FEASIBILITY ASSESSMENT AND SUSTAINABILITY EVALUATION OF WATER SUPPLY OPTIONS FOR IMPLEMENTATION IN DROUGHT AFFECTED AREAS OF GIYANI: ENABLING RESILIENCE TO CLIMATE CHANGE

Report to the

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the South African Department of Forestry, Fisheries and the Environment

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EXECUTIVE SUMMARY

BACKGROUND

South Africa is extremely vulnerable and exposed to the impacts of climate change both within its socio-economic and environmental settings. The marginalized and poor are particularly affected by the impacts of climate change. This advocates for a balanced planning and response to climate change while adapting to the new normal. In the South African context, where water resources are fully allocated in most catchments, shallow groundwater and alluvial aquifers of ephemeral (or dry sand bed) rivers are potentially alternative sources of water. Given the majority of poor and water/food-insecure households in South Africa are still concentrated in rural areas, there is an opportunity to improve water availability and ephemeral rivers have the potential to be alternative water sources for multiple uses (domestic, agricultural crop and livestock production).

Sustainable development is critically dependent on sustainable management of natural resources (e.g. water) and the transition to a low-carbon economy through reduced use of coal-derived electricity. Technologies which increase water resource sustainability through the use of renewable energy can deliver both. Additional water resources and energy made available can then be used for development and sector growth and help to drive job creation.

An indirect benefit of improved and secure water supply is that health risks of dependent communities are minimized. This is particularly important in the context of the coronavirus crisis as people with the least access to essential services like water will feel the most dramatic effects. Large portions of the rural population lack access to basic hand-washing facilities in their homes or they experience partial access or regular shut-offs. Over-crowding and low water access can fuel COVID-19's spread. Investing in long-term water security and access to clean water and sanitation is therefore a matter of public health.

RATIONALE

A comprehensive feasibility study on the utilization of local scale alternative water source interventions and associated technologies for water abstraction and supply has not been done at large scale. This project responds to the primary WRC objective of augmenting drinking water supply, national food security, improving the livelihoods of people in rural communities, and the sustainable utilization and development of water resources. A sustainable and secure water resource will improve the livelihood of rural communities, and provide opportunities for emerging farmers and for further job creation.

The project investigates the technical, socio-economic and environmental feasibility for the establishment of Alternative Water Source (AWS) systems, different groundwater options and Multiple Use Water Schemes (MUS) in order to provide water services for domestic and agricultural purposes. Multiple use water schemes are low-cost, community-driven water supply schemes for domestic water, water for agriculture (irrigation, rain fed), homestead, garden, cattle, habitats for fish and other aquatic resources and rural enterprise water supplies. Water security can be achieved through conjunctive use of a variety of water sources, using a water mix approach while always coupled to demand-side interventions.

However, increased groundwater abstraction to support agricultural intensification as well as other water uses implies increased costs of energy (electricity, diesel for power generators, etc.). Combining MUS with alternative sources of energy (e.g. solar-powered water pumps) would be a very realistic option to reduce environmental impacts, costs and to close the loop of the water-food-energy nexus. Solar panel-powered systems for abstraction of water from non-perennial river sand banks and shallow groundwater represent a relatively new product that hasn't been widely adopted amongst rural communities, giving the opportunity of a secure water source with minimal energy costs. The main project outcome is envisaged to be the augmentation of secure water supplies for multiple uses, especially during drought periods, and the reduction in energy costs of pumping through the use of renewable sources.

OBJECTIVES AND AIMS

This project aimed at investigating the technical, socio-economic and environmental feasibility for the establishment of Alternate Water Source Systems (AWS), different groundwater options and Multiple Use Water Schemes (MUS) in rural communities of Greater Giyani Municipality (Limpopo) in order to provide a secure water source for domestic and agricultural purposes. Specifically, the project proposed to investigate the feasibility of solar panel-powered pumps for abstraction of water from non-perennial river sand banks and shallow aquifers.

AIM 1

The first aim was to examine the feasibility of implementing selected water supply interventions in water scarce areas frequently affected by recurring droughts/climate extremes.

AIM 2

The second aim was to assess the environmental and operational suitability of the proposed interventions.

AIM 3

The third aim was to facilitate the water use authorization process.

METHODOLOGY

The feasibility and implementation of MUS and solar-powered groundwater pumping systems depend on site-specific characteristics. Potential sites for implementation of MUS within Greater Giyani Municipality were considered bearing in mind the following criteria: i) availability and reliability of a water source; ii) community need (water demand); iii) water use diversification opportunity; iv) current infrastructure gaps; v) system set-up logistical complexity/ease; vi) economic activity potential; vii) access to markets; viii) tribal and traditional support; ix) health and hygiene improvements; and x) cultural activity and economic potential.

The feasibility assessment of solar-powered systems for abstraction of shallow groundwater was structured into the following components:

- ***Geophysical feasibility:*** This was conducted in order to evaluate the potential extent of the implementation of the technology in the villages of Greater Giyani Municipalities. A water resource assessment was conducted by making use of available desktop information in order to determine quantity and reliability of the water source. Population size and density as well as water use information were acquired in order to determine if, and how much these systems can satisfy water demand by the community. A field recognisance trip was undertaken to assess potential sites for piloting the technologies.
- ***Technical and engineering feasibility:*** This referred to the technical aspects of AWS and MUS, such as type of pumps, electronics, engineering design for capacity, energy efficiency and consistency between the components, piping, fittings and distribution system as well as practical maintenance of such systems (e.g. pump corrosion and longevity, electronic control and power stabilization, longevity and degradation of solar panels, need for storage reservoirs, maintenance of piping, fittings and distribution system) for a possible larger scale application of the technology. An important part of the operational aspect is the water quality fitness for use and the establishment of a

monitoring programme, in particular for drinking water supply, and the need for water filtration and purification.

- ***Socio-economic feasibility:*** This referred primarily to the cost of installation and operation of the systems (capital investment and running costs), the perception and willingness of the community, the management and technical capacity of the community, the need for training, the opportunity to create/engage small scale enterprises and generate revenue.
- ***Environmental feasibility:*** Beneficial and detrimental impacts on the environment were investigated, in particular related to the water volumes to be abstracted, water quality, vegetation and ecosystems, and the built environment. The regulatory framework was assessed, in particular for water use licensing, environmental legislation and requirements by any water service providers. Alternative options were weighed by combining geophysical and technical feasibility with socio-economics and environmental impacts.
- ***Financial Feasibility:*** It assessed the economic viability of proposed solutions by evaluating the investment costs, operating expenses and financial sustainability.

The core of the methodology for feasibility assessment was the "Toolbox on Solar Powered Irrigation Systems (SPIS)" (GIZ and FAO, 2021). The SPIS Toolbox consists of the following modules:

- The ***Promote and Initiate*** module on promotion and public awareness of SPIS.
- The ***Safeguard Water*** module that calculates water requirements and reports water resource management information.
- The ***Market*** module used to conduct a market assessment.
- The ***Invest*** module that provides a farm economic analysis and calculation on payback on investment.
- The ***Finance*** module that determines feasible financial services.
- The ***Design*** module used to configure and design the system.
- The ***Set Up*** module that provides information on system installation and workmanship.
- The ***Irrigate*** module that calculates recommended irrigation scheduling.
- The ***Maintain*** module that provides guidelines on maintenance, servicing and monitoring.

The SPIS Toolbox was developed primarily for small-scale irrigation. Where necessary and possible, the SPIS Toolbox was adapted and populated with data to fit the multi-purpose of MUS schemes. Three different scenarios were considered in the study area:

1) Solar-powered groundwater pumping system for the primary purpose of small-scale irrigation.
2) Solar-powered groundwater pumping system for the primary purpose of drinking water supply.
3) Mixed agricultural and drinking water use.

A stakeholder engagement field trip was undertaken in September 2021. The purpose of the stakeholder engagement was to meet communities at all potential pilot sites, obtain their support and buy-in for the proposed interventions of establishing Multiple Use Water Services (MUS) and solar-powered groundwater pumping infrastructure, and collect additional data for the feasibility study, in particular by acquiring both bio-physical and socio-economic information on the ground. The community engagement was conducted in the form of consultation workshops organized in clusters of villages.

RESULTS AND DISCUSSION

The feasibility assessment for the implementation of solar-powered groundwater pumping systems was conducted with the SPIS Toolbox (GIZ and FAO, 2021) in terms of geophysical, technical-engineering, socio-economic, environmental and financial feasibility. The SPIS Toolbox was found to be suitable for feasibility assessment of agricultural water use as well as for drinking water supply with some adaptation.

Groundwater yields from boreholes in the area typically range between 1 and 3 L/s (86 and 259 m^3/d). A safe yield of 7.2 m^3/h (2 L/s) could be sustained for about 8 hours per day (57.6 m^3/d). Geophysical parameters indicated that the area is marginally to moderately suitable for solar-powered groundwater systems. It is particularly suitable in terms of solar radiation (4.9 kWh/m^2/d or photovoltaic power output of 1589.3 kWh/kWp), agricultural productivity and market potential. However, water resources are scarce and they need to be managed sustainably. Technical capacity needs to be built.

The SPIS Toolbox was first applied to a hypothetical smallholder irrigation farm (or small village for drinking water supply, where applicable). For the hypothetical farm that irrigates 0.5 ha of vegetables (3 crops per year) with a few cattle heads, the estimated gross farm profit is R251,600/a. The peak water requirement of the farm will be 33.9 m^3/d in the month of December. This volume of water corresponds to the water supply to a village of about 1,350 people at a rate of 25 L per person per day. Given the technical design configuration for the smallholder farm used as an example, the system requires between 1.4 and 1.5 kWp to power the pump with a solar panel surface between 9.3 and 10 m^2.

When solar, grid and diesel power sources were compared, the grid-powered system has the highest Internal Rate of Return, whereas the solar-powered system has the highest Net Present Value and accumulated cash flow over 25 years. The solar-powered system will take 4 years to payback compared to 3 years for the grid-powered system. The diesel-powered pumping system is not financially viable. The solar-powered system has the highest capital investment cost, however starting from year 7, the cumulative costs become lower than for the grid-powered system. Savings in costs of >R400,000 were estimated for the solar-powered system compared to the grid-powered system for a life cycle of 25 years. Feasible financial mechanisms were identified to be: leasing, cooperatives, informal saving groups and pay-per-use. However, it is likely that the solar-powered systems will have to be funded and the operation and maintenance subsidized through donors/governmental institutions, at least during the piloting phase.

Many of the technical issues highlighted during the consultative workshops with communities and stakeholders came down to lack of operations and poor design or maintenance. These were often broken pumps, lack of sufficient pressure head, lack of a reticulation system, non-functional water purification systems (reverse osmosis), non-functional control boards, stolen pumps, stolen electrical cables and similar. It was suggested that this type of repairs and maintenance are within the domain of the water service provider, although there appears to be a lag in communication and time in the resolution of technical issues on the ground.

However, there are examples and potential sites that were visited, which lend themselves very well to build on current infrastructure, e.g. boreholes and water reservoirs have been established, pumps and pipelines are operating, etc. Financial constraints pertaining to the high cost of fuel and electricity appear to be high on the community agendas, which justifies the capital investment in renewable energy sources to power the water supply systems that can be a cheaper option in the long run. Most villages do not have water on tap and accompanying infrastructure, which makes the need for water supply intervention urgent.

Based on the criteria for site selection, the consultative discussions with the community, the level of commitment displayed by local stakeholders and the purpose of the interventions, 9 pilot sites were proposed, namely 4 villages in dire need of water supply for domestic use and 5 small-scale farms: i) Mbhedle, ii) Mayephu, iii) Mzilela and iv) Matsotsosela villages, v) Nhlambeto farm in Dzumeri village (mixed water use), vi) farm with nursery structure in Dzumeri, vii) A hi tirheni Mqekwa farm, viii) Duvadzi farm and ix) Muyexe community project.

Each of these proposed pilot sites have different characteristics in terms of water requirements and the pressure heads to be delivered by the pump depending on the geophysical settings.

The technical design of solar-powered pumping systems was therefore refined for each proposed pilot site using the Design Module of SPIS. Water requirements depend largely on the size of the population to be supplied with water, ranging from 28.8 m^3/d for the pilot site in Mzilela to 58.9 m^3/d for Nhlambeto farm in Dzumeri (mixed water use). Water requirements on farms, assuming the same cropping system and irrigation area as the hypothetical farm, are the same (33.9 m^3/d) because the same climatic data were used. Nhlambeto farm is the only site using shallow groundwater from the river bed alluvium, so it has the lowest total dynamic head requirement of 20 m. A hi tirheni Mqekwa farm pumps water from boreholes that are quite distant from the irrigated field and it requires the highest total dynamic head of 43 m. The village of Mbhedle requires the longest conveyance pipe (>700 m), but the water requirement is quite low, so the estimated total dynamic head is 33 m. The peak power requirements ranged from 1.2-1.3 kWp at Mzilela with the lowest population size to 2.8-3.4 kWp at Matsotsosela with the highest population. This corresponds to a solar panel surface area requirement of 8.0-8.7 m^2 at Mzilela and 18.7-22.3 m^2 at Matsotsosela. Fairly high peak power requirements and large solar panel areas were calculated for Mayephu (large population), A hi tirheni Mqekwa farm and Muyexe community project (large total dynamic head). On the other hand, relatively low peak power requirements and small solar panel areas were calculated for Mbhedle, the Dzumeri farm with nursery and Duvadzi farm, which have generally lower water requirements than the other sites.

Peak power requirements and design of solar panel arrays can be further adjusted based on the equipment specifications and availability on the market from suppliers and manufacturers. The pipeline layout, pipe diameter, installation of tanks, including the use of booster pumps to secure enough water pressure is delivered, can all be adjusted at the time of implementation in order to secure an optimal design and final set up.

The results of the feasibility assessment serve as a scientific foundation to support the application for water use authorization for these new developments. The research team will facilitate the implementation process on behalf of the beneficiaries.

CONCLUSIONS

The following conclusions were drawn from the feasibility assessment for the implementation of the solar-powered groundwater pumping systems and MUS:

- The implementation of solar-powered groundwater pumping systems will result in beneficial impacts on water security, agricultural impact, involvement of local communities and gender equity. However, it may have negative impacts on natural resources, especially if over-abstraction of groundwater occurs, which needs to be controlled through sustainable management of groundwater.

- Groundwater storage should be sufficient to sustain water supply during periods of drought as a reserve, however groundwater recharge will be essential from occasional flood events to render abstraction sustainable.
- For a hypothetical farm that irrigates 0.5 ha of vegetables (3 crops per year) with a few cattle heads, the estimated gross farm profit is R251,600/a. The peak water requirement of the farm will be 33.9 m^3/d in the month of December. This volume of water corresponds to the water supply to a village of about 1,350 people at a rate of 25 L per person per day. Given the technical design configuration for the smallholder farm used as an example, the system requires between 1.4 and 1.5 kWp to power the pump with a solar panel surface between 9.3 and 10 m^2.
- The final design of the system can be refined at each pilot site during the implementation phase. This will depend on:
    - Equipment specification and availability on the market from suppliers and manufacturers
    - Specific borehole yields and other characteristics
    - Required pressure heads and water requirements
    - Pipeline layout, pipe diameter, installation and size of tanks
    - Installation of booster pumps to secure enough water pressure is delivered
    - Photovoltaic arrays arrangements, etc.

A large number of scenarios can be constructed for different cases: multiple use supply for irrigation and drinking water, different irrigated areas, crop rotations, population numbers, hydrogeological settings, groundwater yields and storage, configuration of solar panels, battery and hybrid systems, pump specifications, conveyance pipe layout and size, volume of storage tanks, financial inputs and results, etc. However, it is deemed that the examples provided in this report and recommended pilot sites establish a good starting point and realistic results on the feasibility of implementation of solar-powered groundwater pumping systems.

RECOMMENDATIONS FOR FUTURE RESEARCH AND WAY FORWARD

Based on the criteria for site selection, the consultative discussions with the community, the level of commitment displayed by local stakeholders and the purpose of the interventions, 9 pilot sites were proposed, namely 4 villages in dire need of water supply for domestic use and 5 small-scale farms: i) Mbhedle, ii) Mayephu, iii) Mzilela and iv) Matsotsosela villages, v) Nhlambeto farm in Dzumeri village (mixed water use), vi) farm with nursery structure in Dzumeri, vii) A hi tirheni Mqekwa farm, viii) Duvadzi farm and ix) Muyexe community project.

In terms of securing satisfactory water quality, filters should be used for irrigation water supply, whilst a water purification system is essential for drinking water supply. A monitoring programme needs to be established, based on adequately frequent sampling and analyses for physical, chemical and microbiological vectors at control points, especially for drinking water. Emergency plans should be put in place in the case of water contamination. Regular monitoring of groundwater levels (e.g. monthly) is also strongly recommended to avoid excessive drawdown of groundwater tables beyond sustainable recovery levels.

The involvement and commitment of the local government (Greater Giyani Municipality and Mopani District Municipality) is essential because these are the water service authorities in the area and the mandated water services providers. Along with the mandate, local government will also be the co-owner of the systems and be responsible for maintenance in the long run.

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1. INTRODUCTION

1.1 Climate impacts: Recurring droughts and increased water scarcity

Extreme climate events including tropical cyclones, flooding, veld fires and drought have posed severe impacts on the economy, community and ecosystems over recent years. These events are closely linked to known drivers of climate variability, such as the El Niño Southern Oscillation, together with increased realisation of the consequences of climate change. Actions and interventions responding to the changing climate require the research sector to characterize the likely impacts of climate change and to develop strategies and positions for sectors to respond to identified risks and opportunities. These include determining how important climatic variables are changing, quantifying their natural variability on multi-decadal or longer time scales, improving confidence in climate projections to allow for better risk management, reducing the cost of managing the impacts of climate change, and enabling exploitation of potential opportunities. Within this context, the Water Research Commission (WRC) has identified several problematic areas and also experimented possible interventions to improve water security in light of the changing climate.

Climate change impacts on water resources occur through a modification of the water balance. Projected decrease in rainfall will negatively affect hydrological responses and groundwater recharge. Increased occurrence of extreme climatic events come with negative implications for infrastructure, health, production and economic growth. These impacts will increase water supply pressure in already water stressed environments (WRC, 2018). South Africa is extremely vulnerable and exposed to the impacts of climate change both within its socio-economic and environmental settings. It is a water-stressed country which is facing future drying trends and increased weather variability coupled with climate extremes such as cycles of droughts and floods (Jury, 2019). Furthermore, these situations will affect the marginalised and the rural poor (Petja, 2017). These identified impacts advocate for a balanced planning and response while adapting to the new normal. It is important to adequately plan to respond to both droughts and floods while increasing resilience to these extremes. Future infrastructural development needs to ensure that more flood water is captured and stored. This will reduce the societal vulnerability to the impacts of floods while reserving this extremely high amount of water for use in drier periods and also for groundwater recharge. This current work intends to conduct feasibility assessments in identified water scarce areas prior to the implementation of sustainable water supply interventions. This will in turn contribute to improving the resilience of rural areas to a changing climate which is characterized by recurring climate extremes and also encourage sustenance of rural livelihoods.

In the South African context, where water resources are fully allocated in most catchments, shallow groundwater in alluvial aquifers of ephemeral (or dry sand bed) rivers is potentially an alternative source of water. Water resources contained within these alluvial aquifers have been utilised for centuries by local communities, in particular in resource-poor rural areas through low-tech and unregulated means (Owen, 1989; Love et al., 2011). In a previous WRC project No. K5/2426 on the "Riparian Shallow Groundwater Utilization for Smallholder Irrigation in the Mopani District, Limpopo Province", one of the main outcomes was that sustainable utilization of water resources from an ephemeral river in Limpopo is possible, provided this is done in a controlled and monitored manner (Walker et al., 2018). Given the majority of poor and water/food-insecure households in South Africa are still concentrated in rural areas, there is an opportunity to improve water availability and ephemeral rivers have the potential to be alternative water sources for multiple uses (domestic, agricultural crop and livestock production). A comprehensive feasibility study on the utilization of local scale alternative water source interventions and associated technologies for water abstraction and supply has not been done at large scale. This project aims at investigating the technical, socio-economic and environmental feasibility for the establishment of Alternate Water Source Systems (AWS), different groundwater options and Multiple Use Water Schemes (MUS) in rural communities of Greater Giyani Municipality (Limpopo) in order to provide a secure water source for domestic and agricultural purposes. Specifically, the project proposes to investigate the feasibility of solar panel-powered pumps for abstraction of water from non-perennial river sand banks and shallow aquifers.

1.2 COVID-19 and water resources

As the coronavirus crisis spread throughout the world, it is increasingly clear that people with the least access to essential services like water will feel the most dramatic effects. Major health organizations advise washing hands more frequently – for at least 20 seconds – to prevent outbreaks. Yet 3 billion people, 40% of the world's population, lack access to basic hand-washing facilities in their homes. And that's only part of the problem. Nearly a billion people experience only partial access or regular shut-offs even when they do have piped water, making frequent hand-washing difficult or impossible. Public health depends on secure water resources for all. Governments must take steps to not only expand water access now to control COVID-19, but to create more resilient communities by addressing the root problems of water insecurity. The problem is particularly difficult for the more than 1 billion people living in slums or informal settlements, where over-crowding and low water access can fuel COVID-19's spread and also in rural areas with limited access to water. Investing in long-term water security and access to clean water and sanitation is essential for public health. Funding for water and sanitation not only builds more resilient and thriving communities, but it can improve local economies (Otto et al., 2020). Within the context of this proposed work, proposed interventions will go a long way in ensuring long-term water availability and sustainable use which in turn discourages environmental and health consequences. Implementing this feasibility study will ensure compliance with the prescribed regulations that are aimed at minimizing the spread of COVID-19.

The feasibility study requires to be put in the context of COVD-19 and the risk of future pandemics. As the pathways for spread of SARS-CoV-2 are generally unknown (transport and persistence in water, response to environmental factors, etc.), the feasibility study addresses the following topics:

- The water quality monitoring program will have to include protocols for sampling and analyses of viruses aligned with national guidelines, in particular if the technology is used for drinking water purposes.
- Protocols for financing, operation and maintenance of the water supply system during periods of pandemics and lockdown.
- Socio-economic implications (e.g. impacts on human immunity and health, marketing and economy of safe agricultural products, alternative sources of water during pandemics, etc.).

This is supported with a review of relevant experiences and responses that are known to have worked/not worked in other countries and regions.

In Greater Giyani Municipality, the main implications of COVID-19 are the re-shuffle of budgets in favour of health care and vaccines, which resulted in the majority of developmental projects to be implemented in the medium-term framework being postponed (Greater Giyani Municipality IDP, 2021). Additionally, the pandemic affected the operations and service delivery of the municipality with most staff being forced to work from home due to lockdown regulations, the public participation events as well as tourism development that depends on visitors.

1.3 Outcomes and expected impacts

This project responds to the primary WRC objective of augmenting drinking water supply, national food security, improving the livelihoods of people in rural communities, and the sustainable utilization and development of water resources. A sustainable and secure water resource will improve the livelihood of rural communities, and provide opportunities for emerging farmers and for further job creation. Sustainable development is critically dependent on sustainable management of natural resources (e.g. water) and the transition to a low-carbon economy through reduced use of coal-derived electricity. Technologies which increase water resource sustainability through the use of renewable energy can deliver both. Additional water resources and energy made available can then be used for development and sector growth and help to drive job creation in the sector. In the long run, the communities will be empowered to manage the water resource. An indirect benefit of improved and secure water supply is that health risks of dependent communities are minimized.

The research will inform national government policy in the water sector, e.g. the Water for Growth and Development Framework 2030, and the National Water Resource Strategy (NWRS2, 2013). The core objective is to ensure water for an equitable and sustainable future. The research also responds to the need for adaptation to climate change in the water and agricultural sectors, both nationally (e.g. Climate Change Adaptation Strategy for Water, 2016) and provincially. From the human capacity development point of view, the project contributes novel scientific knowledge to fill the gap in the water sector. University students will benefit from a strong team approach and multi-disciplinary research. Other beneficiaries include the local communities and government offices.

The project investigates the technical, socio-economic and environmental feasibility for the establishment of Alternative Water Source (AWS) systems, different groundwater options and Multiple Use Water Schemes (MUS) in order to provide water services for domestic and agricultural purposes. Solar panel-powered systems for abstraction of water from non-perennial river sand banks and shallow groundwater represent a relatively new product that hasn't been widely adopted amongst rural communities, giving the opportunity of a secure water source with minimal energy costs. Alternative water sources and solutions will improve access to potable and fit-for-purpose water. Multiple use water schemes are low-cost, community-driven water supply schemes for domestic water, water for agriculture (irrigation, rain fed), homestead, garden, cattle, habitats for fish and other aquatic resources and rural enterprise water supplies. Multiple use water schemes also support important cultural values and functions that are essential for local well-being and livelihoods, and they might provide ecological benefits which include flood control, groundwater recharge, water harvesting, water purification and biodiversity conservation. The infrastructure is highly diverse ranging from small-scale soil moisture retention measures to complex, multi-tier mechanized bulk infrastructure. This entails assessment of availability and sustainability of groundwater sources.

Supply-side increases are dependent on local hydrological, geological and meteorological conditions and they must be coupled with demand-side interventions to strengthen resilience at all scales. Supply-side increases can be achieved through, e.g. increasing storage (surface and subsurface), water transfers from other regions, the development of unconventional water sources (e.g. fog water harvesting), and the reduction of evaporation from storage systems (storing water in aquifers), amongst others. Supply-side interventions must be coupled with equally robust demand-side interventions to ensure longer term water availability. Demand-side decreases that will increase resilience include water sensitive design to reduce water usage and increase supply, water saving technologies (low flow devices, low water use sanitation, etc.), and efficient agricultural practices, to name but a few. Water security can be achieved through conjunctive use of a variety of water sources, using a water mix approach while always coupled to demand-side interventions. The main project outcome is envisaged to be the augmentation of secure water supplies for multiple uses, especially during drought periods, and the reduction in energy costs of pumping through the use of renewable sources.

1.4 Project objectives

The main aim of the project was to assess the feasibility and sustainability of water supply-demand interventions in drought-affected areas of Greater Giyani Municipality. Specifically, the project aimed at assessing the feasibility of solar panel-powered pumps for abstraction of shallow groundwater. The specific objectives of the project were:

1) To examine the feasibility of implementing selected water supply interventions in water scarce areas frequently affected by recurring droughts/climate extremes.
2) To assess the environmental and operational suitability of the proposed interventions.
3) To facilitate water use authorization process.

1.5 Structure of the report

This document represents Deliverable 3 "*Reporting*" of WRC project No. C2020.2021-00718 on "Feasibility Assessment and Sustainability Evaluation of Water Supply Options for Implementation in Drought Affected Areas of Giyani".

A comprehensive literature review was conducted to document existing information on solar-powered systems for abstraction of shallow groundwater (Chapter 2). This is followed by a report on data collected for the feasibility assessment at the selected study sites in Greater Giyani Municipality (Chapter 3). The feasibility assessment for different options is structured in Chapter 4 under various headings related to the geophysical feasibility, technical and engineering feasibility, socio-economic feasibility, environmental feasibility and financial feasibility. The proceedings and outcomes of stakeholder engagements are documented in Chapter 5. Chapter 6 reports on the refinement of the technical design for the implementation of solar-powered systems for pumping groundwater at proposed pilot sites. Finally, outcomes, conclusions and recommendations are drawn in Chapter 7.

2. LITERATURE REVIEW

In recent years, a new approach to water supply and provision of water services in rural areas has been proposed, namely multiple use water services (MUS) (Van Koppen et al., 2009). Multiple use water scheme is a community-based water services provision system built on the principles of decentralization, community participation and empowerment, with the objective of improving the provision of water services and the impacts on livelihoods. This approach is particularly suitable to poor rural and peri-urban areas, with the identification of the water resource and the integration of multiple water users being of key importance.

Examples of real-life MUS applications in several countries were presented by Van Koppen et al. (2009), Smits et al. (2010) and Rautanen et al. (2014). These examples of participatory MUS in remote rural areas were meant to provide water for a multitude of users, namely drinking water supply, water for sanitation and hygiene, conventional and unconventional irrigation, micro-hydropower, water mills and livestock watering. Community participation is required to define the sharing of costs and benefits, management of competing demands, preventing over-use of water sources, and achieving necessary institutional reforms since the inception, design and planning stages. Amongst the case studies investigated in several countries by Van Koppen et al. (2009), one of them involved 11 villages (Ward 16) in the Bushbuckridge Local Municipality in South Africa. The main conclusions from these studies were that the participatory MUS approach improved access, availability, quality and reliability of water services in households, however an enabling environment is required at the level of local governance to promote inter-sectorial collaboration and community participation.

MUS can take various forms, and in many instance they already exist in the form of traditional water supply schemes. For example, Walker et al. (2019) indicated that shallow groundwater from ephemeral sand rivers has been utilized in dryland regions for millennia. These water sources are widely utilized in the southern African region by local communities for drinking water, agriculture and livestock watering (Walker et al., 2018). Sand river abstraction points take the form of rudimentary hand-dug pits, open brick-lined wells or more sophisticated buried tanks (Figure 2.1).

Figure 2.1 Examples of installations for shallow groundwater abstraction from sand river aquifers in the Limpopo Province, South Africa.

Martinez-Santos et al. (2020) provided a review on manually drilled boreholes for drinking water supply in low- and middle-income communities, reporting that this method is cost-effective for shallow alluvial aquifers (15 to 50 m) in unconsolidated sediments and soft rocks. Manual drilling methods include augering, sludging, jetting and percussion with the increasing use of solar power for pumping. Martinez-Santos et al. (2020) also compared the characteristics of manually drilled boreholes with excavated wells and mechanized boreholes, discussing advantages and disadvantages of the different methods. Pre-requisites for the successful operation of such boreholes are the development of a regulatory framework, ensuring professional workmanship and maintenance, siting of boreholes in areas clear of potential sources of contamination, protection of groundwater to ensure drinking water quality standards are satisfied, and sustainable abstraction of the water resource to ensure long-term sustainability and water security.

In a previous WRC project (Jovanovic et al., 2018), an investigation of the storage capacity and hydraulic characteristics of a sand river aquifer in Limpopo indicated that sustainable groundwater abstraction from these alluvial aquifers can support smallholder agricultural requirements to supplement water during periods of extended drought. In addition, groundwater is known to be historically under-utilized in Limpopo, although there are potentially high-yielding aquifers in the predominantly fractured rock systems. However, increased groundwater abstraction to support agricultural intensification as well as other water uses implies increased costs of energy (electricity, diesel for power generators, etc.). Combining MUS with alternative sources of energy (e.g. solar-powered water pumps) would be a very realistic option to reduce environmental impacts, costs and to close the loop of the water-food-energy nexus. To our knowledge, such systems are in use very little in South Africa, especially in the rural areas of Limpopo.

Feasibility assessments were conducted in previous international research for MUS (Van Koppen et al., 2009) and solar-powered groundwater pumping systems (Sarr, 2020). In particular, Sarr (2020) conducted a comprehensive assessment of solar-powered pumping systems for smallholder irrigation in the Niayes region of Senegal. Sarr (2020) provided first the results of a survey conducted amongst suppliers, service providers and users of the system. This allowed to establish components, characteristics and specifications of the system, brands, prices, costs of installation and maintenance, etc. A technical, economic and environmental feasibility was then conducted. The technical feasibility was mainly related to sizing the system in relation to the use of solar pumps (individual and collective), the irrigation method (manual, drip, sprinkler) as well as storage reservoirs and distribution systems. The economic feasibility was assessed based on capital, installation and running costs as well as a cost-benefit analysis. The environmental impacts were assessed based on CO_2 emissions of alternative options and a decision support system. The main outcome of the study by Sarr (2020) was that the use of solar-powered pumps for drip irrigation is the best option both in terms of reduced environmental impacts and economic benefits. However, the system needs to be optimized in order to improve water use efficiency and ensure sustainable groundwater abstraction.

Kelley et al. (2010) highlighted that the adoption of solar energy for irrigation is an attractive option, however a technical and economic assessment is required to determine feasibility at specific sites. They assessed the feasibility based on climate data (determining water demand), groundwater availability (depth and recovery rates), costs as well as local policies, in particular those related to carbon emission. The results from five case study sites (in Spain, Saudi Arabia, USA, Lebanon and Jordan) indicated that solar-powered irrigation is technically feasible and sustainable in areas with high solar radiation as long as groundwater has sufficient capacity to recover and enough land is available for solar arrays. The economic benefits outweigh the conventional fossil fuel and electricity systems in the long run, although the initial capital costs are high.

A feasibility assessment is therefore required in order to optimize the design and implementation of solar-powered groundwater pumps as part of MUS systems, as this was not done previously in the case study area of Giyani. In the following sections, a literature review is reported on feasibility assessments done locally and internationally, where experiences can be drawn for application to the environmental and socio-economic conditions of Giyani. The literature search was structured into sections covering the adoption of solar-powered groundwater pumping systems worldwide, the components of solar-powered groundwater pumping systems, the geophysical feasibility, technical and engineering aspects, socio-economic, environmental and financial feasibility, the implications of Covid-19 as well as a review of the Toolbox for Solar Powered Irrigation Systems (SPIS) (GIZ and FAO, 2021).

2.1 Adoption of solar-powered groundwater pumping systems

The use of photovoltaic solar cells for pumping water has been steadily increasing in the last decade, particularly in developing countries such as China and India, but also in many European and African countries (Agrawal and Jain, 2018; Aliyu et al., 2018; Lefore et al., 2021). Aliyu et al. (2018) reviewed a number of applications of solar-powered groundwater pumping systems for a multitude of purposes such as grassland restoration, electricity generation, desalination, mining applications, drinking water and domestic uses. Hartung and Pluschke (2018) reported that there is a growing interested in solar-powered irrigation and conducted a review of historic and current trends that included surveys, interviews and site visits covering many case studies worldwide. GIZ (2020) reported a number of case studies on the viability of the technology in countries on different continents, namely in Chile, India, Kenya and Morocco.

GIZ (2020) summarized some fundamental opportunities for the use of solar-powered groundwater pumping systems such as the growth of photovoltaic cell markets, the need for replacement of old-fashioned diesel power generators, development of agriculture and uptake of innovative technologies especially by smallholders and emerging farmers, remedying unreliable grid power and connection to the grid, job creation and improvement of local economy. Some potential hurdles are seen to be the high initial capital investment, the lack of financing and policies, drop in oil prices, lack of awareness and monitoring, lack of quality assurance and services, exposure of equipment to weather extremes and theft. A SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) was provided by GIZ (2020) and summarized in Figure 2.2.

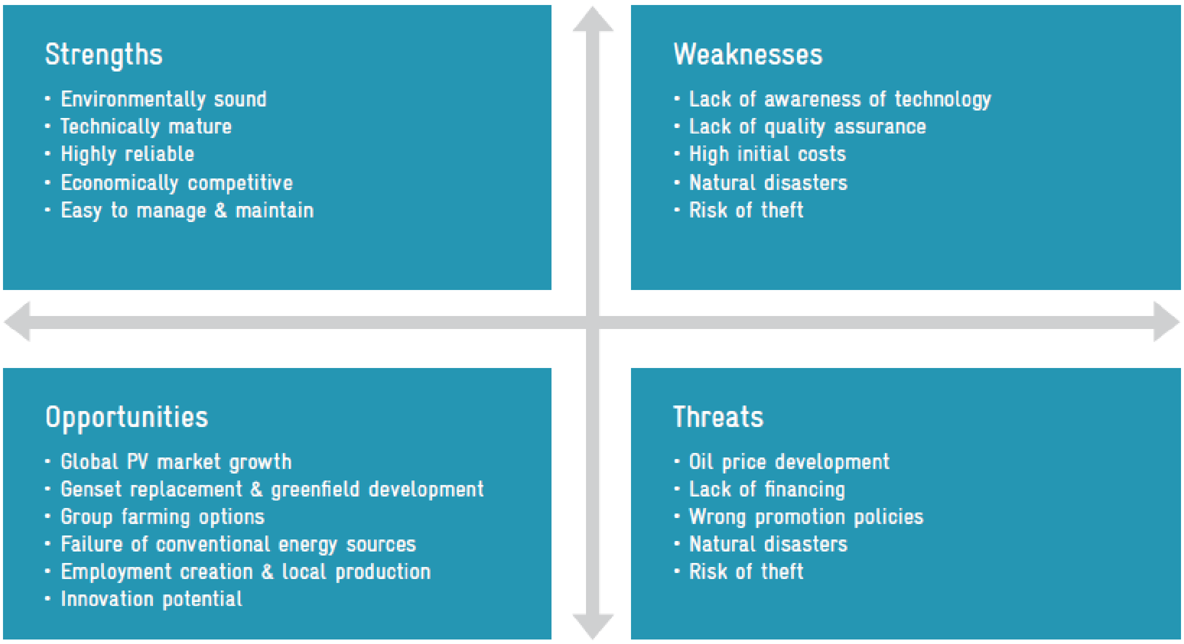


Figure 2.2 SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis for solar-powered groundwater systems, primarily for irrigation (GIZ, 2020).

Hartung and Pluschke (2018) also provided a similar analysis of socio-economic, financial and environmental advantages and disadvantages of solar-powered groundwater pumping systems. Some of the general recommendations of Hartung and Pluschke (2018) were to conduct feasibility studies and impact assessments of solar-powered groundwater pumping systems, promote the technology, explore the opportunity for multiple uses, build capacity and awareness, implement the system in combination with good water management practices, and an appropriate financial and business model that would consider social justice.

2.2 Components of solar-powered groundwater pumping systems

Comprehensive reviews of the components of solar-powered pumping systems were provided by Aliyu et al. (2018), Agrawal and Jain (2018), Hartung and Pluschke (2018), GIZ (2020) and Verma et al. (2020).

A solar-powered system for groundwater pumping is typically composed of:

- Power generator (set of solar panels)
- Mounting or solar tracking accessories
- Electronic components (inverters and pump controllers)
- Hydraulic pump and support structure
- Pipes and fittings
- Tank/reservoir or battery

The system components were also described in detail in other published literature (Maurya et al., 2015; Moeeni and Alam, 2016; Ravikumar et al., 2019). They can be schematically depicted as in Figures 2.3 and 2.4.

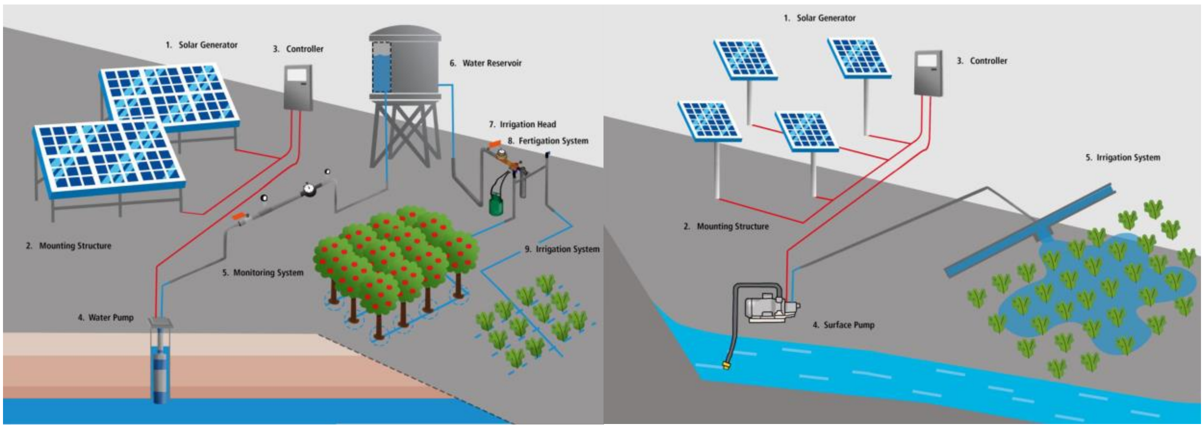


Figure 2.3 Best-practice configuration of solar-powered groundwater pumping system for drip irrigation (left) and for surface irrigation (right) according to GIZ and FAO (2021).

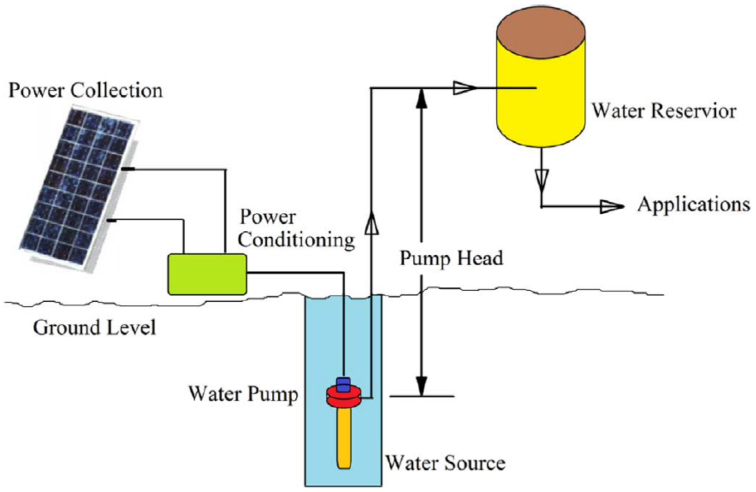


Figure 2.4 System components of solar-powered groundwater pumping system according to Aliyu et al. (2018)

GIZ (2020) recommended monitoring should also be included as integral component of solar-powered groundwater pumping systems. The basic monitoring system should include a water meter and pressure gauges at the filter inlet and outlet. A more extensive monitoring system can include solar irradiance, dynamic groundwater level, rainfall and wind speed.

Alternative systems have also been developed such as those storing energy during sunny parts of the day in batteries, or hybrid systems such as that described by Linn and Ya (2014) (solar/wind/diesel hybrid system with battery storage). Hadidi and Yaichi (2018) advocated the use of solar energy in the Sahara environment, where the demand for agricultural water peaks in hot and dry periods when the maximum amount of solar energy can be harvested. They described two main systems to supply solar energy for pumping groundwater: the one based on continuous pumping during sunshine hours and storage of water in reservoirs; the other based on recharging batteries with solar energy and pumping water on demand.

Aliyu et al. (2018) reviewed research on hybrid systems that improve the reliability of water supply by using complementary sources of energy (solar, wind, electricity and fossil fuels). GIZ (2020) described hybrid systems as those including typically a renewable energy source as the preferred source of energy and a conventional source as a back-up source of energy. GIZ (2020) also underlined that such systems are complex and require specialized skills. In South Africa, Kusakana (2018) proposed a hybrid diesel-photovoltaic system that makes use of a water storage scheme. A simulation of the system for a small farm indicated that the hybrid system would save 71.3% of daily energy cost compared to a diesel generator system.

In instances where the water supply system provides drinking water to households, a water treatment/purification component needs to be added to ensure the risks to human health are negligible. This also implies the need for a routine daily water quality monitoring system. In instances where the water is provided for agricultural use, a filter is required to prevent clogging and scaling. Different types of filter used in agriculture were discussed by GIZ (2020).

Groundwater can also be purified or treated to potable standards in many different ways. Panchal et al. (2020) published a review paper on research done with solar still systems using the principle of distillation to produce potable water. Bouhadjar et al. (2019) conducted successfully a pilot study to reduce F in groundwater used for drinking water supply through a small photovoltaic nanofiltration plant in a rural community of Tanzania. Gonzalez et al. (2019) investigated the removal of As from groundwater for drinking water supply to a community in Nicaragua through a nanofiltration plant. Both the nanofiltration plant and the groundwater pumps were operated with solar energy.

Maintenance of the system consists of inspection of the electrical and plumbing networks, servicing/repair to the pump, cleaning and checking the voltage of solar panels (Sarr, 2020), checking/servicing filters and water treatment/purification installations at ideal time intervals of 2-4 months.

2.3 Geophysical feasibility

Available and reliable water sources are a pre-requisite for the implementation of MUS. In the absence of surface water due to the torrential nature of most rivers in the study area and over-use of river water upstream, groundwater seems to be the logical and reliable source of water for MUS. Experiences from previous research in the study area (Jovanovic et al., 2018) indicated that moderate and controlled abstraction of groundwater can be sustainable and provide a water reserve for periods of prolonged droughts. However, the sustainability of groundwater abstraction will still depend on occasional recharge events.

Some of the major factors involved in the feasibility and performance of operations with solar-powered pumps are groundwater hydraulic characteristics and quality. High-yielding aquifers with high hydraulic conductivities reduce the risk of drying out the wells/boreholes. A maximum pumping flow rate needs therefore to be set to prevent stopping water abstraction. Pumping flow rates also depend on seasonal fluctuations of solar radiation supply energy to solar panels and groundwater levels.

In previous research (Jovanovic et al., 2018), it was found that the regional groundwater table in the study area is generally <20 m (fractured rock aquifers). Borehole yields are usually 1-2 L s^{-1} and the hydraulic conductivity estimated from pumping data is 1.3 m d^{-1}. On the other hand, the sand alluvium in non-perennial rivers has total porosity of about 0.4 and hydraulic conductivity was estimated across a wide range (20-250 m d^{-1}) depending on the location of sampling and the method used to determine it. The maximum thickness of the river sand in the middle of the channel (sand+regolith) is typically 6-9 m based on a geophysical survey (Jovanovic et al., 2018).

Groundwater quality needs to be measured in order to determine potential risks of clogging, scaling and damage to pumps and pipes due to elevated suspended solids, high iron concentrations and carbonates. The quality of groundwater in the fractured rock aquifers of the study area is moderately good with electrical conductivity (EC) ranging between 70 and 280 mS m^{-1} mainly due to elevated Ca, Mg, Na and Cl. Water stored in the sand alluvium of non-perennial rivers is of excellent quality (EC = 20-40 mS m^{-1}), which is evidence of direct recharge by rainfall and runoff (Jovanovic et al., 2018). Monitoring of water quality is, however, recommended in order to identify potential pollutants and pathogens.

Equally to water, the availability of solar radiation and land are pre-requisites for the success of solar-powered groundwater pumping. Rubio-Aliaga et al. (2016) proposed a GIS methodology that integrates the spatial and temporal variation of solar resources with groundwater resources (groundwater depth) to support water management in two areas of Morocco and Spain suitable for solar-powered irrigation. Schmitter et al. (2018) developed a suitability mapping framework for solar pumps utilized by smallholder farmers in Ethiopia. The framework included GIS layers of different variables such as slope, elevation, rainfall, land use/cover, protected areas, solar irradiance, water storage, depth to groundwater, aquifer productivity, proximity to roads, population, rivers and small reservoirs. The results of the GIS model indicated that large areas of Ethiopia could be suitable for application of solar-powered pumps (9% of irrigated land and 18% of dryland). Similarly, Sayed et al. (2019) presented a multi-criteria analysis that included GIS layers of groundwater depth, salinity, solar radiation, topography, distance to road and land use. The analysis was applied to determine the feasibility of solar-powered groundwater abstraction in the Moghra Oasis, Western Desert of Egypt. Suitable areas were identified to be those with low groundwater salinity and groundwater depths <100 m.

2.4 Technical and engineering feasibility

One of the key variables in the utilization of solar energy is the amount of incident solar irradiance because this determines the amount of energy available at the Earth’s surface, and therefore the number and area of solar panels required to generate a certain amount of energy. Elbaset and Ata (2019) provided a procedure to estimate the optimal solar cells area as a function of tilt angle and total irradiance, including the components of direct, diffuse and reflected solar radiation. The most efficient orientation in the southern hemisphere is towards North with a tilt angle equivalent to the latitude, although this may also depend on local atmospheric conditions, altitude, shading and trajectory of the sun. Manual and automatic sun tracking systems can be used to optimize the tilt angle for different times of the day and seasons (Elbaset and Ata, 2019; Abhilash et al., 2021). GIZ (2020) provided an extensive explanation and guidelines on how to install the mounting and solar tracking systems, fixed and variable tilt angles to ensure maximum efficiency of solar panels with minimum usage of land.

Besides solar irradiance, the design of solar-powered groundwater pumping systems involves the planning of hydraulic components. Brahmi et al. (2018) provided a procedure for the design and sizing of a photovoltaic solar pumping system, based on the calculation of water requirements, the necessary hydraulic energy and the necessary electrical power to be provided by the PV generator. The procedure used mathematical equations and charts to optimize the functioning and operation of the photovoltaic generator, the inverter and the pump engine, according to technical specification to ensure reliability and safety. Hadidi and Yaichi (2018) proposed a graphical method and analytical equations to design solar-powered groundwater pumping systems based on water requirements, hydraulic energy and electrical energy requirements (voltage and power controlled by the inverter), available solar energy, configuration and size of the photovoltaic arrays, and pump characteristics. Santra (2021) evaluated different designs of solar-powered groundwater pumps for micro-irrigation in India by making use of different solar panel systems (generating different power) and types of pumps (producing different discharge rates and pressure).

Several software for the design of solar-powered groundwater pumping systems were found in the literature. For example, Girma et al. (2015) conducted a feasibility assessment of solar photovoltaic water pumping systems for drinking water supply in Ethiopia. The feasibility assessment was done with the software PVSyst (https://www.pvsyst.com/download-pvsyst/, accessed on 12 June 2021), including design, simulations and economic analysis. The main outcome of the feasibility study was that the use of solar pumping systems proved to be feasible and it should be encouraged in rural areas of Ethiopia. Similarly, Yorkor and Leton (2017) used the RETScreen software (https://www.nrcan.gc.ca/maps-tools-and-publications/tools/modelling-tools/retscreen/7465, accessed on 12 June 2021) to design solar pumping systems and assess the technical viability of solar energy to provide drinking water to rural communities in Nigeria. The main recommendation was that solar water pumping is a sustainable solution to be considered by policy and decision-makers.

Literature was also found on performance analysis and optimization of solar pumping system with modelling simulations (Salilih et al., 2020; Tiwari et al., 2020; Mohammed et al., 2021). Gao et al. (2013) investigated the sustainability of solar-powered groundwater abstraction for irrigation through modelling water yield and changes in groundwater table under different water balance regimes from an unconfined aquifer in Qinghai Province, China. They demonstrated that, under the specific hydrogeological settings, groundwater yield can meet the water demand, the groundwater levels recover during the non-irrigation season, solar radiation can meet the demand for energy, and the system can reduce costs compared to conventional energy sources thereby increasing income from fresh grass production. In a similar modelling work conducted on grassland irrigation in the Inner Mongolia region of China, Zhang et al. (2014) demonstrated that if groundwater recharge rate is smaller than the pumping rate due to low soil permeability, this may result in lowering groundwater tables. They recommended the system be designed with pumping rates slower than recharge rates to allow groundwater recovery during the night when irrigation and pumping does not take place.

The following parameters are usually considered in the design of solar-powered groundwater pumping systems (adapted from Sarr, 2020):

- Nature of the water source (well, borehole or river);
- Storage method of pumped water (reservoirs, water towers, ground basins or no storage);
- Total depth of water source;
- Static height and dynamic heights of water columns;
- Maximum pumping head;
- Distance from the water source to the storage facility or user;
- Distance between the water source and the solar panels;
- Daily water requirements;
- Required pressure (e.g. method of irrigation: drip, sprinkler, manual, etc.);
- Operating flow rate of the source and maximum pumping flow rate allowing the operation of the pump;
- Area required for the installation and accessibility for maintenance.

In her survey conducted in rural areas of Senegal in support of smallholder irrigation with solar-powered groundwater pumps, Sarr (2020) observed the following range of parameters for various systems used to irrigate surface areas between 0.05 and 1.91 ha:

- Pumping flow rates between 2.5 m^3 h^{-1} and 31 m^3 h^{-1} depending on irrigation method (manual, drip and sprinkler);

- Pressure heads between a minimum of 14.8 m (manual irrigation) and a maximum of 58.5 m (sprinkler irrigation);
- Pump power varying between a minimum of 0.05 kW for manual and a maximum of 4.75 kW for sprinkler irrigation;
- Permissible pumping flow rates and pump power are 50% higher with the use of a storage reservoir than without it.

The technical feasibility depends also on the longevity of the system, the quality of components, cabling, mounting, electronic parts, pumps, etc. and proper maintenance of the system. Studies on the efficiency of solar-powered groundwater pumping systems were found in the literature. For example, Aliyu et al. (2018) provided a critical review on the efficiency of solar-powered systems, by reviewing international research advances on the configuration of solar panels, tracking and concentrating solar panels, effects of heating due to exposure to high temperatures and cooling by water sprays, performance degradation, types of water pumps and required water heads, the design of control and data acquisition systems, and maintenance. Aliyu et al. (2018) also discussed the design of the system based on different approaches: i) calculation of required input power and water output, ii) sizing of components and iii) sizing based on cost analysis. In a similar study conducted by Hadwan and Akholidi (2018) in Yemen, the performance of solar-powered groundwater pumping systems was reviewed and assessed considering environmental conditions, manufacturing technology, design and utilization. The factors considered were variations of solar spectrum, attenuation of sunlight in the atmosphere, angle of incidence, photovoltaic cell temperature, soiling and dust accumulation, shading and mismatching of solar panels, degradation of solar panels and falling groundwater depths.

Detailed guidelines for the design of solar-powered groundwater pumping systems were provided by GIZ (2020) and GIZ and FAO (2021). GIZ (2020) also reviewed a number of software and tools available for design from different developers and manufacturers of equipment. Hartung and Pluschke (2018) provided a diagram on data requirements for design and planning solar-powered groundwater pumping systems for irrigation (Figure 2.5).

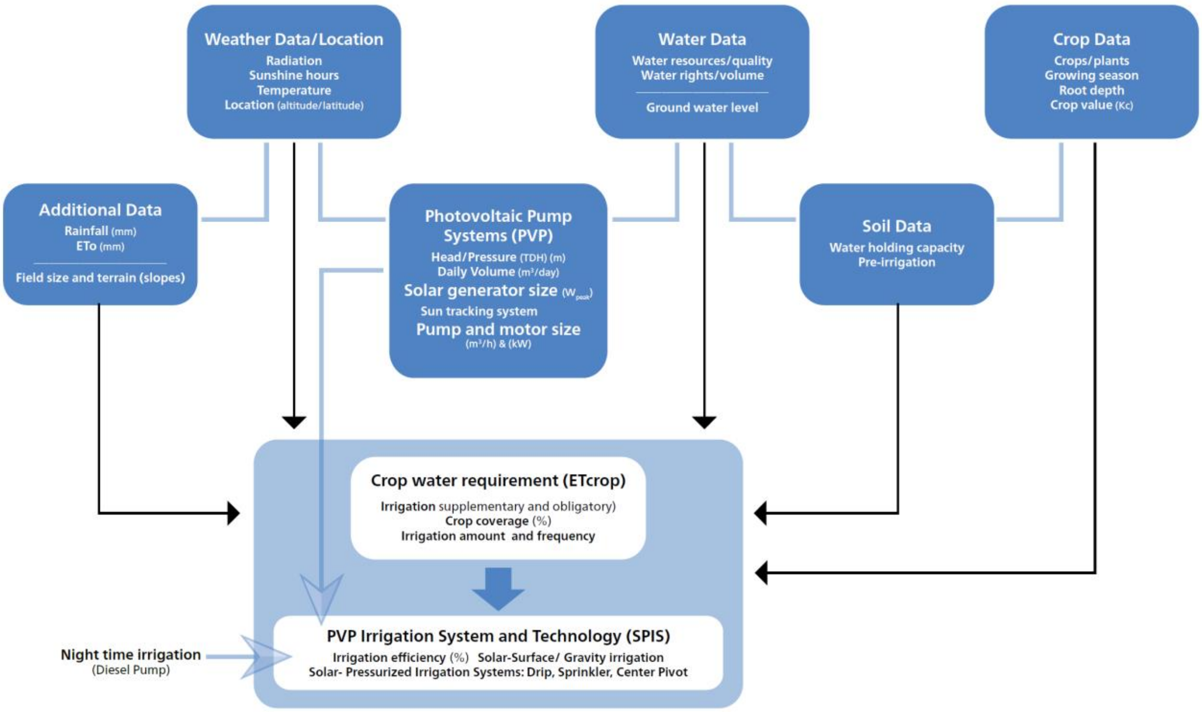


Figure 2.5 Diagram summarizing the data requirements for design and planning of solar-powered groundwater pumping systems for irrigation (Hartung and Pluschke, 2018).

2.5 Socio-economic feasibility

Although electric motors and internal combustion engines are the most common types of engines used in water pumping systems, difficulties in accessing electricity and high fuel costs may be limitations in securing required water volumes. Rural areas are at the bottom of the fuel supply chain and they are often unable to obtain fuel or means are not available for the purchase of fuel. Solar and wind energy are potentially alternative sources of energy in rural areas that may impact positively on the use of clean energy and improve livelihoods.

GIZ (2020) investigated the perception of solar-powered groundwater pumping systems by users and stakeholders in several countries. It was found that acceptance of this new technology depends on the technical reliability and after-sales service, financial support mechanisms, farm size and structure, and system configuration. Ali et al. (2016) conducted a field survey in Pakistan to determine the factors and impacts for the adoption of water pumps for irrigation powered from different energy sources. The results of multi-variate statistics and propensity score matching indicated that educated, younger and wealthier farmers are keener to adopt water pumps powered by alternative energy sources. Water pumps were also found to improve crop productivity and farm income. The importance of access to credits and subsidies as policy support to the adoption of solar powered pumps was emphasized due to the country's energy crisis and frequent load shedding of grid electricity.

A business model for management and maintenance of solar-powered groundwater abstraction systems needs to be put in place. Ideally, this needs to be implemented and run by communities. Batakari et al. (2019) reported on several business models adopted in the Eastern Gangetic Plains of India and Nepal through subsidies to small and marginal farmers. The main constraints to the implementation of groundwater use were identified to be the high investment costs (i.e. establishment of boreholes and equipment) and the fragmentation of land (i.e. the distribution network). Bastakoti et al. (2019) discussed the establishment of three types of business models, namely:

1) Individual-owned schemes, typical for large farms and wealthy farmers that install, operate and manage the system individually;
2) Community-owned schemes, typical for small farms where farmers don't have the means for large capital investment and they come together in a cooperative to cover the costs; and
3) Entrepreneurial schemes, typical for small farms, where one or more entities install and manage the schemes, and charge farmers for water use and services as pay-as-you-go; thereby, a groundwater market is established with market or government-regulated water charges.

GIZ (2020) classified business models somewhat differently into:

1) Ownership model (individual, collective, leased/rented)
2) Operation model (individual, collective, service provider)
3) Financing model (individual or collective loan, subsidy, leased/rented)

In a study conducted by Shah et al. (2018) in South-East Asia, policies were recommended to promote solar-powered groundwater pumps in such a way to reduce groundwater abstraction in geographic areas of groundwater scarcity (groundwater depletion zone) and increase abstraction in areas that are rich in groundwater (groundwater abundance zone). Seven different policy and business models were analysed in relation to the geographic areas: i) a subsidy model; ii) a no-subsidy model (suitable mainly to commercial farmers); iii) building of small solar energy power plants by investors on government land; iv) farmers renouncing to free grid power connections in exchange for free solar pumps on their land; v) farmers leasing land to solar energy companies; vi) service providers for solar power irrigation; vii) farmers' cooperatives establishing small solar power plants on their land.

Rathore et al. (2018) discussed the poor success of a solar-powered irrigation and drinking water program launched by the Indian government with a target to install 1 million solar-powered water pumps by 2020-21. The reasons for poor uptake of solar-powered water pumping were identified to be lack of awareness, lack of skilled workforce, policy and regulations, and poor infrastructure. It was recommended that the government should develop a roadmap for growth and development of solar-powered water pumping systems, given the clear advantages of the technology reflecting on the reduction of carbon emissions, availability of solar radiation especially during periods of maximum irrigation requirements, and lower costs compared to conventional diesel and electricity-based water pumping.

The international trends are that businesses that supply equipment for the system supply also services such as planning and design, agricultural services, maintenance, data collection and monitoring, and Internet platform services as a one-stop-shop (Hartung and Pluschke, 2018). Hartung and Pluschke (2018) also proposed a number of mechanisms for financing and strategic subsidies. They highlighted, however, that provision of cheap, subsidized solar energy may backfire, as the risks of groundwater over-abstraction increase especially if the users are not aware about water use efficiency and sustainable management implications. Standardization, quality control, capacity development, training, promotion and appropriate policies become then very important mechanisms to improve water management. Hartung and Pluschke (2018) highlighted aspects around social and gender justice to provide opportunities and empower smallholder farmers and women, which is very relevant to many South African rural communities. The choice of the appropriate business model depends ultimately on the community and the social set-up.

2.6 Environmental feasibility

GIZ (2020) discussed some of the potential environmental and sustainability impacts when utilizing solar-powered groundwater pumping systems. These are:

- The carbon footprint in comparison with different sources of energy;
- Noise and exhaust fumes generation compared to other sources of energy;
- The energy payback period;
- The recycling od solar panels, classified as e-waste;
- The risk of groundwater depletion and contamination; and
- Soil and groundwater salinization.

The processes of water supply, along the chain of groundwater abstraction, conveyance, treatment, distribution, use and wastewater treatment/disposal, require energy (Rothausen and Conway, 2011). Pumps are the main tools used to move water in the supply chain

(Scherer, 2017). However, the energy requirements for pumping water are considerable. It was estimated that about 7% of total world energy consumption is used for water supply (Hoffman, 2004). Different sources of energy have been traditionally used worldwide to abstract water: human energy, animal energy, wind energy, solar energy, fossil fuels and hydropower (Maurya et al., 2015). GIZ (2020) reviewed the most common energy sources for pumping water for irrigation: petrol or diesel engines, natural gas and wind. GIZ (2020) also discussed several types of pumps used for water abstraction (displacement pumps, centrifugal, submersible, turbine and jet pumps). Shinde and Wandre (2015) reported that hand pumps, submersible electric pumps with diesel fuel generator, diesel direct drive drilling engines, and submersible solar pumps are the most commonly used pumps in remote communities, depending on socio-economic, technical and environmental aspects. Despite the advantages of non-renewable energy sources in terms of profitability and reduced environmental footprint, the use of energy sources based on fossil fuels (oil, coal, gas) outweighs by far solar energy. In the Giyani area, the most common sources of energy for groundwater pumps are electricity and diesel for power generators.

Besides the high cost of diesel and electricity, these forms of energy are non-renewable, they contribute to global warming and they negatively impact the environment due to CO_2 emissions (Edenhofer et al., 2012). Hartung and Pluschke (2018) reported that solar pumps can potentially reduce GHG emissions per unit of energy used for water pumping (CO_2-eq kWh^{-1}) by 95% to 97% compared with pumps operated with grid electricity and by 97% to 98% compared with diesel pumps. Santra (2021) also estimated large reduction in CO_2 emission with solar photovoltaic pumping systems compared to conventional grid-electricity and diesel-operated systems. Reductions in CO_2 emissions were also estimated by Powell et al. (2019) when a combined solar and diesel system was used to irrigate cotton with groundwater in New South Wales, Australia.

Alternative non-renewable energy sources need to be explored and made available for sustainable abstraction of groundwater. The use of solar energy could be a logical choice in areas that receive high levels of radiation and low seasonal rainfall. Solar energy could therefore be adopted both to reduce the costs of water pumping and maintenance, and to reduce the environmental footprint (Sarr, 2020). An environmental feasibility study was required in the area of Giyani to determine the viability of switching from the use of diesel and electricity to solar energy for shallow groundwater pumping.

Availability of land is a specific issue to consider in the planning and design of solar field investments (GIZ, 2020). There needs to be sufficient and, ideally, unproductive land to install solar panels, water tanks, pump houses, pipelines, etc. Land in rural villages and agricultural land is not always available or it needs to be traded-off for different uses. The installation may require some earthworks, which is also a form of impact on land (Merino et al., 2018).

Sarr (2020) investigated the environmental impacts of different alternative options for smallholder irrigation by making use of a decision-support system that considered five categories: (i) natural resources, (ii) biological life, (iii) socio-economic, (iv) political and (v) economic impact. Each category consisted of sets of criteria and factors. The results indicated that both the use of diesel pumps and solar-powered pumps may bear negative impacts on natural resources, in particular over-abstraction of groundwater. This is especially pronounced with solar-powered pumps that have low operational costs and may encourage farmers to abstract more water leading to groundwater over-abstraction (Hartung and Pluschke, 2018; Bastakoti et al., 2019). This was corroborated by Gupta (2019) in an econometric study conducted in India, where it was found that the adoption of solar pumps led to expansion of intensively cultivated crops and area, and consequently increased groundwater consumption by 16-39%. Awareness needs therefore to be raised amongst farmers to use water efficiently.

Closas and Ras (2017) discussed the technological, socio-economic and environmental limitations of solar-powered groundwater pumping, and gave recommendations on sustainability and policy. Technological limitations are related to the need for solar radiation above a certain threshold for prolonged periods, the fluctuating demand for water that may not match the production of power, and the design and maintenance that require specific skill sets. Socio-economic limitations are equally important for the success of the technology, such as the dependence on subsidies for initial capital costs, access to finance, the need of a market for procurement, sales and service provision, land tenure issues, equitable access to the technology, etc. The environmental limitations in terms of availability and reliability of water resources is fundamentally important. It is very often assumed that the groundwater resource is unlimited. Closas and Ras (2017) highlighted that financial and economic costs should reflect the availability of water resources and potential over-abstraction as subsidies may often mask the true costs of groundwater depletion. Groundwater abstraction needs to be monitored in order to prevent depletion and ensure the sustainability of this technology. Subsidies need to be targeted and aligned to design regulations and water requirements. Ultimately, multi-sector strategies need to be developed involving different ministries (e.g. agriculture, energy, water resources, etc.) to produce sustainable and integrated policies.

Lefore et al. (2021) also underlined the importance of improving policies and institutions to be inclusive of a variety of stakeholders, objectives and approaches. Specifically, they identified that the main drivers of solar-powered pumping for drinking water supply and irrigation in Sub-Saharan Africa are the lack of energy infrastructure and the potential to improve rural livelihoods. However, the expansion of the technology in Sub-Saharan Africa is generally driven through external funding and donors in the absence of local policies and initiatives. Lefore et al. (2021) therefore proposed a framework to support policy, regulation and monitoring in order to achieve investments for solar-powered irrigation that would be environmentally sustainable, socially equitable and contributing to food security. The framework is based on the elements shown in Figure 2.6, in particular: i) enhancing equitable access to solar-powered irrigation (access to finance, access to markets, and equitable and inclusive access to technology, especially for women); and ii) improving environmental sustainability (integrated water and land management, efficient irrigation management). Improving environmental sustainability can be achieved through appropriate management of both groundwater and agricultural water on farms. The framework should be applied across government levels, sectors and stakeholders, and it is deemed to be applicable to local conditions and needs.

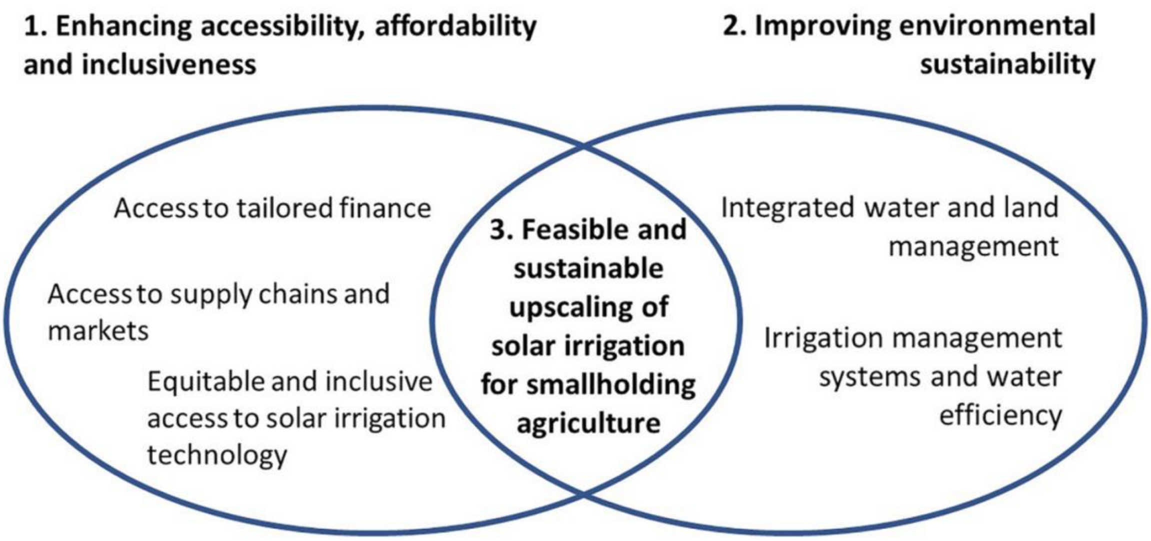


Figure 2.6 Framework for sustainable and equitable expansion of solar-powered groundwater pumping for smallholder irrigation (Lefore et al., 2021).

Agrawal and Jain (2018) proposed 14 determinants for sustainability of solar-powered irrigation systems that can be summarized as follows:

- Economic sustainability (peak daily water requirements; depth or distance to the water source; solar radiation levels; system quality and after-sales services; scales of farming; access to inputs and crop markets; utilization factor; cost of alternative solutions)

- Environmental sustainability (water use efficiency; reduction of CO_2 emission; management of e-waste)
- Social sustainability (technology awareness; reduced confidence of users due to poor quality products, services and maintenance; security issues; co-benefits from multiple water and electricity uses; gender empowerment by reducing time spent for collecting water)

Agrawal and Jain (2018) also proposed strategies to promote adoption and expansion of the technology, including building awareness, prioritizing areas for deployment, business models, subsidies and policy support.

Some additional environmental impacts were identified in the literature. The adoption of solar-powered groundwater pumps is generally regarded as beneficial from the socio-economic and political perspectives, with minimal impacts in terms of CO_2 emissions. Besides reducing carbon emissions, Aliyu et al. (2018) provided evidence that such systems can enhance carbon sequestration by increasing biomass production through irrigation of grasslands and crops. Recent research on large concentrating solar power plants in Spain demonstrated that these installations require groundwater for cooling and generate saline effluent, often with chemical additives, that may recharge and impact groundwater and wetlands (Merino, 2018).

In previous research, life cycle assessments were frequently used as methods to assess environmental impacts. For example, an environmental impact assessment was conducted in Iran to determine energy use efficiency, emissions and environmental damage occurring in irrigation systems under barley production (Ghasemi-Mobtaker et al., 2020). The authors used a life cycle assessment method (ReCiPe2016) to evaluate different scenarios under surface and sprinkler irrigation supplied with photovoltaic energy. They concluded that renewable energy outweighs by far conventional forms of energy (fossil fuels and electricity) in terms of environmental benefits. Armanuos et al. (2016) conducted a life cycle assessment with software SimaProv v. 8.04.30 to compare the environmental performance of groundwater pumping systems with diesel and solar power in Egypt. The results were that using diesel is more harmful compared to solar power in terms of natural resources, human health, climate change and ecosystem quality.

Rubio-Aliaga et al. (2019; 2021) used a multi-criteria decision-making process to compare diesel, solar-powered and electricity groundwater pumping systems with water storage facilities, using a case study of an aquifer in Spain utilized for irrigation. They adopted analytic hierarchy process and order performance by similarity to identify optimal solutions in terms of energy, economic and environmental criteria. The energy criterion refers to the nominal power of the system. The economic criteria included the investment in the energy system and water infrastructure, maintenance and operation costs, and sales of surplus energy. The environmental criterion consisted of CO_2 emissions. Additional criteria were evaporation from the water storage facilities and jobs created. The preferred solutions of the ranking system were direct pumping over water storage, with direct grid pumping and solar energy (net energy metering and isolated pumping) being the preferred sources of energy. Diesel pumping was deemed acceptable for shallow groundwater and small areas, despite its negative impacts on the environment and energy dependence.

2.7 Financial feasibility

The development of water supply schemes, in particular for irrigation where large volumes of water are required, faces many financial constraints. Besides the need for arrays of solar panels and pumps of suitable power, irrigators need to invest in the irrigation distribution network and systems, and likely tanks and reservoirs for water storage. They also incur in running and maintenance costs.

Amongst all costs, the cost of energy is one of the most recurrent and highest in intensive irrigated agricultural systems (Masiyandima and Sow, 2015), especially for smallholder farmers that are using diesel and electricity pumps for irrigation. It was estimated that the cost of pumping water and irrigation can be up to 20-25% of the total cost of rice production in the Senegal River Valley (Masiyandima and Sow, 2015). In the same region, the cost of fuel used to cultivate 1 ha of land was estimated to be 3,762 € a^{-1} on average. In addition, the source of energy (diesel and electricity) may not always be available and accessible to water users. The supply of energy is therefore a major limiting factor in the development of rural areas.

Photovoltaic (PV) solar generators could represent a potential alternative source of energy to reduce the cost of electricity consumption. Solar energy systems can be designed and sized on-site, they can be operated autonomously or as part of a grid, and have a low environmental footprint. The price of photovoltaic panels, pumps and electrical components is declining, which is another advantage for widespread implementation of this technology (GIZ, 2020). Orientative costs of the various components of solar-powered groundwater pumping systems were given by Hartung and Pluschke (2018). Connection to the grid for electricity supply during periods of non-operation was discussed by Hartung and Pluschke (2018), however there may be implications to the feasibility of this practice in rural and remote areas as well as in relation to the energy providers. The different modes of grid-connectivity and supply were discussed by Jadhav et al. (2020) for a case study in Maharashtra, India, and by Aghajanzadeh and Therkelsen (2019) in the USA.

Although the technology is mature, the adoption is not widespread due to the high initial capital investment and the specialized skills required in design, installation and maintenance. As the energy supplied by solar panels is variable depending on solar radiation levels, pumps of a larger size need to be adopted in the design compared to energy sources that provide a constant level of energy. These financial limitations and technical complexities are the reasons why, in most cases, the technology is subsidized (GIZ, 2020).

Economic indicators that can be used in determining the viability of solar-powered groundwater pumps as well as for financial comparisons with traditional water pumping systems are: capital investment cost, Net Present Value (NPV), Benefit Cost Ratio (BCR), Internal Rate of Return (IRR), Payback Period (PBP), and Life Cycle Cost (LCC) (Sarr, 2020). In her study conducted in Senegal, Sarr (2020) calculated that the capital investment costs are much higher when using sprinkler and drip irrigation compared to manual irrigation due to the costs of the irrigation system. The capital costs increase further when a storage reservoir is used. However, the costs can be reduced if groups of farmers use the same source of water and pump, especially for drip irrigation. In terms of Benefit-Cost Ratio, drip irrigation and sprinkler irrigation with PVC pipes showed to be the most profitable, with Payback Period being reached after 6 years on average depending on the type of pump. Hartung and Pluschke (2018) estimated a wide range of Payback Periods (between 0 and 25) depending on whether the system is subsidized, the cost of fuel and electricity and the type of water use, e.g. production of intensive cash crops is highly recommended to pay off the initial capital investment in a shorter time. Powell et al. (2019) estimated an IRR of 23% and a payback over 5 years by combining the traditional diesel energy supply system with solar photovoltaic for groundwater irrigation of cotton in New South Wales, Australia.

Kamel and Dahl (2005) presented a comparative economic assessment between diesel-powered groundwater pumping and the use of hybrid systems in Egypt. They utilized the HOMER (Hybrid Optimization Model for Electric Renewables, US National Renewable Energy Laboratory, Colorado) software to optimize combinations of power sources (photovoltaic, wind turbines, diesel generators and battery banks) based on capital, replacement, operation and maintenance costs. The results indicated that hybrid systems are more viable than diesel both in terms of economics and environmental impacts. This was the case despite diesel is subsidized in Egypt. Girma et al. (2015) conducted a life cycle cost analysis for solar powered groundwater pumping systems for drinking water supply in rural areas of Ethiopia. They demonstrated that the use of solar energy for drinking water supply from groundwater is more economical than diesel-based systems.

GIZ (2020) recommended NPV and IRR as the most common indicators of a cost-benefit analysis in order to assess the financial viability. To compare different alternatives, a comparative analysis of Life-Cycle Costs, annual operation costs and annual financing costs of each alternative should be considered.

2.8 Implications of COVID-19

The limitations imposed by the COVID-19 pandemic have major implications on aspects such as research development and innovation in water and agricultural research as well as the logistical functioning of research activities during the lockdown period. Given the unknowns around the virus and the severe impacts on human health, research on the transport and spread of the vector through water has been initiated by WRC, in particular related to domestic water and wastewater effluent (https://www.nicd.ac.za/wp-content/uploads/2021/07/COVID-19-Special-Public-Health-Surveillance-Bulletin-Vol-19-Issue-1.pdf, accessed on 10 September 2021). Secondary effects involved are those related to improving human nutrition to strengthen the immunity and health of the population and possibly mitigate the impacts of the pandemic. As a result, the marketing and economy of the water and agricultural sectors have been affected both in terms of safety issues and lockdown restrictions. As social distancing restrictions are imposed in most of the world's countries, this put limitations on travelling and gatherings to conduct research and implementation, hold meetings and attend conferences. It also impacted on the timing of experiments, field work and sampling as well as laboratory work. Stakeholder engagement in the form of workshops and personal contact had to be put on hold.

A set of COVID-19 Vulnerability Indicators has been developed in order to identify vulnerabilities in communities based on transmission potential and health susceptibility (https://pta-gis-2-web1.csir.co.za/portal2/apps/, accessed on 29 May 2021). The purpose is to identify areas in need of interventions and early response to COVID-19 and other communicable diseases. Transmission potential was determined based on practices that prevent social distancing and good basic hygiene. Health susceptibility represents areas where large numbers of people are potentially more susceptible to COVID-10 due to factors such as age and underlying health conditions. The vulnerable areas are shown in Figure 2.7 for the Mopani District (Mopani District Municipality, 2020). The areas with higher vulnerability are those that are more densely populated and with higher poverty (Greater Giyani, Greater Letaba, Greater Tzaneen and mining areas in Ba-Phalaborwa).

Response to COVID-19 is organized in the Mopani District through re-prioritization of budget, the establishment of 5 quarantine facilities, the provision of water through 4 water trucks and 145 water storage tanks, social support through delivery of food parcels and the provision of hand sanitisers at taxi ranks (Mopani District Municipality, 2020).

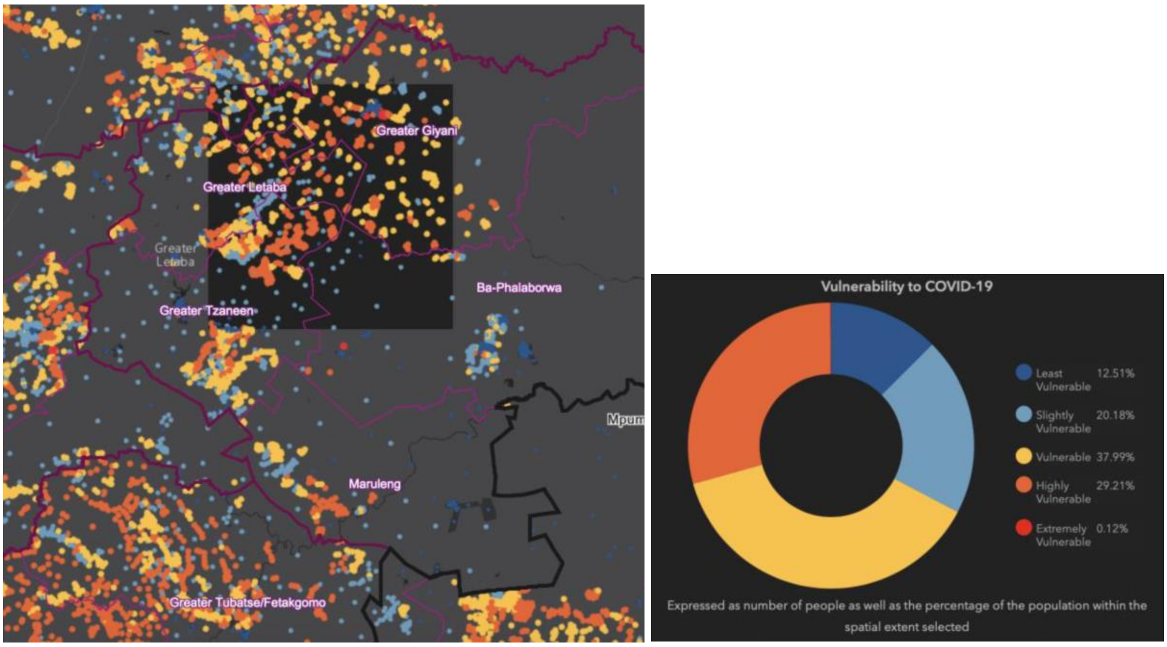


Figure 2.7 Areas vulnerable to COVID-19 in the Mopani District Municipality (Mopani District Municipality, 2020).

Given the new circumstances, any future program of water quality monitoring will have to include detection and quantification of viruses according to protocols recommended by specialist scientists and enforced through government regulations, besides the conventional measurements of microbiological parameters that are standard for drinking water and agricultural water use. Measures for the implementation of research in communities and the management of water supply by the community will have to adhere to safety protocols in terms of provision of sanitizers, wearing masks, securing clean water for personal hygiene, social distancing and gatherings.

2.9 Toolbox on Solar Powered Irrigation Systems (SPIS)

International knowledge and experiences were combined by GIZ and FAO (2021) into the "Toolbox on Solar Powered Irrigation Systems (SPIS)" available at https://energypedia.info/wiki/Toolbox_on_SPIS, accessed on 8 June 2021. A print screen of the landing page menu of the toolbox is shown in Figure 2.8. The toolbox consists of a handbook structured in modules and a number of tools in Excel and Word. The modules include the following information:

- Information for agricultural advisors and financial service providers on the operating principles of SPIS and the components (***Get Informed*** module)
- The ***Promote and Initiate*** module includes activities on promoting and public awareness on SPIS, and two tools, namely *SPIS Rapid Assessment* and *Impact Assessment Tool*.
- The ***Safeguard Water*** module analyses the principles of sustainable groundwater management, and two tools, namely a tool to calculate crop or livestock *Water Requirements* and a *Water Resource Management Checklist*.
- The ***Market*** module explains how to conduct a market assessment with a *Market Assessment Tool*.
- The ***Invest*** module provides guidance to project funders through a *Farm Analysis Tool* and a *Payback Tool*.
- The ***Finance*** module provides guidance to farmers on financial services through a *Finance Deployment Tool*.
- The configuration and design of the system is explained in the ***Design*** module that includes a *Site Data Collection Tool*, a *Pump Sizing Tool* and a *SPIS Suitability Checklist Tool*.
- The ***Set Up*** module explains how to install the system including the *PVP (Photovoltaic Pumping) Acceptance Test* and *Workmanship Quality Check*.
- The ***Irrigate*** module provides guidance on irrigation scheduling based on the *Soil Tool*.
- Guidelines on maintenance, servicing and monitoring are provided in the ***Maintain*** module with two tools, namely *Maintenance Checklist* and *Water Application Uniformity Guide*.

The guidelines and tools provided in the Toolbox on SPIS (GIZ and FAO, 2021) are applicable to the current feasibility assessment in Greater Giyani Municipality. Most of the data and information collection was therefore geared towards populating the SPIS Toolbox.

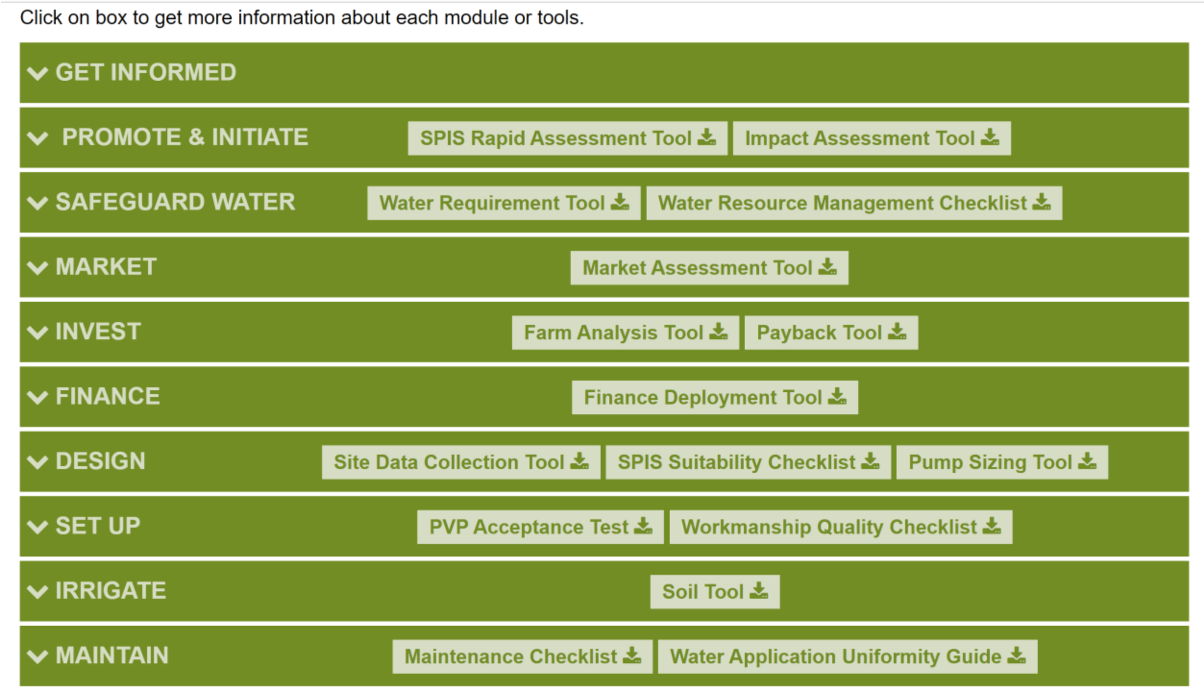


Figure 2.8 Print screen of the landing page menu of the "Toolbox on Solar Powered Irrigation Systems (SPIS)" available at https://energypedia.info/wiki/Toolbox_on_SPIS, accessed on 8 June 2021.

3. DATA COLLECTION

3.1 Location

The study area is located in Greater Giyani Municipality (Mopani District) in the Limpopo Province (Figure 3.1). Greater Giyani is a rural municipality which has a single semi-urban area, Giyani town. The municipality, demarcated into 31 wards, has 62 councillors and covers an area of 2967.27 km² (Greater Giyani Local Municipality IDP, 2021). The municipality has 10 traditional authority areas comprised of more than 97 villages. Giyani town is the only urban area in the municipality and is the largest centre of population concentration, employment opportunities, shopping and recreational facilities. Greater Giyani Municipality has a population of 256,300 with a slight tendency to decline mainly due to migration to cities. Giyani has a large number of rural settlements that are scattered and not easily accessible as the road conditions are bad and this has implications for economic activity in the municipality. Major environmental challenges are air and water pollution, deforestation, veld and forest fires, soil erosion, over-grazing, wetland protection and challenges linked to informal settlements (Greater Giyani Local Municipality IDP, 2021).

Figure 3.1 Local Municipalities in the Limpopo Province. Greater Giyani Municipality is outlined in the red oval.

3.2 Selection of study area

A number of criteria have been considered for selection of sites for implementation of MUS within Greater Giyani Municipality. The criteria set can be summarized as follows:

- Availability and reliability of a water source (groundwater borehole or shallow wells in sand river banks)
- Community need (water demand) – baseline of zero and less than 25 L per person d^{-1} for drinking water supply to households; crop water requirements for small farming
- Water use diversification opportunity
- Current infrastructure gaps
- System set-up logistical complexity/ease
- Economic activity potential, e.g. agriculture, value-added products (level 2 and 3)
- Access to markets – geographic access (level 2 and 3)
- Tribal and traditional support
- Health and hygiene improvements (level 1)
- Cultural activity and economic potential (tourism level 2 and 3)

Levels 1, 2 and 3 signify the following:

- **Level 1:** Level 1 allows access to the villages for basic domestic uses such as every-day activities.
- **Level 2:** In level 2, water is supplied to livestock and small irrigation.
- **Level 3:** Level 3 allows access to water for small farms, this allows the farm to develop and grow crops accordingly. Level 3 also uses a business component allowing the farm to supply various food stores.

A preliminary broad list of potential sites for MUS is summarized in Appendix A (Table A1).

Seven case study villages have been selected based on the criteria above and shown in the Google Earth map in Figure 3.2. The villages extend between the perennial Great Letaba and the non-perennial Molototsi River. Water is available in these villages from groundwater boreholes or from shallow groundwater along the rivers/river banks, from an earth dam at Xihlakati, and from a water plant that needs upgrade and booster pumps at Nwamarhanga. The water source is quite reliable given borehole yields and shallow groundwater yields from the river banks.

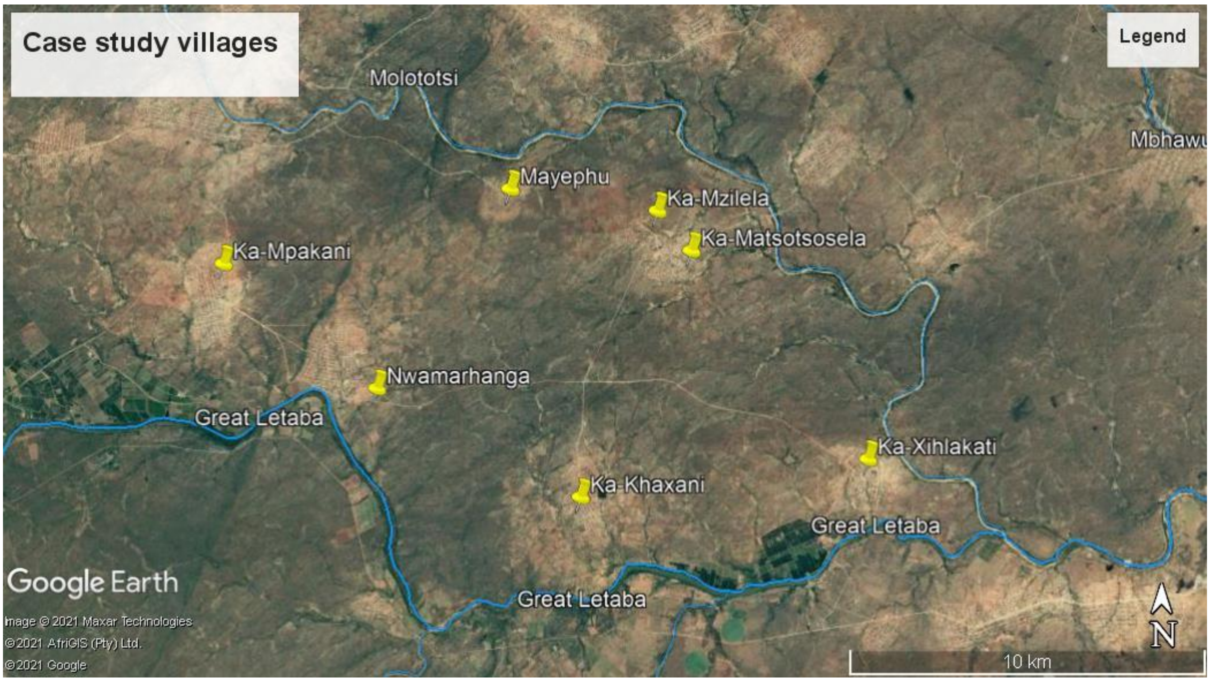


Figure 3.2 Case study villages for the implementation of Multiple Use Systems (MUS) on a Google Earth map. The Great Letaba and Molototsi Rivers are also shown on the map.

The village with the largest population is Nwamarhanga (5677 people, Appendix A). To satisfy the demand of 25 L per person d^{-1}, the village would require about 142 m^3 d^{-1} at a pumping rate of 1.64 L s^{-1}. A borehole with yields of 2 L s^{-1} (typical good groundwater yield observed in the area) would therefore not be sufficient to satisfy the demand if water is pumped only during daylight when solar panels supply power. More boreholes will therefore have to be installed or sufficient power supplied to pump overnight. If water use diversification is planned, more water (boreholes) will be required.

In previous research conducted by Jovanovic et al. (2018), it was estimated that a 100 m reach of the dry Molototsi River stores 2,700 m^3 of water in the sand banks. This is sufficient to irrigate ~0.66 ha of vegetables for one season, assuming irrigation water requirements of 4,000 m^3 ha^{-1}. The total volume of water stored in the sand banks of the Molototsi River in the reach of quaternary catchment B81H (~66 km) was estimated to be ~1.78 Mm^3 a^{-1}.

The infrastructure gaps are generally linked to the availability and cost of energy that hampers the provision of water, to the need for additional boreholes, earth dams, storage tanks and reservoirs, water distribution systems, pumps, electrical and pipe fittings, and water filtration/purification systems. Some of this infrastructure such as boreholes and pumps is available in the selected villages (Appendix A). Logistically, the villages are at a maximum distance of ~9 km from each other, in proximity of river courses and fairly easy to access.

There is potential for intensive agricultural production and value-added products with access to both informal and formal markets in the urban areas of Giyani (~50 km North) and Tzaneen (~70 km South-West). Other economic development activities could relate to tourism potential. Because of the current lack of water supply, MUS systems would definitely benefit livelihoods, cultural activities, and improve sanitation, hygiene and health. Tribal and traditional support to improvement of services is very strong in the area.

3.3 Climate

The climate in Greater Giyani Municipality is summer rainfall sub-tropical, although climatic conditions vary considerably due to variations in elevation. Average air temperatures are usually lower in the western parts compared to the eastern parts, along the slope from the mountainous escarpment to the lowveld. The average annual temperature ranges about 18°C in the higher elevation areas to more than 28°C in the eastern, with an average of 25.5°C. Maximum temperatures are experienced in January and minimum temperatures occur in July. The area receives between 200 and 450 mm a^{-1} of rainfall, predominantly during summer. Rainfall occurs in a single rainy season running from October to March, mostly in January and February. Rainfall is strongly influenced by the topography, along the West-East gradient. The average potential mean annual gross evaporation (as measured by A-pan) ranges from 1,300 mm in the western mountainous region to 2,000 mm in the northern and eastern areas. The highest evaporation occurs during the period October to January while the lowest occurs in June (DWAF, 2003).

Figure 3.2 depicts daily weather variables measured with an automatic weather station in Giyani from 2012 to 2020 (courtesy of the Agricultural Research Council). The weather station in Giyani (Lat: -23.32403; Long: 30.68730; Alt: 463 m) is currently not operating. The Agricultural Research Council, however, is providing weather data for 2021 from automatic weather stations at Gravelotte Primary School (Lat: -23.9386; Long: 30.61899; Alt: 590 m) and ZZ2 BHB farm (Lat: -23.5779; Long: 30.14135; Alt: 671 m). Weather data collected at Gravelotte Primary School and ZZ2 BHB for 2021 are presented in Figures 3.3 and 3.4, respectively. The Penman-Monteith reference evapotranspiration (Allen et al., 1998) was calculated with the ETo calculator (Annandale et al., 2002).

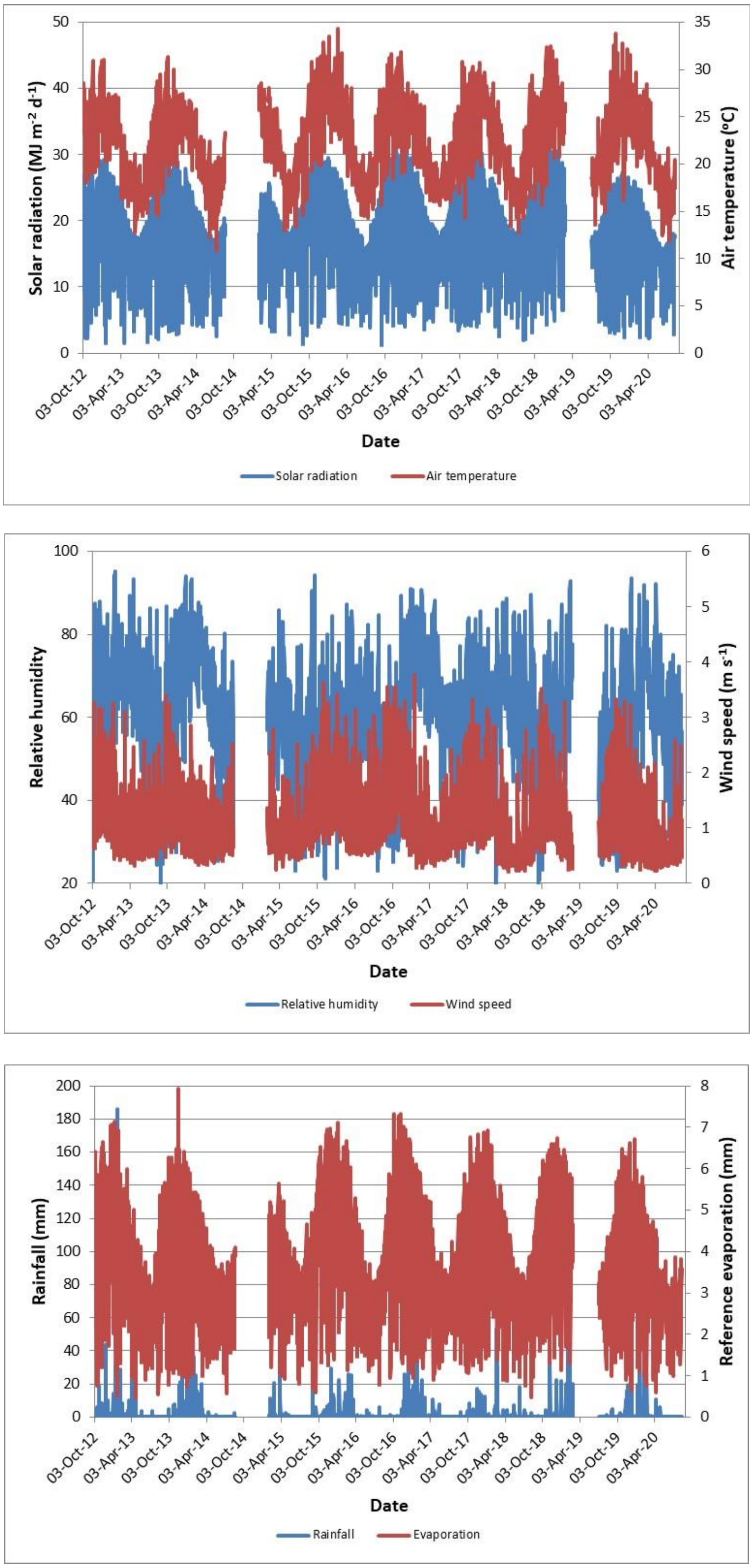


Figure 3.3 Daily weather variables measured with the automatic weather station in Giyani from 2012 to 2020 (Agricultural Research Council).

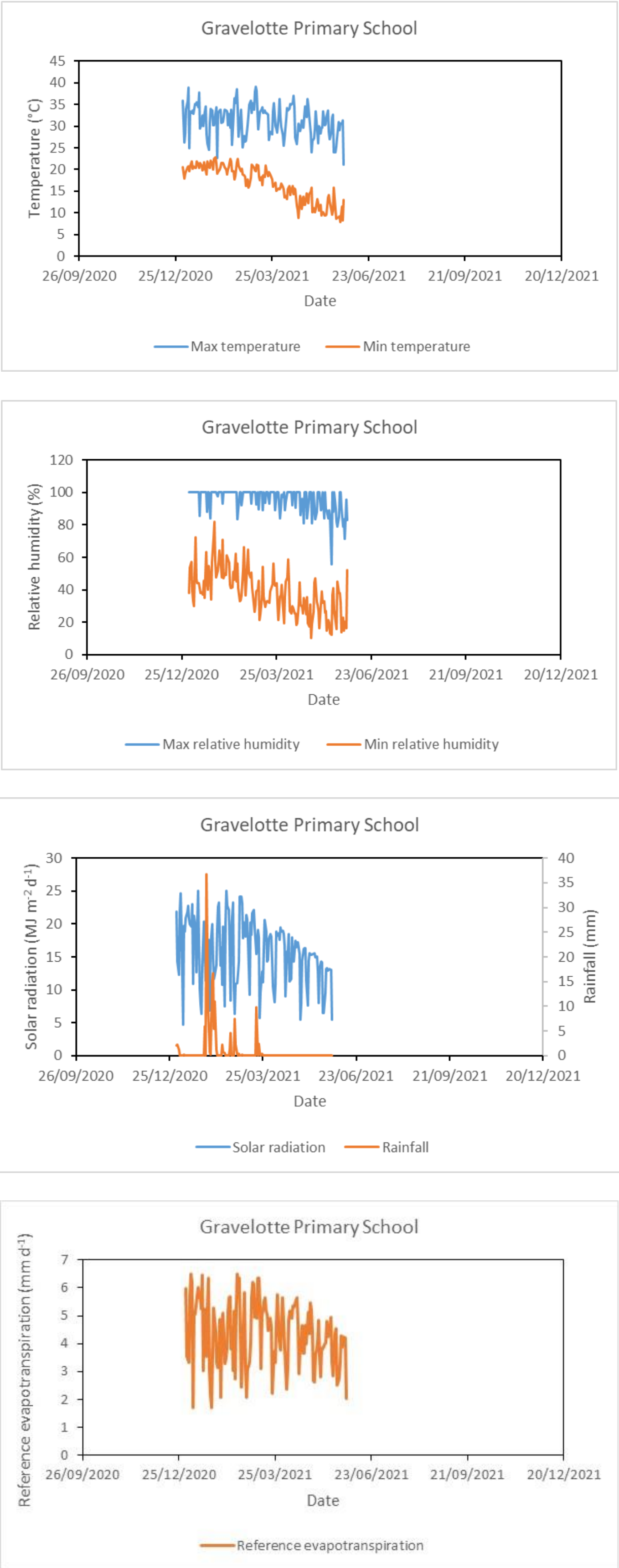


Figure 3.4 Daily weather variables measured with the automatic weather station at Gravelotte Primary School during 2021 (Agricultural Research Council).

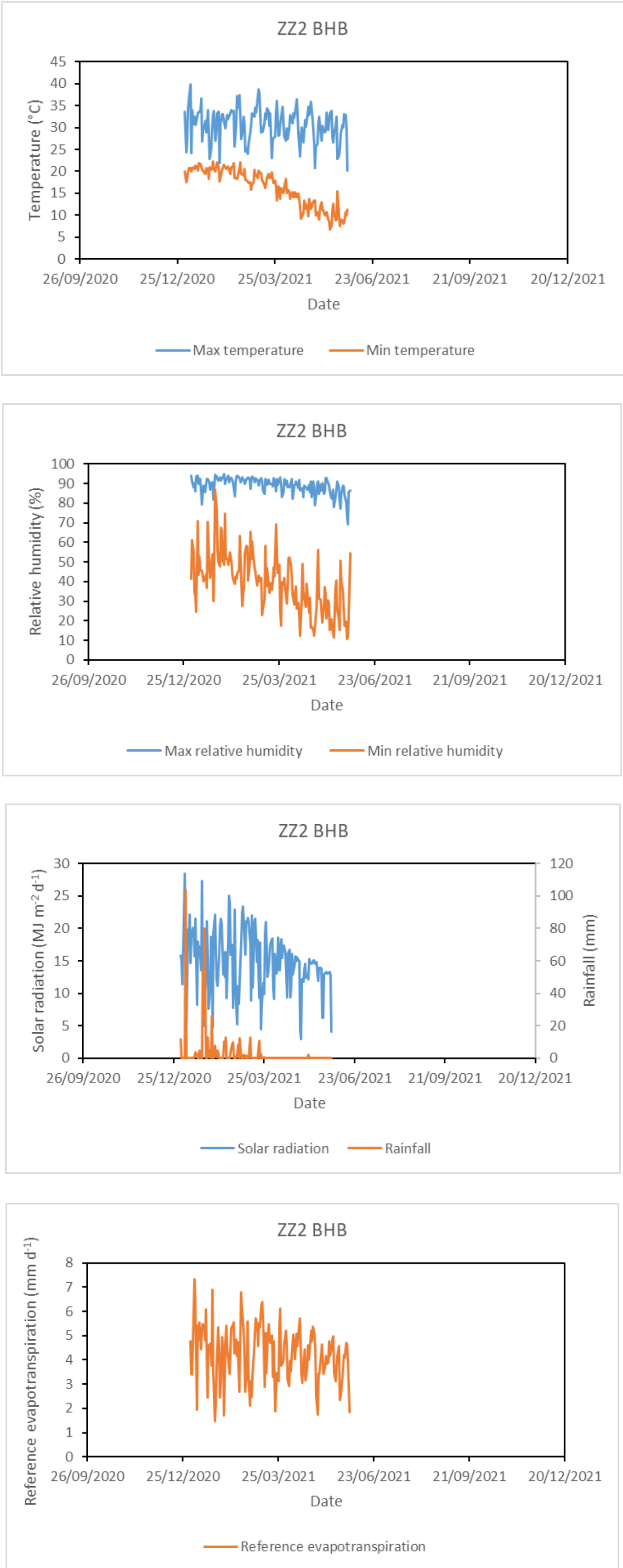


Figure 3.5 Daily weather variables measured with the automatic weather station at ZZ2 BHB during 2021 (Agricultural Research Council).

3.4 Hydrology

Greater Giyani Municipality is located within the Luvuvhu and Letaba catchments. The major rivers (Klein Letaba, Middle Letaba and Great Letaba rivers) all flow in an easterly direction. The main perennial river is the Great Letaba, fed by tributaries such as the Middle Letaba and Nsami. Other non-perennial tributaries of the Great Letaba are the Malatsi, Mbaula and Molototsi.

Mean annual runoff (MAR) map is represented in Figure 3.5 (DWAF, 2003). MAR ranges from 400 mm in the eastern part to less than 20 mm in the western parts. Surface water runoff was found to be strongly correlated with rainfall, with the areas of high rainfall in the Drakensberg and Soutpansberg contributing a significant proportion of the runoff. Some 45% of the total surface runoff flows down the Klein and Great Letaba Rivers (most of which is contributed by the Great Letaba River) and a further 45% is contributed by Luvuvhu and Mutale Rivers.

Afforestation in the upper reaches of the Great Letaba, Luvuvhu and Klein Letaba Rivers (in descending order of magnitude) results in relatively large reductions in streamflow (DWAF, 2004). Substantial infestations of invasive alien vegetation are found in the Luvuvhu and Great Letaba River catchments. Cultivation practices and over-grazing also impact on the surface runoff, sediment loads as well as infiltration to groundwater. The natural MAR and the estimated requirements for the ecological component of the ecological reserve are summarised in Table 3.1. The ecological reserve represents the minimum environmental flow that needs to be secured in order to sustain the natural ecosystem, according to the South African National Water Act (NWA; Act No. 36 of 1998).

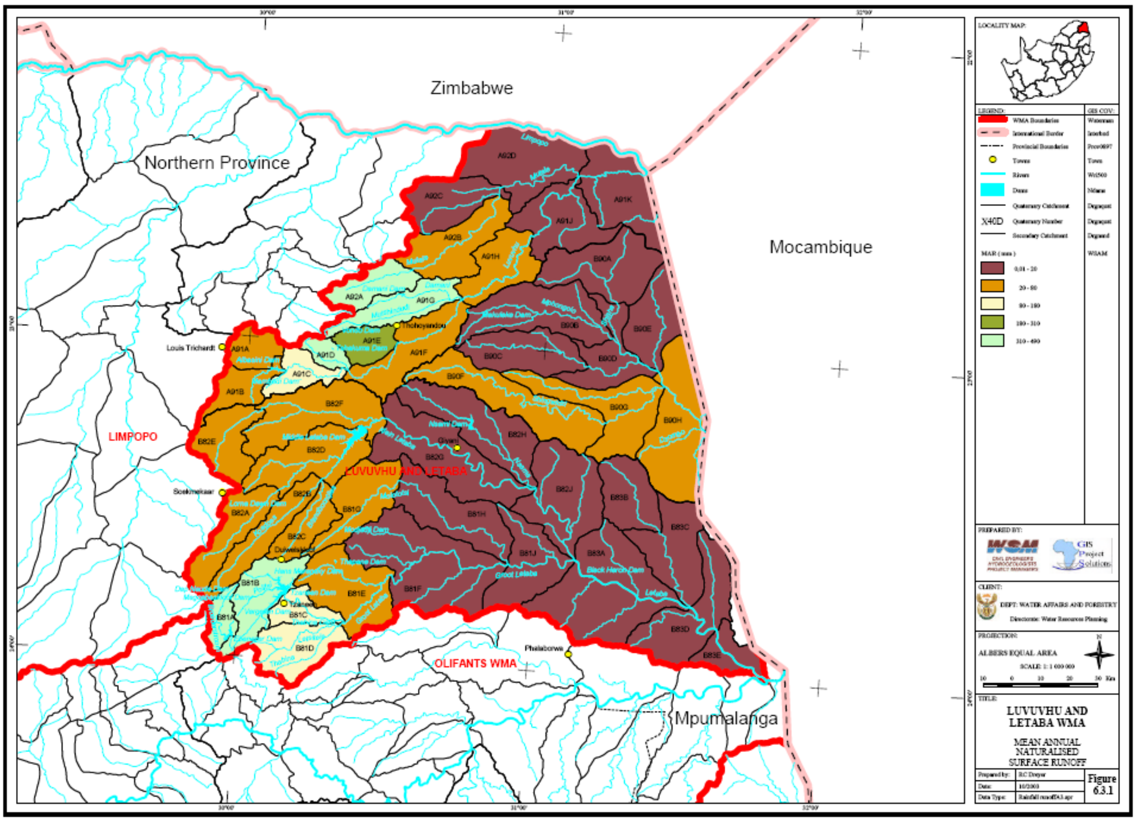


Figure 3.6 Mean annual runoff (MAR) in the Luvuvhu and Letaba catchments (DWAF, 2003).

Table 3.1 Natural Mean Annual Runoff (MAR) and ecological reserve in the Luvuvhu and Letaba catchments (million m³ a^{-1}) (DWAF, 2003).

Sub-area	**Natural MAR** (Mm³ a^{-1})	**Ecological reserve** (Mm³ a^{-1})
Luvuvhu/Mutale	520	105
Shingwedzi	90	14
Great Letaba	382	72
Klein Letaba	151	20
Lower Letaba	42	13
TOTAL	1185	224

The study area for MUS is located mainly between the Great Letaba and the non-perennial tributary Molototsi. The Molototsi is an ephemeral river draining quaternary catchments B81G and B81H, as shown on the Digital Elevation Model (DEM) map in Figure 3.6. The Molototsi River flow is regulated by the Modjadji Dam in the upper reaches. The dam is used to supply water to the urban/domestic sector. The impacts/activities identified in B81G to runoff/effluent from urbanization are serious. They are large from agricultural land, erosion, urban areas, sedimentation, grazing/trampling and vegetation removal. The impacts/activities identified in B81H to runoff/effluent from urban areas are small. They are moderate in terms of agricultural land and exotic vegetation and large impacts are identified at crossings of low water, and due to erosion, sedimentation and vegetation removal. Serious impacts occur from grazing/trampling. No critical impacts were identified and no important wetlands were indicated (DWA, 2013).

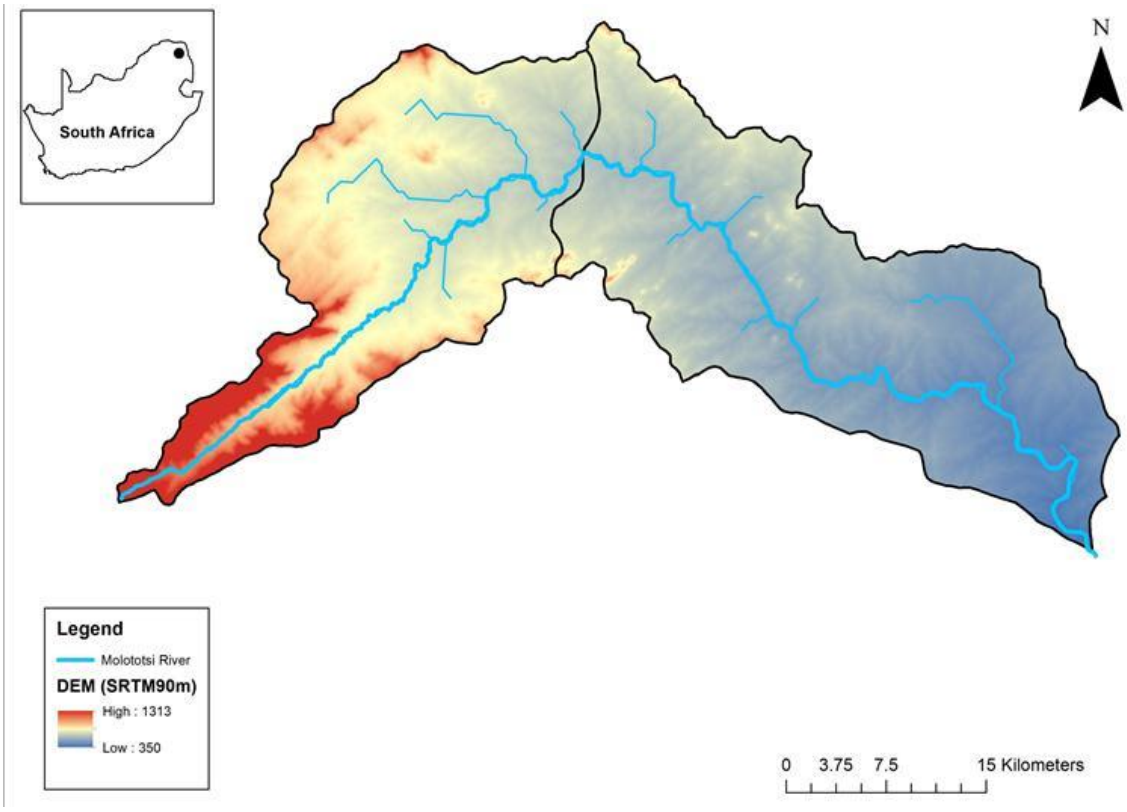


Figure 3.7 Digital elevation model (DEM) for the Molototsi River catchment with draining quaternary catchments B81G (left) and B81H (right) (Jovanovic et al., 2018).

The MAR and flow requirements for the Molototsi catchment are presented in Table 3.2. The river has a minimal baseflow, being of torrential nature (mostly floods).

Table 3.2 Mean Annual Runoff and flow requirements for the Molototsi river.

Quaternary catchment and biophysical node (DWA, 2013)	Natural Mean Annual Runoff nMAR (10^6 m^3 a^{-1})	Low flow required (% of nMAR)	Total flow required (% of nMAR)
B81G at node 00164	16.72	0.4	6.6
B81H at node 00171	25.84	1.0	6.5

The water quality is generally high in nutrients, salts, algal growth and turbidity due to the presence of the GaKgapene wastewater treatment works, populated areas and agricultural activities. Quaternary catchments B81G and B81H fall therefore into moderate priority Resource Units (RU), with moderate ecological and socio-cultural importance. The upper reach B81G has low, whilst the lower reach B81H has high water resource use importance.

3.5 Geology

The geomorphic features of the study area include low mountains of the Great Escarpment (to the West), undulating and irregular plains, hills and lowlands (Lowveld towards the East). The area is at the interface between the granitic-greenstone of the KaapVaal Craton and the metamorphic (predominantly gneiss rocks, but also schist) of the Southern Marginal zone of the Limpopo Mobile Belt (Holland, 2011). Figure 3.7 represents a map of the regional geology of the Molototsi catchment obtained from the South African Council for Geoscience. Information on the local geology is available from Holland (2011).

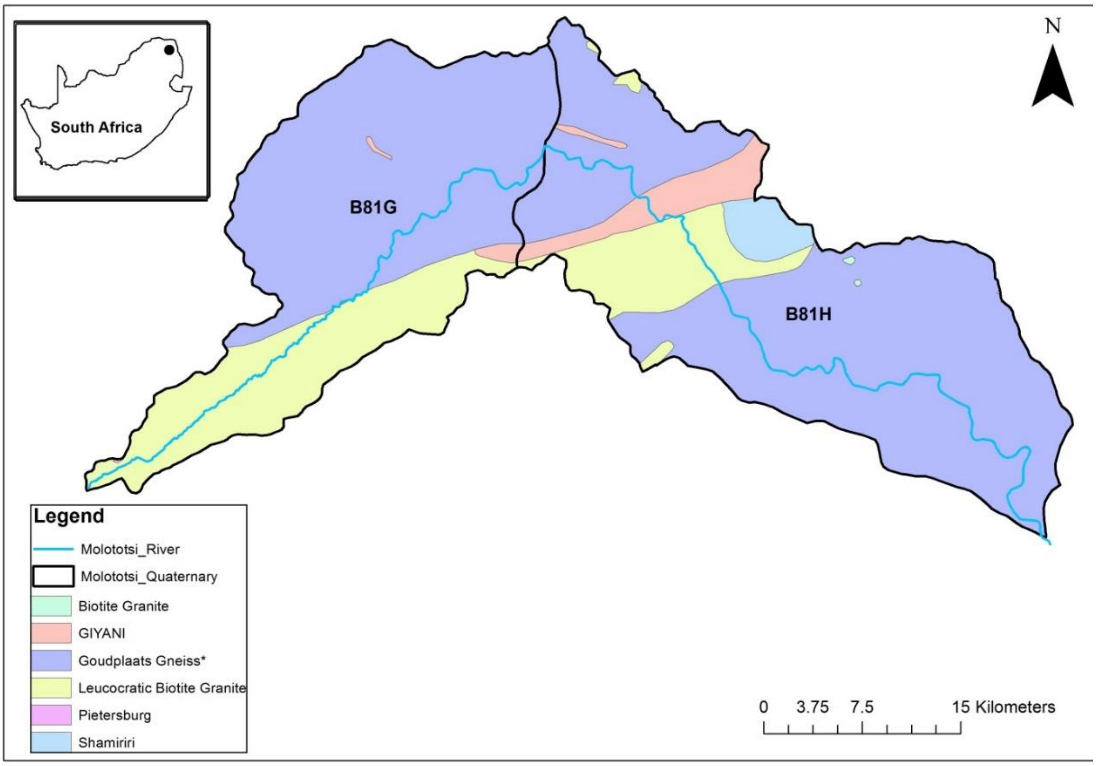


Figure 3.8 Digital map of the geology of the Molototsi quaternary catchments (data obtained from the South African Council for Geoscience), and delineation of the quaternary catchments (Jovanovic et al., 2018).

3.6 Hydrogeology

Both B81G and B81H are located predominantly in the Lowveld Plains, according to the Groundwater Resource Units (GRU) classification based on topography, surface-groundwater interactions and groundwater yield characteristics (DWA, 2014). Portions of B81G lie on the Escarpment (11%) and in Foothills and Valleys (26%), and portion of B81H (5%) in the Giyani-Gravelotte GRU. An extensive description of the geology and groundwater characteristics of these GRUs is available in DWA (2014).

The estimated groundwater use is 30-40% of groundwater recharge (DWA, 2014). Borehole yields are moderate to high, with 34% boreholes in B81G and 56% of boreholes in B81H yielding more than 2 L s^{-1}. Groundwater quality is good to marginal with an overall better quality in B81G compared to B81H. The groundwater contribution to baseflow is negligible, and it occurs mainly as interflow. Detailed information on groundwater characteristics can be found in DWA (2014).

According to DWA (2014), groundwater is moderately utilized in B81G, and abstraction can be increased up to harvest potential with little or no impact on baseflow. It is estimated that groundwater abstraction can be increased from 5.06 Mm^{-3} a^{-1} to 6.78 Mm^{-3} a^{-1}, with a 0.05

Mm^{-3} a^{-1} reduction in baseflow. In B81H, groundwater use is low and it can be increased up to harvest potential with little or no impact on baseflow. Groundwater abstraction can be increased from 2.62 Mm^{-3} a^{-1} to 7.97 Mm^{-3} a^{-1}, with no reduction in baseflow. The siting and feasibility of additional groundwater production boreholes need to be confirmed.

Limited groundwater development may therefore be feasible in the Molototsi catchment, given groundwater is abstracted below harvest potential, groundwater yields and quality are reasonable, and groundwater contributes little to baseflow. Based on the Resource Quality Objectives, the groundwater use in the Molototsi catchment can increase up to a sustainable level (harvest potential). The increase in groundwater use could provide the opportunity for limited expansion of water supply.

Geohydrological data for the area can be obtained from the National Integrated Water Information System (NIWIS) of the South African Department of Water and Sanitation (https://www.dws.gov.za/NIWIS2/, accessed on 1 June 2021) and from the Groundwater Resource Information Project (GRIP) database for Limpopo (http://griplimpopo.co.za/, accessed on 1 June 2021). Both groundwater levels and quality can be obtained from these databases. Most data are recent (last 10 years) with some gaps in time.

3.7 Land use/cover

Land use/cover data are depicted on the map in Figure 3.8 for the Molototsi catchment (National Land Cover map 2013/14; Geoterraimage, 2014). The land use/cover is predominantly thicket/dense bush (mopani trees), woodland/open bush, grassland, cultivated subsistence land and urban settlements (villages). The mountainous areas in the upper reaches of the Molototsi catchment are likely to receive more rainfall that sustains water use by natural forests and plantations. The main economic activities are agriculture (citrus, mango and tomatoes), tomato processing (secondary sector) and eco-tourism (tertiary sector) (DWA, 2014). Large part of the catchment consists of arable land with subsistence farming dominating over commercial farming. Communal grazing is also common. Grassland is often over-grazed due to over-stocking leading to soil erosion. The land is almost entirely part of the former homeland with scattered villages and subsistence farming, and with considerable utilization of ecosystem goods and services.

Makhado et al. (2009) estimated that 59.4% of the total area of the Greater Giyani Municipality consisted of cultivated areas and 30% was covered by woodland and bushland. The town of Giyani accounted for 0.7% of the total area, while 5.4% was taken up by villages. The degraded areas accounted for approximately 5.0%.

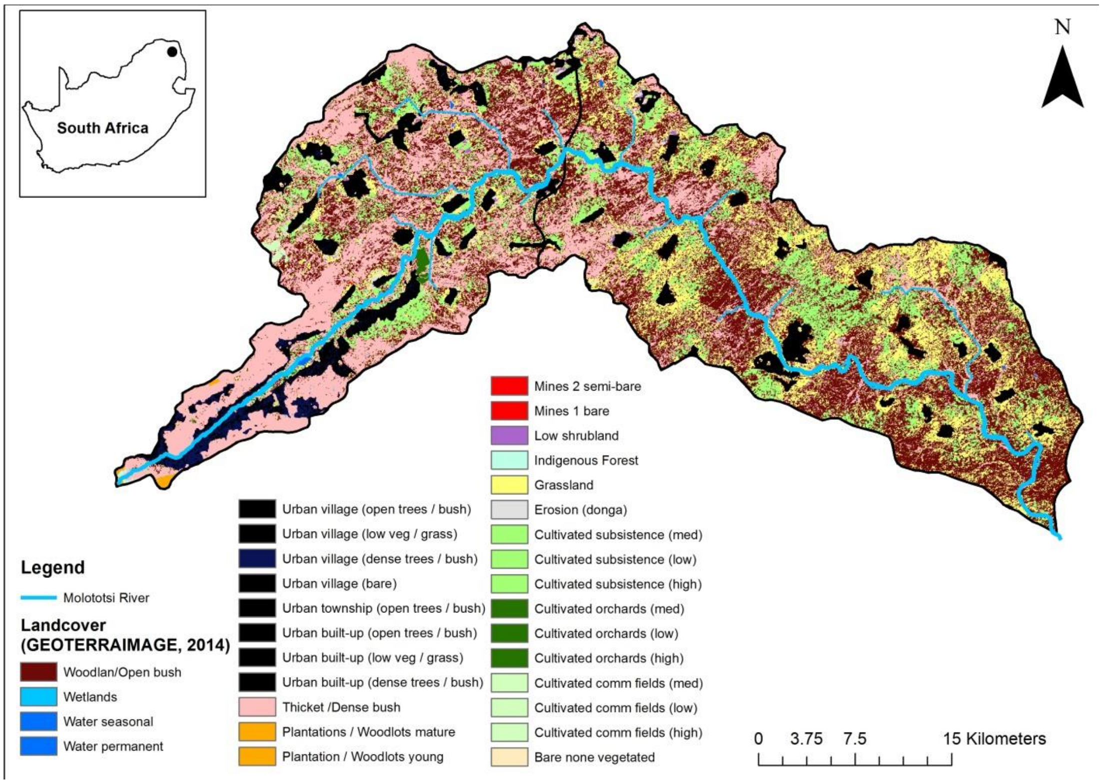


Figure 3.9 Land cover digital map of the Molototsi River catchment (National Land Cover map 2013/14; Geoterraimage, 2014) (Jovanovic et al., 2018).

3.8 Soil types

Soil mapping in South Africa is available at high resolution only for specific areas and it is generally linked to individual projects and soil surveys. Land type maps were, however, produced by the South African Agricultural Research Council (ARC) through the Agricultural Geo-referenced Information System (AGIS). Land types relate to certain soil properties, for example infiltrability, hydraulic conductivity or soil water storage capacity. Figure 3.9 represents the land type map of the Luvuvhu and Letaba catchments.

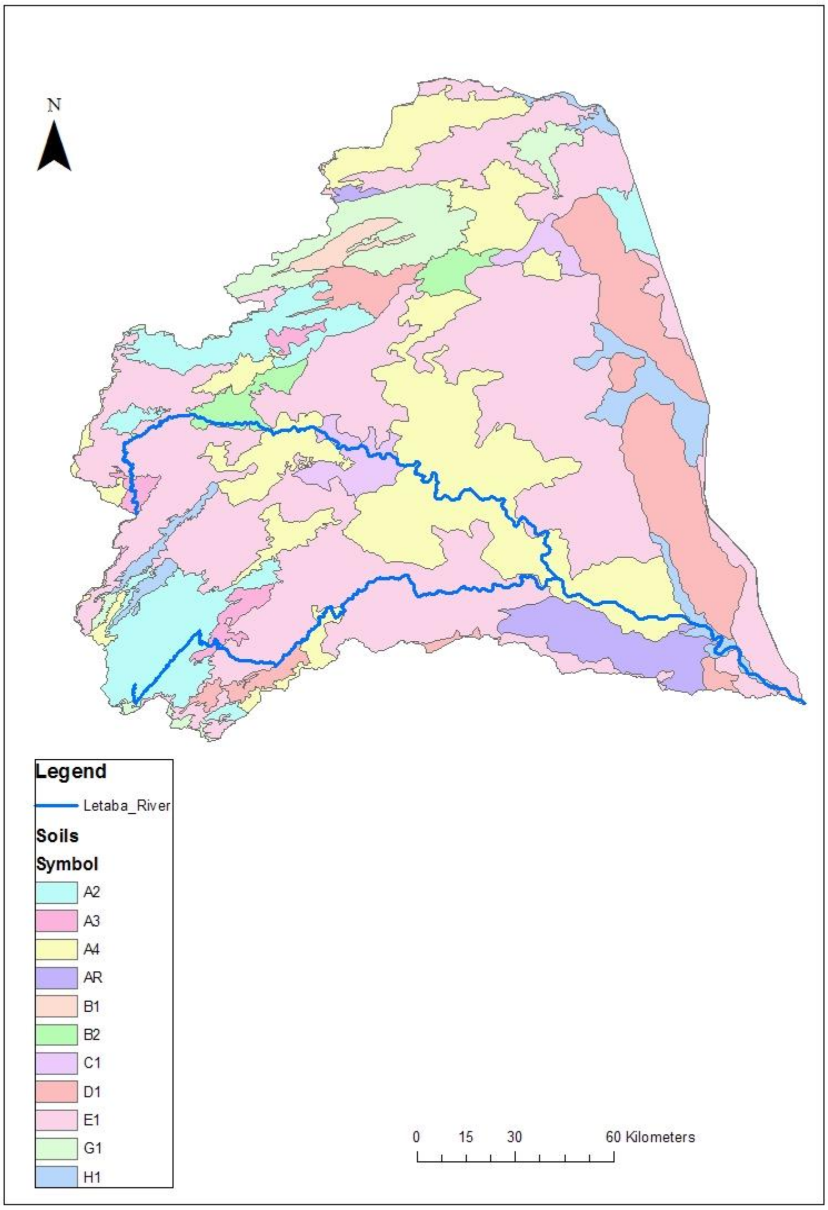


Figure 3.10 Land types in the Luvuvhu and Letaba catchments (Agricultural Research Council).

The symbols matched to each colour signify the following:

A2 – Red and yellow, massive or weakly structured soils with low to medium base status (association of well drained Ferralsols, Acrisols and Lixisols)

A3 – Red and yellow, massive or weakly structured soils with low to medium base status (association of well drained Ferralsols, Acrisols and Lixisols and one or more of Regosols, Leptosols, Calcisols and Durisols)

A4 – Red, massive or weakly structured soils with high base status (association of well drained Lixisols, Cambisols, Luvisols)

AR – Red, yellow and greyish excessively drained sandy soils (Arenosols)

B1 – Red, yellow and greyish soils with low to medium base status (association of Ferralsols, Acrisols, Lixisols and Plinthosols. In addition, other soils with plinthic and gleyic properties may also be present)

B2 – Red, yellow and greyish soils with high base status (association of Lixisols, Cambisols, Luvisols and Plinthosols. In addition, other soils with plinthic and gleyic properties may also be present)

C1 – Soils with a marked clay accumulation (association of Luvisols, Planosols and Solonetz. In addition one or more of Plinthosols, Vertisols and Cambisols may be present)

D1 – Black and red, strongly structured clayey soils with high base status (association of Vertisols, Phaoezems, Kastanozems and Nitisols. In addition one or more Leptosols, Calcisols and Cambisols may be present)

E1 – Soils with minimal development, usually shallow on hard or weathering rock, with or without intermittent diverse soils. (association of Leptosols, Regosols, Calcisols and Durisols. In addition one or more of Cambisols, Luviso)

G1 – Rock with limited soils (association of Leptosols, Regosols, Durisols, Calcisols and Plinthosols)

H1 – Soils with negligible to weak profile development usually occurring on recent flood plains (association of Fluvisols, Cambisols, Luvisols and Gleysols)

The soil taxonomy is given according to the World Reference Database of the Food and Agriculture Organization of the United Nations (http://www.fao.org/soils-portal/data-hub/soil-classification/world-reference-base/en/, accessed on 1 June 2021).

3.9 Water availability and requirements

Due to the high rainfall on the escarpment in the western boundary of the Luvuvhu/Letaba catchments, the Great Letaba and the Luvuvhu/Mutale sub-areas have relatively large water resources. These catchments are very different from the Lower Letaba where the water resources are negligible. The total local yields calculated in 2000 for the Great Letaba, Klein Letaba and Luvuvhu/Mutale sub-areas were 159 million $m^3 a^{-1}$, 32 million $m^3 a^{-1}$ and 115 million $m^3 a^{-1}$ respectively (DWAF, 2004). The largest user of the available water resources is irrigation, while other significant users include forestry and rural domestic water use, international requirements and transfers out of the catchments. In 2000, the total water requirements for the Great Letaba, Klein Letaba and Luvuvhu sub-areas were 181 million m^3 a^{-1}, 37 million m^3 a^{-1} and 119 million m^3 a^{-1} respectively.

The Middle Letaba catchment on the Klein Letaba River measures about 1,800 km^2 and has a natural MAR of 72 million m^3 a^{-1}. The Middle Letaba Dam has a storage capacity of about 184 million m^3, which is 256% of the natural MAR. The Lower Klein Letaba catchment measures about 2,500 km^2. The Nsami Dam on the Nsama River has a capacity of 24.4 million m^3 and the yield of the dam is about 1 million m^3 a^{-1}. Extensive development has occurred in recent years with a total of 3,700 ha of irrigation. About 5,600 ha have been afforested. Numerous farm dams have been constructed (DWAF, 2004).

The gross surface water availability in the Klein Letaba sub-area was estimated at 27 million m^3 a^{-1} in 2003 (DWAF, 2004). Most of this water was derived from the Middle Letaba Dam and the smaller dams upstream. Groundwater was significant in the Klein Letaba catchment, and according to 2003 estimates this resource was about 30% of the utilisation in the sub-area at the time. The available surface water was estimated at 21 million m^3 a^{-1} (at a 1:50 year assurance) after allowing for the ecological reserve, which reduced the gross yield by an estimated 4 million m^3 a^{-1} and invasive alien plants, which reduced the yield by a further 2 million m^3 a^{-1} (Table 3.3).

The contribution of groundwater to the available water in the Klein Letaba sub-area was estimated to be about 9 million m^3 a^{-1}. This groundwater use mostly occurred upstream of the Middle Letaba Dam where it was used to supplement surface water supplies for irrigation. Groundwater was also used to supply most of the rural population in the sub-area, but much of this has been replaced by reticulated supply from the Middle Letaba Dam.

According to DWAF (2004), there had been uncertainties about the available water resources in the Klein Letaba catchment. Conflicting figures were given for the yield of the major dams, particularly the Middle Letaba Dam. In 1978, the historical yield of the dam was quoted as 56 million m^3 a^{-1}. In a 2002 report (DWAF, 2002) the yield was quoted as 16 million m^3 a^{-1}. The reasons for the discrepancy included the fact that the Middle Letaba Dam was not constructed at the site originally planned (i.e. at the confluence of the Middle and Klein Letaba rivers) where the yield would have been much higher. The droughts of the 1990s and 2010s were a factor in the low yield of the dam together with upstream development such as farm dams and irrigation. Use from the Middle Letaba Dam was planned on a yield figure of 56 million m^3 a^{-1}, but a much lower water yield was realised.

Table 3.3 Water availability in the Klein Letaba sub-area (DWAF, 2004).

Water resource category	Amount available (million m^3 a^{-1})
Gross surface water	27
Ecological reserve	-4
Invasive alien plants	-2
Net surface water	21
Groundwater	9
Return flows	2
Total	32

Table 3.4 summarizes the water requirements by sector in the Klein Letaba River catchment in 2000. The Klein Letaba sub-area was regarded as a water deficit area, if the ecological reserve was taken into consideration. When the ecological reserve was disregarded, the deficit was considered negligible.

Table 3.4 Local water requirements in the Klein Letaba River catchment (at 1:50 year assurance) in the year 2000 (DWAF, 2004).

User sector	Water requirement (million m^3 a^{-1})
Irrigation	25
Urban	3
Rural	8
Industrial and mining	0
Afforestation	1
Power generation	0
Total local requirements	37

The water supply and demand status in the Klein Letaba River in 2003 can be summarized as follows:

- Most of the water use in the Middle and Klein Letaba was for irrigation (estimated requirements 25 million $m^3 a^{-1}$) and domestic use (11 million $m^3 a^{-1}$);
- It was established that original estimates of the yield of the Middle Letaba dam were much higher than was found to be the case later;
- The underestimate of the yield of the dam together with rapidly increasing supply from the dam to meet domestic requirements had resulted in irrigators downstream of the dam experiencing serious deficits, to the extent that they had ceased operating – no water was available for irrigation;
- At the time it was established that water use in Giyani was inefficient and wasteful – the strategy stated that water conservation and demand measures were soon to be implemented in this area;
- The broad strategy put forward for the Klein Letaba sub-area was to urgently implement water conservation and demand management measures in the Giyani area. These interventions were reported to be already in progress in 2003;
- The strategy put forward for the sub-area resolved that compulsory licensing was not going to solve the problem of deficits downstream of the Middle Letaba Dam and compulsory licensing was not recommended as an urgent action;
- A longer term strategy for dealing with the problem of water deficits was put forward and entailed:
    - Building a better understanding of water use, and especially the sources of supply in the Klein Letaba sub-area, a detailed water resource and utilisation assessment was recommended;
    - No issuing of licenses for new irrigation;
    - Meeting increasing domestic water requirements from water conservation and demand management that would be applied in the Giyani area;
    - Using the Nandoni dam as a source of water for the longer term;
    - Developing groundwater to supply community gardens; and
- Constructing a dam on the Klein Letaba River to increase water yield – it was stated that the feasible dam sites were not particularly suitable and any dam in the catchment would be very expensive.

3.10 Water resource management

The Mopani District is the water service authority through an agreement for Water Service Provision (WSP) to municipalities. Within the Mopani District, the Great Letaba River supplies water to Great Letaba and Greater Tzaneen Municipalities, the Olifants catchment to Maruleng and Ba-Phalaborwa Municipality, while the Klein Letaba catchment supplies water to the Greater Giyani Local Municipality (Mopani District Municipality IDP, 2016/2017). Due to low rainfall and frequent droughts, in particular in the eastern parts of the Mopani District, water resources are limited and a backlog exists in water services (Greater Giyani Municipality IDP, 2013/2014).

Water sources within the Mopani District are streams, wells and boreholes, with most water supply depending on dam capacity. The Greater Giyani Municipality is supplied with water from the Middle Letaba Dam (collecting water from the Middle Letaba River, the Koedoes River, Brandboontjies River and small streams) and the Nsami Dam (collecting water from the Nsama River). Besides dams, infrastructure includes reservoirs, reticulation networks, especially in urban areas, street-taps and boreholes pumps. However, the existing infrastructure is insufficient to meet the requirements of the entire Greater Giyani Municipality (Greater Giyani Municipality IDP, 2013/2014). During the drought of 2009/2010, the water level in the Middle Letaba Dam dropped to the point that Greater Giyani Municipality was declared a disaster area and emergency funding was provided to alleviate the drought.

The reasons for inadequate water supply infrastructure in Greater Giyani Municipality are that villages are sparse, which makes it difficult and expensive to provide a reticulation system (Mopani District Municipality IDP, 2016/2017), coupled with unwillingness of consumers to pay for basic water services, illegal water connections to bulk pipelines especially in rural areas, and vandalism (Mopani District Municipality IDP, 2013/2014).

The current infrastructure in Giyani is therefore inadequate to supply water to the whole of the municipal area. The Mopani District provides 56 ML d^{-1} (24 ML d^{-1} from Middle Letaba Dam and its treatment water works, 3.6 ML d^{-1} from Mapuve water works and 28 ML d^{-1} from Nsami Dam and its treatment water works). The Department of Water and Sanitation has undertook a large project for the refurbishment of water infrastructure by putting in new pipelines and upgrading of the existing water plants. However, the demand for water in villages has also increased and 42.83% of the households do not have access to water supply (Greater Giyani Municipality IDP, 2021).

Greater Giyani Municipality provides free basic water services to households, and it subsidizes diesel and electricity used for pumping water to the communities. Rainfall patterns impact directly economic development, in particular agriculture. As a result of surface water shortage, the local community has turned towards utilization of groundwater. Boreholes are used in communities where there is an acute shortage of water, while 33.8% of households have no access to electricity. Sanitation is also a major problem, which also contributes to health hazards and groundwater pollution. Pit latrines are used by 45.5% of the population and 74.9% have no sanitation facilities at all. The Department of Water and Sanitation is planning to build a new sewer treatment works (Greater Giyani Municipality IDP, 2021).

Mmbadi (2019) conducted a study on the nature and extent of water supply problems and water security in Greater Giyani Municipality. He found that lack of water supply and erratic and shortening summer rainfall seasons are some of the major causes of water shortages in the study area. The community relies mainly on boreholes for water supply, and sometimes on water abstraction directly from rivers. Rainwater harvesting is practised during the summer rainfall season, and some households resort to purchasing water from vendors. Communities are therefore relatively well adapted to cope with water scarcity in the short term, but they are vulnerable in the case of prolonged droughts and in view of population growth and climate change. Mmbadi (2019) recommended investments in water supply distribution systems, the establishment of more groundwater boreholes and maintenance of existing ones.

Mmbadi (2019) also outlined that the major infrastructural project to transfer water from the Nandoni Dam in Vhembe District to Greater Giyani Municipality (villages of KaDzumeri, KaHomu, Muyexe, KaNgove and Mageva) was recently halted. As a result, villagers still travel long distances to collect water from boreholes and rivers, thereby increasing the risk of disease outbreaks. The water transfer project from the Nandoni Dam is meant to provide the main water supply to the study area, whilst the MUS are seen as supplementary water provision during periods of more frequent and prolonged droughts. The implementation of MUS in the study area is therefore essential and urgent in order to secure water provision to the population.

3.11 Socio-economic characteristics

The population is relatively evenly distributed throughout the study area, living both in urban areas (Giyani and Tzaneen) and in informal rural villages and settlements. Sixty percent of the population is unemployed, and 78% have no individual income. Of those who are employed, 8.37% are employed in the agriculture sector (Greater Giyani Municipality, 2010).

In his investigation, Mmbadi (2019) reported the demographic characteristics of three villages in the study area, as outlined in Table 3.5 (Statistics SA, 2011).

Table 3.5 Demographic characteristics of three villages in the study area according to Mmbadi (2019), extracted from Statistics SA (2011).

Village	Area (km^2)	Population	Households	Average members per household
KaDzumeri	5.6	6,436	1,477	4.4
Mageva	6.62	7,324	1,965	3.7
KaNgove	5.49	6,376	1,545	4.1

The main sectors contributing to the Gross Domestic Product in Greater Giyani Municipality are the public sector (public administration and local government services), tourism, agriculture, retail (formal and informal) and transport (Greater Giyani Municipality, 2013/14). Agriculture is an important activity thanks to favourable climate, variety of products and potential in processing agricultural products. Most of the rainfed cultivation and cattle herding are practised as subsistence farming on communal lands. Irrigated agriculture makes a significant contribution to the economy and is a major user of water. Farmers who practice irrigation in the study area market their crops through both formal and informal markets (hawkers, local markets, supermarkets and national fresh produce markets). Agricultural land in the Greater Giyani Municipality is predominantly Government land and it is administered by chiefs, under the Permission to Occupy (PTO) system of land tenure. There are currently about 18,600 ha of land under claim, which makes the land redistribution and reform process sensitive and in need of good management, given that the two main strategic activities in the municipality are tourism and agriculture, and both require land for expansion (Greater Giyani Municipality IDP, 2021). These strategic activities are in competition with mining and urban development, which makes rational land use a priority, e.g. in terms of designing solar power harvesting fields.

Several socio-economic indicators were previously reported for the Limpopo Province that are deemed to resemble the conditions in Greater Giyani Municipality. The Human Development Index (HDI), based on health, education and income indicators, was amongst the lowest in the country (0.59 for the Limpopo Province; UNDP, 2003). The poverty rate indicated that 77% of the population lived below the poverty income line in 2001 (Southern African Regional Poverty Network, 2004), the rural areas being particularly exposed to poverty. The Water Poverty Index (WPI; World Resources Institute, 2006), based on the impact of water scarcity and water provision to human populations, was found to be well below the country's average in the adjacent Olifants Basin, although no data are available for Greater Giyani Municipality.

3.12 Legal framework

In the National Water Act (NWA Act No. 36 of 1998), water is designated as a national resource. Under the NWA, a licence is required for all water uses (this excludes water for reasonable domestic use, small gardening and animal watering, general authorizations and existing lawful water uses). A water licence is valid for a maximum period of 40 years and is subject to a review period, which may not be at intervals of more than five years. A licence can be increased at each review period but not for more than the review period. This is known as the "revolving licence".

The NWA makes provisions for the establishment of water management institutions to manage water resources within a specified geographical area, such as Water User Association (WUA). The purpose of the WUA is to undertake water management activities on behalf of a group of stakeholders within a water resource area. These stakeholders may include farmers (both commercial and smallholder), domestic water users, local government, industries, etc. The principal function of WUAs is to ensure fair and reliable water supply to its members, who may be people whose livelihoods depend directly on predictable and reliable water supply such as irrigation or livestock farmers. Some of the ancillary functions which can be taken on by WUAs include bulk municipal or domestic water supply functions (authorised by a Water Services Authority) or development support to assist the establishment of historically disadvantaged farmers. It is envisaged that the institutional entity for management of MUS may partially resemble a WUA.

The environmental impacts are regulated by the National Environmental Management Act (NEMA Act No. 107 of 1998) and the NEMA Environmental Impact Assessment (EIA) Regulation No. 982 of 2014. Activities requiring a basic or full EIA are listed in NEMA EIA Regulations No. 983, 984 and 985 of 2014. The activities of relevance include those related to bulk abstraction and transportation of water, water storage facilities and dams, activities affecting watercourses, wastewater treatment and management.

4. FEASIBILITY ASSESSMENT

The feasibility assessment focuses on measures that will increase the resilience of the rural periphery to drought and implement alternative options that will contribute to water security and manage consequences of climate change in the most vulnerable areas. The purpose is to provide practical adaptive solutions (tested and experimented through research and practice elsewhere) to deal with the consequences of climate change in rural communities and municipalities with rural-urban interface. The outputs of the feasibility assessment serve as a scientific foundation to support justification for water use authorization within these new developments. The team will facilitate the implementation process on behalf of the beneficiaries.

The feasibility assessment of solar-powered systems for abstraction of shallow groundwater was originally structured into the following components:

- ***Geophysical feasibility:*** This assessment was conducted in order to evaluate the potential extent of the implementation of the technology in the villages of Greater Giyani Municipalities. For this purpose, a water resource assessment was conducted by making use of available desktop information in order to determine quantity and reliability of the water source. Data collection (Chapter 3) included climatic data (SAWS and ARC), digital elevation models (DEM), spatial land cover/land use maps (NLC), geological and hydrogeological maps (CSIR, CGS and DWS), soil and land type maps (ARC), streamflow and groundwater information including water quality (DWS). Population size and density as well as water use information were acquired in order to determine if, and how much these systems can satisfy water demand by the community. A field recognisance trip was undertaken to assess potential sites for piloting the technologies.
- ***Technical and engineering feasibility:*** This section refers to the technical aspects of AWS and MUS, such as type of pumps, electronics, engineering design for capacity, energy efficiency and consistency between the components, piping, fittings and distribution system as well as practical maintenance of such systems (e.g. pump corrosion and longevity, electronic control and power stabilization, longevity and degradation of solar panels, need for storage reservoirs, maintenance of piping, fittings and distribution system) for a possible larger scale application of the technology. The systems aim at providing secure and cheap water at low-cost energy, being self-sustainable and closing the loop of the water-energy-food nexus. An important part of the operational aspect is the water quality fitness for use and the establishment of a

monitoring programme, in particular for drinking water supply. The need for water filtration and purification needed to be assessed.

- ***Socio-economic feasibility:*** This section refers primarily to the cost of installation and operation of the systems (capital investment and running costs). The perception and willingness of the community was evaluated because the AWS and MUS systems are primarily meant to be run by the community. The management and technical capacity of the community was assessed, as well as the need for training. The opportunity to create/engage small scale enterprises for the operation of the systems and the potential to generate revenue was also investigated.
- ***Environmental feasibility:*** Beneficial and detrimental impacts on the environment were investigated, in particular related to the water volumes to be abstracted, water quality, vegetation and ecosystems, and the built environment. The regulatory framework was assessed, in particular for water use licensing, environmental legislation and requirements by any water service providers. Water use licensing triggers the need for monitoring, water quality control and reporting, so an institutional arrangement needs to be proposed in order to operate the activity. Alternative options were weighed by combining geophysical and technical feasibility with socio-economics and environmental impacts.
- ***Financial Feasibility:*** This section assessed the economic viability of proposed solutions by evaluating the initiation costs (purchases, equipment, cost of licenses and permits, etc.), operating expenses (operations and maintenance costs, risks and opportunities), and the financial sustainability (e.g. cost recovery, etc.) to support the development.

The main methodology follows the process recommended in the SPIS Toolbox (Figure 2.8; GIZ and FAO, 2021). The SPIS Toolbox was developed primarily for small-scale irrigation. The detailed explanation and application of each module and tool of SPIS Toolbox is given in the following sections. Where necessary and possible, the framework of the SPIS Toolbox was adapted or modified to fit the multi-purpose of MUS schemes. Three different scenarios were considered in the study area:

4) Solar-powered groundwater pumping system for the primary purpose of small-scale irrigation using water from dry river bed aquifers.
5) Solar-powered groundwater pumping system for the primary purpose of drinking water supply using groundwater from boreholes established in villages.
6) Multiple agricultural and drinking water use.

Where applicable, the SPIS tools have been populated with different data to represent systems dedicated to both small-scale irrigation and drinking water supply. In addition, a section on water quality is provided, including water purification systems for drinking water and filtration systems for irrigation.

4.1 SPIS Rapid assessment tool

The ***SPIS Rapid assessment tool*** is part of the ***Promote and initiate*** module. It is mostly related to the socio-economic feasibility and it is used to investigate the market potential in a specific area. It consists of a report on aspects of SPIS that need to be considered both for drinking water supply and agricultural irrigation. According to the report template, the following aspects need to be considered:

- Background of the site (irrigated agriculture, solar energy, financial services for agriculture and energy)
- Potential and opportunities for SPIS (experience with SPIS in the country, market players)
- Promotion of SPIS in the country (by government, donors and other stakeholders)
- SWOT analysis (strengths, weaknesses, opportunities and threats)

Solar Energy Adoption Worldwide

Energy and economic growth have been established in literature to have direct association. Fossil fuels have been used since the beginning of humanity, and they have driven both the global industrial and green revolutions. The benefits of availability and convenience have made fossil fuels to be widely accepted (Nhamo and Mukonza, 2016). As the globe moves towards a more sustainable and environmentally friendly development and growth path, viable alternatives to replace the burning of fossil fuels, particularly increasing the usage of renewable energy have developed. In the shift to a low-carbon, cleaner, and greener energy mix, technological innovation is considered to be crucial. Solar technologies are part of the renewable energy sources that have received a lot of attention over the last decade, resulting in a dramatic increase of their usage (Solomon et al., 2021). Solar energy has the greatest advantage of being widely available all around the planet and it can help many fossil-fuel economies like South Africa with lessening their reliance on imported energy. The development of solar energy technology can help solve the energy supply's unpredictability and, to some extent, enhance supply security (Banks, 2005).

To fully realize solar energy's enormous potential, a wide range of policies are required, as well as incentives for early implementation. As part of efforts towards the realization of solar energy's potential, non-economic barriers are being removed, public-private partnerships are being formed, research and development is being subsidized, and effective encouragement and support for innovation is being increased. As the usage of renewable energy sources grows around the world, policymakers and suppliers are becoming more interested in these technologies (Winkler, 2005). These technologies are seen as sources that could provide long-term reliability while reducing greenhouse gas (GHG) emissions, which contribute to global warming and, eventually, climate change (Solomon et al., 2021). In most sunny countries like South Africa, solar thermal electricity and solar photovoltaic power are competitive with oil-fuelled energy generation technologies. Even though the cost of solar energy harvesting and storage has been steadily decreasing over the past years, new business and funding models are still needed to encourage further adoption of off-grid solar electricity and heat process technologies in underdeveloped nations (DoE, 2011).

Solar Energy Adoption in SA

To begin with, solar energy is becoming more widely accepted in South Africa, and the South African government is dedicated to the establishment of a viable solar energy program. Given the emerging issues with its major electricity utility, Eskom, the government is firmly committed to assisting its energy supply growth. Following the Copenhagen 18/12 COP15 promise, the government is also under pressure to meet their obligation in reducing its carbon impact (RSA, 2001). To this purpose, legislation have been put in place, organizations have been established, and on-the-ground efforts have been launched to encourage the adoption and use of solar energy in the country. Contrary to the 1980s package, which mainly consisted of small-scale installations, mostly off-grid and in rural regions, the new package is comprehensive.

South Africa has a long history of solar ventures as larger commercial size projects were already implemented towards the end of the1990s, however solar installations built at the time were quite small in size, measuring in the tens of kW range (Malaudzi et al., 2012). In order to assist the development and deployment of solar energy technology, certain governments have enacted, and others are still deciding on introducing policies that will favour both the deployment and development of solar energy technologies (Banks, 2005). Nonetheless, only a few countries have been able to fully achieve the implementation of complete policies, institutions, and programs to date. The South African government has devised several initiatives and policies to encourage the development and deployment of renewable energy projects in response to the increased interest in solar energy (DoE, 2011). In 2014, the application of solar energy technology increased. Growing worldwide energy use, particularly in emerging nations, and a significant rise in oil prices at the end of 2014 also resulted in an increased uptake. Policies and the increasing cost-competitiveness of electricity from renewable sources have also helped the adoption of solar energy technologies (Solomon et al., 2021).

Solar Energy Policies

South Africa's ANC government began planning and transition work in the renewable energy sector after assuming power in 1994. During the first phase of the National Electrification Programs, the 1998 White Paper on Energy was written. The main goal of the resulting projects was to fast track the roll-out of electricity in urban and rural areas within the country that were underdeveloped, this was done between 1994 and 1999 (DoE, 2011). The goal of the White Paper from 1998 was to broaden the energy market and diversify energy sources. The White Paper essentially laid the groundwork for decoupling electricity generation, transmission, and distribution. But the paper had shortfalls, for example, the minimum technical criteria for independent power producers (IPPs) entering the energy market was not covered in the paper. As a result, the mistakes from the White Paper were corrected in the White Paper on Renewable Energy which was published in 2003 (RSA, 2011). The South African government established a number of policies and strategies building up from the aforementioned papers; a summary of these policies and strategies is given in Table 4.1.

Table 4.1 Solar Energy Legislations in South Africa.

Policy/Legislative framework	Provisions on renewables and solar
White Paper on Energy Policy of the Republic of South Africa (December 1998)	The White Paper is designed to ensure smooth implementation of economically feasible technologies and applications. The aim of the paper was to address some of the challenges the renewable energy sector has been facing. This is done by making sure that national resources are directed to the development of renewable technologies.
White Paper on Renewable Energy Policy of the Republic of South Africa (November 2003)	It sets a target of 10 000 GWh from renewable energy that would result in consumption from biomass, wind, solar and small-scale hydro energy systems by 2013.
Integrated Energy Plan 2003	The Plan expands on what needs to be done by South Africa in meeting its energy needs. The Plan is a result of The National Energy Act No. 34 of 2008. The aim is broadening sources of energy in order to improve energy efficiency.

Policy/Legislative framework	Provisions on renewables and solar
Electricity Regulation Act of 2006	The Act resulted in the establishment of the regulatory body NERSA. The role of the body is to determine electricity traffic and grant licenses for the generation, distribution and transmission of electricity.
Integrated Resource Plan 2010-2030 (IRP) focus on electricity	The Plan recognises solar PV as a viable option that could produce 300 MW per year as from 2012. The greatest concern expressed in the plan is the degree to which energy efficiency demand-side management (EEDSM) has an impact on impending generation options.
The solar technology roadmap (STEM)	The roadmap identified the challenges that solar technologies face. It highlights the need for policies and incentives that can accelerate deployment of the technologies in South Africa. The roadmap was instrumental in paving the way for localisation efforts to enable the government to achieve its New Growth Path aspirations.
Department of Energy Draft 2012 Integrated Energy Planning Report	The aim of the Planning Report was to ensure that the country can meet current and future energy service needs. This must be done in a more efficient and sustainable way.
Green Industries Initiative	The Initiative was established to help support the New Growth Path. This is done by supporting and investing in renewable energy projects. To this end, IDC has allocated R25 billion over the five years to 2015/16 for the development of green industries within the country. The Green Industries SBU will disburse the greater part of this funding. The Green Energy Efficiency Fund (GEEF) was established in 2011 and the Green Accord was signed in the same year. Two years later, the country witnessed the construction of the first two concentrated solar projects in South Africa through this funding.
Green Fund	The government established the Green Fund to fund green initia-tives in the country. Numerous projects have been funded to date, including solar projects such as iShack in Cape Town. The project is a scalable off-grid solar electricity utility for informal settlements.

Policy/Legislative framework	Provisions on renewables and solar
Green Industrial Policy Action Plan	To promote local economic development, the Green Industrial Policy Action was established to support green industries. The materials and the manufacturing component used in assembling solar technologies is a concern expressed in the plan.
Green Economy Accord	The accord endorses government commitment to move towards a greener economy. The accord recognises that a green economy is a driver for an equitable society that will create green jobs to grow the economy

Manufacturing Companies of Solar and other Renewable Technologies

In South Africa there is a vast range of renewable energy technology, these technologies are either manufactured locally or internationally. The majority of wind and hydro generators available in the country are locally produced with some of the hydro, wind, and solar Photovoltaic (PV) energy produced being exported to other countries (Mulaudzi et al., 2012). Table 4.2 provides a list of local companies that manufacture renewable energy technologies.

Table 4.2 List of Companies that Manufacture Renewable Energy Technologies.

Company	Business type	Technology	Location
Solar Deluxe	Manufacturers, wholesale supplier	Solar water heating	Cape Town, Western Cape
Budget Solar (Pty) Ltd	Manufacturers/wholesale/importer	Solar electric power	Somerset West, Western Cape
Pre-plan energy	Installer/developers	Wind, biogas, Solar Photovoltaic	Alberton, Gauteng
Solartech	Manufacturers and installers	Solar water heating	Lonehill, Gauteng
Solar heat exchange	Manufacturers and installers	Solar water heating	Johannesburg, Gauteng
Solar Beam	Manufacturers/installers	Solar water heating	Rivonia, Gauteng

Company	Business type	Technology	Location
Environment Save Energy	Manufacturer	Wind turbine and solar photovoltaic	Port Elizabeth, Eastern Cape
Green Wind Power and automation	Manufacturer/wholesale supplier	Wind turbine	Cape Town, Western Cape
Solardome SA cc	Design and installation	Solar water heating, solar thermal storage	Stellenbosch, Western Cape
Renergy Technologies	Manufacturer, exporter, importer	solar panel, solar batteries, solar water heating	Elandsfontein, Gauteng
All power trust	Manufacturers/ importers/exporters	Solar electric power	Port Elizabeth, Eastern Cape
Inti Solar	Manufacturers and installers	Solar water heating	Fourways, Gauteng

Institutions linked to Solar Energy Upscaling in South Africa

The South African government has established a number of major agencies and projects in addition to the renewable energy strategy plan. These organizations and initiatives have various missions, but they all work together to advance the national solar energy adoption and upscaling goal. Table 4.3 provides a description of the organizations and programs targeted at supporting solar energy adoption and scaling as summarised by Nhamu and Mukonza (2016).

Table 4.3 Description of the organizations/ institutions targeted at supporting solar energy adoption and scaling.

Institution	Function and role in solar energy
Department of Energy (DoE)	The DoE is the custodian of South Africa's energy policy. It is responsible for establishing a national framework that will allow the generation of renewable energy-based electricity in the country.
Departmental of Environmental Affairs	The role of the department is to monitor and regulate environmental impact, such as greenhouse gas emissions, ecosystem degradation, waste management and water use. The department is also responsible for Eskom and IPP operations through environmental impact assessments (EIAs). Before a project commences, it must obtain approval from the Department (i.e.

Institution	Function and role in solar energy
	license/permit) to build a power station, major power lines and sub-stations. The guiding Act of this process is the National Environment Management Act of 1998 (Act No. 107 of 1998).
Department of Science and Technology	The department develops, implements and monitors science and technology policy and programmes. It is the custodian of technology research and development (and manages the South African Energy Grand Challenge).
Department of Trade and Industry (DTI)	The DTI is responsible for the development and implementation of the up scaled Industrial Policy Action Plan. It has identified green industries, and specifically the energy sector (solar and wind energy, solar water heating, energy efficiency), as priorities for the country's industrial policy The aim of the policy plan is to promote long-term industrialisation and industrial diversification of renewable energies and solar energy is an integral part. It also assists in establishing a domestic manufacturing base to support renewable technology development and deployment. The DTI also makes recommendations to the DoE on targets related to local content and employment creation for all projects participating in the REIPP procurement programme.
National Treasury	Is involved in budgeting and financing strategic national projects like the Solar Park as well as research in carbon taxation.
Municipalities	Municipalities are responsible for securing the delivery of basic services (including energy) in urban areas and for many aspects of integrated development planning. They are also a conduit that channels national government subsidies directed towards energy provision.
National Energy Regulator of South Africa (NERSA)	They regulate electricity tariffs, and grant licenses for the generation, distribution and transmission of electricity.
South African Local Government Association (SALGA)	It has a stake in the implementation of renewable energy policies at the local level. It has also supported research on how ready the country is to move towards a green economy.
South African National Energy Development Institute (SANEDI)	The mandate of the Institute is to coordinate and undertake applied research in energy development and demonstration. The institute was established by DoE and the Department of Science and Technology in October 2010, as part of the state energy financing entity, the Central Energy Fund (CEF). SANEDI is tasked with developing human capital in the energy research sector and maintaining a culture of innovation in the energy sector.
Council for Scientific and Industrial Research (CSIR)	It is a leading scientific and technology research, development and implementation organisation in South Africa and also deals with solar energy.

Institution	Function and role in solar energy
RECORD	The institution carries out research and collaborative projects that involve mapping current and future solar technologies. Research and development are necessary to establish how the country can meet its energy needs, as outlined by the different policies in terms of the short term milestone of 2020, the medium term (2030) and the long term (2050). The institute was influential in setting up a solar measuring station project and in the release of the new solar resource map for South Africa. It is involved in the construction of MET solar stations in specific locations in South Africa. Through applied energy research, the institution has established the concept of a centre for solar technology, development and innovation.
South African Photovoltaic Industry Association (SAPVIA)	The association is a group of key players in South Africa's PV market, who have the knowledge, experience, initiative and determination to drive the growth of the industry. It promotes higher uptake of the technology and provides advice to key decision makers on sustainable PV technology.
Southern Africa Solar Thermal and Electricity Association (SASTELA)	This is an association of CSP actors in Southern Africa and on the African continent. The association comprises developers, manufacturers, utilities, engineering companies, financial institutions and research institutions. SASTELA's aim is to promote growth in the emerging solar thermal electricity industry.
Sustainable Energy Society of Southern Africa (SESSA)	The primary objective of the organisation is to promote the use of renewable energy (such as solar water heaters), heat pumps and green energy industries (like bioenergy and wind to hydropower). The organisation was established to support Eskom in the solar rebate programme.
South African National Energy Agency Association (SANEA)	It plays a significant role in the future of energy in South Africa by bringing various stakeholders together to identify and implement sustainable and efficient solutions.
Eskom	Eskom is a key player and the sole buyer of solar electricity; it is therefore a player and a referee in the process. Eskom has a challenge to ensure that clean electricity is produced in future to reduce the grid emission factor. Regarding the promotion of solar projects, Eskom has constructed a 100 MW CSP demonstration plant in Upington in the Northern Cape Province.
South African Renewable Energy Council	The Renewable Energy Council in South Africa is an umbrella body that coordinates and aligns the activities of its key stakeholders.
South African Renewable Energy Technology Centre (SARETEC)	The centre was established to provide training for technicians in terms of installation, operation and maintenance of solar PV and wind turbine facilities

Available Solar Technologies

Solar energy systems harness the sun's energy to generate power. Photovoltaics (PV), concentrated solar power (CSP), and heating and cooling systems are three of the most common sources of solar energy. Solar PV technologies operate by converting energy from the sun directly to electricity; CSP make use of the sun's heat to power utility-scale electric turbines; and, finally, heating and cooling systems use thermal energy to deliver hot water and cooling systems like air conditioning.

Solar Energy Pros and Cons

The absence of fuel costs is a feature of solar energy systems; the direct cost is the initial investment in the solar energy system. The development and spread of affordable, limitless, and clean solar energy technology will have enormous long-term benefits and advantages throughout the planet (Malaudzi et al., 2012). Solar energy technologies improve a country's energy security by reducing its dependency on imported energy. Most importantly, solar is a self-sufficient energy source that improves sustainability, minimizes pollution, and decreases the cost of climate change mitigation, resulting in fossil fuel costs remaining lower than they would be otherwise (Nhamo and Mukonza, 2016). Although solar energy is increasingly being recognized as a future source for clean electricity, it is vital to note that it is not without its drawbacks. Integration into the national grid, energy harvesting and storage for future use, as well as cost reductions for non-panel equipment, financing, and installation are all potential problems for solar energy. Despite these obstacles and the reliance on policy and financial incentives for solar energy development, solar development is expected to become more cost-effective in the coming years. The pros and cons of using solar energy are summarised in Table 4.4.

Table 4.4 Solar energy advantages and disadvantages.

Advantages	**Disadvantages**
It is an abundant, renewable energy source	As the technology is in an evolving stage, the efficiency levels of conversion from light to electricity are in the range of 10 to 17 per cent, depending on the technology used.
This technology is omnipresent, and it can be captured for conversion on a daily basis.	The initial investment cost of this technology is high. At present, the technology is surviving because of subsidy schemes provided by governments.

Advantages	Disadvantages
It is a non-polluting technology, which means that it does not release GHGs.	Solar energy is heavily dependent on atmospheric conditions.
It is a noiseless technology as there are no moving parts involved in energy generation.	Solar energy is available only during daytime. Most load profiles indicate peak load in the evening/night time. This necessitates expensive storage devices, like batteries, which need to be replaced every three to five years. The cost of the battery is 30 to 40 per cent of the system cost.
This technology requires low-maintenance, because there are no moving parts.	As the efficiency levels are low, the space required is relatively high. For instance, with existing technologies, the land required for putting up a 1 MW solar PV power plant is between six to nine acres.
It can be installed on a modular basis and expanded over a period of time.	
It is the most viable alternative for providing electricity in remote rural areas, as it can be installed where the energy demand is high and it can be expanded on a modular basis.	

Progress on Solar Energy Usage

The White Paper's fifth goal which was aimed at addressing the demand for alternate energy sources, especially renewable energy sources, emphasized the government's desire to make solar power and non-grid electrification systems more sustainable. This included the development of various solar technology applications such as but not limited to solar pump water supply systems, solar heating systems for homes, hybrid electrification systems, and wind power (Solomon et al., 2021). In 2011, the country had already installed around 484 000 m^2 of solar water heater panels and this number only represented less than 1% of the potential market. Additionally, the construction of 18 big utility-scale solar plants with a combined capacity of 630 MW commenced in 2013 (Banks, 2005). According to the report by the Department of Energy (DoE), 593 MW was produced by grid-connected PV installations in January 2015. Overall South Africa has shown little progress in meeting the aim established in the 2003 White Paper on Renewable Energy Policy (DoE, 2011).

In light of this, the Renewable Energy Independent Power Producer Programme (REIPPP) was established and significant progress has been made under this program in terms of permitting numerous companies to enter the industry, establishing adequate financial and fiscal instruments, and technology advancement. The REIPPPP was launched in 2011, replacing the 2009 Renewable Energy Feed-in Tariff (REFIT) program. The program creates a solid enabling environment for Independent Power Producers (IPPs) to participate in the renewable energy industry by procuring specific megawatt allocations as stipulated in the 2010 Integrated Resources Plan (DoE,2011). Onshore wind, PV, concentrated solar power, landfill gas, biomass, small hydro, and biogas are among the technologies covered by the REIPPP Programme. The motivation behind establishing REIPPP was for it to contribute to the aim of 3,725 MW, leading to economic, social, and environmental growth that is sustainable. Additionally, it was also intended to grow South Africa's renewable energy industry. The program has attracted local and international entrepreneurs and investors, who have invested extensively in renewable energy in South Africa. The REIPPP has led to the construction of 92 private energy plants to generate power (Malaudzi et al., 2012).

The 92 IPPs are spread across the country's nine provinces, with the Northern, Eastern, and Western Cape provinces holding the majority of renewable energy facilities. REIPPPP's innovative design involves a competitive bidding technique based on the best price and contribution to socio-economic development, with a 70 percent price and 30 percent economic development weighted (Malaudzi et al., 2012). According to the Department of Energy, around 4,294 GWh of REIPPPP energy has been connected to the national grid, resulting in 4.4 metric tonnes of carbon dioxide equivalent emissions reduction and the total electricity that was generated had a grid emission factor (GEF) of 1.015 t CO_2/MWh. When comparing the REIPPPP to the REFIT program, which never took off, it has been successful. Even though there has been a notable rise towards investments in renewable energy in recent years, it still remains far below what is required to allow the transition to a sustainable energy sector (Winkler, 2005).

Clearwater Mall has installed a new solar PV system worth approximately R8 million. The system comprises of 2,000 solar panels of 250 W spread across a 4,000 m^2 surface area, making it Africa's largest rooftop solar system. It generates 843 MWh/a, lowering carbon emissions by approximately 884 t/a and conserving approximately 1,000 t/a of coal that would otherwise be used to generate energy. The solar panel system minimizes reliance on the power grid and saves up to 10% of the mall's total use. Solar energy is the most readily available resource in South Africa. It presents itself to a variety of potential applications, and the country's solar-equipment business is growing. Annual photovoltaic (PV) panel assembly capacity is 5 MW, and several South African enterprises manufacture solar water heaters.

Solar power is increasingly being used for water pumping as part of the Department of Water and Sanitation's rural water provision and sanitation program. To some extent, solar water heating is used; domestic 330,000 m^2 and swimming pools 327,000 m^2 (middle- to high-income), business and industry 45,000 m^2 and agricultural 4,000 m^2 are the current installed capacities.

Financing Partnership with Public and Private Sector for Renewable Energy Projects

For the development of solar projects, the government recognized the benefits of public-private partnerships (PPPs), an excellent example of such partnerships is the RustMo1 Solar Farm (7 MW solar plant) which is already connected to the national grid and produces electricity for Eskom. Eskom hydropower constructed a CSP with a capacity of 100 MW in Upington, the project is among the largest in Sub-Saharan Africa. In October 2009, the South African government signed a Memorandum of Understanding with the Clinton Climate Initiative (CCI) for the purpose of conducting a pre-feasibility study to investigate the possibility of establishing a solar park in the Northern Cape Province (Nhamo and Mukonza, 2016). A preliminary analysis indicated that the Northern Cape Province is the best area for solar irradiation. A solar park is similar to an industrial park in that it provides infrastructure, access to land, water supply, and feeder lines to energy transmission systems (Nhamo and Mukonza, 2016). The primary goal was to encourage the construction of solar energy facilities.

The Development Bank of Southern Africa (DBSA) has been a crucial partner in mobilizing the necessary funds. The DBSA also manages project bankability studies and conducts iterative financial analyses to determine the costs and benefits of various financing instalments (RSA, 2001). South African banks have provided about 60 per cent of the financing for REIPPPP and development finance institutions and foreign financiers provided the balance and are ready to fund further REIPPPP projects (RSA, 2001).

The DTI declared in 2009 that it expects one million solar water heaters (SWHs) to be installed in homes and commercial buildings over the next five years. The government's SWH initiative is handled by Eskom and it is sponsored by a Division of Revenue Act (DoRA). The initiative has been implemented in several municipalities including City of Tshwane, Sol Plaatjie, and Naledi. The private sector is also involved, and shows willingness towards building a strong and self-sustaining SWH industry. As a result, some commercial banks, insurance companies, and generous benefactors have joined and are spearheading various SWH initiatives across the country (Malaudzi et al., 2012). The Department of Energy (DoE) introduced the Standard Offer incentive program in 2015, which will offer financial support to all Energy Efficiency and Demand Side Management (EEDSM) activities. The scheme's goal is to broaden the opportunities for securing the much-needed, long-term financial support for the program. It is crucial to highlight that the South African SWH industry has taken off as a result of energy efficiency rules and targets that are part of a broader demand management plan (DoE, 2011).

Conclusion

From the examination of policies, institutions, and programs that are carried out in the country, it's evident that the South African government has made substantial progress in boosting solar uptake and upscaling. South Africa has little choice but to promote renewable energy, particularly solar energy, due to its massive carbon footprint, the continuous load shedding crisis within the country, and the Copenhagen 2009 pledges and commitment.

4.2 Impact assessment tool

The ***Impact assessment tool*** is part of the ***Promote and initiate*** module. It is mainly related to the environmental feasibility and socio-economics. The tool consists of a spreadsheet that includes:

1) An input checklist sheet with a list of questions grouped to assess and weigh the socio-economic and environmental feasibility under the following categories:
    a. Population change and migration
    b. Women's role
    c. Minority and indigenous groups
    d. Income and amenity
    e. Regional effects in the country
    f. User involvement
    g. Natural resources and environment
2) An input data sheets that provides an overview on socio-economic aspects of beneficiaries.

The input data of the Impact assessment tool were populated to include both the case of drinking water supply and agricultural irrigation. The results of the input data are automatically summarized in output graphs in the spreadsheet.

Input checklist sheet

For each question in the input checklist, the user is given the option of choosing whether impact occurs (Yes or No), the weighting of the impact (Low, Medium or High) and the magnitude of the impact (Positive impact very likely, Positive impact possible, Neutral, Negative impact possible or Negative impact very likely). The Input checklist sheet was filled with information based on the long-term research and experience gained in the study area, as well as based on feedback from stakeholder engagement during field visits. Sources of data and information were added to the ‘comment’ fields in the spreadsheet. Some fields in the input checklist were not investigated in the project and/or not relevant to the specific study sites, such as population migration, legal aspects of gender issues, cultural heritage issues, socio-political organization, sea water intrusion, etc. In that case, the weighting of the impact was chosen to be low and the magnitude of the impact neutral to avoid bias in the calculation. The spreadsheet file with the detailed information entered is available from the authors. Figure 4.1 presents the output graphs obtained from the Input checklist sheet by categories.

For the category on population change and migration (Figure 4.1), demographic changes in population due to migration were not investigated in this project. However, the project will undoubtedly ensure improvements in employment and economic opportunities, which may contribute to a decrease in population migration from the study area. Concerning women’s role (Figure 4.1), the role of women in relation to heritage, inheritance, marital status, land tenure and gender impacts on downstream users were not investigated. However, the project is expected to positively impact on gender equity both for women working in households, employed women and women farmers. The social status of women will improve through the provision of water supply and service, market opportunities, integration and equitable access to resources and institutions, time relief for other activities such as education, leisure and training. Similarly, the project will impact positively on the lifestyle, livelihood of minority and indigenous groups (Figure 4.1), although the impacts on socio-organizational, cultural and heritage issues were beyond the scope of investigation.

A major positive impact of the project is expected in terms of income and amenities (Figure 4.1). The project will contribute to economic changes, improving of livelihoods, well-being, equitable distribution of income and business opportunities with spin-offs in terms of diversification of production, technical services and markets, creation of agricultural services, employment opportunities and building of infrastructure. The project is not expected to impact substantially political changes and social harmony. The project is expected to impact regional effects in the country to a lesser extent (Figure 4.1) because it is still in its pilot phase, however it can provide a good demonstration site for upscaling. Institutional efficiencies at local and regional level have been considered through the involvement of key stakeholders that have a mandate to influence policies. Although the improvement of food supply is targeted to local communities, there is a realistic chance that produce be marketed outside the study area, in markets in Giyani, Limpopo and other Provinces. The project will also contribute to strengthening the agricultural products value chain (transport, marketing and processing), although this is not the primary target of the project. Particular attention was devoted to User involvement (Figure 4.1) through the engagement of key stakeholders from funding organizations, local government and affected communities. Public participation was ensured through workshops and field visits, during which credit and marketing opportunities were discussed. The views, needs, preferences and traditional practices of stakeholders were also discussed. Training of communities and relevant stakeholders in the use of the solar-powered water supply systems is also an important component of the project in order to ensure successful and sustainable implementation.

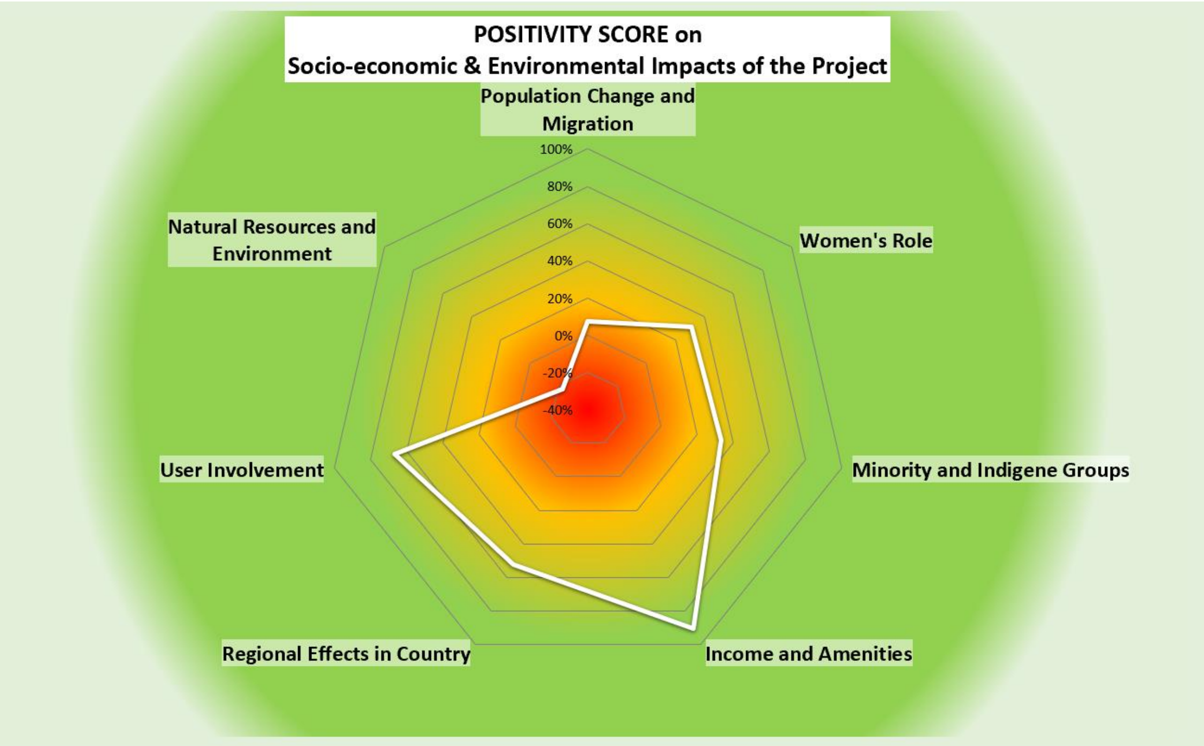


Figure 4.1 Screen printout of the socio-economic and environmental impacts of the project calculated with the Input checklist sheet of the Impact assessment tool (GIZ and FAO, 2021).

Concerning the impacts on natural resources and environment (Figure 4.1), the effects of increased evapotranspiration has been considered in a previous study (Lebea et al., 2021) emanating from the project funded by the Water Research Commission (Jovanovic et al., 2018). It was estimated that the seasonal evapotranspiration of tomato, a common vegetable in the area, is about 450 mm/a. This figure could be representative for other vegetables commonly grown in the area. Given the climatic and soil conditions, it would be possible to grow three vegetable crops per year in the area. This would amount to a water consumption through evapotranspiration of about 1350 mm/a or 13500 m^3/ha. Comparatively, a village with a population of about 1500 would consume a similar volume of water per year at a provision rate of 25 L per person per day (minimum water demand according to accepted international and national standards). Sustainable water abstraction limits can be set for each specific site (borehole, well), for example by switching off the pump automatically when a certain groundwater level has been reached (this was the case of a farm borehole described by Jovanovic et al., 2018). Although groundwater baseflow has not been assessed, it is inevitable that some impacts on downstream users would manifest with increased groundwater abstraction. This would particularly impact downstream communities and the Kruger National Park.

It should be noted that a disconnect was observed between the regional groundwater table and the sand river bed aquifer in the Molototsi River (Jovanovic et al., 2018), with surface-groundwater interactions occurring at very localized sites. Conceptually, the sand river bed aquifers appear to be recharged mainly through surface runoff and occasional flow events that occur on average a few times per year. This is the topic of a current WRC project investigation. Groundwater quality as a result of irrigation return flow is not deemed to be a problem mainly because the farms are spaced apart. Salinization and other impacts on the soil (acidification, alkalinisation, waterlogging) are not expected in the short-term, however this should be monitored in the long-term. However, land degradation through soil erosion represents a big problem in the area and it manifests through sheet and especially gulley erosion. Soil compaction was also observed to occur below the ploughing layer.

Groundwater quality is generally fit for drinking and especially agriculture. The quality of water in the sand bed river aquifers is excellent because recharge occurs directly from rainfall (Jovanovic et al., 2018). However, water quality needs to be monitored according to standards and protocols, especially for drinking water purposes, to determine any potential risks from all non-point and point pollution sources. Although formal waste collection sites do not exist in the area, including e-waste, batteries, plastics, etc., the volume of waste generated by the solar-powered pump systems is sufficiently small to be stored at localized sites and it will not represent a problem. However, the increased use of fertilizers and pesticides will have to be monitored for adherence to protocols.

Input data sheet

The input data sheet contains information on socio-economic data. The affected villages are those indicated in Figure 3.2. Their population size was extracted from Appendix A:

- Mayephu 1940
- Mpakani 5590
- Mzilela 1150
- Matsotsosela 2302
- Nwamarhanga 5677
- Khaxani 2910
- Xihlakati 2060

The total affected population is therefore 21629 and the average population size in the villages is 3090. Based on the minimum requirement of 25 L per person per day, a village of 3090 would require the provision of about 28200 m^3/a.

Small-scale farms will be affected by the project. Two examples of small-scale farms in the area Mhlambeto Multi-purpose Agricultural Primary Cooperative Ltd. (23.562495° S; 30.700291° E; 430 m) and Duvadzi Youth Organic Agricultural Co-operative farm (23.566533° S; 30.819982° E; 404 m). Both farms are run by local male emerging farmers and their family under Permission to Occupy. Most of the time, they employ 1 permanent staff and 5 to 10 seasonal staff. In the South African context, emerging farmers can be defined as historically disadvantaged farmers, aspiring to become fully commercial, selling at least 60% of the produce to the market with a turnover of less than half a million rand per annum (Zantsi et al., 2018).

4.3 Water requirement tool

The ***Water requirement tool*** is a spreadsheet as part of the ***Safeguard water*** module. It is mainly related to the technical and engineering feasibility, and it is one of the key tools for the design and implementation of the solar-powered pumping systems. The Water requirement tool is a spreadsheet that makes use of the FAO methodology (FAO, 1986) based on the FAO 56 Bulletin to calculate crop water requirements (Allen et al., 1998; Pereira et al., 2021). In addition, livestock water requirements are calculated based on the recommendations of the Government of Western Australia (2017).

For the purpose of estimating crop water requirements, a hypothetical cropping pattern was chosen in the Water requirement tool with three tomato crops grown on 0.5 ha and planted on 1 December, 1, May and 1 October of the year. Tomato is a popular vegetable in the area and its water consumption is generally higher than other common vegetables (worst case scenario of crop water requirements). Crop growing period was from 135 to 158 days according to FAO 56 guidelines (Allen et al., 1998). Drip irrigation with 90% efficiency was selected as well as normal spacing of plants. Weather data from the weather station in Giyani from 2012 to 2020 (Figure 3.2) were used as inputs. Monthly average temperatures were entered in the spreadsheet to calculate reference evapotranspiration ETo and average monthly rainfall was added to calculate effective rainfall (Allen et al., 1998). For livestock water requirements, it was hypothesized that the farm breeds 5 adult dry cattle. The results of farm water requirements are shown in Table 4.5 and Figure 4.2.

Table 4.5 Screen printout of the Water requirement tool depicting a summary of monthly water requirements for crop production, livestock and total.

Crop Water Requirements

Crops	Area in ha	January	February	March	April	May	June	July	August	September	October	November	December
		Crop Water need [m³/day]											
Tomato	0.5	10.1	22.1	29.9	12.1	-	-	-	-	-	-	-	7.2
Tomato	0.5	-	-	-	-	10.4	15.3	19.8	27.8	24.8	6.9	-	-
Tomato	0.5	19.8	4.8	-	-	-	-	-	-	-	13.4	20.6	26.2
none		-	-	-	-	-	-	-	-	-	-	-	-
none		-	-	-	-	-	-	-	-	-	-	-	-
Total	1.5	29.9	26.9	29.9	12.1	10.4	15.3	19.8	27.8	24.8	20.3	20.6	33.4

Livestock Water Requirements

Livestock	Ø Heads	January	February	March	April	May	June	July	August	September	October	November	December
		Livestock Water need [m³/day]											
Cattle (adult, dry)	5.0	0.5	0.5	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.5	0.5
		-	-	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-
Total	5.0	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.5

Total Water Requirements

		January	February	March	April	May	June	July	August	September	October	November	December
		Total Water need [m³/day]											
Crops	1.5 ha	29.9	26.9	29.9	12.1	10.4	15.3	19.8	27.8	24.8	20.3	20.6	33.4
Livestock	Ø 5 heads	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.5
Total	1.5 ha and Ø 5 heads	30.4	27.4	30.4	12.3	10.7	15.5	20.0	28.0	25.0	20.8	21.1	33.9

Highest daily water need: **33.9** m³ in the month of December. Pump utilization rate: **68%** Yearly Water need in m³: **8 386**

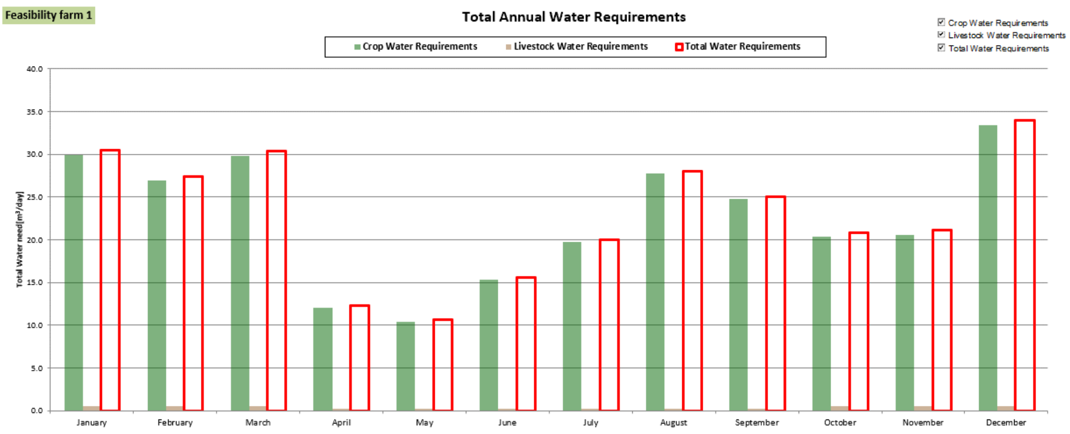


Figure 4.2 Screen printout of the Water requirement tool output graph showing monthly water requirements for crop production, livestock and total.

Monthly crop water requirements vary depending on the season, with the highest values recorded in the summer months (December to March) and the lowest in winter (April to July), on the atmospheric evaporative demand, effective rainfall and overlapping crop growing seasons (planting dates) (Table 4.5 and Figure 4.2). The maximum crop water requirement of 33.4 m^3/d was calculated in December whilst the minimum was in May (10.4 m^3/d). Livestock water requirement was negligible compared to irrigation water requirement. The seasonal patterns of total water requirement for the farm was therefore similar to crop water requirement with a peak in December (33.9 m^3/d). A volume of 33.9 m^3/d would equate to the water supply to a village of about 1350 people at a rate of 25 L per person per day.

Total annual water requirement for the farm was calculated to be 8,386 m^3/a. Pump utilization rate was calculated to be 68% depending on the monthly fluctuations in water requirement, as the pump has to satisfy the water demand in the peak month and it is under-utilized in the remaining months of the year. Different scenarios of crops, cropping patterns and planting dates can be built to optimize water requirements and pump utilization. The combinations are infinite; however this will depend on the farmer's choice and other farming activities.

4.4 Water resource management checklist

The ***Water resource management checklist*** is part of the ***Safeguard water*** module and it is mostly related to the geotechnical feasibility. It is in the format of a checklist spreadsheet and it doesn't perform any calculations. It consists of information on the water source, ecological observations, efficient water management, water administration and access, water extraction license and evaluation for the purpose of sustainable groundwater management and legitimate use of groundwater.

For the purpose of populating the Water research management checklist, boreholes on Duvadzi farms were used and the information typed in the checklist is summarized below. The boreholes were drilled by the Limpopo regional office of the Department of Water and Sanitation in 2017 for the purpose of monitoring groundwater levels during the WRC project No. K5/2426 on "Riparian Shallow Groundwater Utilization for Smallholder Irrigation in the Mopani District (Limpopo Province)". Boreholes H14-1701, H14-1702 and H14-703 were established in June-August 2016 on Duvadzi farm adjacent to the Molototsi River (Figure 4.3). An old borehole DUV1 already existed on the farm (Figure 4.3).

Figure 4.3 Location of old borehole (DUV1 marked yellow dot and label) and boreholes established in 2016 (H14-1701, H14-1702 and H14-703 marked with orange dots and labels) on a Google Earth map. Direction of faults (light blue lines) and dykes (light green lines) are shown on the maps. The location of the river bed open well commonly used to abstract water from the sandy alluvium is marked in blue.

Boreholes were established according to standards (Figure 4.4). An alternative water source is an open well (about 2 m in diameter) that is occasionally built with bricks in the alluvium of the Molototsi sand river (Figure 4.4).

Borehole characteristics are summarized in Table 4.6. Borehole logs and other information are available in Jovanovic et al. (2018). Steel casing with diameters ranging from 165 to 250 mm is installed depending on the depth. Steel perforated casing is usually installed at depths of 18-24 m. Final blow yield of the boreholes ranged from 1 to 3 L/s.

Figure 4.4 Potential water sources: groundwater boreholes (left) and open wells in sand river beds (right).

Table 4.6 Borehole characteristics at Duvadzi farm.

Borehole No.	**H14-1701**	**H14-1702**	**H14-1703**
Collar height (m)	0.15	0.31	0.26
Borehole depth (m)	120	120	102
Water strike depth (m)	22	31; 47; 77	27
Groundwater depth below collar height (m)	13.62	13.67	18.25
Final blow yield (L/s)	3	3	1
Casing diameter (mm) and material	177 (0-18 m) - steel	177 (0-12 m) - steel	177 (0-18 m) - steel
Perforated casing diameter (mm) and material	177 (18-24 m) - steel	177 (12-18 m) - steel	-
Borehole diameter (mm)	250 (0-24 m) 165 (24-120 m)	250 (0-18 m) 165 (18-120 m)	250 (0-18 m) 165 (18-102 m)

Groundwater levels in boreholes H14-1702 and H14-1703 were measured hourly with Solinst loggers and the data are shown in Figure 4.5. For comparative purpose, rainfall data measured at the weather station in Giyani are also reported. Groundwater was not abstracted during the period of measurement (September 2016-May 2018), so the groundwater level data are an indication of the static level. The groundwater level variations over almost two years did not fluctuate more than 1 m, they did not exhibit any seasonal trends and responded very little to rainfall. This is an indication of the hydraulic discontinuity between the regional groundwater and the sand river bed aquifer. The regional groundwater table is below the groundwater level in the sand river alluvium and the make of the two aquifers is very different which results in hydraulic discontinuity. In addition, the groundwater quality in the river sand bed resembles the quality of rain water, whilst higher salinity and ionic concentrations were observed in the regional groundwater. Stable isotope analyses also resulted in differentiation of water sample, although they gave some indication that localized baseflow may occur at localized sites. The groundwater quality analyses can be found in Jovanovic et al. (2018) and this is further discussed in Section 4.17 of this feasibility assessment.

Abstraction did not take place from boreholes H14-1702 and H14-1703, so it is not possible to provide a dynamic groundwater level after abstraction has taken place. However, abstraction from other boreholes in the area indicated drawdown levels up to 7 m after pumping during office hours followed by groundwater level recovery overnight (Jovanovic et al., 2018). The estimated radius of influence was in the region of 50 m. A safe yield of 7.2 m^3/h (2 L/s) could therefore be sustained for about 8 hours per day (57.6 m^3/d).

Under the observed ecological conditions, there was no trend of salinity increase, vegetation mortality, increased frequency of dry running of pump on the farm and surrounding areas. Concerning water management, water is abstracted at appropriate pressure, measured and recorded with a water volume meter. The irrigation system on the farm is controlled for leakages, however the infrastructure is seldom maintained.

From the administrative perspective, the boreholes are public property of the Department of Water and Sanitation that installed them, and they are located on land under Permission to Occupy. A formal agreement exists with the farmer to access the land and the borehole; however this expires upon completion of the WRC research project. There is no water use license because the water use is Schedule 1 (use of water that is likely to have no significant impact on water resources) as the farmer plants crops under irrigation on well less than 1 ha and the site was used for research purposes.

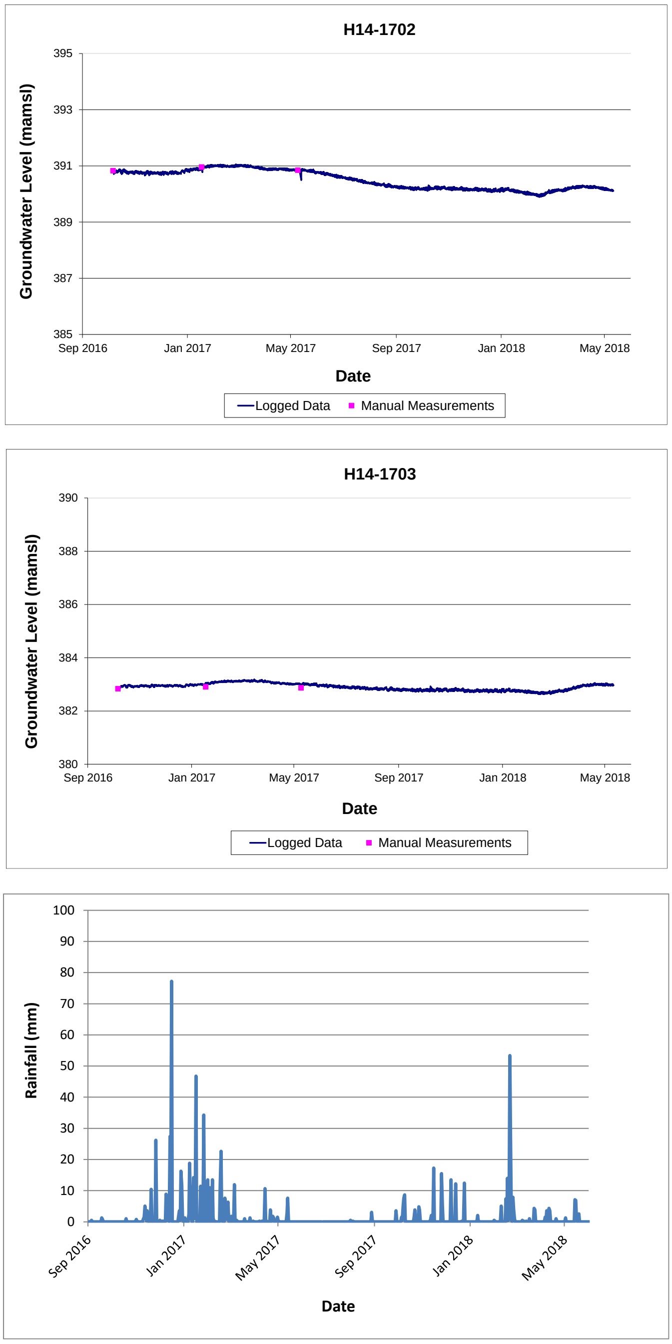


Figure 4.5 Hourly groundwater levels (elevation) measured with Solinst loggers and manual readings taken with a dip meter at boreholes H14-1702 and H14-1703 (top and middle graph), and daily rainfall measured at Giyani weather station (bottom graph) in the period from September 2016 to May 2018.

The system has not been implemented and evaluated, however a water use license may be required before implementation. Safe yields and pump capacities need to be aligned to the water license. At this stage, the pump flow rate is sufficient to irrigate small plots with no ecological impact, although considerable water leakages and losses occur from time to time, usually due to pipe fittings.

The alternative option of open wells in the sand river bed (Figure 4.5) is widely used in the area and it is a very attractive option because of the shallow occurrence of groundwater (<2 m deep) and the high hydraulic conductivity of alluvial sand. According to the study by Jovanovic et al. (2018), a 300 m reach of the Molototsi River could store about 8,100 m^3 of water, which is sufficient to irrigate ~2 ha of vegetables for one season, assuming irrigation water requirements of 400 mm (4,000 m^3 ha^{-1}). The volume of water stored in the river bed is therefore by no means large, however it could represent a useful reserve during periods of severe drought, with recharge being essential from occasional flood events. An alternative could be to increase this reserve capacity through the establishment of sand dams (Jovanovic et al., 2018).

4.5 Market assessment tool

The ***Market assessment tool*** in the ***Market*** module is part of the socio-economic feasibility. The Market assessment tool consists of a few spreadsheets to pre-check for solar-powered systems suitability, for setting weights of inputs, geophysical parameters, business conditions and output results.

Figure 4.6 represents a screenshot of the critical geophysical parameters (Market assessment tool, Input pre-check). Site-specific geophysical parameters are of critical importance and any score of 0 indicates that the site is not suitable for installation of solar-powered groundwater pumps. The predominant land cover in the area was chosen to be shrubland based on the global land cover CCI (Climate Change Initiative) map of the European Space Agency (http://maps.elie.ucl.ac.be/CCI/viewer/index.php, accessed on 2 September 2021). Shrubland is deemed to be marginally suitable for solar-powered groundwater systems. However, the annual solar irradiance is deemed to be highly suitable based on the Global Solar Atlas of the World Bank (https://globalsolaratlas.info/map, accessed on 2 September 2021). The specific photovoltaic power output in the area is estimated to be 1589.3 kWh/kWp. The monthly average air temperature and precipitation were filled based on measurements in the Giyani weather station from 2012 to 2010 (Figure 3.2) resulting in moderate suitability. The overall score for critical geophysical parameters was 6 out of 9 resulting in marginal to moderate suitability (Figure 4.6).

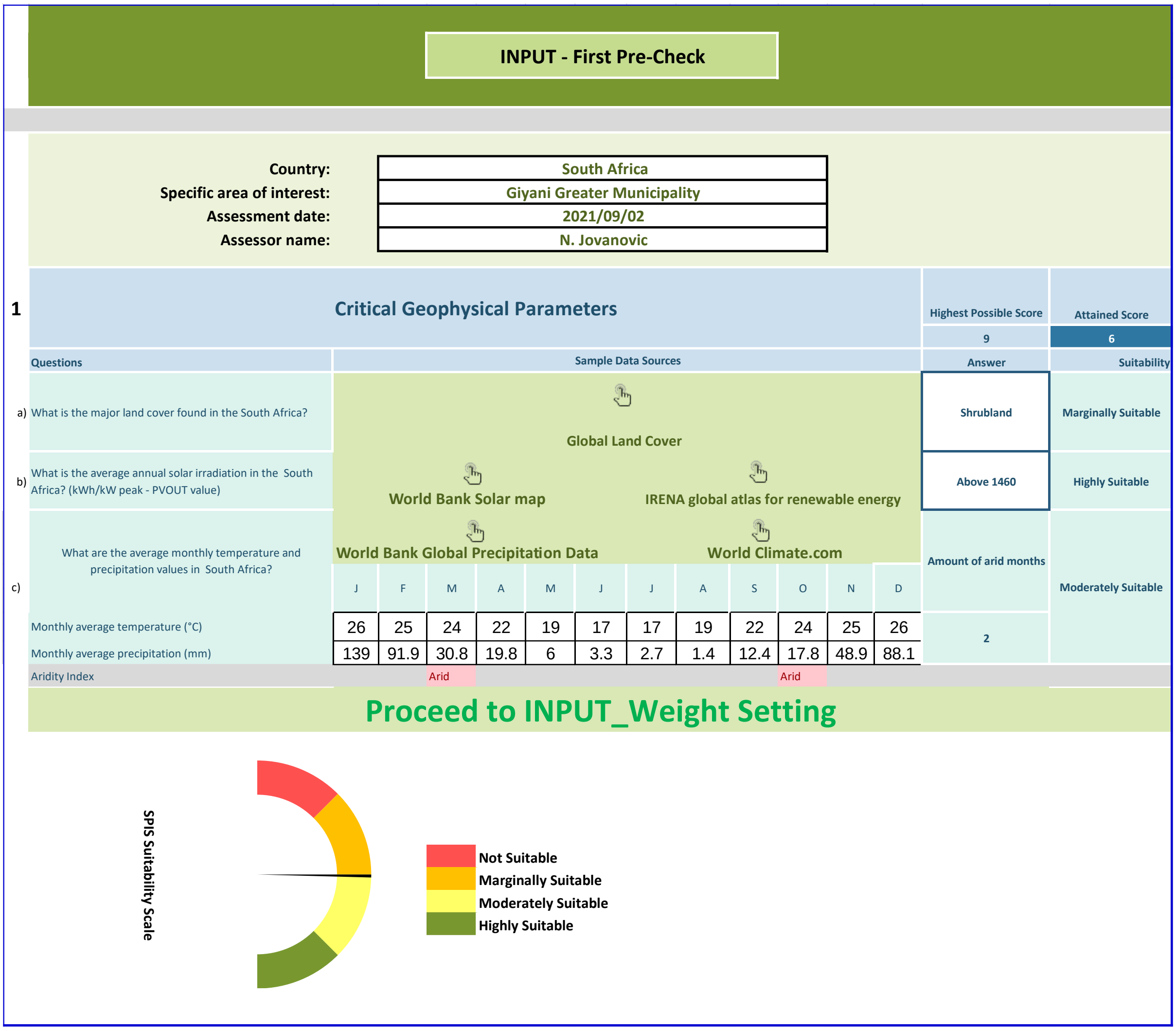


Figure 4.6 Screenshot of the calculation of critical geophysical parameters (Market assessment tool, Input pre-check).

The sheet Input Geophysical parameters in the Market assessment tool is used to define some additional non-critical geophysical parameters and their relevance, such as groundwater depth, frost occurrence, general topography and type of farming. The sheet Input Business conditions is in the form of a questionnaire and it is used to define the business conditions and their relevance, such as government interventions, development organization interventions, financing, availability and cost of alternative sources of power for pumping, technical capacity for SPIS, awareness of solar PV and irrigation technologies, significance of agriculture in the local economy, land use right, ownership and tenure, transportation and communication infrastructure. Appropriate parameters were chosen from drop-down lists and by making use of links to web sites provided within the tool to extract general information from global reports and databases. The relevance was selected based on given categories (inconsequential, slightly important, important, very important and critical). The input weightings in the Input – Weight settings sheet were kept as default.

The resulting output of the Market assessment tool is shown in Figure 4.7. The total score for market potential of SPIS in Greater Giyani Municipality was 53.23% with a number of input parameters being inconsequential and others being rated as important.

The site has high market potential in terms of climatic and geophysical settings. Government interventions result in moderate market potential mainly due to lack of policies and laws promoting solar energy. However, government interventions scored much higher than the initial default weight settings. The involvement of development organizations such as GIZ results in high market potential (default inputs were used for development organization interventions). Financing by end users and institutions as well as availability of alternative power sources, subsidies and costs result in moderate market potential. A low market potential score was obtained for technical capacity, mainly because of a lack of training programs and University curricula on solar technologies. However, awareness and adoption of solar technologies is increasing and the presence of suppliers results in a high market potential. The significance of agriculture in the local economy is comparatively low compared to other sectors (e.g. mining and industry) resulting in marginal market potential. The relevance of land tenure is important, whilst the transportation and communication infrastructure is good but deemed to be inconsequential, both resulting in moderate market potential.

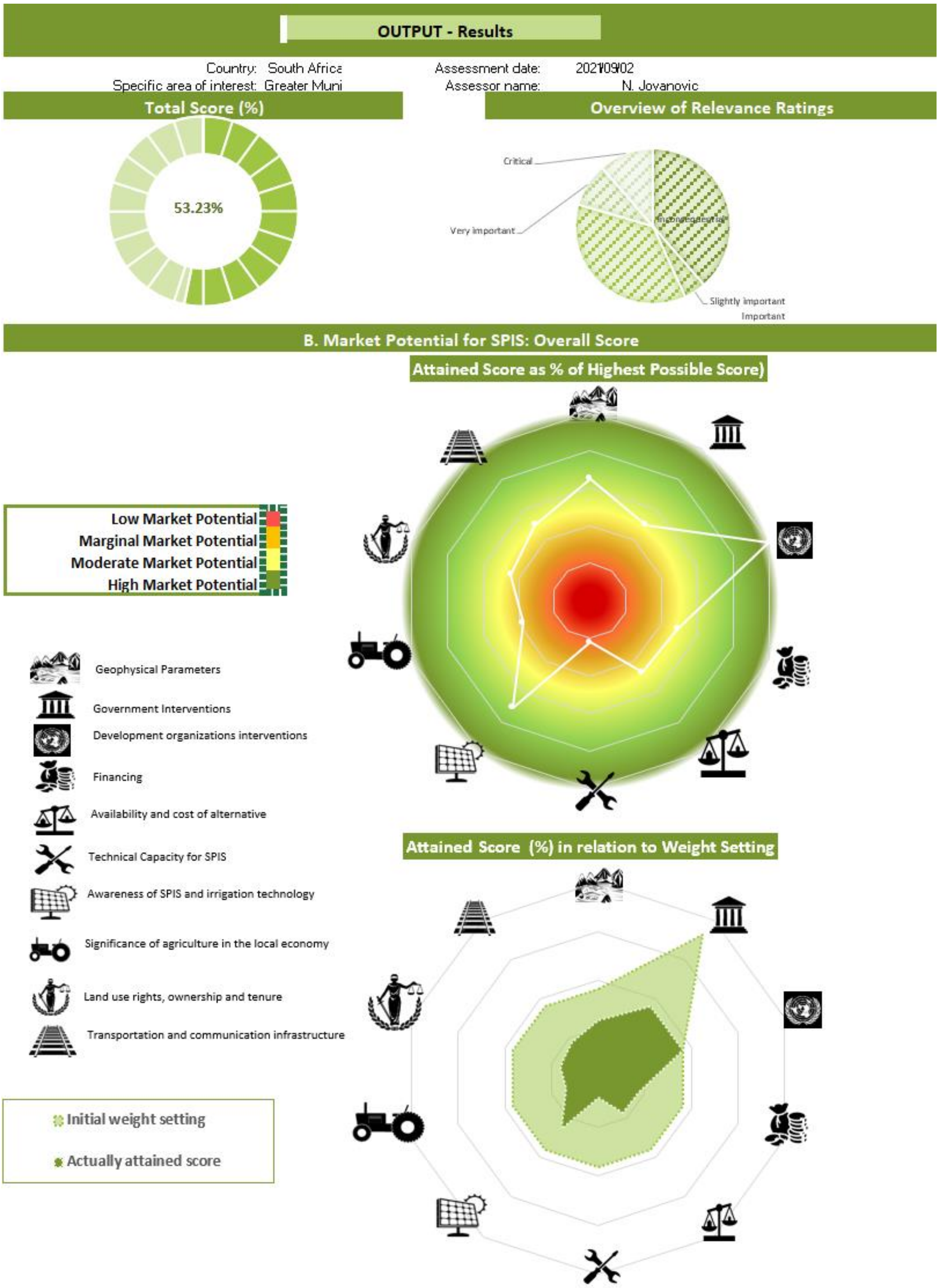


Figure 4.7 Screenshot of the Market assessment tool output.

4.6 Farm analysis tool

The ***Farm analysis tool*** is part of the ***Invest*** module. It is related to the financial feasibility. The Farm analysis tool allows one to do a financial analysis of a farming enterprise to assess agricultural productivity and profitability. It can be used to establish a baseline or for planning, to identify unnecessary costs, optimize agricultural activities and farming inputs. It is therefore specifically targeted to support the use of solar-powered groundwater pumps for agricultural irrigation and it is farm-specific.

The Farm analysis tool consists of spreadsheets with an initial basic assessment to calculate profit/loss, general information on the farm, available equipment and assets, costs and income of current/future crops, livestock and by-products, other income not directly related to crops and livestock (e.g. sale or rental of equipment), financing and loan repayments, fixed and variable costs. The last sheet presents the results of the calculation of gross profitability of the farming business. The inputs are entered per year with a supplementary sheet to calculate annual profitability based on seasonal monthly variations.

The Quick check sheet in the Farm analysis tool requires entering the following annual costs as inputs:

- Seasonal and perennial crop expenses (seedlings, fertilizer, pesticides, etc.)
- Livestock expenses (new heads, fodder, slaughtering, veterinary expenses, etc.)
- Operation and maintenance costs of infrastructure, fixed and movable equipment (e.g. buildings and reparations, irrigation equipment, machinery and implements, etc.)
- Labour costs
- Sales and distribution costs
- Costs of management and administration

The Quick check sheet then requires to enter the annual income:

- Sales of seasonal and perennial crops, livestock and associated by-products
- Lease income
- Services income

The General information sheet includes the details of the farm, size and tenure of the property and land classification (seasonal crops, perennial crops, greenhouses, pasture, fallow land). The Equipment and assets sheet requires entering costs of purchase of existing equipment, estimated actual value of the equipment, age and life span for the following items selected from a drop down list: livestock shed, garage/workshop/warehouse, greenhouses, ox carts, vehicles, tractors, agricultural machines and implements, irrigation equipment, water pumps, solar panels and boreholes/wells.

Sheet Seasonal crops and Perennial crops include details of crop types, by-products, yields, prices and sales. The costs are detailed in terms of variable costs such as seeds/seedlings, manure and fertilizers, plant protection, labour (family members, temporary and permanent staff), traction and mechanization (own equipment and rented), infrastructure (maintenance and expansion), irrigation and other costs. Similar detailed inputs are entered in sheet Livestock: types of heads, by-products, prices and sales; costs such as fodder and fodder concentrates, veterinary services, traction and mechanization (own equipment and rented), infrastructure (maintenance and expansion), water supply and other costs. Other income such as sale of water, hiring equipment, leasing out storage space, land or labour can be entered in the Other income sheet on a monthly basis. The Financing sheet requires information on any credit and loans. The Fixed and variable costs sheets require entering general costs on a monthly basis. In particular, this includes fixed costs such as membership fees, insurance costs, land tax, social fund contribution, leasing fees for equipment, rental costs for land and others. Variable costs are maintenance and repair, fuel and lubricants, water, electricity and gas, transport fees, salary costs and others. It should be noted that some of the information required in this spredsheet may be difficult to obtain as it is of such a personal nature that it may trigger ethical clearance requirements and compliance to the new Protection of Personal Information Act (PoPIA).

The Farm analysis tool provides an output sheet (Farm income statement sheet) where a summary of the financial viability of the farm is reported in a tabular format and costs are plotted on a graph (Figure 4.8). In this example, the calculation was done for a hypothetical smallholder farm but based on realistic income and cost inputs. The emerging farmer has 5 ha of land under Permission to Occupy tenure. Two ha are under rainfed seasonal crops (e.g. maize), 0.5 ha is under irrigation (three seasons of vegetable crops) and 2.5 ha are under fallow land in rotation. The farmer has 5 heads of cattle. The information on income and costs of production was collected from local farmers and extension officers of the Limpopo Department of Agriculture and Rural Development. The results of the farm financial viability are summarized in Figure 4.8.

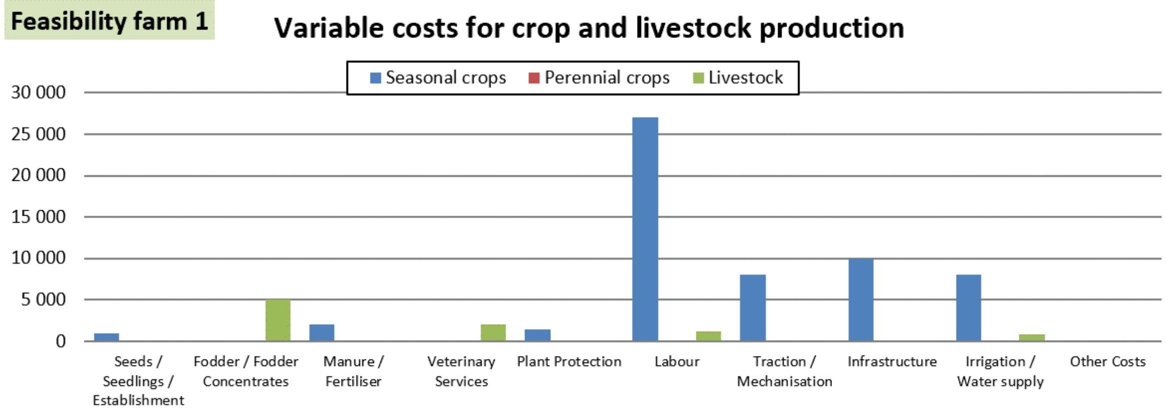
INVEST – Farm Analysis Tool

8 FARM INCOME STATEMENT

Farm code: Feasibility farm 1

+	Gross value of seasonal crop production	300 000	ZAR	+	90%
+	Gross value of seasonal crop by-product production	10 000	ZAR	+	3%
+	Gross value of perennial crop production	0	ZAR	+	0%
+	Gross value of perennial crop by-product production	0	ZAR	+	0%
+	Gross value of livestock production:	15 000	ZAR	+	4%
+	Gross value of livestock by-product production:	7 500	ZAR	+	2%
+	Gross value of other income:	2 000	ZAR	+	1%
-	Anticipated losses of total sales (reduction factor)		%		
=	**GROSS FARM INCOME**	**334 500**	***ZAR***	=	100%
-	Total fixed costs	0	ZAR	+	0%
-	Total general variable costs (for regular expenses)	16 000	ZAR	+	19%
-	Total specific variable costs for crop and livestock	66 900	ZAR	+	81%
=	**TOTAL COST**	**82 900**	***ZAR***	=	**100%**

Feasibility farm 1



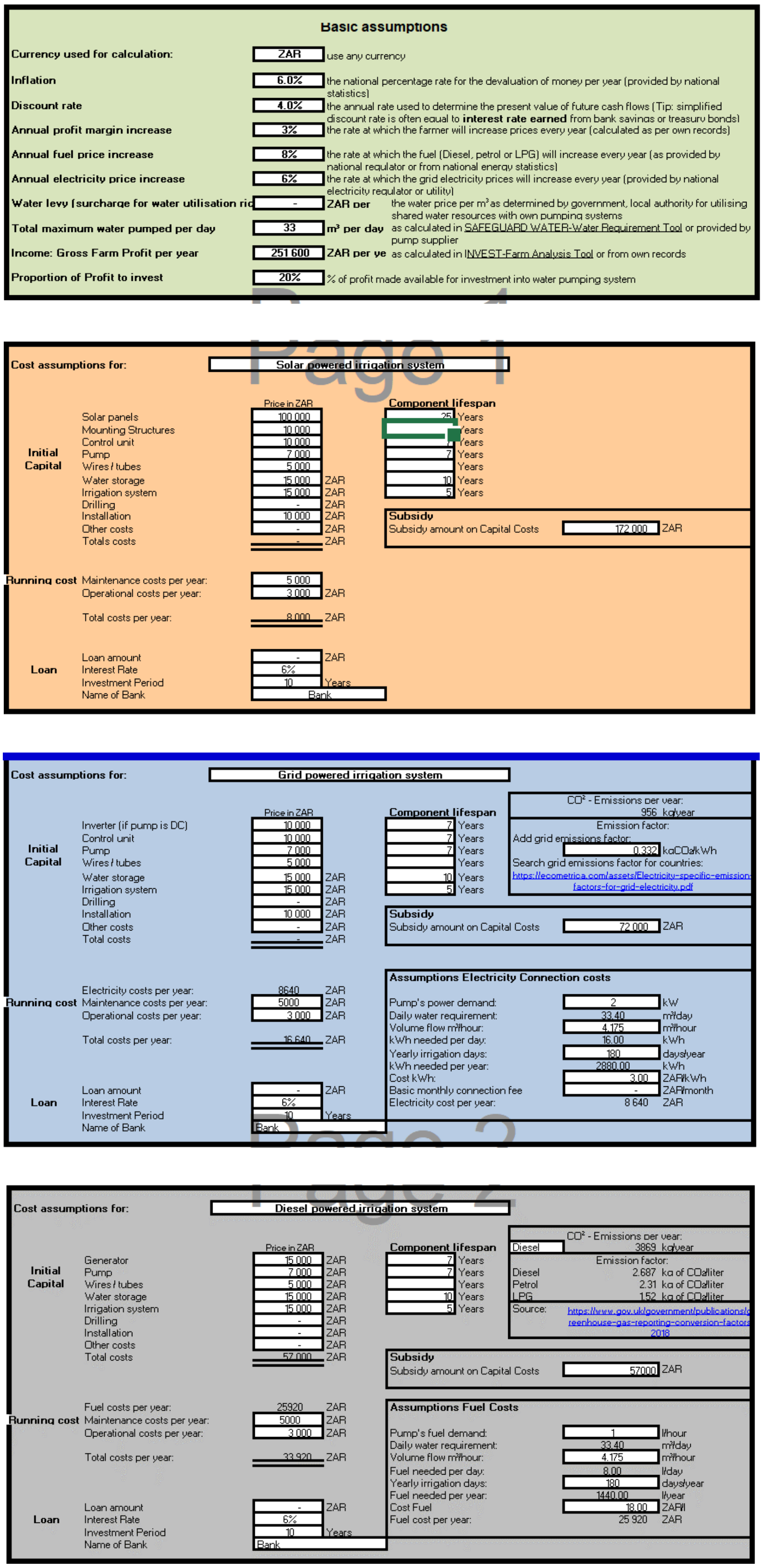
=	**GROSS FARM PROFIT**	**For period 2021 to 2022**	**251 600.00**	***ZAR***
		Farm Profit Margin	**75%**	
		average profit per ha of seasonal crops:	**168 333**	*ZAR per ha*
		average profit per ha of perennial crops:	**no crops**	*ZAR per ha*
		average profit per head of livestock:	**2 621**	*ZAR per head*
		total crop area under cultivation:	**1.5**	*ha*

Figure 4.8 Screenshot of the Farm income statement output sheet summarizing the calculation of the farm income and costs (top table), the breakdown of variable costs of production (middle graph) and the gross farm profit (bottom table).

4.7 Payback tool

The ***Payback tool*** is part of the ***Invest*** module and it is related to the financial feasibility. Along with the Farm analysis tool, it is one of the key tools for the design and implementation of the solar-powered pumping systems. The Payback tool compares the financial feasibility of three different pumping options by taking into account investment and operational costs, anticipated income and basic economic conditions such as inflation rates. The three pumping options are: solar-powered, grid-powered and diesel-powered. The tool was developed to calculate the feasibility of different pumping options for agricultural irrigation, however it could also be adapted to calculate the feasibility for drinking water supply and multiple use schemes depending on the inputs used. The Payback tool is a spreadsheet file consisting of two sheets: an Input sheet for data entry of anticipated income and expenditures for pumping; an Output sheet for analysis of results automatically generated from the Input sheet.

The Input sheet was populated with realistic figures for basic assumptions, costs for solar-powered irrigation system, grid-powered irrigation system and diesel-powered irrigation system. The input data used are summarized in Figure 4.9 in the form of screenshots of the Input sheet. For a fair comparison, it was assumed that capital costs are subsidized for all three system and no bank loan was taken. The gross farm profit was R251,600/a (Section 4.6, Farm analysis tool) and the proportion of profit to invest in paying off the pumping system was assumed to be 20%. The initial capital and running costs for the three options were entered as shown in Figure 4.9. The components life spans were estimated according to general knowledge and based on specifications of manufacturers. For the grid-powered system, the pump's power demand was estimated to be 2 kW, the required pump's flow was 4.2 m^3/h for 8 h of work per day (peak water demand was calculated to be 33.4 m^3/d) with 180 d of irrigation per year. The cost of electricity was assumed to be R3/kWh (Figure 4.9). For the diesel-powered pumping system, the additional inputs were fuel demand of the power generator estimated to be 1 L/h and the cost of fuel assumed to be R18/L (Figure 4.9).



Basic assumptions

Currency used for calculation:	ZAR	use any currency
Inflation	6.0%	the national percentage rate for the devaluation of money per year (provided by national statistics)
Discount rate	4.0%	the annual rate used to determine the present value of future cash flows (Tip: simplified discount rate is often equal to **interest rate earned** from bank savings or treasury bonds)
Annual profit margin increase	3%	the rate at which the farmer will increase prices every year (calculated as per own records)
Annual fuel price increase	8%	the rate at which the fuel (Diesel, petrol or LPG) will increase every year (as provided by national regulator or from national energy statistics)
Annual electricity price increase	6%	the rate at which the grid electricity prices will increase every year (provided by national electricity regulator or utility)
Water levy (surcharge for water utilisation rig	-	ZAR per — the water price per m³ as determined by government, local authority for utilising shared water resources with own pumping systems
Total maximum water pumped per day	33	m³ per day — as calculated in SAFEGUARD WATER-Water Requirement Tool or provided by pump supplier
Income: Gross Farm Profit per year	251 600	ZAR per ye — as calculated in INVEST-Farm Analysis Tool or from own records
Proportion of Profit to invest	20%	% of profit made available for investment into water pumping system

Cost assumptions for: Solar powered irrigation system

		Price in ZAR		Component lifespan
Initial Capital	Solar panels	100 000		25 Years
	Mounting Structures	10 000		Years
	Control unit	10 000		Years
	Pump	7 000		7 Years
	Wires / tubes	5 000		Years
	Water storage	15 000	ZAR	10 Years
	Irrigation system	15 000	ZAR	5 Years
	Drilling		ZAR	
	Installation	10 000	ZAR	
	Other costs	-	ZAR	
	Totals costs		ZAR	
Running cost	Maintenance costs per year:	5 000		
	Operational costs per year:	3 000	ZAR	
	Total costs per year:	8 000	ZAR	
Loan	Loan amount	-	ZAR	
	Interest Rate	6%		
	Investment Period	10	Years	
	Name of Bank	Bank		

Subsidy
Subsidy amount on Capital Costs 172 000 ZAR

Cost assumptions for: Grid powered irrigation system

		Price in ZAR		Component lifespan
Initial Capital	Inverter (if pump is DC)	10 000		7 Years
	Control unit	10 000		7 Years
	Pump	7 000		7 Years
	Wires / tubes	5 000		Years
	Water storage	15 000	ZAR	10 Years
	Irrigation system	15 000	ZAR	5 Years
	Drilling	-	ZAR	
	Installation	10 000	ZAR	
	Other costs	-	ZAR	
	Total costs		ZAR	
Running cost	Electricity costs per year:	8640	ZAR	
	Maintenance costs per year:	5000	ZAR	
	Operational costs per year:	3 000	ZAR	
	Total costs per year:	16 640	ZAR	
Loan	Loan amount	-	ZAR	
	Interest Rate	6%		
	Investment Period	10	Years	
	Name of Bank	Bank		

CO² - Emissions per year: 956 kg/year
Emission factor:
Add grid emissions factor: 0.332 kgCO2/kWh
Search grid emissions factor for countries: https://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf

Subsidy
Subsidy amount on Capital Costs 72 000 ZAR

Assumptions Electricity Connection costs

Pump's power demand:	2	kW
Daily water requirement:	33.40	m³/day
Volume flow m³/hour:	4.175	m³/hour
kWh needed per day:	16.00	kWh
Yearly irrigation days:	180	days/year
kWh needed per year:	2880.00	kWh
Cost kWh:	3.00	ZAR/kWh
Basic monthly connection fee	-	ZAR/month
Electricity cost per year:	8 640	ZAR

Cost assumptions for: Diesel powered irrigation system

		Price in ZAR		Component lifespan
Initial Capital	Generator	15 000	ZAR	7 Years
	Pump	7 000	ZAR	7 Years
	Wires / tubes	5 000	ZAR	Years
	Water storage	15 000	ZAR	10 Years
	Irrigation system	15 000	ZAR	5 Years
	Drilling	-	ZAR	
	Installation	-	ZAR	
	Other costs	-	ZAR	
	Total costs	57 000	ZAR	
Running cost	Fuel costs per year:	25920	ZAR	
	Maintenance costs per year:	5000	ZAR	
	Operational costs per year:	3 000	ZAR	
	Total costs per year:	33 920	ZAR	
Loan	Loan amount	-	ZAR	
	Interest Rate	6%		
	Investment Period	10	Years	
	Name of Bank	Bank		

Diesel — CO² - Emissions per year: 3869 kg/year
Emission factor:
Diesel 2.687 kg of CO2/liter
Petrol 2.31 kg of CO2/liter
LPG 1.52 kg of CO2/liter
Source: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018

Subsidy
Subsidy amount on Capital Costs 57000 ZAR

Assumptions Fuel Costs

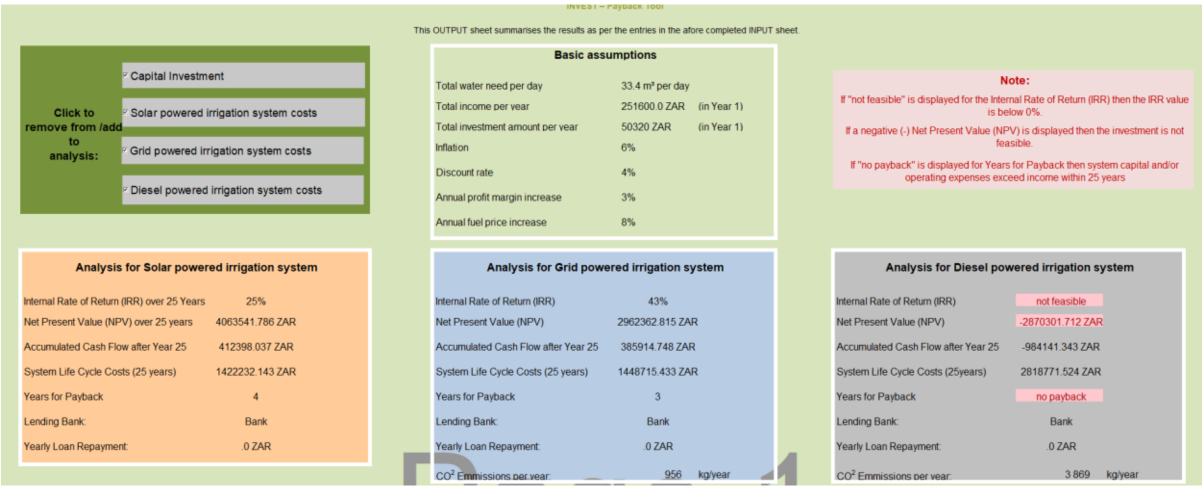
Pump's fuel demand:	1	l/hour
Daily water requirement:	33.40	m³/day
Volume flow m³/hour:	4.175	m³/hour
Fuel needed per day:	8.00	l/day
Yearly irrigation days:	180	days/year
Fuel needed per year:	1440.00	l/year
Cost Fuel	18.00	ZAR/l
Fuel cost per year:	25 920	ZAR

Figure 4.9 Screenshot of the Payback input sheet summarizing basic assumptions, costs for solar-powered irrigation system, grid-powered irrigation system and diesel-powered irrigation system.

The Output sheet of the Payback tool summarizes the results of the financial feasibility in tabular and graphical format for Internal Rate of Return (IRR) and Net Present Value (NPV) over 25 years, accumulated cash flow after 25 years, system life cycle costs for 25 years, years of payback, yearly loan repayment (if applicable) and yearly CO_2 emissions of the three systems. Figure 4.10 presents the results of the calculation in tabular format and the graph of comparative accumulated income and system costs over 25 years for the solar-, grid- and diesel-powered irrigation systems. It is evident from the results that the grid-powered system has the highest IRR, whereas the solar-powered system has the highest NPV and accumulated cash flow over 25 years. The system life cycle cost is the lowest for the solar-powered system that will take 4 years to payback compared to 3 years for the grid-powered system. With the current input data, the diesel-powered pumping system is not financially viable. For diesel-powered pumping to be viable, the gross profit of the farm should be at least R390,000 per year. Likewise, if a proportion of the profit for payback is <20%, none of the systems would be feasible. Of course, this is a financial calculation that justifies the investment of funders in the case that the pumping systems are subsidized to the farm. Emissions of CO_2 will occur from the grid-powered system and especially from the diesel-powered system (Figure 4.10).

The cumulative income and system costs over 25 years are shown in the graph in Figure 4.10. The solar-powered system has the highest capital investment cost that reflects in the first few years on the graph. The solar-powered capital investment is paid back after 4 years and, starting from year 7, the cumulative costs become lower than for the grid-powered system. From then on, the solar-powered system has the lowest costs throughout the lifespan of 25 years, amounting at >R400,000 less costs than the grid-powered system at year 24. Fluctuations of the curves depend on the replacement value and life span of the various components. The cumulative costs of solar-powered systems increase sharply after 25 years, which is the time span of solar panels when these will have to be replaced. The cost of diesel-powered systems is by far the highest over-shooting the adjusted capital investment value from year 9 (Figure 4.10).

Many other examples of calculation can be constructed. If the irrigated area is increased or more population needs to be supplied with water, this would imply increased water requirements, more solar panels needed, a more powerful pump (kW) to satisfy the delivery of required flows as well as more kWh consumed. This scenario could be financially more viable because the gross farm profit would increase; on the other hand, it would increase the risk of groundwater over-abstraction and jeopardize the geophysical feasibility.



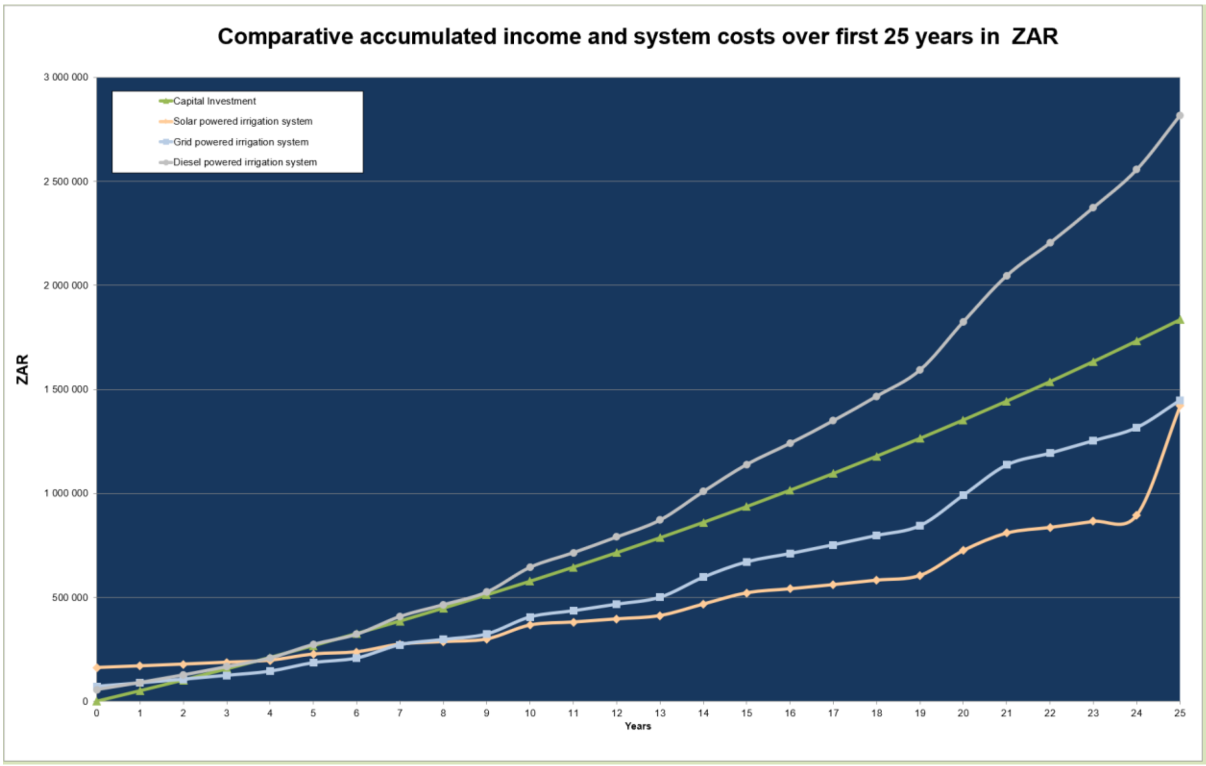


Figure 4.10 Screenshot of the Payback output sheet summarizing the results of the financial feasibility of solar-, grid- and diesel-powered irrigation systems (top table) and the comparative accumulated income and system costs over 25 years (bottom graph).

4.8 Finance deployment tool

The ***Finance deployment tool*** in the ***Finance*** module relates to the socio-economic feasibility. It is used to identify possible financial products and services available on the market for the use of solar-powered systems. The financial products and services can be: commercial bank loans, development bank loans, MFIs (microfinance institutions), value-chain loans, leasing, cooperatives, informal saving groups or pay-per-use. The Finance deployment tool is a spreadsheet questionnaire. Depending on the Yes/No answer to the questionnaire, the tool excludes potential financial products and services.

For the specific study site, the users are not expected to have collateral assets, soft collateral or other guarantees for loans, alternative sources of income, established value chains or cooperative programs, and they don't possess initial capital. However, the users have bank accounts, mobile devices, they are able to pay commercial interest rates and they live in communities with common goals and reciprocal trust. They may be willing to use solar-powered pumps without buying them, pay monthly fees into a common trust and depend on other users according to an agreed schedule. Specifically, agricultural water users require regular supply of water for irrigation and livestock, they are subsidized by government and there is interest from the private sector to purchase their products. After exclusion of unfeasible financial mechanisms, the following options are available: ***leasing, cooperatives, informal saving groups and pay-per-use***.

4.9 Site data collection tool

The ***Site data collection tool*** is part of the ***Design*** module; however it is also relevant to the ***Maintain*** and ***Safeguard water*** modules. It is related to the technical and engineering feasibility. The Site data collection tool is in the format of a Word checklist consisting of sheets with information to be filled under the following categories:

1. General information
    - History of the system/farm, geographical location and meteorological data
2. Water supply situation
    - Water source, water quality, water availability, water ownership
    - Complementary to the Water resource management tool in Safeguard water module (Section 4.4)
3. Energy supply situation
    - Public grid supply, off-grid supply, conventional generator
4. Agricultural production

   - Terrain, soil type, soil salinity, cash crop type, crop rotation, irrigation demand, livestock type, livestock quantity, livestock water demand
   - Complementary to the Soil tool in the Irrigate module (Section 4.14)
5. Water pumping technology –
   - Conventional water pump (pump type), photovoltaic pumping system (solar cell type, solar generator, mounting system, controller/inverter, pump unit), determination of pumping head (direct feed-in, tank system)
   - Complementary to the Pump sizing tool in the Design module (Section 4.11)
6. Irrigation technology
   - Irrigated area, feed pipe, water distribution system, filter systems, fertigation/chemigation (fertilizer/pesticide application), monitoring
7. Management requirements
   - Players in farm management, strategic management (time frame >5-20 years), tactical management (time frame <1 year), operational management (time frame 1 day)
8. Financial assessment
   - Investment and operations cost, financial strategy, labour requirements, fees, duties and charges, agricultural production and revenue
   - Complementary to Farm analysis tool and Payback tool in Invest module (Sections 4.6 and 4.7)
9. Ecological impacts
   - Environmental impacts
   - Complementary to Water resource management tool in Safeguard water module (Section 4.4)
10. Training and acceptance
    - Extent of training and skills development measures

4.10 SPIS suitability checklist

The ***SPIS suitability checklist*** is part of the ***Design*** module. It is related to both the geophysical, and technical and engineering feasibility. The SPIS suitability checklist is a spreadsheet that consists of a semi-quantitative questionnaire. Questions represent key criteria to determine sustainability strength and they are scored and combined to produce a basic rating on all aspects of solar-powered pumping viability. The tool is meant to assist suppliers, development and extension offices to verify whether a farmer can benefit from the solar-powered pumping system.

The questions relate to data availability/quality to design the system, skills and capabilities, market and financial resources, natural resources and water availability, options for power supply and efficient water use. The tool was applied for the study area and the total score was 50 corresponding to the recommendation "*The site seems to be very suitable to be equipped with SPIS*".

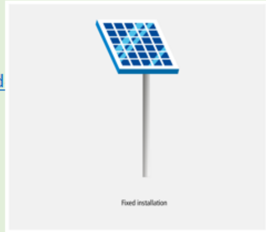
4.11 Pump sizing tool

The ***Pump sizing tool*** is part of the ***Design*** module. It is related to the technical and engineering feasibility and it is one of the key tools for the design and implementation of solar-powered pumping systems. The Pump sizing tool is a spreadsheet that calculates the required pumping head, power and pump type. It consists of an Input head calculation sheet to calculate the required pumping head, an Input pressure loss sheet to calculate head losses depending on piping and fittings, and an Output results sheet that calculates the required peak power of the system in kWp and the solar panel surface area in m^2 depending on the input data. The tool includes an additional sheet with a glossary of the terminology. An example of calculation is presented here for a farm that abstracts water from a dry sand river alluvium to irrigate 0.5 ha of vegetables (3 crops per year) with drip irrigation and water storage tanks.

In the Input head calculation sheet, general input data (basic assumptions) and input data related to the water pressure configuration of the system (determination of pumping head) are entered. This is shown in Figure 4.11. It was assumed that an average of 6 sun hours per day occur at an average solar irradiation of 4.9 $kWh/m^2/d$ calculated from the weather data measurements at Giyani weather station (Figure 3.2). A default solar system power loss of 25% was assumed and a fixed (non-tracking) solar panel array. The estimated water source yield was 173 m^3/d (2 L/s) with 50% sustainable extraction rates. Daily water pumping rate was 33.9 m^3/d corresponding to peak water requirements in the month of December (Table 4.5). Farms usually use 1.5 inch or 40 mm conveyance pipes and the length is 150 m (Figure 4.11, top table). Realistic components for the calculation of pumping head were also entered in Figure 4.11 (bottom table).

Basic assumptions		
Sun hours per day:	6.0	h/day
Daily solar irradiation (PVOUT-**photovoltaic power potential**):	4.9	kWh/m²
Solar system losses:	25	%
Photovoltaic array type:	fixed	
Estimated water source yield:	173	m³/day
Sustainable extraction from water source:	50%	%/day
Daily water pumping rate:	33.9	m³/day
Pipeline diameter:	1 1/2	inch
Pipeline length:	150	m

http://globalsolaratlas.info/d



Determination of Pumping Head			
H_{total}	Total Dynamic Head		
H_s	Static Water Level	2	m
D	Drawdown	2	m
H_e	Elevation Difference Well to Tank Stand	10	m
H_t	Height of Tank Inlet from Ground	3	m
H_o	Height of Tank Outlet (to irrigation area)	2	m
H_l	Head Loss in Pipeline	8	m
H_{fi}	Head Loss in Fittings (from **INPUT_Pressure Loss**)	0.4	m
H_m	Head Loss in Water Meter	1	m
H_f	Head Loss in Filter/Fertigation	1	m
H_{irrig}	Pressure Irrigation System	20	m
Irrigation scheme pressure requirement		2	bar

Figure 4.11 Screenshot of the Input head calculation sheet summarizing the input data grouped as basic assumptions (top table) and determination of pumping head (bottom table).

Pressure losses due to valves and fittings are calculated in the Input pressure loss sheet, where the user enters the number of valves and fittings in the configuration (Figure 4.12). Realistic figures were entered based on the piping system configuration.

Irrigation system configuration

Type of connector	Quantity (current system)	
32º Elbow	0	
22.5º Elbow	0	
11.25º Elbow	0	
Gate Valve	1	
90º Elbow	3	
Tee	1	
Reducer	1	
Check Valve/Non-Return Valve	0	
Total Pressure Loss in Valves and Fitting	**0.396**	**m**

Figure 4.12 Screenshot of the Input pressure loss sheet used to calculate pressure losses depending on number of valves and fittings.

The Output sheet calculates the estimated power required and surface area of the solar panels given the specific inputs in the example (Figure 4.13). In this particular design, given the inputs of water and flow requirement, total dynamic head, a fixed photovoltaic array type, the average sun hours and total solar irradiance per day, and the tank storage, it was calculated that the system requires between 1.4 and 1.5 kWp (1.9 to 2 expressed in horse power HP) with a solar panel surface area between 9.3 and 10 m^2. In the given configuration, a booster pump is required to generate the required water pressure in the drip irrigation system at the outlet of the tank/reservoir (Figure 4.13).

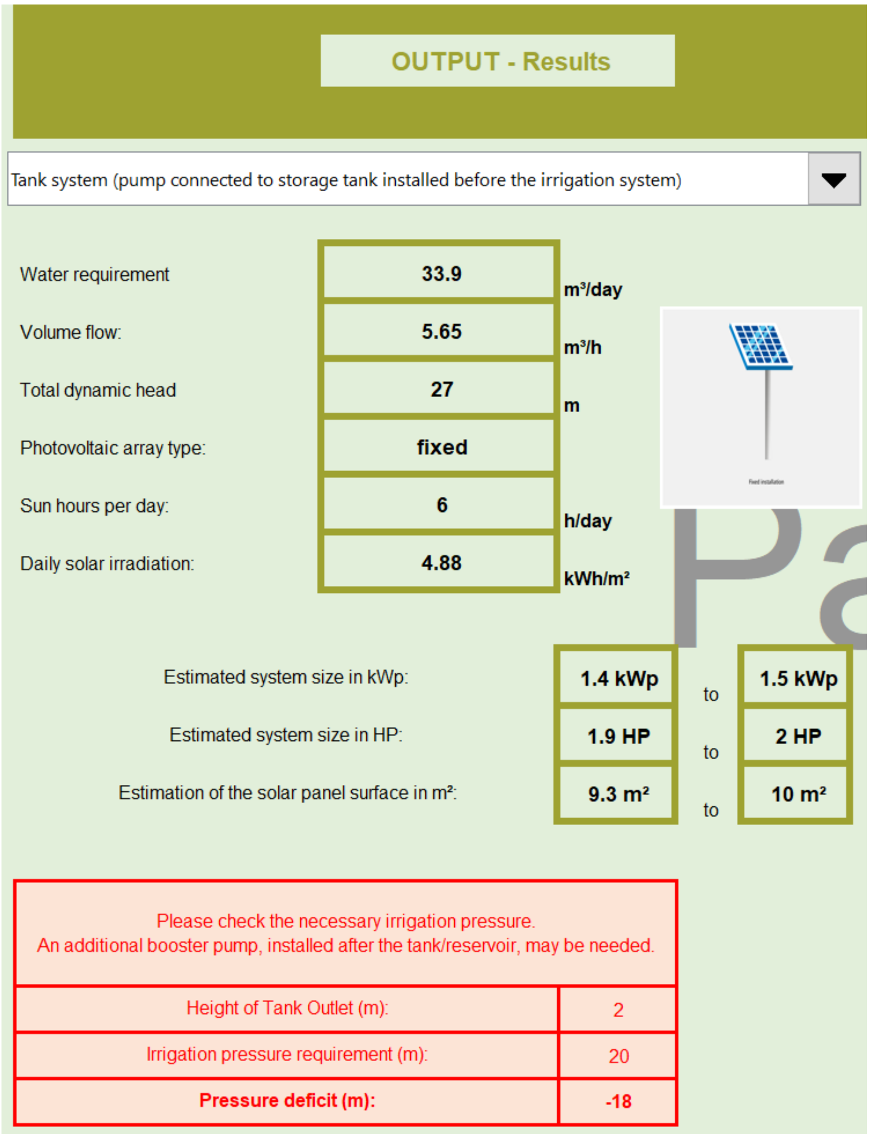


Figure 4.13 Screenshot of the Output sheet of the Design pump sizing tool showing the estimated power required and surface area of the solar panels given the specific inputs in the example.

4.12 PVP acceptance test

The ***PVP acceptance test*** is part of the ***Set up*** module. It is related mainly to the technical and engineering feasibility. The PVP acceptance test is a Word file that provides a guideline on how to check the difference between the designed and the actual performance of the pumping system. This test can therefore be applied only after the system has been installed or during its operation.

In order to perform the acceptance test, the following variables are measured/calculated to obtain actual values after installation/during operation:

a) Tilt angle

In the southern hemisphere, solar panels should face North to maximize power generation. Solar azimuth angle can be measured with a magnetic compass. The optimal tilt angle of the solar panel is geographic latitude ±10°. The tilt angle should be at least 15° to allow rain and dirt to wash off the surface of the solar panel. The tilt angle can be checked with a protractor and building level.

b) Solar irradiance

Actual solar irradiance can be measured with a solar radiation sensor connected to a data logger. The sensor needs to be installed on the solar panel inclined plane.

c) Solar panels electrical output power

Actual output power of the solar panels can be calculated as a function of peak power, solar irradiance and a temperature correction factor (https://energypedia.info/wiki/File:SET_UP_%E2%80%93_PVP_Acceptance_Test_V1.0.docx, accessed on 5 September 2021).

d) Total pumping head

Actual total pumping head can be calculated as the sum of the dynamic groundwater level in the borehole/well and the pressure in the pipeline. The dynamic groundwater level can be measured with a dip meter and the pressure in the pipeline with a calibrated pressure gauge.

e) Water flow

Actual water flow can be measured with a water volume meter or with a bucket of known volume by measuring how long it takes to fill.

Measurements of solar irradiance, solar panels electrical output power and water flow should be done under clear sky conditions for at least two levels of radiation, orientatively 800-1000 W/m^2 and 500 W/m^2.

The final test is between the measured water flow and the theoretical water flow based on specific motor pump curves. The pump curves relate the theoretical water flow to power and total dynamic head, they are usually derived empirically and provided by the pump manufacturer. Measured water flow should be within ±15% of theoretical water flow. If measured water flow is outside this range, further checks should be done on the calculations, the cable wiring of the pump motor and the instrumentation used (radiation sensor, pressure gauge, water flow meter).

4.13 Workmanship quality checklist

The ***Workmanship quality checklist*** is part of the ***Set up*** module. It is related mainly to the technical and engineering feasibility. The Workmanship quality checklist is a spreadsheet questionnaire that is used to inspect the installation has been done correctly. This quality check can therefore be applied only after the system has been installed.

The Workmanship quality checklist consists of a few sets of questions grouped under the following categories:

1) ***General*** (components of the system, instructions on operation and maintenance of the components, training, security and protection measures)
2) ***Solar generator*** (solar panels, cabling, mounting)
3) ***Mounting structure*** (placement, corrosion, robustness)
4) ***Controller/inverter*** (security and protection measures, ventilation, grounding/earthing)
5) ***Water pump*** (security and protection measures, cabling)
6) ***Monitoring system*** (security and protection of sensors and gauges)
7) ***Reservoir*** (security and protection of feeder pipes, foundation, robustness, accessibility, cover)
8) ***Irrigation head*** (accessibility and maintenance)
9) ***Fertigation system*** (storage facility for chemical/fertilizers, health and safety protocols)
10) ***Irrigation system*** (reparability, drip laterals according to design, clogging, leakages)

The spreadsheet provides columns for comments, annotations and action plans. Although the Workmanship quality checklist can be used to assess best practices, safety requirements and overall quality and longevity of the installation, it is not meant to replace component compliance by the manufacturers and official performance verifications.

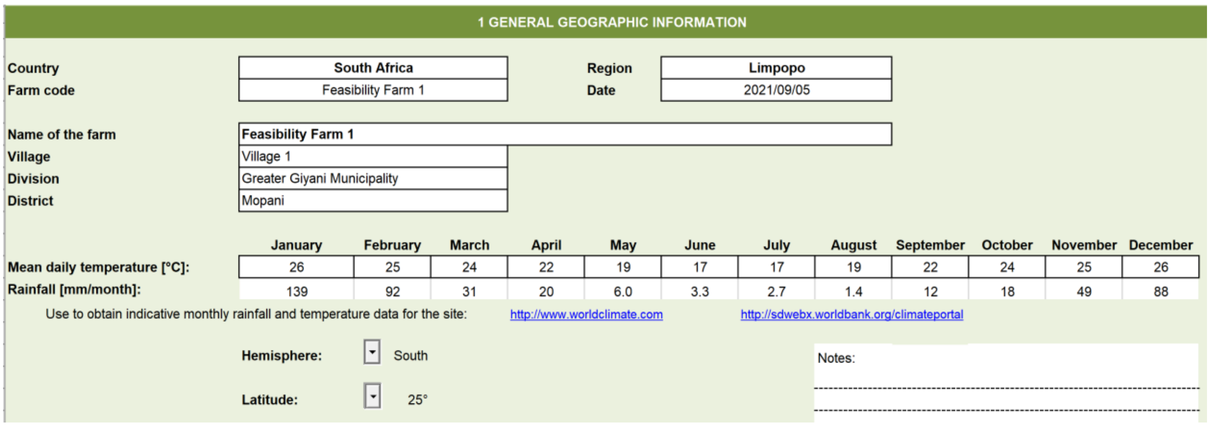
4.14 Soil tool

The ***Soil tool*** in the ***Irrigate*** module is part of the technical and engineering feasibility and it relates only to systems that use water for irrigation. The purpose of the tool is to calculate a suitable irrigation schedule according to crop and soil type. The tool is therefore not strictly-speaking essential for the design of solar-powered pumping schemes; however it is useful for farm management of agricultural water.

The Soil tool is a calculation spreadsheet that consists of the following sheets: Geographic data, Texture calculator and Irrigation schedule. An additional sheet (How this tool works) provides the theoretical explanation on the calculations performed and sources. For the purpose of demonstration, an example was used for a smallholder farm in the study area.

Geographic data

The sheet Geographic data is used to enter inputs on the site location and climatic characteristics (Figure 4.14).


1 GENERAL GEOGRAPHIC INFORMATION

Country	South Africa	Region	Limpopo
Farm code	Feasibility Farm 1	Date	2021/09/05
Name of the farm	Feasibility Farm 1		
Village	Village 1		
Division	Greater Giyani Municipality		
District	Mopani		

	January	February	March	April	May	June	July	August	September	October	November	December
Mean daily temperature [°C]:	26	25	24	22	19	17	17	19	22	24	25	26
Rainfall [mm/month]:	139	92	31	20	6.0	3.3	2.7	1.4	12	18	49	88

Use to obtain indicative monthly rainfall and temperature data for the site: http://www.worldclimate.com http://sdwebx.worldbank.org/climateportal

Hemisphere: South

Latitude: 25°

Notes:

Figure 4.14 Screenshot of the Geographic data sheet in the Soil tool with general input data required.

Texture calculator

Sheet Texture calculator is used to determine soil textural characteristics. In the example in Figure 4.15, soil textural analyses conducted in the laboratory (Jovanovic et al., 2018) indicated that the soil has 82% sand particles, 11% clay and 7% silt, which corresponds to a loamy sand texture. This is generally representative also for other farms in the area.

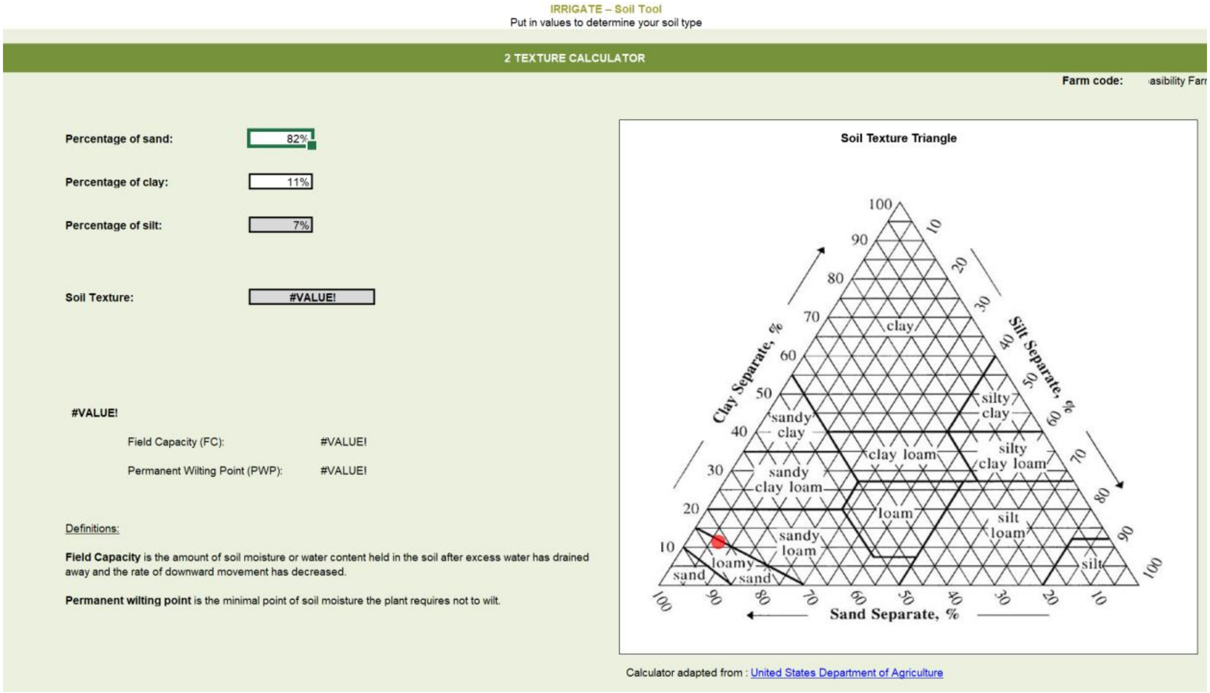


Figure 4.15 Screenshot of the Texture calculator sheet in the Soil tool with input data related to the soil. The type of soil is denoted with a red dot on the soil texture triangle.

Irrigation schedule

In the Irrigation schedule sheet, additional inputs are required such as the crop, area, planting date, crop growing time, irrigation method and cropping density. The same example was used as in the Water requirements tool (Section 4.3) for a 0.5 ha tomato crop planted on 1 December under drip irrigation with normal spacing. In the example, soil was chosen to be silty with a shallow rooting depth (Figure 4.16).

The results of the Irrigation schedule are shown in the screenshot in Figure 4.17. According to the calculations, the recommended irrigation schedule ranges from 36 m^3 every 5 days in December when the crop is in its initial growing stage to 90 m^3 every 3 days in March when the crop reaches its maximum evapotranspiration levels. Irrigation frequency between 3 and 5 days is consistent with common practices on smallholder farms in the area. Given this schedule, the proportional area irrigated daily is between 20% (in December and January) and 33% (in March). A reservoir capacity of up to 30 m^3 is required in March for daily rotational irrigation. The graph in Figure 4.17 summarizes irrigation intervals and water applications per irrigation event over the crop growth period.

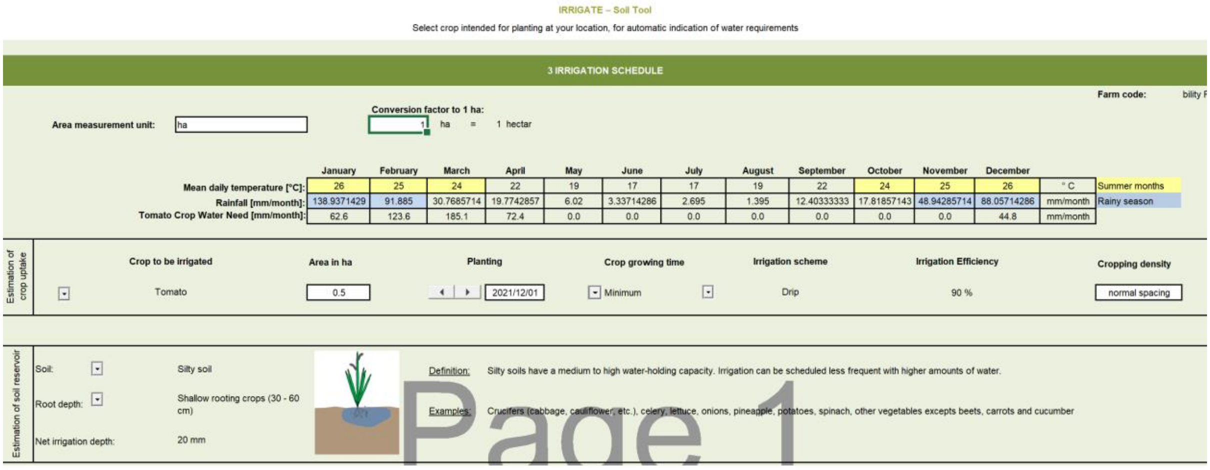


Figure 4.16 Screenshot of the Irrigation schedule sheet in the Soil tool with input data related to the crop example.

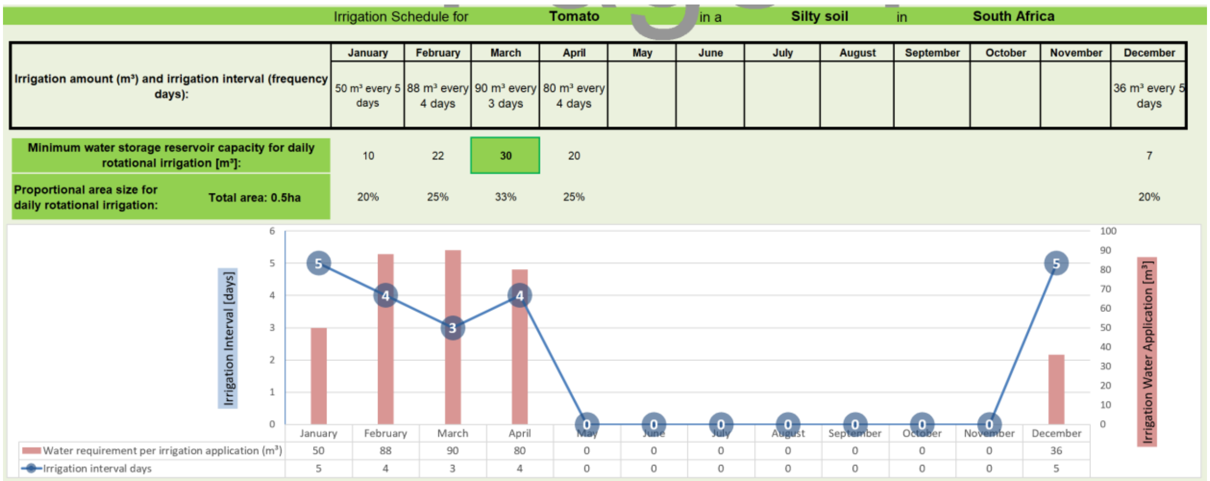


Figure 4.17 Screenshot of the Irrigation schedule sheet in the Soil tool with input data related to the crop.

4.15 Maintenance checklist

The ***Maintenance checklist*** is part of the ***Maintain*** module. It is mainly related to the technical and engineering feasibility. The Maintenance checklist is a spreadsheet questionnaire that provides guidance for routine maintenance of solar-powered pumping systems, such as maintenance plans, selection of service providers, routine protocols and procedures, documentation and monitoring. This Maintenance checklist can therefore be applied after the system has been installed.

The Maintenance checklist consists of a few sets of questions grouped under the following categories:

1) ***General*** (instructions and checklist for maintenance for solar generator and irrigation system, support services)
2) ***Solar generator*** (security and protection infrastructure, signs of misuse or forced entry, robustness of mounting, corrosion, shadowing of solar panels, technical defects on solar panels, functioning of controller/inverter, ventilation)
3) ***Conveyance system*** from the well to the reservoir (changes to connections, pipes, pump inlet free from debris and sediments, functioning of pump, leakages and bends of pipes, buried pipes)
4) ***Reservoir*** (visible damages, regular flushing every 1-4 months, algal growth)
5) ***Irrigation head*** (filter cleaning and replacement, leakages)
6) ***Irrigation system*** (visible damages, changes to connections, pipes, leakages and bends of pipes, uniformity application, dripper clogging and flushing)

The spreadsheet provides columns for description of problems and recommendations. Although the Maintenance checklist can be used to assess the maintenance of the system, it is not meant to replace maintenance instructions and protocols by manufacturers on the different components of the system.

4.16 Water application uniformity guide

The ***Water application uniformity guide*** is part of the ***Maintain*** module. It is mainly related to the technical and engineering feasibility, only for systems that use water for irrigation. The Water application uniformity guide is a calculation spreadsheet to determine whether irrigation water is distributed uniformly over the irrigated field. It can be applied once the system has been installed. It consists of two sheets: Instructions and Calculation tool.

The Instructions sheet explains the importance of irrigation uniformity so that each area of the field receives consistent amounts of water, uniform crop growth is maintained, water stress and losses of water through drainage, leaching of nutrients and yield reductions are prevented. Irrigation uniformity also facilitates irrigation scheduling and applications of fertilizers/chemicals, especially through fertigation. Amongst various indicators of irrigation uniformity, the Water application uniformity guide uses distribution uniformity (DU) expressed as percentage. An acceptable DU is >80% for fields irrigated with drips or sprinklers. A distribution uniformity <80% could indicate leaks, blockages, design or maintenance problems that need to be addressed. Under these circumstances, it is not recommended to apply fertilizers/chemicals.

Field DU tests can be conducted for micro-irrigation (drip, microjets) and overhead irrigation (sprinkler). Irrigation uniformity under drip-irrigation depends on the water pressure in the distribution pipes, design and properties of emitters, clogging and wearing of emitters, water quality and temperature. It can be performed by measuring emitter flow rates along the distribution laterals. This is done by measuring water volumes collected in catch cans over a known period of time. Uniformity tests for sprinkler irrigation should be performed during calm days to avoid results skewed by wind drift, with catch cans placed between lateral lines and spaced uniformly between sprinklers.

The Calculation tool in the Water application uniformity guide is used to calculate the DU based on field test data. A screenshot of the Calculation tool sheet is shown in Figure 4.18 with a hypothetical example. Water depth or water volumes collected with the catch cans are entered in the appropriate column and ranked from the smallest to the highest in the “Ranking” column. The tool outputs the average water depth or volume, the average lowest quartile and DU (Figure 4.18).

MAINTAIN – Water Application Uniformity Guide

Enter values into white (non-colored) cells!

Farm name:	Feasibility Farm 1		
SPIS supplier name:	NN		
SPIS installer name:	NN		
Measurement date:	NN		
Catch can number	**Water depth (mm)**	**Ranking** *1 is smallest amount, 12 is highest amount*	**Lowest Quartile (mm)** *Only transfer the first 3 smallest amounts here*
1	4	3	3
2	5	3	3
3	4	4	4
4	5	4	
5	4	4	
6	4	4	
7	5	4	
8	4	4	
9	4	4	
10	3	5	
11	4	5	
12	3	5	
Total=	49		10
Average Catch Overall=	**4.083333333**	**Average Lowest Quartile=**	**3.333333333**
DU=	**81.63265306**	**If >80% then OK**	

Figure 4.18 Screenshot of the Calculation tool sheet in the Water application uniformity guide to calculate distribution uniformity (DU) of irrigation.

4.17 Water quality considerations and water purification/filtration

Source water quality needs to be fit for a particular use, e.g. drinking water, irrigation, livestock. The Department of Water Affairs and Forestry (DWAF, 1996) provided guidelines to assess water fitness for use in South Africa. This fairly old document is still adopted as guidelines; however it is recognized that water quality thresholds and ranges are also dependent on water management, in particular in the case of agricultural water use. Water quality (both surface and groundwater) needs to be analysed in order to test its fitness for use. A water purification/filtration system needs to be installed should the water quality pose any risk, in particular to human health in the case of domestic water use.

Water quality measurements

Water quality measurements for possible water sources in the study area were conducted during previous WRC research (Jovanovic et al., 2018). Both groundwater samples collected from boreholes and from the sand river alluvial aquifer were analysed. The results are summarized in Table 4.7.

It was deemed that groundwater samples collected from selected boreholes give a fair representation of the ranges of groundwater quality in the area. The groundwater analyses showed that electrical conductivity (EC) in samples obtained from boreholes varied from 68 to 284 mS m^{-1} (Table 4.7). Groundwater is suitable to marginally suitable for agricultural water use according to the South African Water Quality Guidelines (DWAF, 1996). In any case, any build-up in groundwater and soil salinity should be monitored. The groundwater EC does not make it suitable for drinking, although it won't cause adverse effects in the short term (DWAF, 1996). Values of groundwater pH were from 6.9 to 8.5. High alkalinity as $CaCO_3$ was generally recorded (data not shown), which classifies these waters as very hard water according to DWAF (1996). Dissolved organic carbon (DOC) was low (data not shown) and consistent with undisturbed watersheds (DWAF, 1996). Fluoride was below or equal to the recommended standard of 1 mg L^{-1} for human consumption (DWAF, 1996) and below the recommended standard of 2 mg L^{-1} for non-ruminants (DWAF, 1996). The groundwater quality is predominantly NaCl, with occasionally high readings of Ca and Mg, and low SO_4. High Cl readings could affect some crops sensitive to Cl (DWAF 1996). Sodium adsorption ratio (SAR) is generally low to marginal for agricultural water use in well-drained soils (DWAF, 1996), except for borehole H14-1698 (SAR = 8.6), which is located in the alluvium before a dam.

The quality of groundwater sampled in the Molototsi river bed is very good (Table 4.7) and the water is fit for human consumption based on the inorganic as well as DOC analyses (DWAF, 1996). The river bed groundwater was slightly more alkaline than the groundwater sampled from boreholes, it had lower EC, lower concentrations of inorganic constituents, especially Mg, Na, F and Cl. It had also a very low SAR. The marked differences in quality between the groundwater and the river bed water may be an indication of a lack of connectivity between the two groundwater systems, that land activities are not affecting directly the river bed water, and that river bed water is primarily recharged via surface runoff and less through baseflow. N in nitrate and nitrite were below the guideline of 10 mg L^{-1} for human consumption (DWAF, 1996) with some exceptions. Occasionally elevated values of N (above levels recommended for human or cattle consumption) was possibly due to activities in the nearby villages. Groundwater analysed in a borehole drilled privately in a village indicated particularly elevated N (Table 4.7), which is testimonial of potential risks of contamination of groundwater resources in villages that don't have a sanitation system. Caution should be exercised in using boreholes within village perimeters for drinking water supply. A water purification treatment is essential in these cases.

Table 4.7 Groundwater quality measurements in the study area during the period 2012-2017.

Sampling point	Coordinates and altitude (m)	Date of sampling	pH	EC (mS m^{-1})	Turbidity and sediment content (%)	Cations and anions ($mg\ L^{-1}$)										SAR
						Ca	Mg	Na	K	NH_4	F	Cl	N as NO_2 + NO_3	P as PO_4	SO_4	
Borehole AHM1	23.57006 S; 30.65691 E; 464	February 2012	6.86	284	0.204	147	131	169.6	11.9	-	n/d	633	13.5	n/d	38	2.4
		October 2015	7.4	108	-	47	32	151	5.4	0.07	0.9	37	1.1	<0.05	14	4.2
Borehole AHM4	23.56904 S; 30.65921 E; 467	October 2015	7.4	215	-	89	103	159	2.7	9.3	0.8	391	<0.1	0.49	16	2.7
		January 2017	7.3	112	-	50	57	101	2.4	4.6	0.7	58	<0.1	0.32	7.2	2.3
Borehole H14-1698	23.56888 S; 30.65794 E; 467	January 2017	8.5	68	-	10	7	145	0.9	0.31	0.8	11	0.2	3.7	11	8.6
Surface dam	23.567190 S; 30.660314 E; 465	January 2017	7.3	11	-	11	3.3	5	3.8	0.61	0.1	2.8	<0.1	<0.05	2	0.3
Borehole Mzilela	23.592186 S; 30.817377 E; 417	February 2012	6.95	127.5	0.105	65.5	76.0	45.1	4.0	-	n/d	87	31.8	n/d	44	0.9
Molototsi River bed	23.56807 S; 30.81998 E; 375	February 2012	7.78	21.3	0.060	10.8	4.9	15.8	8.9	-	n/d	16	n/d	n/d	3	1.0
		October 2015	7.5	41	-	34	11	29	3.9	0.57	0.3	29	<0.1	<0.05	35	1.1
		January 2017	7.9	17	-	13	4.8	13	3.3	0.08	0.2	9.2	0.3	0.06	4.2	0.8
	23.56861 S; 30.73363 E; 408	October 2015	8.2	41	-	30	11	35	4.2	0.08	0.2	44	0.2	<0.05	12	1.4
Borehole DUV1	23.56589 S; 30.81945 E; 384	October 2015	7.3	240	-	91	99	241	12	0.17	1.0	387	6.2	0.05	39	4.2
Borehole H14-1702	23.56536 S; 30.82118 E; 397	January 2017	7.7	130	-	57	46	147	7.9	0.08	1.0	235	<0.1	<0.05	30	3.5
Private borehole in village	-	July 2016	8.3	255	-	134	106	226	6.2	<0.05	0.5	440	151	<0.05	53	3.5

Water use for irrigation

Water quality fitness for irrigation is evaluated mainly based on physical, chemical and microbiological indicators. Physical indicators are primarily turbidity and total suspended solids that could cause clogging of pipes, fittings, sprinkler nozzles and drippers. Chemical indicators are pH, EC, cations and anions that can cause unfit pH, high salinity, high SAR, scaling in pipes and fittings, and toxic effects of individual elements (Cl, B, etc.). Microbiological indicators are used for potential risks of clogging due to algal growth as well as water-borne pathogens when water is applied directly to leaves of freshly consumed produce.

Water quality can be improved with filters that are particularly necessary in drip irrigation systems to prevent clogging of emitters and reductions in pressure along the water distribution system. Clogging of emitters can be caused by particles (sand, clay), organic material (algae, bacteria) and chemical precipitates (carbonates). Different types of filters are available such as screen filters, disc filters and granulate/sand filters (GIZ and FAO, 2021). Sand filters are most commonly used by small scale farmers in the study area. Filters need to be adapted to the flow rate of the pump, cause minimal pressure loss along the distribution line, be easy to maintain and long-lasting. Regular cleaning, maintenance and replacement of filters is essential.

Given the water quality tests reported in Table 4.7, groundwater quality may be suitable to marginal for agricultural water use mainly due to marginally high salinity levels. However, this is not expected to affect yields of salinity-tolerant crops, soil salinization and permeability, or cause toxicity effects and major impacts on the overall ecosystem through leaching and non-point source pollution. The use of filters is recommended and monitoring of soil properties is required to prevent longer term negative effects. There may be a realistic risk of emitters' clogging by precipitates and sediments, which may negatively impact on the farm economics (reduced water distribution uniformity, water pressure delivery problems, shorter life of irrigation systems). The water quality in the sand river alluvium is excellent as it originates directly from rainfall via overland flow and vertical recharge.

Domestic water use

The water quality requirements for domestic use are much more stringent compared to agriculture and subject to the South African National Standard for drinking water SANS 241: 2015 (Table 4.8). The comparison between the water quality measured in Table 4.7 and the national standards (Table 4.8) indicated that some water purification treatment will be required in order to render the water fit for domestic use. This is particularly true as pathogens such as total coliforms and E. coli need to be reduced to a negligible risk. Besides water purification, regular monitoring and analyses by accredited laboratories will be essential.

Table 4.8 South African National Standard for drinking water SANS 241:2015.

Parameter	Unit	Risk	Standard limit
pH at 25 ^{0} C	pH Unit	Operational	$\geq$ 5.0 - $\leq$ 9.7
Conductivity at 25 0 C	mS/m	Aesthetic	170
Turbidity	NTU	Operational Aesthetic	1 5
Free Chlorine	mg/L	Chronic Health	5
Colour	mg/L	Aesthetic	15
Calcium as Ca	mg/L	Aesthetic/Operational	150
Magnesium as Mg	mg/L	Aesthetic/Health	70
Sodium as Na	mg/L	Aesthetic	200
Potassium as K	mg/L	Operational / Health	50
Zinc as Zn	mg/L	Aesthetic	5
Chloride as Cl	mg/L	Aesthetic	300
Fluoride as F	mg/L	Chronic Health	1.5
Sulphate as $SO_4{}^{2-}$	mg/L	Acute Health Chemical Aesthetic	500 250
Total Dissolved Solids	mg/L	Aesthetic	1,200
Nitrate and Nitrite Nitrogen as N	mg/L	Acute Health Chemical	12
Ammonia Nitrogen as N	mg/L	Aesthetic	1.5
Iron as Fe	µg/L	Chronic Health Aesthetic	2,000 300
Manganese as Mn	µg/L	Chronic Health Aesthetic	400 100
Aluminium as Al	µg/L	Operational	300
Total Coliforms count	cfu/100mL	Operational	10
E.Coli (<1 taken as 0)	cfu/100mL	Acute Health Micro	0
Heterotrophic Plate Count	cfu/ mL	Operational	1,000
Cytopathogenic Viruses	cfu/10 L	Acute Health Micro	0
Cryptosporidium Species	cfu/10 L	Acute Health Micro	0
Gardia Species	cfu/10 L	Acute Health Micro	0
Chloroform	mg/L	Chronic Health	0.3
Bromodichloromethane	mg/L	Chronic Health	0.06
Dibromochloromethane	mg/L	Chronic Health	0.1
Bromoform	mg/L	Chronic Health	0.1
Combined Trihalomethanes	mg/L	Chronic Health	1
Phenols	µg/L	Aesthetic	10
Nitrate as N	mg/L	Acute Health Chemical	11
Nitrite as N	mg/L	Acute Health Chemical	0.9
Antimony as Sb	µg/L	Chronic Health	20
Arsenic as As	µg/L	Chronic Health	10
Cadmium as Cd	µg/L	Chronic Health	3
Chromium as Cr	µg/L	Chronic Health	50
Cobalt as Co	µg/L	Chronic Health	500
Copper as Cu	µg/L	Chronic Health	2,000
Lead as Pb	µg/L	Chronic Health	10
Mercury as Hg	µg/L	Chronic Health	6
Nickel as Ni	µg/L	Chronic Health	70
Selenium as Se	µg/L	Chronic Health	40
Vanadium as V	µg/L	Chronic Health	200
Cyanide	µg/L	Acute Health Chemical	200
Total Organic Carbon as C	mg/L	Chronic Health	10

Microbiological monitoring should not only include total coliforms and E. coli, but also viruses and parasites. The Covid-19 pandemic has borne implications in terms of water quality monitoring, in particular the recent results obtained in WRC research related to Covid-19 detection in wastewater effluent (https://www.nicd.ac.za/wp-content/uploads/2021/07/COVID-19-Special-Public-Health-Surveillance-Bulletin-Vol-19-Issue-1.pdf, accessed on 10 September 2021). Future program of water quality monitoring will therefore have to include detection and quantification of viruses according to protocols recommended by specialist scientists and enforced through government regulations, besides the conventional measurements of microbiological parameters that are standard for drinking water and agricultural water use. Measures for the implementation of MUS in communities and the management of water supply by the community will have to adhere to safety protocols in terms of provision of sanitizers, wearing masks, securing clean water for personal hygiene, social distancing and gatherings, especially during periods of lockdown restrictions.

A water quality monitoring programme should include sampling and analyses in accredited laboratories at control points based on the HACCP principles (Hazard Analysis Critical Control Point), e.g. monitoring at the point of groundwater abstraction, storage tank, etc. The frequency of monitoring should be adapted to the water use, e.g. at least weekly or more frequent for drinking water and yearly for agricultural water use. In the case of contaminated samples, an emergency plan for a system shutdown should be put in place.

Besides monitoring of water quality, a monitoring programme needs to be established for regular monitoring of groundwater levels in order to avoid excessive drawdown of groundwater tables beyond sustainable recovery levels. Groundwater level monitoring of static levels (allowing for groundwater recovery after pumping) needs to be conducted at least on a monthly basis with portable dip meters. This should allow one to determine seasonal and abstraction trends over time and to put intervention measures in case of excessive groundwater drawdown. Measures can include the temporary shutdown of the system or pumping until shallower drawdown depths are reached.

Water purification/filtration

A filtration/purification system will be an added component to the solar-powered irrigation system as it is necessary for the supply of drinking water for domestic use and sometimes agricultural use. Water purification is referred to as the process that removes harmful toxins and contaminants in water (Harikishore and Yun, 2016). The objective is to remove substances like pathogens as well as man-made contaminants and pollutants. Some of these contaminants can be harmful and that is why it is important to remove them in order to improve the appearance, smell and taste of the water (Wang et al., 2015). Water purification is also important and vital because bacteria and viruses are able to grow in it and it may cause humans to become ill. Luckily, for Africa we have plenty of sun that reaches the ground on most days of the year. Solar insolation thus provides free energy in order to purify the water. Solar energy can be used in two different ways to purify the water, firstly it can be converted into electricity by making use of the photovoltaic panels which will then be used to drive a pressure pump for reverse osmosis to take place. Secondly, distillation is a process that separates different components in the liquid through the processes of evaporation and condensation. According to Ozcan and Gencten (2016), this process produces nearly pure water as it provides complete separation from the solutes. The electricity that is produced from the solar panels can also be used to heat the water. For domestic application, distillation is often used as the solar energy can be used directly to heat the water which in many cases it is the simpler and more inexpensive alternative.

For the implementation of this solar-powered system in Giyani, Limpopo, a purification/infiltration system is of utmost importance as water will not only be used for agricultural purposes but also for domestic purposes. Having water that is clean, safe and of good quality is vital and therefore standard requirements for good water quality should be met.

As seen in Figure 4.19, a graphical representation of a SPIS was designed and a filtration/purification was inserted as an extra component. As mentioned above, this is to ensure that water is free from undesired chemical compounds, organic and inorganic materials and biological contaminants.

The main purpose of water purification is to provide water that is clean to drink. The procedure conducted to purify water reduces the concentration of various contaminants that can be found in the water such as suspended particles, bacteria, algae, viruses and fungi. Most communities will rely on natural bodies of water as in-take sources for the purification of water and for day-to-day use. These resources may either be classified as surface water or groundwater and may include underground aquifers, streams, rivers and lakes. The quality to which water must be purified is usually and typically set up by government agencies. Governments make use of set maximum concentrations of harmful contaminants that can be reduced in safe water. Some of the common parameters used to analyse water quality and contamination levels include the presence of suspended solids, radioactive materials, pH, odour, colour and taste.

Water purifier systems are used in many households to remove pollutants from tap water with the help of either biological, physical or chemical processes. People have become very aware of the risk of drinking contaminated water therefore leading to the increased usage of filters in households. Law (2005) stated that the most popular types of water purification systems included membrane filters, reverse osmosis, distillation and ultraviolet light. Membrane filters made from ceramic and nano-filters are often used to filter larger molecules such as viruses, bacteria, salt and metal. On the other hand, reverse osmosis works where untreated water will flow through fine filtered membranes at a certain pressure so that water is able to pass through. However, the contaminants will remain behind. Furthermore, it is safe to say that different types of water purifiers remove different pollutants and no single technique will completely remove all the contaminants from the water (Yusof et al., 2020).

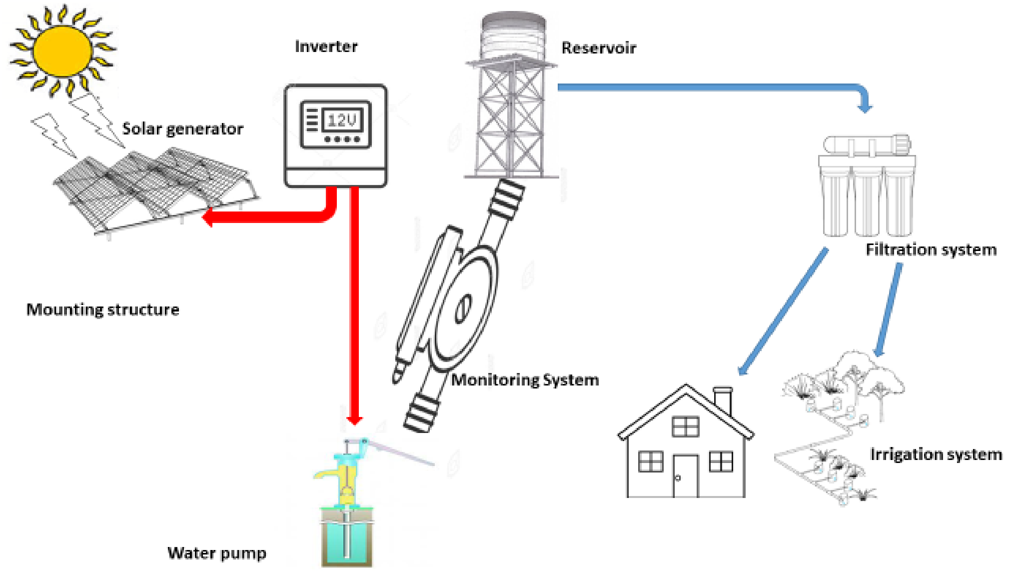


Figure 4.19 Graphical representation of a solar-powered irrigation system with an added infiltration system.

5. STAKEHOLDER ENGAGEMENT

5.1 Community workshops

A stakeholder engagement field trip was undertaken in the week 27 September – 1 October 2021 to Giyani in cooperation with Tsogang Water and Sanitation, the Water Research Commission and the Department of Forestry, Fisheries and Environment. The purpose of the stakeholder engagement was to meet communities at all potential pilot sites, obtain their support and buy-in for the proposed interventions of establishing Multiple Use Water Services (MUS) and solar-powered groundwater pumping infrastructure, and collect additional data for the feasibility study, in particular by acquiring both bio-physical and socio-economic information on the ground. The community engagement was conducted in the form of consultation workshops organized in clusters of villages. The consultation workshops were organized and facilitated by Tsogang Water and Sanitation in collaboration with ward councilors and with the participation of key local representatives, such as local water committee members, managers and operators, farmers' committee members, ward members, government representatives (e.g. Limpopo Department of Agriculture and Rural Development), traditional leader office representatives, NGO representatives, farmers, citizens and volunteers. Covid-19 protocols for face-to-face engagement gathering were followed according to regulations (wearing of masks, measuring body temperature, social distancing, etc.). The consultation workshops were structured according to the following program:

- **Public awareness and promotion of intervention.** This consisted of presenting the project proposal to raise public awareness and promote the interventions amongst key community members.
- **Design and installation of technology.** The design and installation of the equipment and infrastructure was explained to the community.
- **Investment and financing.** The modes of investment and financing of the interventions was communicated to the community and the requirements for long-term sustainability.
- **Operation and maintenance.** The requirements for operations and maintenance of the equipment and infrastructure, including safety and security issues, were tabled and discussed with the main intent to secure a sense of ownership by the community.
- This was followed by extensive **discussion and exchange of information** on the site-specific problems, constraints and opportunities, where the community was encouraged to make suggestions on possible solutions.

- **The way forward** was then explained to the communities, including the completion of the current feasibility study and the project proposal to international funders, so that no misleading expectation is raised.
- The individual workshops concluded with **physical visits to sites** where the communities proposed interventions to take place.

The workshop presenters included Tsogang Water and Sanitation, the University of the Western Cape, the Water Research Commission through its Climate Change Lighthouse programme which deals with research and interventions on climate change, and the Department of Forestry, Fisheries and Environment through its climate change adaptation unit which deals with building climate change resilient communities that are able to adapt to the impacts brought by climate change such as water scarcity. The presenters were each given a slot to talk about their role on the project. Lastly, representatives from the Limpopo Department of Agriculture and Rural Development communicated to farmers how they can get assistance. The importance of farmers obtaining a Permission to Occupy (PTO) for land and water licenses for abstracting water prior to the installation of infrastructure was specified.

The workshop program was arranged in the format of presentations first, then followed by a questions and discussion session where the community members were given the chance to ask or seek clarity from the panel. Apart from asking questions, each village was given a chance to state/list their water challenges and indicate how they wish these challenges to be resolved. Community members were also allowed to comment on their views about the proposed project and the use of solar powered water pumps, if they are in support of the project or not. The last part of the program for each village/cluster consisted of site visits to view the existing water supply systems that are currently being used.

The originally drafted community engagement program is available in Appendix B of this report.

5.2 General considerations

The villages have boreholes that are either connected to a national grid power line or are powered through the use of fuel (diesel or petrol) in order to pump water. Over the years, water supply for domestic and agricultural use in these villages has been through the use of water pumps. The pumped water has helped small scale farmers within the villages to be able to produce more crops to sell to the locals and markets. However, since their crop produce increased, this also meant they needed to pump more water for irrigation and this became a challenge due to the rapid increase in both fuel and electricity costs. The constant rise in the prices of these traditional sources of power brought challenges for the emerging farmers as it became expensive for them to pump enough water for their crops. This threatened their produce and income. These challenges also affect the community at large as the locals cannot afford to either buy their own fuel or electricity for water pumps and the local government is not always prompt in assisting and subsidizing the communities by supplying them with electrical power or diesel.

These challenges brought about the opportunity to consider other alternative power sources which can be efficient for pumping water, and meet the water needs of the community as a whole at much lower costs. Solar water pumps are suitable for use in rural areas and they are cheaper to use as compared to diesel and electricity. Specific visits to each village were made to identify/assess the conditions in terms of the water challenges that exist, the state of their water infrastructure, their water uses and most importantly to educate the community about solar water pumps and their benefits. The field visits were also about engaging the community members on their willingness to accept and support the use of solar panels as an alternative power source for their water abstraction. Gaining the approval/support from the community is important for any project prior to its implementation. In order to achieve this, it was important that the community is educated on what these systems do and how they are beneficial for them in that solar water pumps use energy from the sun which is freely available and abundant. Also, the water pumped can be used for varying purposes such as for irrigation by local farmers, for domestic use by members of the community and for livestock supply, depending on the water quality.

Given the water scarcity in the area and the lack of regular water supply in the villages, the main outcome of the workshops was that the communities are in urgent need and very supportive of the proposed interventions. This was evidenced through the attendance to the workshops, the participation in the discussion following the presentations of the research team and explicit expressions of support. The communities are also willing to be trained in the operation and maintenance of the systems. Concerns were, however, expressed about the potential risks of theft and vandalism.

Most of the challenges put forward during the community workshops revolve around the following problems on the ground:

- **Lack of water supply system** due to lack of infrastructure or break-ups and damages to infrastructure.
- **Lack of secure water supply**. In some instances, villages are connected to bulk water infrastructure, but water supply is not regular, in most cases occasional (once a week to once a month).

- **Distance to be covered by villagers to collect water** on a daily basis. This includes collection points from water cistern trucks that are regularly organized by the Municipality to deliver water in some villages.

Based on the discussions that took place on the specific problems encountered in each village, there appears to be a trend of disconnection between the ward level and the local government, specifically Mopani District Municipality which is the formal water services provider. Water supply problems on the ground are usually reported by ward councilors, however these are seldom addressed swiftly because of the cumbersome procedures of obtaining approvals at council level that includes only a few ward representatives. It was reported that water committee members operate water supply systems on a voluntary basis with little support from Mopani District Municipality.

5.3 Site visits

Community workshops were organized in seven villages or clusters of villages. A description and summary of the findings in each village/cluster of villages is presented below.

Mphagani and Zava

The villages with a population of about 1500 people have seven boreholes, two of which are operational for domestic use. The other boreholes are dry or have poor water quality, specifically high pH, and the water is not potable. They are grouped in one area with no reticulation and they experience frequently problems with diesel pumps. The boreholes have been established by the Department of Water and Sanitation and their characteristics can be obtained from Mopani District Municipality. The village has one big reservoir and two 10 m^3 JoJo tanks which are currently not in use. Other reservoirs are in poor state and collapsing. These problems have forced the villagers to resort to illegal connections. One other major concern raised is that the Municipality does not maintain the infrastructure and it is not clear whether the responsibility lies with the local government or contractors, in case of boreholes or equipment being installed privately or repaired at own initiative.

Farmers' committee members raised the question of poor support from the Department of Agriculture, whose extension officers are currently working on skeleton staff due to lockdown restrictions and budget cuts that prevent them from travelling to the villages. The Department of Agriculture advised that farmers need to be pro-active and approach Government offices to explore and apply for funding schemes on an annual basis.

The ward councilor is very supportive of the project and took the research team to visit three sites. The first site is borehole MPA.21.001, which is associated with a reservoir situated about 1 km away and it is not functional. The second site is a borehole not numbered from where groundwater is used for domestic use by the adjacent suburb. The borehole and infrastructure are maintained by the community users. The third site is the VVV farm. The farm cultivates a variety of vegetables (peppers, cabbage, tomato, chillies, watermelons and maize) and it irrigates with drippers. The produce is sold on the market. Drip-irrigation makes use of water pumped from the Greater Letaba River, situated 1.4 km away, and two power generators. The farm spends about R200 of diesel per day to irrigate 4 hours per day with drip-irrigation. The coordinates of all boreholes and sites visited are summarized in Table 5.1, together with their description.

Khaxani and Xitlakati

The villages are located near the confluence of the Molototsi River into the Greater Letaba River. This is an area that collects drainage water in the catchment and it is relatively rich in water. Water is collected into a large earth dam and groundwater is consistently found <10 m deep. The communities use boreholes as a back-up when the dam runs dry. The dam runs dry during droughts, but not boreholes. There is a water committee in the ward.

The challenges in the villages are mainly of technical nature. There were two operational boreholes, however the pumps in these boreholes were stolen so there is a need for new pumps. The boreholes are used to pump water to a tank that is elevated above ground level. The villages have a water reticulation system for water distribution from the tank that was built in 2017. However, the reticulation system needs a booster pump to increase the water pressure because water cannot reach all parts of the villages. The main bulk water pipeline is not connected to the storage tank. The boreholes were drilled in 1994, although no information on borehole characteristics is available. Mopani District Municipality should be contacted in connection with borehole characteristics.

The farmers in the villages indicated that start-up farming equipment is expensive and also the high costs for getting/renewing a PTO, for which fees are payable to the office of the traditional leader. They requested facilitation in the PTO process. The erection of fences and their costs was also indicated as a challenge. There are no dams or pipes that can supply water from the river to farms. The farmers therefore established boreholes independently, however the water volumes were not sufficient for farming. The farmers use furrow irrigation and they were not aware about the water rights requirements.

The two operating boreholes with pumps were visited. They were established by the Department of Water and Sanitation and numbered H14-0121 and H14-0771. The site descriptions are given in Table 5.1. In addition, an abandoned, previous cooperative farming site was visited. The equipment and assets were stolen and vandalized.

Matsotsosela, Mzilela and Mayephu

Matsotsosela is supplied with water through the bulk water supply system (dam water) from Xitlakati only once per week. In Matsotsosela, there are four boreholes, one of which is dry with no water. Two of the four boreholes are meant to be powered by electricity, but they are not electrified. There is one borehole that is close to a reservoir but it is old and therefore not functional. Households practice subsistence farming, however they are willing to move to a larger scale farming. There is no water storage infrastructure. There is one operating borehole, however water cannot reach all areas and it does not supply the entire village, the cost of electricity is very high. Boreholes H14-0026 and H14-0025 were visited, both established by the Department of Water and Sanitation. Boreholes H14-0026 is not functional whilst borehole H14-0025 is operational, it is located 1 km from the reservoir and it supports various villages, but it needs a stronger pump because the pressure head is too low (Table 5.1).

Mzilela has three boreholes which are not electrified. Water can only be accessed once a month through the bulk water system supply. Only one borehole is operational with a booster pump that fills reservoir tanks. A new borehole was drilled by Mopani District Municipality; however the diesel is not supplied for pumping. The community has a poultry project which they are struggling to operate due to high electricity costs.

In Mayephu, there are 21 boreholes in total and, out of these, two were newly drilled and they have not been connected to the grid power yet. The boreholes are H14-1815 and H14-1818 established by the Department of Water and Sanitation (Table 5.1). One of the two boreholes (H14-1818) is situated at a location in the village that may cause contamination, it is not connected to the electricity grid and not functional. The other functional borehole (H14-1815) is located at about 1 km from the village's reservoir. It has sufficient water. In this village, water is pumped from this borehole five days a week (from 7:00 to 14:00), and the pumping is sufficient to refill the tanks for only a day of water supply. These boreholes produce enough water for daily pumping, however energy supply is an issue. There are major limitations due to fuel costs for the power generator. The fuel consumption is about 210 L per 10 days. According to community members, the installation of solar energy equipment could be economically beneficial at this site to adjust and increase the pumping hours. The system is not monitored by local government. It is operated by the water committee member on a voluntary basis. The water committee member and operator of the system feels his work needs to be recognized by local government because he volunteers to provide services for them.

The municipality often sends a truck to supply water to the community but the water is never enough to supply the whole village, it's on a first-come first-served basis and each household is allocated 60 L per day.

The Mayephu village does not have any agricultural activities due to the lack of water. Mzilela cooperative farm, a study site of the EAU4Food international project (2010-2014), is not operating any more due to a court case on PTO between the women's cooperative and new younger aspiring farmers. The borehole, pump and water storage tank are still in place.

Mbhedle, Loloka, Mghonghoma and Gumela

In Mbhedle village, there are six boreholes, one of them dried up and one is almost in the middle of the village. Only one borehole is currently working and there is no reticulation system in place. This therefore forces community members to travel long distance and transport water canisters manually on a daily basis. The groundwater pumped is also used for livestock supply. The available pumps in the village are powered through electricity and diesel. The operating borehole uses a diesel engine. The diesel engine has been modified to fit wheels, and it has to be transported to the borehole each time water is pumped to prevent theft (>700 m distance). The water pumped from the boreholes is not enough for supplying the whole community. Some water users have to rotate while others don't get water at all. Any repairs to the equipment (e.g. pumps) take long to get organized.

Loloka is a fairly large village that houses about 700 households. In Loloka, there are four boreholes of which only one is functional. Two of the boreholes never worked. The water pumped from the one functional borehole does not reach the entire village. The major setback in the village is that the electric grid transformer that is supposed to power the pumps has not been operational. Groundwater availability does not seem to be a challenge. Villagers have since resorted to buying water from those who have been fortunate enough to have drilled boreholes at the back of their yards. The little water that is available in Loloka has to be shared with Mbhedle village. The village is close to the Molototsi River that gives an option to abstract groundwater from the river sand alluvium.

During the consultative discussion, community members asked about the criteria used to select villages for development and whether the Mopani District Municipality is involved.

A site visit took place at Duvadzi farm. The emerging farmer under PTO has 4 boreholes established by the Department of Water and Sanitation, three of them during a recent WRC project. Borehole logs and characteristics are available from previous WRC projects (Jovanovic et al., 2018). The farm is adjacent to the Molototsi River and the farmer often pumped water directly from the river sand with a diesel pump for small scale irrigation. The farm is now electrified and equipped with pumps. Electricity bills are fairly high if the farmer wants to irrigate.

It is not certain how many boreholes exist in the village of Mghonghoma. Some new boreholes were established by Mopani District Municipality and left unequipped. There seem to be eight boreholes that were drilled in the village and only one is fully operational. The community does not have a storage facility for the pumped water and water cannot reach all households. Villagers have to carry the pumps in and out, preventing them from being stolen. The watering points require travelling long distances. The village is in need of a small earth dam that could be used for livestock watering, as borehole water is used for livestock at this point in time.

Guwela has five boreholes and out of the five, two are not working (one is powered by diesel and the other through electricity). The boreholes are situated/located in such a manner that they cover the whole community. Guwela has five zones and one of them has more water compared to the rest (Zone 1), it receives water twice a week.

Dzumeri and Mageva

Dzumeri has seven sections and only three sections have boreholes that are operational. In the remaining 4 sections, community members buy water from people having drilled boreholes in their private yards. The village has 6 boreholes in total and only two are working. The two operational boreholes are powered by electricity and they are yielding enough water. The other four boreholes in the village have either collapsed or the yield is too low. One of the two functional boreholes is located at a distance from the community, meaning villagers have to travel far in order to access water since there is no reticulation system. The community indicated a need for water to be brought closer to the village, they also believe that their farming can flourish if they were to have access to adequate water. Some farms have stopped operating due to lack of water supply.

Dzumeri spreads along the Molototsi River. A lot of water drains and it can be found along the Molototsi River. There are 3 boreholes along the Molototsi River that would be good sites for the water supply system. The community needs to pump water closer to the village due to long travel distance on steep slopes. The community also put forward the idea of building a small dam on the Molototsi River that could capture high flows.

During the consultative discussion, community members indicated that villagers are in dare need of water and they need this project to start as soon as possible. The community is very willing and positive about taking care of the equipment. Ward counsellor is also Head of Staff of the traditional leader. Community members asked whether the intervention include people that intend to start farming or only people that already farm. They were also interested whether the project will benefit all the community or only farmers. The representative of the Limpopo Department of Agriculture and Rural Development informed the community that PTOs can be obtained via the Municipality upon approval from the traditional leader (the approval is part of the documentation submitted to the Municipality).

Three boreholes along the Molototsi River were visited (Table 5.1). They are between 150 and 200 m deep and very good-yielding (about 6 L/s). They operate on electricity. However, the community needs to drive to the site to fetch water because of steep slopes. There is need to uplift the water to the village. Boreholes were drilled by Mopani District Municipality and they are marked with the Department of Water and Sanitation markers. Mr Ntshlaisi at Mopani District Municipality can be contacted on boreholes specifications. Additional boreholes are located in the village and they were visited (Table 5.1). One borehole pumps water to the community on street taps, but it doesn't have a reservoir, which makes it inconvenient to operate. Another borehole is in the village, and it is accompanied with 5 JoJo tanks mounted on an elevated structure that is easily visible from the main road.

Three farms were also visited in Dzumeri and adjacent suburbs (Table 5.1). The first farm is a vegetable farm with two boreholes. According to the farmer, a former school principal, it is not clear whether the borehole yield is sufficient and the pressure head appears to be low. The boreholes are operated with electricity. The second farm is A hi tirheni Mqekwa farm located in Daniel Ravalela village. It is a mixed family farm with a mango orchard and vegetables that was used as study site in previous WRC projects. There are 9 boreholes on the farm, 4 of which are fairly new and they were drilled by the Department of Water and Sanitation in 2016. Borehole logs and characteristics are available from previous WRC projects (Jovanovic et al., 2018). The farm is adjacent to a dam. The farmer used diesel pumps and an electricity line was connected to the farm a few years ago. However, the electricity costs are extremely high (R5000 per month). The third farm is Nhlambeto farm and it is located in Dzumeri village on the Molototsi River banks. The emerging farmer was growing vegetables until last year abstracting water from the river bed for irrigation. He was recently asked by the community to stop abstracting water because this lowers the groundwater level and other water users cannot dig deep in the river bed to collect water for household consumption. As a result, the farmer stopped farming. However, the problem could be resolved by installing a deeper abstraction point. Based on previous geophysical measurements, the river sand alluvium is between 4 and 6 m deep.

Muyexe

Muyexe village has 12 boreholes in total and only four are working. The community receives water from the bulk water system from the Nsami Dam, however this supply is often cut off for periods of about 1-2 months. During those periods, the village depends on borehole water and it uses it for domestic and livestock supply. One borehole is connected to the main bulk water supply system. The other three boreholes can be accessed by the community, but the travelling distances to cover are large. A water purification system exists but it was only functional for the first six months, after which it broke down due to electrical cables supplying power to the system being stolen.

The village of Khakhala does not have boreholes, except two boreholes that are not currently operating because not connected to the electricity grid. Water is needed for domestic use and livestock. Bulk water is supplied only once in a month.

During the consultative discussions, community members inquired whether the water purification plant can be restored, when is the project anticipated to start and how much resources need to be put by the community.

Two boreholes were visited that are operational and delivering water through a reticulation system to street taps, however the pressure is low and the purification system (reverse osmosis) for these boreholes is not functional (the one because of cable theft, and the other because of the electrical control box out of order). Electricity is used for both boreholes and the bill is paid by the Municipality.

A farming site was visited where the Muyexe community project was developed in 2013-14 through the rural development program. The Limpopo Department of Agriculture and Rural Development is currently rehabilitating the site. The farm has drip-irrigation laterals, a main conveyance pipe system and fertigation tanks already installed. One new borehole has a low yield. An older borehole of the Department of Water and Sanitation has a very good yield, but the pump needs repairs. The packhouse built on the premises consists of offices and storage space. The site has also a storage building and a nursery. The site was damaged by a storm recently.

Table 5.1 Summary of stakeholder engagements in villages in Greater Giyani Municipality, sites visited and brief description.

Villages	Borehole or site visited	Coordinates		Description
		Latitude	Longitude	
Mphagani and Zava	Borehole No. MPA.21.001	-23.6163549°	30.6974356°	Non-operational site, reservoir 1 km away from borehole.
	Borehole not numbered	-23.607153°	30.701548°	Groundwater used for domestic use by adjacent suburb, maintained by the community.
	VVV farm	-23.642872°	30.745509°	Vegetable farm using water from the Greater Letaba River (1.4 km away); large costs of water pumping with power generators (R200 per day).
Khaxani and Xitlakati	Borehole No. H14-0121	-23.672363°	30.810192°	Groundwater pumped from a drainage dip with sufficient water to an elevated reservoir for domestic water supply through a reticulation system, but pressure head is insufficient.
	Borehole No. H14-0771	-	-	-
	Cooperative farm	-	-	Abandoned farm, equipment and assets stolen/vandalized, no fence.
Matsotsosela, Mzilela and Mayephu	Borehole No. H14-0026	-23.60106°	30.829530°	Borehole not functional.
	Borehole No. H14-0025	-23.600749°	30.825683°	It supports several villages, 1 km from reservoir, but pressure is too low and it needs a stronger pump.
	Borehole at Mzilela	-23.592869°	30.17120°	It was established by Mopani District Municipality, a booster pump is sufficient to fill tanks, however no diesel is supplied to operate it.
	Borehole No. H14-1815	-23.589623°	30.778480°	It has sufficient water yield, about 1 km from the village’s reservoir, fuel is costly (about 210 L per 10 days).
	Borehole No. H14-1818	-	-	Not connected to grid and not functional.
Mbhedle, Loloka, Mghonghoma and Gumela	Duvadzi farm	-23.566067°	30.819647°	Emerging farmer with 4 boreholes adjacent to Molototsi River. The farm is electrified and equipped with pumps with fairly high electricity bills.

Villages	Borehole or site visited	Coordinates		Description
		Latitude	Longitude	
Dzumeri	Borehole No. H14-1160	-23. 573073°	30.709654°	In the vicinity of the Molototsi River, not operational.
	Borehole No. H14-1831	-23.573086°	30.709498°	Adjacent to the Molototsi River, fully operational.
	Borehole No. H14-1002	-23.573258°	30.709205°	Adjacent to the Molototsi River, not operational.
	Borehole No. H14-1002	-23.572867°	30.70856°	Adjacent to the Molototsi River, not operational.
	Borehole No. H14-1159	-23.573291°	30.710591°	Adjacent to Molototsi River and bridge, it has an electrical pump and a reverse osmosis system for water purification, however not operational.
	Borehole No. H14-0128	-23.577744°	30.715934°	Borehole in village, operational with electricity connected to a reticulation system of street taps, no storage tanks available.
	Borehole No. not recorded	-23.573411°	30.681213°	Borehole in village with 5 JoJo tanks.
	Farm with nursery/poultry structures	-23.592095°	30.706697°	Emerging farmer with two boreholes, borehole yields are not clear, pressure head is too low.
	A hi tirheni Mqekwa farm	-23.569625°	30.659922°	Emerging farmer with 9 boreholes, the farm is electrified and equipped with pumps with extremely high electricity bills.
	Nhlambeto farm	-23.562523°	30.700264°	Emerging farmer abstracting water from the Molototsi River bed, he was recently asked to stop farming by other water users due to drop in groundwater level.
Muyexe	Borehole No. not recorded	-	-	Delivering water through a reticulation system to street taps, however the pressure is low and the purification system (reverse osmosis) is not functional (electrical cable theft). Electricity is used and paid by the Municipality.
	Borehole No. not recorded	-	-	Delivering water through a reticulation system to street taps, however the pressure is low and the purification system (reverse osmosis) is not functional (electrical control box out of order). Electricity is used and paid by the Municipality.
	Development Program farm	-	-	Two boreholes (one with low yield and one with high yield that needs the pump to be repaired). Packhouse, offices, storage building, nursery and drip-irrigation system are available and under rehabilitation.

5.4 Potential pilot sites

Based on the stakeholder engagement with communities and the field visits undertaken in the last week of September 2021, sites were proposed for piloting the MUS and solar-powered groundwater pumping systems. The criteria developed and reported in Chapter 3 of this report aided in the selection of potential piloting sites. Substantially, the criteria consisted of presence of a reliable water source (groundwater or sand river alluvium) and some established infrastructure. It should be highlighted here that the interventions are not meant to replace the bulk water supply, which is a mandate of local government and water service providers. For that reason, existing infrastructure would be useful to build-on and add value to, through technologies like solar photovoltaic cells. Criteria were also the potential for water use diversification, system and logistical complexity, and business development (e.g. building-on agricultural value-chains and value-added products, access to markets, other cultural and economic potential, etc.).

It should be highlighted that the adoption of MUS from the same water source is somewhat logistically challenging, e.g. in the case of water use for households and agriculture. This is firstly because the sources of water are usually far apart. Small farms are usually outside villages, and there would be a need for long pipelines to connect the water source for agricultural and domestic use. The second reason is that the water quality requirements are much stricter for domestic use than for agriculture. In most instances, a water purification system (reverse osmosis) would be required for domestic use, whereas a standard sand filter could be sufficient for agricultural water use.

All communities are in dire need of interventions because they do not have running water on tap, and therefore they would benefit through the water supply and reduce the risks related to health and hygiene. The communities, tribal and traditional authorities appeared to be very supportive of the project. This looks promising in terms of the transfer of the ownership, operation and maintenance of the equipment and infrastructure to the communities. However, security systems will have to be put in place to reduce the risks of theft and vandalism.

The project is to be seen as an emergency intervention due to the lack of water on tap in some communities and during periods of water shortages due to extended droughts. It is therefore supplementary to the bulk water supply systems and infrastructure. However, this will depend on specific site conditions and, in certain instances, it will be possible to link MUS and solar-powered water supply to the main bulk water supply system. This makes the participation of the local government imperative, especially the water service providers, and the formal steps of approval will have to be defined well. Similarly, the participation of the Department of Water and Sanitation and the issuing of water licenses, where required, is also essential.

As a result of the considerations above, nine pilot sites were considered for piloting the project: 4 village sites, 4 small farms and one site with mixed uses (domestic and agricultural). The sites are summarized in Table 5.2 along with a description/justification and potential links to existing bulk water supply systems. The sites were also visually documented in photos in Figures 5.1-5.9.

Table 5.2 Pilot sites with description/justification and their links to bulk water supply.

Village	Site	Description/justification	Links to bulk water supply and infrastructure system
Mbhedle	Village population = 1230	No bulk water supply, villagers have to walk up to 0.7 km to collect water. Boreholes have been established. Community members proposed the site.	Emergency intervention independent of bulk water infrastructure. Borehole abstraction without reticulation.
Mayephu	Village population = 1940	No bulk water supply. Boreholes have been established. Diesel expenses subsidised by local government are extremely high. Community operator is very committed.	Emergency intervention independent of bulk water infrastructure. Borehole abstraction into a reservoir.
Mzilela	Village population = 1150	Bulk water supply is seldom available due to water shortage (once per month). Boreholes have been established.	Emergency intervention linked to bulk water supply. Boreholes supplement bulk water supply.
Matsotsosela	Village population = 2300	Bulk water supply is seldom available due to water shortage (once per week). Boreholes have been established.	Emergency intervention linked to bulk water supply. Boreholes supplement bulk water supply.
Dzumeri	Nhlambeto farm	Groundwater is abstracted from sand river bed. There is competition for water between domestic users and farm that caused a drop in groundwater level. However, the problem could be resolved by installing a deeper abstraction point (4-6 m deep).	Emergency intervention independent of bulk water supply. Mixed water use.
Dzumeri	Farm with nursery/poultry structures	Farmer very committed. Boreholes have been established, but water availability is uncertain. There is a possibility for mixed water use thanks to the vicinity of village.	Emergency intervention independent of bulk water supply.
Dzumeri (Daniel Ravalela)	A hi tirheni Mqekwa farm	Farmer very committed. Boreholes have been established, but electricity bills are astronomical. There is a possibility for mixed water use thanks to the vicinity of village.	Emergency intervention independent of bulk water supply.
Loloka	Duvadzi farm	Farmer very committed. Boreholes have been established. Groundwater can also be abstracted from sand river bed.	Emergency intervention independent of bulk water supply.
Muyexe	Muyexe community project	Community project through the Rural Development Program currently being rehabilitated. Excellent infrastructure (boreholes, drip-irrigation system, pack-house, offices, storage space and nursery). There is a possibility for mixed water use thanks to the vicinity of village.	Intervention can be linked to bulk water supply.

Figure 5.1 Community workshop in Mbhedle.

Figure 5.2 Top: Borehole H14-1815 in Mayephu. Bottom: Village reservoir about 1 km from borehole; cost of fuel to pump water into the reservoir is very high.

Figure 5.3 Top: Borehole at Mzilela. Bottom: Village reservoir; a booster pump is sufficient to fill tanks; however no diesel is supplied by Municipality to operate it.

Figure 5.4 Top: Borehole H14-0025 in Matsotsosela. Bottom: The borehole is operating at low pressure; the pump pressure head needs to be increased.

Figure 5.5 Top: Nhlambeto farm in Dzumeri. Bottom: Abstraction of groundwater from sand river bed.

Figure 5.6 Top: Farm in Dzumeri with structures for poultry/nursery. Bottom: Farm in Dzumeri with cultivation of vegetables.

Figure 5.7 A hi tirheni Mqekwa farm in Daniel Ravalela (Dzumeri): cultivation of vegetables (top) and established borehole (bottom).

Figure 5.8 Duvadzi farm in Loloka.

Figure 5.9 Muyexe community project: packhouse and office building (top); storage shed and nursery (bottom).

6. TECHNICAL DESIGN FOR POTENTIAL PILOT SITES

Each of the proposed pilot sites has specific characteristics and there are subtle geophysical, technical, environmental and socio-economic differences between them. However, the pilot sites are sufficiently similar to each other (same climate, geology, water supply issues, institutional set-up and socio-economic settings), so that that the feasibility assessment for a hypothetical small farm irrigating 0.5 ha or village of 1000-1500 people (Chapter 4 of the feasibility assessment) can generally be used as a basis.

The modules and tools in the SPIS Toolbox (Figure 2.8) that include questionnaires, general information of the area and maintenance are common for all pilot sites. This is the case of the Promote & Initiate module that includes the Rapid Assessment Tool and the Impact Assessment Tool, the Market Module (Market Assessment Tool), the Finance Module (Finance Deployment Tool), the SPIS Suitability Checklist in the Design Module, the Set Up Module that includes PVP Acceptance test and Workmanship Quality Checklist, and the Maintain Module (Maintenance Checklist).

However, the technical design of the solar-powered pumping system changes from site to site depending on the water requirements and the pressure head to be delivered by the pump depending on the geophysical settings. This is particularly relevant to the Pump Sizing Tool in the Design Module of the SPIS Toolbox that calculates the peak power requirements (kWp) and the solar panel surface area (m^2) as a function of the water requirements (m^3/d) and the total dynamic head (m) (Figure 4.13). The Site Data Collection Tool in the Design Module also changes depending on the specific site, however this tool doesn't perform any calculations. The income/profit of each farm is different (Module Invest, Farm Analysis Tool) and this will also affect the calculation of payback and economic returns (Payback Tool). However, the latter is not seen as noteworthy because the capital investment will be subsidized. Water requirements change depending on cropping systems and irrigated area on farms (Water Requirement Tool in Safeguard Water Module) as well as depending on the population size for domestic water supply. The results of the Soil Tool (Irrigate Module) and Water Application Uniformity Guide (Maintain Module) change depending on the soil characteristics, cropping systems, irrigation systems and farming practices, however these are management tools that don't affect the technical design of the solar-powered pumping system.

In this Chapter, we refined the technical design of the solar-powered pumping systems for each proposed pilot site using the Pump Sizing Tool in the Design Module. For the pilot sites supplying water for domestic use, we calculated the water requirements by multiplying the population of the village by 25 L per person per day. For the pilot sites suppling water to farms, we assumed the crop water requirements of the hypothetical farm described in Chapter 4 that irrigates three vegetable crops per year on 0.5 ha of land. The required hydraulic head to be delivered by the pump (total dynamic head) was estimated for each proposed pilot site (both domestic use and farms) based on the geophysical characteristics observed and recorded during the field visits. We used then the Pump Sizing Tool to recalculate both the peak power of the pump and the solar panel surface area for each pilot site. The results are summarized in Table 6.1.

Water requirements depend largely on the size of the population to be supplied with water, ranging from 28.8 m^3/d for the pilot site in Mzilela to 58.9 m^3/d for Nhlambeto farm in Dzumeri (Table 6.1). It should be noted that the Nhlambeto farm in Dzumeri is meant to provide water for a mixed use, namely the emerging farm and a portion of the population in the village of about 1,000 people. It would be impossible to supply the entire Dzumeri population of 6970 with water from one single source. Water requirements on farms, assuming the same cropping system and irrigation area, are the same (33.9 m^3/d) because the same climatic data were used.

Total dynamic head was estimated based on groundwater depth (static and drawdown level), height of the storage tank, ground level gradients, pipeline length and diameter, pressure losses as well as pressure required at point of use (Figures 4.11 and 4.12). The various components of the total dynamic head were estimated in excess to provide a safety gap for sufficient pressure to be delivered by the pump. Groundwater depth was estimated to be 20 m based on the common occurrence in the area and a groundwater drawdown of 5 m was considered. Pipeline length was estimated based on the information collected during site visits. The conveyance pipe diameter was assumed to be 60 mm for domestic water supply and 40 mm for irrigation. Both pipeline length and diameter affect greatly the pressure losses and therefore the total dynamic head. Pressure required at point of use was assumed to be 2 b for farms and 3 b for domestic use on tap.

Nhlambeto farm is the only site using shallow groundwater from the river bed alluvium, so it has the lowest total dynamic head requirement of 20 m (Table 6.1). A hi tirheni Mqekwa farm pumps water from boreholes that are quite distant from the irrigated field, and with a conveyance pipe diameter of 40 mm, it requires the highest total dynamic head of 43 m. The village of Mbhedle requires the longest conveyance pipe (>700 m), but the water requirement is quite low, so the estimated total dynamic head is 33 m.

The combination of water requirements, total dynamic head and pipe layout is used to calculate peak power requirements and solar panel surface area (Figure 4.13). The calculated peak power and solar panel surface area requirements were summarized in Table 6.1 for the pilot sites. The peak power requirements ranged from 1.2-1.3 kWp at Mzilela with the lowest population size to 2.8-3.4 kWp at Matsotsosela with the highest population. This corresponds to a solar panel surface area requirement of 8.0-8.7 m^2 at Mzilela and 18.7-22.3 m^2 at Matsotsosela. Fairly high peak power requirements and large solar panel areas were calculated for Mayephu (large population), A hi tirheni Mqekwa farm and Muyexe community project (large total dynamic head). On the other hand, relatively low peak power requirements and small solar panel areas were calculated for Mbhedle, the Dzumeri farm with nursery and Duvadzi farm, which have generally lower water requirements than the other sites.

Peak power requirements and design of solar panel array can be further adjusted based on the equipment specifications and availability on the market from suppliers and manufacturers. The pipeline layout, pipe diameter, installation of tanks, including the use of booster pumps to secure enough water pressure is delivered, can all be adjusted at the time of implementation in order to secure an optimal design and final set up.

Table 6.1 Water requirements, total dynamic head, pipeline length and diameter, power supply required (peak kW) and solar panel surface area estimated for each proposed pilot site with the Pump Sizing Tool (GIZ and FAO, 2021).

Village	Site	Water requirements (m^3/d)	Total dynamic head (m)	Pipeline length (m)	Pipeline diameter (mm)	Peak power (kWp)	Solar panel surface (m^2)
Mbhedle	Village population = 1230	30.8*	33	1000	60	1.5-1.7	10.0-11.3
Mayephu	Village population = 1940	48.5*	30	50	60	2.2-2.7	14.3-18.0
Mzilela	Village population = 1150	28.8*	29	50	60	1.2-1.3	8.0-8.7
Matsotsosela	Village population = 2300	57.5*	30	50	60	2.8-3.4	18.7-22.3
Dzumeri	Nhlambeto farm	58.9**	20	300	60	1.7-2.0	11.0-13.0
Dzumeri	Farm with nursery/poultry structures	33.9	35	150	40	1.7-2.0	11.3-13.3
Dzumeri (Daniel Ravalela)	A hi tirheni Mqekwa farm	33.9	43	300	40	2.1-2.6	14.0-17.3
Loloka	Duvadzi farm	33.9	35	150	40	1.7-2.0	11.3-13.3
Muyexe	Muyexe community project	33.9	40	250	40	2.0-2.5	13.0-16.7

*Calculated as population x 25 L/person/d

**Calculated as farm water requirement + requirement of 1,000 people (fraction of population of Dzumeri)

7. CONCLUSIONS

This document represents the final report of WRC project No. C2020.2021-00718 on the feasibility assessment of solar-powered groundwater pumping systems. Based on the information available, a realistic example of design of a solar-powered groundwater pumping system in the area of Greater Giyani Municipality was provided to serve as background and scientific evidence on the feasibility of such systems, and to provide a case for advocating the implementation of pilot sites in the area.

The proposed geographic location for pilot sites is between the Great Letaba perennial river and the Molototsi non-perennial river. The area is particularly dry with rainfall below the recorded values at Giyani weather station. For example, during the drought in 2016/17, measurements of rainfall on farms indicated values of about 200 mm/a (data not shown). Several sites can be potentially piloted using water sources from existing boreholes and wells in dry river sand beds, with population in villages ranging between 1000 and >5000 and several smallholder farms operating along the non-perennial river. Most villages do not have water on tap and accompanying infrastructure, which makes the need for water supply intervention urgent.

Feasibility assessment with SPIS Toolbox

The feasibility assessment for the implementation of solar-powered groundwater pumping systems was conducted with the SPIS Toolbox (GIZ and FAO, 2021) in terms of geophysical, technical-engineering, socio-economic, environmental and financial feasibility. The SPIS Toolbox was found to be suitable for feasibility assessment of agricultural water use as well as for drinking water supply with some adaptation. Some information required by the Toolbox will have to be completed through data collection on the ground or after the installation of the solar-powered pumping systems. The tools of the SPIS Toolbox populated with inputs and the calculations performed are available from the Authors.

The following conclusions were drawn from the application of the SPIS Toolbox:

- The implementation of solar-powered groundwater pumping systems will result in beneficial impacts on water security, agricultural impact, involvement of local communities and gender equity. However, it may have negative impacts on natural resources, especially if over-abstraction of groundwater occurs, which needs to be controlled through sustainable management of groundwater.
- Groundwater yields from boreholes in the area typically range between 1 and 3 L/s (86 and 259 m^3/d). A safe yield of 7.2 m^3/h (2 L/s) could be sustained for about 8 hours per day (57.6 m^3/d).

- Groundwater storage should be sufficient to sustain water supply during periods of drought as a reserve, however groundwater recharge will be essential from occasional flood events to render abstraction sustainable.
- Geophysical parameters indicated that the area is marginally to moderately suitable for solar-powered groundwater systems. It is particularly suitable in terms of solar radiation (4.9 kWh/m^2/d or photovoltaic power output of 1589.3 kWh/kWp), agricultural productivity and market potential. However, water resources are scarce and they need to be managed sustainably. Technical capacity needs to be built.

The SPIS Toolbox was applied to an example of smallholder irrigation farm (or small village for drinking water supply, where applicable) and the following results were obtained:

- For a typical farm that irrigates 0.5 ha of vegetables (3 crops per year) with a few cattle heads, the estimated gross farm profit is R251,600/a.
- The peak water requirement of the farm will be 33.9 m^3/d in the month of December. This volume of water corresponds to the water supply to a village of about 1,350 people at a rate of 25 L per person per day.
- When solar, grid and diesel power sources are compared, the grid-powered system has the highest Internal Rate of Return, whereas the solar-powered system has the highest Net Present Value and accumulated cash flow over 25 years.
- The solar-powered system will take 4 years to payback compared to 3 years for the grid-powered system. The diesel-powered pumping system is not financially viable.
- The solar-powered system has the highest capital investment cost, however starting from year 7, the cumulative costs become lower than for the grid-powered system.
- Savings in costs of >R400,000 were estimated for the solar-powered system compared to the grid-powered system for a life cycle of 25 years.
- Feasible financial mechanisms were identified to be: leasing, cooperatives, informal saving groups and pay-per-use. However, it is likely that the solar-powered systems will have to be funded and the operation and maintenance subsidized through donors/governmental institutions, at least during the piloting phase.
- Given the technical design configuration for the smallholder farm used as an example, the system requires between 1.4 and 1.5 kWp to power the pump with a solar panel surface between 9.3 and 10 m^2.
- In terms of securing satisfactory water quality, filters should be used for irrigation water supply, whilst a water purification system is essential for drinking water supply.
- A monitoring programme needs to be established, based on adequately frequent sampling and analyses for physical, chemical and microbiological vectors at control

points, especially for drinking water. Emergency plans should be put in place in the case of water contamination.

- Regular monitoring of groundwater levels (e.g. monthly) is also strongly recommended to avoid excessive drawdown of groundwater tables beyond sustainable recovery levels.

Outcomes of consultative workshops and proposed pilot sites

Many of the technical issues highlighted during the consultative workshops with communities and stakeholders came down to lack of operations and poor design or maintenance. These were often broken pumps, lack of sufficient pressure head, lack of a reticulation system, non-functional water purification systems (reverse osmosis), non-functional control boards, stolen pumps, stolen electrical cables and similar. It is suggested that this type of repairs and maintenance are within the domain of the water service provider, although there appears to be a lag in communication and time in the resolution of technical issues on the ground.

However, there are examples and potential sites that were visited, which lend themselves very well to build on current infrastructure, e.g. boreholes and water reservoirs have been established, pumps and pipelines are operating, etc. Financial constraints pertaining to the high cost of fuel and electricity appear to be high on the community agendas, which justifies the capital investment in renewable energy sources to power the water supply systems that can be a cheaper option in the long run.

The involvement and commitment of the local government (Greater Giyani Municipality and Mopani District Municipality) is essential because these are the water service authorities in the area and the mandated water services providers. Along with the mandate, local government will also be the co-owner of the systems and be responsible for maintenance in the long run.

Based on the criteria for site selection, the consultative discussions with the community, the level of commitment displayed by local stakeholders and the purpose of the interventions, 9 pilot sites were proposed, namely 4 villages in dire need of water supply for domestic use and 5 small-scale farms: i) Mbhedle, ii) Mayephu, iii) Mzilela and iv) Matsotsosela villages, v) Nhlambeto farm in Dzumeri village (mixed water use), vi) farm with nursery structure in Dzumeri, vii) A hi tirheni Mqekwa farm, viii) Duvadzi farm and ix) Muyexe community project.

Each of these proposed pilot sites have different characteristics in terms of water requirements and the pressure head to be delivered by the pump depending on the geophysical settings. The technical design of solar-powered pumping systems was therefore refined for each proposed pilot site using the Pump Sizing Tool in the SPIS Toolbox. The following results were obtained:

- Water requirements depend largely on the size of the population to be supplied with water, ranging from 28.8 m^3/d for the pilot site in Mzilela to 58.9 m^3/d for Nhlambeto farm in Dzumeri (mixed water use).
- Nhlambeto farm is the only site using shallow groundwater from the river bed alluvium, so it has the lowest total dynamic head requirement of 20 m (Table 6.1). A hi tirheni Mqekwa farm requires the highest total dynamic head of 43 m.
- The peak power requirements ranged from 1.2-1.3 kWp at Mzilela with the lowest population size to 2.8-3.4 kWp at Matsotsosela with the highest population. This corresponds to a solar panel surface area requirement of 8.0-8.7 m^2 at Mzilela and 18.7-22.3 m^2 at Matsotsosela.
- The final design of the system can be refined at each pilot site during the implementation phase. This will depend on:
    - Equipment specification and availability on the market from suppliers and manufacturers
    - Specific borehole yields and other characteristics
    - Required pressure heads and water requirements
    - Pipeline layout, pipe diameter, installation and size of tanks
    - Installation of booster pumps to secure enough water pressure is delivered
    - Photovoltaic arrays arrangements, etc.

  However, the main outcomes and calculations done in the technical design for each piloting site (Chapter 6) are not expected to change dramatically in principle.

A large number of scenarios can be constructed for different cases: multiple use supply for irrigation and drinking water, different irrigated areas, crop rotations, population numbers, hydrogeological settings, groundwater yields and storage, configuration of solar panels, pump specifications, conveyance pipe layout and size, volume of storage tanks, financial inputs and results, etc. However, it is deemed that the examples provided in this report establish a good starting point and realistic results on the feasibility of implementation of solar-powered groundwater pumping systems.

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APPENDIX A

Table A1. Broad list of potential sites for implementation of Multiple Use Systems (MUS).

Name of the Village	Counsellor	Contact	Population	Tribal / Settlement	Ward	Current Source/ Infrastructure	Current water utilisation needs	Supply	Need
1. Mzilela	Calvin Mashimbye	060 447 6884	1150	Dzumeri	27	Borehole- Diesel, Municipality	Livelihood	When diesel is available	Water provision
2. Matsotsosela	Calvin Mashimbye	060 447 6884	2302	Dzumeri	27	Borehole- Diesel, Municipality	Livelihood	When diesel is available	Drilling of additional boreholes
3. Mayephu	Calvin Mashimbye	060 447 6884	1940	Dzumeri	27	Borehole- Diesel, Municipality	Livelihood	When diesel is available	Water Provision
4. Khaxani	Calvin Mashimbye	060 447 6884	2910	Dzumeri	27	Borehole- Diesel, Municipality	Livelihood	When diesel is available	Drilling of additional boreholes
5. Xitlakati	Calvin Mashimbye	060 447 6884	2060	Dzumeri	27		Livelihood		Earth dam
6. Mphagani	Malungani Elia	078 122 4980	5590	Dzumeri	28	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity	Earth dam and water reticulation
7. Nwamarhanga	Malungani Elia	078 122 4980	5677	Dzumeri	28		Livelihood		Booster pumps and upgrading of water plant
8. Homu 14 C	Mhlongo M. Calvin	078 348 6417	3000	Homu	12	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Drill boreholes for new residential sites.
9. Homu 14A	Khosa Masenyani A.	073 728 3887	4 059	Homu	9	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Water reticulation and reconnection of reservoirs
10. Homu 14B	Khosa Masenyani A.	073 728 3887	4 866	Homu	9	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Water reticulation and reconnection of reservoirs
11. Mapayeni	Mkhubele M. Jackson	072 308 6251	4 220	Homu	31	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Water/ Boreholes

Name of the Village	Counsellor	Contact	Population	Tribal / Settlement	Ward	Current Source/ Infrastructure	Current water utilisation needs	Supply	Need
12. Nwa Khuwani	Mkhubele M. Jackson	072 308 6251	1100	Homu	31	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Water/ Boreholes
13. Vuhehli	Mkhubele M. Jackson	072 308 6251	1890	Homu	31	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Water/ Boreholes
14. Hlomela	Gaveni Bridget	078 585 5562	1530	Thomo	19	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Refurbish boreholes which are not functioning
15. Ndindani	Gaveni Bridget	078 585 5562	1820	Thomo	19	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Refurbish boreholes which are not functioning
16. Mahlathi	Gaveni Bridget	078 585 5562	2681	Thomo	19	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Refurbish boreholes which are not functioning
17. Muyexe	Mashele Basani I.	073 468 9388	4100	Thomo	18	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Provide water for the village extension
18. Gawula	Mashele Basani I.	073 468 9388	2680	Thomo	18	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Repair the water tank which is leaking+J34
19. Khakhala	Mashele Basani I.	073 468 9388	2100	Thomo	18	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Provide boreholes to alleviate water shortages
20. Loloka	Maluleke Noel	073 442 5745	1420	Dzumeri	24	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Water reticulation

Name of the Village	Counsellor	Contact	Population	Tribal / Settlement	Ward	Current Source/ Infrastructure	Current water utilisation needs	Supply	Need
21. Mghonghoma	Maluleke Noel	073 442 5745	1260	Dzumeri	24	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Water reticulation
22. Guwela	Khosa Sally	083 588 7292	1530	Dzumeri	23	Borehole- Diesel, Municipality	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Water reticulation
24. Dzumeri	Mkansi Xigiya B.	083 539 8782	6970	Dzumeri	25	3 Borehole- Electricity	Livelihood	Does not cover all livelihood needs due to water quantity/ when diesel is available	Water reticulation
25. Mageva	Mkansi Xigiya B.	083 539 8782	6990	Dzumeri	25	2 Borehole-Diesel, Municipality	Livelihood	When diesel is available	Electrify borehole
26. Loloka	Maluleke Noel	073 442 5745	1420	Dzumeri	24	(Duvadzi farm) Sand bank/Borehole- Diesel, electricity	Irrigation	When diesel, electricity is available	Booster pumps and equipping borehole
27. Dzumeri	Mkansi Xigiya B.	083 539 8782	6970	Dzumeri	25	(Nhlambeto farm) Sand bank/Borehole- Diesel, electricity	Irrigation	When diesel, electricity is available	Booster pumps and equipping borehole
28. Makhwivirini	Mkansi Xigiya B.	84 539 8782	-	Dzumeri		(A hi tirheni Mqekwa farm) Borehole- Diesel, electricity	Irrigation	When diesel, electricity is available	Booster pumps and equipping borehole
29. Zava	Malungani Elia	0781224980	5677	Dzumeri	27	(Malabela Nyiko) Great Letaba River- Diesel	Irrigation	Diesel pump is having challenges	Electric connection and pump
30. Zava	Malungani Elia	0781224981	5677	Dzumeri	27	(Zava community garden) Great Letaba River- electricity	Irrigation	When electricity is available	Irrigation pipes
31. Xitlakati	Mashimbye Calven	0827106435	2060	Dzumeri	27	(Geremba Manzini) Great Letaba River- electricity	Irrigation	Irrigation pipes are leaking and losing a lot of water	Irrigation pipes
32. Xitlakati	Mashimbye Calven	0827106436	2060	Dzumeri	27	(Malatji Kenny G) Great Letaba River- electricity	Irrigation	When electricity is available	Electric bill, pump and irrigation pipes

Name of the Village	Counsellor	Contact	Population	Tribal / Settlement	Ward	Current Source/ Infrastructure	Current water utilisation needs	Supply	Need
33. Xitlakati	Mashimbye Calven	0827106437	2060	Dzumeri	27	(Tharaga Maria) Great Letaba River- Petrol	Irrigation	When petrol is available and requires electric connection	Electric connection, pump and irrigation pipes
34. Xitlakati	Mashimbye Calven	0827106438	2060	Dzumeri	27	(Mega) Great Letaba River- electricity	Irrigation	Irrigation pipes are blocked and need to be replaced	Irrigation pipes
36. Makhuva	Mabunda Khensani	0761023045	3602	Makhuva	29	(Noko Zandile) Great Letaba River- Diesel	Irrigation	Diesel pump always have some mechanical challenges and irrigation pipes are blocked	2 Pistol Lister pump and irrigation pipes
37. Mbaula	Mabunda Khensani	0761023046	2941	Makhuva	29	(Beauty Malatji) Great Letaba River- Petrol	Irrigation	Diesel pump always have some mechanical challenges and irrigation pipes are blocked	2 Pistol Lister pump and irrigation pipes
38. Mbaula	Mabunda Khensani	0761023047	2941	Makhuva	29	(Billy Mkansi) Great Letaba River- Petrol	Irrigation	Diesel pump always have some mechanical challenges and irrigation pipes are blocked	2 Pistol Lister pump and irrigation pipes
39. Mbaula	Mabunda Khensani	0761023048	2941	Makhuva	29	(Malesa Samuel) Great Letaba River- electricity	Irrigation	Electricity	Irrigation pipes
40. Mapuve	Shivuri Daison	0835518408	4061	Siyandhani	7	(MT Agric farm) Klein Letaba River- Diesel	Irrigation	Diesel pump always have some mechanical challenges and irrigation pipes are blocked	Diesel pump, irrigation pipes and water reservoir
41. Ngove	Rikhotso Risimati	08377289182	6376	Ngove	21	(Mike Mabunda) Klein Letaba River- Diesel	Irrigation		
42. Ngove	Rikhotso Risimati	08377289182	6376	Ngove	21	(Xaka ra vuswa farm) Klein Letaba River- Petrol	Irrigation	Diesel pump always have some mechanical challenges and irrigation pipes are blocked	2 Pistol Lister pump and irrigation pipes
43. Nkomo 22B	Baloyi Emmanuel	0731727193	6816	Mahumani	10	(Malungani farm) Klein Letaba River- Diesel	Irrigation	Diesel pump always have some mechanical challenges and irrigation pipes are blocked	Diesel pump, irrigation pipes

Name of the Village	Counsellor	Contact	Population	Tribal / Settlement	Ward	Current Source/ Infrastructure	Current water utilisation needs	Supply	Need
44. Nkomo 22B	Baloyi Emmanuel	0731727194	6816	Mahumani	10	(Muponisi Mathebula farm) Klein Letaba River- Diesel	Irrigation	Diesel pump always have some mechanical challenges and irrigation pipes are blocked	2 Pistol Lister pump, irrigation pipes and water reservoir
45. Vuhehli	Makhubela Masenyani	0723086551	1703	Homu	31	(Valoyi Madyela Henhla farm) Klein Letaba River- Petrol	Irrigation	The pump has mechanical challenges	Honda diesel pump
46. Nkomo 22B	Baloyi Emmanuel	0731727193	6816	Nkomo b	10	(Tiyisela Farm) Klein Letaba River- Diesel	Irrigation	Diesel pump machine has mechanical challenges and insufficient irrigation pipes	Diesel pump generator, pressure pump, irrigation pipes and water reservoir

APPENDIX B

Table A2. Community engagement program.

WATER RESEARCH COMMISSION

T S O G A N G

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TZANEEN 0850
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Fax: (015) 307 5299
Email: tsogang@pixie.co.za

Reg. No. 95-06600-08 VAT No. 4850152606

WATER RESEARCH COMMISSION VILLAGE VISIT SCHEDULE

Date	Time	Name of the Village	Councellor	Contact number
27.09.2021	10:00	Mphagani Zava	Malungani Elia	078 122 7980
27.09.2021	13:00	Khaxani Xitlakati	Mashimbye Calvin	067 728 8965
28.09.2021	09:00	Matsotsosela Mzilela Mayephu	Mashimbye Calvin	067 728 8965
28.09.2021	12:00	Loloka Mghonghoma Guwela	Maluleke Noel Khosa Sally	073 442 5745 083 588 7292
29.09.2021	09:00	Dzumeri Mageva	Mkansi Xigiya	083 536 8782
29.09.2021	13:00	Homu 14A Homu 14B Homu 14C Mapayeni N'wa Khuwani Vuhehli	Khosa Masenyani A. Mhlongo M.Calvin Mkhubele M.Jackson	073 728 3887 078 348 6417 072 308 6251
30.09.2021	09:00	Muyexe Gawula khakhala	Mashele Basani I.	073 468 9388
30.09.2021	12:00	Hlomela Ndindani Mahlathi	Gaveni Bridget	078 585 5562

TSOGANG MANAGING DIRECTOR:

KENNY PHASHA

082 809 1039

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