 boreholes across the seven ward areas. The data on the types of boreholes in the Mankweng Cluster suggests varying uses of energy sources across different wards.

Table 1: The types of boreholes used in the Mankweng Cluster

Wards	Types of borehole systems	Count	Frequency (%)
Ward six	Electrified boreholes	6	9.68
	Diesel-powered boreholes	2	3.23
Ward seven	Electrified-borehole	4	6.45
	Diesel-powered boreholes	1	1.61
	Handpump borehole	2	3.23
	Solar-powered borehole	1	1.61
Ward twenty-five	Electrified-boreholes	4	6.45
	Diesel powered-boreholes	2	3.23
Ward twenty-six	Electrified-borehole	6	9.68
	Handpump borehole	2	3.23
Ward twenty-seven	Electrified-boreholes	5	8.06
	Manual handpumps	1	1.61
Ward twenty-eight	Electrified boreholes	7	11.29
	Diesel power-boreholes	5	8.06
	Manual handpumps	4	6.45
	Solar-powered boreholes	1	1.61
Ward thirty-four	Solar powered-boreholes	2	3.23
	Electrified-boreholes	3	4.84
	Manual handpumps	1	1.61
	Diesel power-boreholes	3	4.84
Total		**62**	**100**

The different types of boreholes used in the Mankweng Cluster for groundwater abstraction are depicted in Table 1. Ward Six has 6 electrified boreholes (9.68%) and 2 diesel-powered boreholes (3.23%), but it lacks handpump and solar-powered boreholes. Ward Seven has 4 electrified boreholes (6.45%), 1 diesel-powered borehole (1.61%), 2 handpump boreholes (3.23%), and 1 solar-powered borehole (1.61%), meaning all types of energy sources are present. Ward Twenty-five has 4 electrified boreholes (6.45%) and 2 diesel-powered boreholes (3.23%), but does not have handpump or solar-powered boreholes. Ward Twenty-six features 6 electrified boreholes (9.68%) and 2 handpump boreholes (3.23%), lacking diesel-powered and solar-powered options. Ward Twenty-seven includes 5 electrified boreholes (8.06%) and 1 manual handpump (1.61%), but no diesel-powered or solar-powered boreholes are present. Ward Twenty-eight is the most diversified, with 7 electrified boreholes (11.29%), 5 diesel-powered boreholes (8.06%), 4 manual handpumps (6.45%), and 1 solar-powered borehole (1.61%), covering all energy types. Finally, Ward Thirty-four has 2 solar-powered boreholes (3.23%), 3 electrified boreholes (4.84%), 1 manual handpump (1.61%), and 3 diesel-powered boreholes (4.84%), lacking any energy source.

The findings from this study reveal that the use of electrified boreholes is more prevalent than any other borehole, with solar-powered boreholes being the least used. A similar study by Rilwanu (2016) conducted in Nigeria highlights a lower number of solar boreholes, with 26 boreholes using solar and 112 boreholes not using solar. In the case of South Africa, Piliso et al. (2021) reveal that, before 2008, South Africa's electricity costs were among the lowest globally, which made it an attractive option for irrigation and other energy-intensive activities. However, issues arose when Eskom, the national energy supplier, struggled to meet growing demand due to inadequate infrastructure and insufficient maintenance (Inglesi-Lotz, 2023). This led to load shedding, significant tariff increases, and a decline in service quality (Piliso et al., 2021). Yet, the transition to solar has been slow, as the agricultural sector has historically depended on electricity, which, until recently, was both affordable and reliable (Piliso et al., 2021).

Out of 62 boreholes found in the Mankweng Cluster, only 28 boreholes are functioning and 34 boreholes are not functioning as depicted in Table 2. The implication of these results is that boreholes are experiencing major challenges that impact negatively on their proper functioning, thus becoming unreliable to supply water to the communities.

Table 2: Functionality and nonfunctionally of boreholes in the Mankweng Cluster

Functionality & nonfunctionally	Count	Frequency (%)
Functionality	23	37.1
Non-Functionality	39	62.9
Total	**62**	**100**

A study by Rilwanu (2016) also found that the number of non-functioning boreholes in Nigerian communities is higher than the number of functioning boreholes. Similarly, Jovanović et al. (2023, p. 9) argued that the non-functionality of boreholes is “due to breakups and damages." This indicates that the state of boreholes in many rural areas is unsatisfactory and requires urgent attention

The existing boreholes in the Mankweng Cluster face several persistent challenges that contribute to disruptions in water supply and exacerbate water scarcity in the area. As shown in Table 3, these challenges include 33 cases (28.2%) of power cuts, 28 (23.9%) cases of a lack of diesel supply, 18 (15.4%) cases of vandalism, 20 (17.1%) cases of poor water quality, and 18 (15.4%) cases of inadequate maintenance.

Table 3: Challenges associated with boreholes in the Mankweng Cluster

Challenges	Count	Frequency (%)
Power-cut	33	28.2
Lack of diesel supply	28	23.9
Vandalism and theft	18	15.4
Poor water quality	20	17.1
Poor maintenance	18	15.4
Total	**117**	**100**

The findings from the study illuminate five key themes related to the challenges associated with the boreholes in the Mankweng Cluster, namely: (i) power-cut off—known in South Africa as "load-shedding," (ii) lack of diesel supply, (iii) vandalism and theft, (iv) poor water quality, and (v) poor maintenance of borehole systems. These themes were discussed to identify the complexities these challenges pose on existing boreholes and the broader issue of water scarcity in rural communities.

- ***Power-cut off***

Findings from this study revealed serious concerns about the electrified boreholes in the Mankweng Cluster. The ward councillors and the household members highlighted the issue of poor borehole operation due to electricity interruptions and a lack of diesel supply. In wards 26, 27, 28, and 34, participants expressed dissatisfaction with the boreholes, saying, “The electrified boreholes are usually not operating due to power cuts, and this disrupts the supply of water” (Participants 46-105). Similar research by Jovanović et al. (2023) and Piliso et al. (2021) also raised concerns about boreholes that operate on grid power, always not operative due to no electricity supply. Rilwanu (2016) reported that many boreholes in Nigeria have failed due to unreliable and often expensive electricity, which is insufficient to meet the daily water needs of large communities. Jovanović et al. (2023) also reported that in Greater Giyani Municipality in Limpopo Province, boreholes are either connected to the national grid or powered by fuel (diesel or petrol) for water pumping, and this strategy is not efficient to extract groundwater due to unreliable electricity. Additionally, Phiri et al. (2020) revealed similar electricity problems in Malawi, where electric-powered water pumping systems are at risk due to inadequate grid electricity, leaving some without power and others non-operational during outages. Similarly, the findings in this study align with Phiri et al. (2020), as electrified boreholes in the Mankweng Cluster face the same challenges, frequently becoming inoperative during power outages due to unreliable grid electricity. Yorkor & Leton (2018) mentioned that the lack of electricity for water pumping is the greatest challenge affecting the supply of safe drinking water in rural areas of River State in Nigeria. Additionally, Al-Khateeb (2021) argues that a continuous electricity supply is essential for all components of water supply systems to function, as water is moved through distribution networks by pumped or gravity-fed systems that require electricity. These disruptions in electricity, as observed by previous scholars and confirmed in this study, highlight the unreliability and inefficiency of current groundwater abstraction methods, ultimately placing communities at risk of water scarcity.

- ***Lack of Diesel Supply***

Diesel-powered boreholes also face challenges, especially in communities like the Mankweng Cluster, where the municipality struggles to keep up with public services. The costs of buying diesel were expressed by the municipal officials, headmen, and ward councillors. The municipal officials mentioned that “the municipality is experiencing financial problems, and the cost related to buying diesel makes it difficult to ensure proper supply of diesel for all boreholes operating with diesel” (municipal technician). Similar sentiments were raised by the ward councillors and the headmen, who shared similar sentiments about the costs associated with the boreholes. According to Jovanović et al. (2023), although these boreholes have helped communities with drinking water supply and small-scale farming, the rising cost of traditional energy sources has made water pumping increasingly expensive. Phiri et al. (2020) supported this, noting that diesel-powered systems are vulnerable to oil price fluctuations, fossil fuel depletion, pollution, noise, transportation, and high maintenance costs. Furthermore, Phiri (2020) noted that the Malawian government also installed diesel-powered boreholes and handed them to farmers for free, but most are no longer in use due to the farmers' inability to meet maintenance and fuel costs. This shows that the contingency plan related to addressing water scarcity in many rural areas is ineffective as these boreholes are unable to supply communities with their water needs, resulting in fruitless expenditure.

- ***Manual Pumping***

Manual pumping adds another layer of complexity due to the physical effort required, making the process time-consuming and tedious. The spatial distribution of these boreholes requires exhausting journeys for water collection, disproportionately impacting the daily routines of women and children, who often bear the responsibility of procuring water for households (Maziwisa & Lenaghan, 2020). Respondent 105 in Ward 28 mentioned a scenario where she walks long hours to collect water from a manual borehole, which affects her health: “I travelled more than 45 minutes to a communal borehole, and when I got there, I still had to use my energy to pump the water; since that day, I have been having back pain." Rilwanu (2016) found that the use of human energy to pump water from manually operating boreholes impacts negatively on the health of people. As a result, while manual boreholes have provided rural areas with water access for many years, they have not succeeded in offering everyone a fair, efficient, and long-lasting method of accessibility.

- ***Poor water quality***

Additionally, various concerns about the quality of existing boreholes significantly impact the lives of people, especially in rural areas (Harvey, 2014). Water from boreholes in the Mankweng communities is often saline and needs treatment before distribution, but municipalities struggle to maintain proper water quality. The experiences with poor water quality were echoed by all the households, ward councillors, and headmen expressing bad experiences of the water quality in terms of taste and smell. In wards 28 and 34, the ward councillors mentioned that the salinity of borehole water is due to the fact that the water is not perfectly purified before supply. Taonameso et al. (2018) also conducted a study in the Thulamela local municipality, Limpopo Province, detecting water quality contamination and a risk of coliforms and Escherichia coli in boreholes. These results highlight the need to consider regular water quality testing to identify and monitor contaminants and to install filtration and purification systems to remove harmful substances. This study seeks to bridge the water quality gaps in the literature and borehole implementations by incorporating water treatment systems into solar-powered systems.

- ***Vandalism and theft***

The findings from this study further reveal that existing boreholes are facing challenges of vandalism and theft. This challenge was expressed by the Polokwane Municipal officials and the ward councillors, emphasising that vandalism of boreholes is committed by the residents of the Mankweng Cluster who benefit from the service. The challenge of vandalism and theft of borehole equipment was highlighted in different studies, including Jovanović et al. (2023; p. 11), as one of the major challenges affecting water supply systems in rural areas. Piliso et al. (2021) found that water supply systems, including boreholes, are vulnerable to theft and vandalism in South Africa, largely due to a lack of security. In their study, Piliso et al. (2021) found that many users specified the increased need for borehole security. This concern was also echoed in another study that "providing adequate security is the major solution to the problems of borehole performance for water supply" (Rilwanu, 2016: 284).

- ***Poor maintenance of boreholes***

Poor maintenance of water supply systems including boreholes continues to be a major challenge in many rural areas. Households, headmen, and ward councillors in the Mankweng Cluster expressed deep concerns about the poor maintenance of boreholes, highlighting a significant issue in the community's water supply. A household member from ward 34 stated, “We’ve reported the same problem multiple times, but the boreholes remain in a state of disrepair (Respondent 98). Furthermore, one headman expressed frustration, saying, “The boreholes break down often, and when they do, it takes weeks, sometimes months, for any repair work to be done” (participant 109). Additionally, a ward councillor from Ward 28 echoed these concerns, noting, “Our community suffers because the maintenance teams are not well-equipped or skilled to fix the recurring issues” (Respondent 106). These sentiments are supported by studies such as Malima (2020) & Obeta & Nkwankwo (2015), which highlight that the ineffective operation and poor maintenance of water infrastructure in rural areas are often due to a lack of skilled technicians. This lack of technical expertise leads to improper repairs, exacerbating the deterioration of these crucial water supply systems. This study suggests that solar-powered boreholes should be protected by a security fence to avoid theft and vandalism. Furthermore, increasing public participation during the planning and implementation phases could enhance a sense of public service ownership, thus enabling communities to protect and sustain infrastructure that benefits them (Longwe et al., 2019). Given the concentration of poor water supply and food-insecure households in rural South Africa, there is an opportunity to improve water availability through the use of shallow groundwater and ephemeral rivers as alternative sources (Crookes, 2018).

In light of the lower utilisation of solar-powered boreholes to supply the community of the Mankweng Cluster, the study explored the community's interest in the usage of solar-powered boreholes for groundwater supply. Table 5 illustrates the respondent’s views on the utilisation of solar-powered boreholes in the Mankweng Cluster. The results show overwhelming support for this improvement, with 108 (92.3%) of participants expressing a desire to have these boreholes upgraded to solar-powered systems. However, some of the household members (7.7%) were unsure about the initiative. This uncertainty may stem from a lack of trust, likely due to their experiences with poor existing water supply systems in their communities, which has eroded confidence in promises of improvements.

Table 5: The state of need for solar-powered boreholes

Responses	Count	Frequency (%)
Agree	108	92.3
Unsure	9	7.7

Disagree	0	0
Total	**117**	**100**

The Polokwane Municipality has previously attempted to enhance water supply systems, but these efforts have largely been unsuccessful, leaving many systems non-operational and residents without adequate water supply. Furthermore, no respondent (0) showed disagreement with the improvements in the implementation of solar-powered boreholes in the Mankweng Cluster. A study by Odesola (2020) confirms the demand for solar energy to power boreholes as the study designs a solar-powered irrigation system. Solar-powered systems, such as boreholes, are especially gaining traction as they provide a sustainable and clean energy solution that meets the growing need for reliable power in many regions” (Odesola, 2020, p. 471). The findings of this study also aligned with Jovanović et al. (2023), who found that solar-powered boreholes are becoming more appreciated due to their ability to pump water every day and ensure continuous water supply.

The Characteristics and Components of the Proposed Solar-Powered System

This study presents a comprehensive borehole system configuration designed to ensure a reliable and sustainable water supply, incorporating advanced components for optimal performance. As shown in Figure 2, the system features a rotating monocrystalline solar panel (also known as a solar tracker), a power conditioning unit, a water purification system, a storage tank, and a submersible pump. Drawing on the works of other scholars, this study utilises monocrystalline photovoltaic (PV) modules (Ashokkumar et al., 2020; Yokor & Leton, 2018). The choice of monocrystalline PV panels is driven by their superior efficiency of up to 22% and their long lifespan of over 25 years, making them ideal for ensuring uninterrupted water supply in rural communities. Although monocrystalline panels are more expensive than polycrystalline options, their higher efficiency and durability justify the investment. The number of PV panels required for the system is determined by the desired output power and the solar irradiance available at the location. According to Shinde & Wandre (2015), the Polokwane area has an average solar irradiation of more than 2100 kWh/m2, which is fairly sufficient to power borehole systems. To maximise the efficiency of the PV panels, it is crucial to consider both the tilt and azimuth angles. The proposed system incorporates a solar tracker that adjusts the tilt angle of the PV panels throughout the day, ensuring they remain aligned perpendicularly to the sun's rays. A solar tracker follows the sun's movement and keeps the PV modules positioned at an angle that maximises energy production (Elbreki et al., 2016). In regions with high direct sunlight, solar trackers can be more cost-effective, requiring fewer panels to achieve the same energy output as fixed systems (Elbreki et al., 2016). Therefore, careful financial planning for the implementation and maintenance of this system is essential.

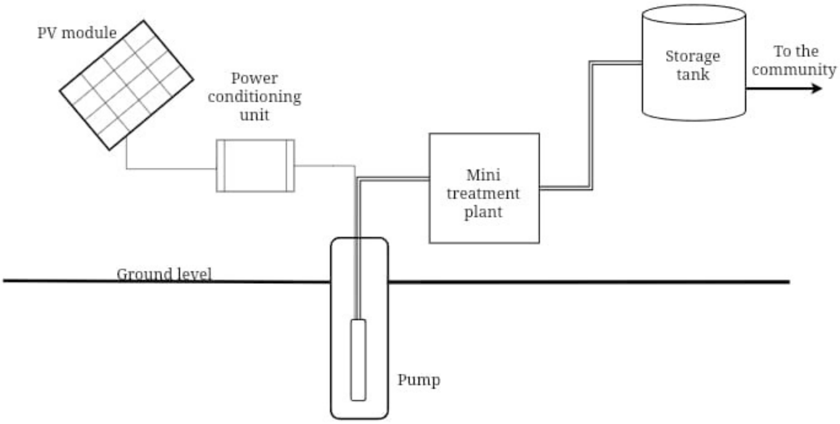

Figure 2: Proposed solar-powered borehole system
Prototype: Meisie Rasakanya

The power conditioning unit in the system includes a DC-DC converter, a battery, and a DC-AC inverter, supporting an AC-powered water pumping system, which is crucial for the submersible pump used for groundwater abstraction. These submersible pumps, powered by electricity generated by the PV cells and stored in rechargeable batteries, are highly efficient for drawing water from boreholes and transferring it to a storage tank, as described by Closas & Rap (2017). Tiwari et al. (2021) emphasised the need to operate solar-powered water pumping systems within their specified head conditions to achieve maximum efficiency. To address this, the proposed system will employ multistage submersible centrifugal pumps, which are well-suited for consistent performance under varying operational conditions. The size of the solar pumps will be determined by factors such as well depth, pipe system losses, and the required water flow rate. To enhance the quality of the abstracted water, the system incorporates a mini-water treatment plant using membrane technology, particularly nanofiltration. This technology effectively removes organic molecules, natural organic matter (NOM), and divalent ions from groundwater, as demonstrated by Tahaikt et al. (2021). The system's storage tank has a capacity of 20,000 litters (20 m3), and the pump is capable of delivering 30,000 litters (30 m3) of water per day, ensuring sufficient storage to meet daily needs and provide a reserve for emergencies.

Considerations of solar-powered borehole system

- ***Financial consideration***

The financial feasibility of solar energy has been highlighted through comparisons with traditional energy sources in various case studies. Solar energy offers potential cost savings exceeding ZAR 400,000 (22,586.00 USD) over a 25-year lifecycle compared to grid electricity (Jovanović et al., 2023). In contrast, diesel-powered systems are deemed financially unfeasible (Jovanović et al., 2023). Al-Khateeb (2021) attributes the rapid growth of solar-powered water systems to several factors, primarily including significantly decreasing installation costs and improved efficiency, lower maintenance expenses, greater reliability and resilience, and a reduced carbon footprint, especially in regions where fossil fuels currently power water supplies, as seen in Iraq. Nevertheless, other research, such as studies by Jumaat et al. (2018), Longwe et al. (2019), and Jovanović et al. (2023), points out that the major challenge in deploying solar-powered boreholes is the high initial capital investment. Consequently, it is likely that such investments will need to be subsidised through government or donor funding. In this study, financial analysis suggests that a fully configured solar-powered system could cost approximately R 148,052 (8,358.65 USD), encompassing both operational and capital expenditures. If sold for R210, 000 (11,850.91 USD), the system could yield a profit of R62, 000 (3,498.84 USD), reflecting a 40% profit margin. This demonstrates that the project is financially viable and offers a healthy profit margin, making it a worthwhile investment for the community. Therefore, community and local government engagement is crucial, as these stakeholders will jointly own and be responsible for the system's long-term operation and maintenance.

- ***Geo-hydrological consideration***

Implementing solar-powered groundwater pumping systems can have positive effects on water security, agricultural productivity, community engagement, and gender equality (Al-Khateeb, 2021). Nonetheless, there are potential downsides, particularly concerning natural resources. One major concern is the risk of excessive groundwater abstraction, which must be managed sustainably to avoid detrimental impacts (Crookes, 2018). This study builds on research by Tleane & Ndambuki (2020), who used Geographic Information Systems (GIS) to investigate groundwater issues in Polokwane Municipality, specifically near Makotopong within the Mankweng Cluster. Their findings highlight that estimating groundwater recharge has transitioned from a minor issue to a critical concern in hydro-geologic research, essential for the sustainable development of groundwater resources. Understanding groundwater recharge is crucial, as it indicates the volume of groundwater that can be extracted without depleting the aquifer. Various methods for estimating recharge, such as water-table fluctuation (WTF) and chlorine mass balance (CMB), can be used depending on data availability (Tleane & Ndambuki, 2020). The Integrated Development Plan of Polokwane Municipality (2021-2022) notes that shallow groundwater yields in the area are moderately high, making boreholes a viable option for community use. However, a significant challenge is ensuring the long-term sustainability of groundwater abstraction and mitigating the risk of overexploitation (Al-Khateeb, 2021). du

Toit & Sonnekus (2014) emphasise that overexploitation is a common issue, particularly in regions with extensive irrigation or poorly managed well fields serving large towns. This problem can be mitigated through effective groundwater management practices (du Toit & Sonnekus, 2014).

- ***Biophysical consideration***

According to Al-Khateeb (2021), the yields of specific boreholes and the characteristics of aquifers dictate the required pressure heads and water demands. The peak power requirements and the design of solar panel arrays can be fine-tuned based on the specifications of the equipment and the availability of components from suppliers and manufacturers, as well as the configuration of photovoltaic arrays (Al-Khateeb, 2021). The configuration and various components of the borehole system can be adjusted during implementation to ensure an optimal design and final setup (Jumaat et al., 2018). Although the system proposed in this study is designed with a preferred type of solar panel, pump, battery, and storage tank, the optimal design and setup will be finalised during the implementation phase. Al-Khateeb (2021) emphasises that multiple scenarios can be created to address different needs, such as water supply for irrigation and drinking, adjusting for varying irrigated areas, crop rotations, and population sizes. Establishing a solid foundation and realistic results from existing literature is advisable to assess the feasibility of implementing solar-powered groundwater pumping systems. Jovanović et al. (2023) further emphasise that solar-powered groundwater pumping systems should be viewed as emergency interventions and adaptation measures for climate change. These systems aim to improve well-being and health, reduce school absenteeism, and alleviate the burden of water collection on women and girls. They are not intended to replace bulk water supplies but can be integrated with existing bulk water systems where feasible. Therefore, the goal of implementing solar-powered boreholes in the Mankweng Cluster is to complement existing water supply systems, such as community taps, household taps, and water tankers, while reducing the overexploitation of bulk water provided by Lepelle Northern Water (a public utility serving the Polokwane Municipality) and addressing issues of intermittent water supply. Consequently, the implementation of solar-powered boreholes represents a significant milestone and a “fruitful expenditure” initiative, as it enhances water supply and addresses the water scarcity currently affecting many people.

Conclusion and Recommendations

The purpose of this study was to evaluate the current issues related to the Polokwane rural water supply, particularly the limitations of existing borehole systems, and to propose a solar-powered borehole system tailored to Polokwane's unique geographic, socioeconomic, and climatic conditions. The proposed system integrates key components such as a purification system, power conditioning unit, rotating solar panel, submersible pump, and storage tank. The findings of this study indicate that the existing boreholes are inadequate and insufficient for providing clean drinking water to the communities. This aligns with similar challenges faced across various parts of Africa, where boreholes suffer from issues like power outages, vandalism, poor maintenance, diesel shortages, and a lack of community involvement in the design and implementation phases. Additionally, beyond domestic use, solar-powered boreholes have been proven to have the potential to supply water for various sectors, including agriculture, thereby supporting food security and poverty alleviation in rural areas. This study supports the notion that solar-powered boreholes can effectively address issues such as intermittent water supply, poor water quality, lack of water access, and the burden on women and children who must travel long distances to manually pump water. The solar-powered borehole system proposed in this study aims to mitigate problems associated with grid power dependency, diesel costs, climate change, and water scarcity. Given the abundance of groundwater and clean energy in Limpopo Province, implementing a PV solar panel system to pump and extract groundwater is recommended as a viable solution tailored to the Polokwane's unique geographic, socioeconomic, and climatic characteristics. To ensure the sustainability of solar-powered boreholes and a sense of ownership within the community, the study recommends integrating community involvement in water management and educating residents on water conservation.

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