Check for updates

© 2019 The Authors
749

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

Review of sustainable solar powered water supply system design approach by Water Mission Malawi

B. Longwe*, M. Mganga and N. Sinyiza

Water Mission Malawi, Post Office Box 31871, Capital City, Lilongwe 3, Malawi

*Corresponding author. E-mail: blongwe@watermission.org

Abstract

Water Mission's extensive experience in designing, constructing and supporting solar-powered pumping solutions demonstrates the technological viability and cost effectiveness for delivering safe water to people, particularly in rural areas. Water Mission follows a unique design approach that uses conventional but relatively unique engineering specifications in terms of hydraulics, power requirement, water treatment and distribution, having tested them in different geographical environments. Water Mission incorporates a community-managed sustainability model into the design to ensure a longer life span for the project by promoting a well-defined maintenance and sustainability plan. This approach was applied to ten projects in 2015 in Kasungu, Lilongwe and Blantyre districts where installation, monitoring and evaluation were done and subjected to Water Mission's standards for qualification to hand them over to the beneficiary communities at the end of one year post installation. The paper is a review and discussion of the steps that Water Mission follows in its design process to come up with a sustainable project with solar energy. The paper also illustrates the non-compromise stand by Water Mission when it comes to the hand-over criteria for its projects by following and respecting the results of the prescribed evaluation test. It highlights detailed advantages and disadvantages of the design approach and presents recommendations. It is concluded that the approach can be replicated elsewhere in Malawi as a solution to water supply.

Key words: design, reliability, solar power, sustainability, water mission

INTRODUCTION

Water Mission (WM) is a non-profit Christian engineering organization providing sustainable safe water and sanitation solutions, headquartered in Charleston, South Carolina, United States of America. Among the country offices is Malawi, with a headquarters in Lilongwe established in 2009. Its work focusses on community-managed safe water projects through solar power. Community management is where, after project completion, responsibility for management and ownership is granted to the community. The underlying principles of community management are that the community feels the ownership for the system and therefore, is willing to pay for water services, learn to manage the system themselves and is able to cover the costs of its Operation and Maintenance (O & M) (Moriarty *et al.* 2013).

In 2015, the organization constructed and installed ten UNICEF-funded solar powered water supply projects in Blantyre, Kasungu and Lilongwe Districts in Malawi. WM believes in sustainability of the projects being installed as such; there is so much emphasis on engagement of communities to participate in the entire installation process and build a sense of ownership. The

This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (http://creativecommons.org/licenses/by/4.0/).

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

model builds on the engineering principles and incorporates a social, technical and financial sustainability plan by involving and training communities to prepare in advance for how they will carry on with the project once it is handed over to them.. As cited by Mwangi & Daniel (2012), the sustainability of a water supply scheme can be argued to be the maintenance of an acceptable level of services throughout the design life of the water supply system after the project has been transitioned to the community.

Groundwater constitutes the largest readily available freshwater reserve on earth. It plays an essential role in the domestic water supply system for small towns and rural regions, where it represents a relatively clean, reliable and cost-effective resource (Bovolo *et al.* 2009). Access to the water requires pumping using various technologies, fossil, electricity, wind and solar power being among the most common. Among these, solar-based technologies have been found to be in the best interest of the communities considering their environmental friendliness, cost effectiveness, efficiency and sustainability.

There is generally limited access to safe water in Malawi as communities are mostly dependent on surface water and boreholes fitted with hand pumps. According to Boulenouar *et al.* (2018), boreholes fitted with hand pumps are the main technology that is used in rural areas of Malawi to supply water, even though some areas have piped gravity-fed schemes as well as shallow wells. In 2014, rural water coverage was estimated to be at 84%, yet the functionality rate was around 77% as of 2016 (Boulenouar *et al.* 2018).

When development actors leave, it is ultimately the responsibility of local permanent stakeholders to ensure that services continue. However, in the context of the least developed countries like Malawi, there are often major financial and human capacity barriers to the institutional sustainability of these services that are not obvious at first. The cost of developing 41 boreholes is so high, such that one borehole serves a limited number of people who reside around the point. This calls for many holes to be drilled to reach out to a larger population in the community. Anecdotal evidence and studies by national governments, donor organizations and implementing bodies to determine if investment in water supply systems has produced the intended benefits indicate that around 35% of improved water sources are non-functional at any one time (Lockwood & Mansour 2017).

UNICEF (1999) estimates indicate that some three hours per household per day are being lost to water hauling by those rural households in Africa that do not have access to a minimum level of service such as a hand-dug well or a hand pump-equipped borehole. Some 258 million people lack access to improved water in rural areas of Africa today; these people comprise about 37 million households. At three hours per day, 365 days a year, 40,515 million (40 billion) hours are lost annually to this necessary but unproductive chore, largely undertaken by women and girls. This time could otherwise be used for activities such as childcare, education and agricultural production.

There are a number of potential benefits to improved access to water supply, in addition to the reduction of disease. The reasons that many communities give for placing a high priority on improved water supply usually relate to benefits other than health. These benefits are of particular importance to women. A closer, cleaner source of water can produce immediate and far-reaching improvements in women's lives such as convenience, time and energy saving, prevention of injuries as a result of walking short distances and can be an entry point for development for improved livelihoods in communities. In the absence of safe water therefore, these cannot be achieved.

Millions of people around the world live with limited access to water. In many communities, ground water is extracted through electric water pumps, which use diesel to fuel their systems. However, these systems not only require costly, regular servicing and the purchasing of fuel, they emit carbon dioxide, polluting the atmosphere. Sustainability is best defined pragmatically as 'whether or not something continues to work over time (Abrams 1998). He further explained that at one level

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

sustainability is very simple. It is whether or not something continues to work. For a water service, this would mean that water continues to be available for the period for which it was designed in the same quantity and at the same quality for which it was designed.

Abrams (1998) holds that if a person can turn the tap in 15 or 20 years' time and the water comes out at the same rate and quality as the day the scheme was commissioned, then it is a sustainable supply (provided, of course, that at some time the scheme had not become derelict and had to be completely rehabilitated). If the water flows in the system as per design, then all of the many elements that are required for sustainability must have been in place. There must have been money for recurring expenses and for the occasional repair, there must have been acceptance from the consumers of the service, the source supplying the service must have been adequate, the design must have been properly done and there must have been sound construction. Solar Water Pumping, or photovoltaic water pumping (PVP), provides an alternative. After years of research and technological advances, it has proven to be operationally, financially, and environmentally sustainable. In recent years, the cost of solar technology has dropped tremendously. Prices for the solar panels used in these systems have dropped up to 80%. In addition, these panels last around 25 years, requiring little maintenance throughout this time.

These factors have made Solar Water Pumping an extremely viable way to expand energy access across developing countries and communities, while creating a strong resistance to shifts in rainfall caused by climate change or unreliable seasonable patterns. Some governments have opted to subsidize the cost of solar pumping, increasing the pool of shared learning for this emerging technology. Even though solar water pumping is ready for mainstreaming and has started to take off in some parts of the world, its benefits remain largely unknown to communities, governments, and development institutions. This paper highlights the process that WM follows to design a sustainable project powered by solar and managed by the beneficiary communities.

MAIN OBJECTIVE

The main objective of this write up was to review the design approach of the solar powered sustainable water supply systems under WM.

Specific objectives

Subsequently, the paper intends to achieve the following specific objectives:

a. To highlight the steps that WM follows to design a solar powered water supply system
b. To explain the practical process of installing a solar-powered community-managed safe water system
c. To illustrate the community-managed sustainability model developed and applied by WM in managing solar powered water supply projects.

METHODOLOGY

Ten projects were selected from a pool of WM's implemented projects to be reviewed against the systematic procedure for designing, installing and sustaining a community project model. The selected projects were all installed and commissioned in 2015 (Table 1) as follows.

The design procedure used by WM was applied across all the projects and the same installation processes were followed. Systematic and tested WM trainings were administered in all communities to build plans for sustainability.

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

Table 1 | Installed projects and their locations in Blantyre, Lilongwe and Kasungu Districts

Name of project	Serviced population	GPS location	Traditional authority	District
Namaela	5,348	15°54′27.9″S 34°54′27.9″E	Somba	Blantyre
Chikavumbwa	5,217	15°34′57.7″S 35°02′23.6″E	Kapeni	Blantyre
Andiseni	10,524	15°40′39.2″S 34°54′41.0″E	Kunthembwe	Blantyre
Muonekera	4,275	15°24′44.4″S 34°56′38.4″E	Chigalu	Blantyre
Dicksoni	2,604	14°14′58.0″S 33°39′41.0″E	Masula	Lilongwe
Ukwe	3,782	13°49′34.6″S 33°36′07.9″E	Kabudula	Lilongwe
Chimbayo	2,840	13°50′30.7″S 33°32′07.3″E	Kabudula	Lilongwe
Kalumbu	2,613	14°08′22.7″S 33°56′49.9″E	Kalumbu	Lilongwe
Mangwazu	1,827	13°00′02.69″S 33°22′46.9″E	Kaphaizi	Kasungu
Chamatete	3,285	13°10′48.3″S 33°21′58.4″E	Kawamba	Kasungu

Technical design procedure

The WM's technical design started with the estimation of population coming from the site assessment data. The data was used to establish the water demand for the community based on the per capita needs, as in Table 2 below.

Table 2 | Basic water requirements used for the designs

Survival needs: water intake (drinking and food)	2.5–3 litres per day	Depends on the climate and individual physiology
Basic hygiene practices	2–6 litres per day	Depends on social and cultural norms
Basic cooking needs	3–6 litres per day	Depends on food type and social and cultural norms
Total basic water needs	7.5–15 litres per day	

Source: The Sphere Project: Humanitarian Charter and Minimum Standards in Humanitarian Response, 2011 Edition.

Based on the estimated demand, an analysis of possible water sources in the catchment area was done to validate the water availability and its quality. Water demand estimation factors were in the aspect of population growth, possible penetration (anticipated number of people to use the safe water in the community out of the total population). The design also considers the possible layout that could cover the population with respect to walking distances and patronage for sustainability. In this regard, tap points are identified on the Google Earth maps using the hand-held Global Positioning System (GPS) coordinates collected during the assessment.

The next step in the process was to determine the storage needs for the system. A traditional WM system storage capacity uses a 10 000 litre tank. This was determined by weighing the demand needs, system water production capacity and expected level of consumption to ensure that at any point the people needed water, they had it in supply. The storage also ensured that the system has some water for the night but also by day-break as the solar picks up.

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

Hydraulic design used EPANET software to determine the supply (from water source to tank) and distribution systems (from tank to tap). It took into account pipe diameters in reference to the elevations and lengths on the Google Earth maps using the Hazen-Williams formula to estimate frictional losses. WM used a minimum pressure of 3 m at the tap points and a water demand of 20 litres per minute. The supply side had a water source which, in the context of this review, was a borehole, drilled deep enough and with a 24-hour yield test conducted. The results of the yield test brought up borehole parameters, namely the static and dynamic water levels. The pump was set 3 m below the dynamic water level for easy cooling and optimal operation.

Water quality was analysed once a borehole had been drilled to determine the need and type of treatment that would be required to produce safe water. The results were compared against the World Health Organization (WHO) standards, the Malawi Bureau of Standards and the WM determined standards to ensure that the best quality of service was attained. The water treatment was done by a WM portable chlorinator (Figure 1). The water treatment gadget was factored into the EPANET analysis to ensure that the power calculations take care of its frictional losses by assigning to it the right pump and accessories design curves. In this review, the projects were installed with Grundfos 11 SQF-2 models which have a high head and low discharge and also Grundfos 16 SQF-10 with a lower head and high volume of discharge.

Figure 1 | Basic Water Mission portable chlorinator.

Regarding the power requirement, WM ensured the best quality panels were used for installations. The projects under review were fitted with the Solar World brand of panels. The power calculations in the WM design used a system factor of safety of 1.6 and this was compounded as the system was assumed to run on a 6.5 peak solar hours radiation. Once the design was in place, a bill of quantities was developed with all costed elements including the labour required and the software that assisted in ensuring the system was sustainable, called 'Financial Sustainability Worksheet' in WM's language.

Installation process

The installation process began with the development of the water sources, in which case boreholes were drilled by a subcontracted service provider but entirely supervised by WM staff from survey point to final report production to ensure best quality. A 24-hour yield test was conducted to give surety that a system that runs for 6.5 hours in the daytime could be sustained by such a source. The solar panels were installed facing true north using a compass and verified by a GPS considering

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

the sun's movement being from East to West. WM used its own trained technicians with specialization in plumbing, solar installation and welding.

The installation team was led and supervised by Engineers to put the design on the ground. In the interest of sustainability, the community was involved with mobilization of locally found building materials for the project installations and the provision of a labour force for trenching the pipe routes. Participation is also aimed at increasing the sense of ownership over the water supply within community members. A history of top-down service delivery by governments and NGOs frequently leaves a legacy of dependency in the villages on external assistance. Consequently, in the event of failure in the water supply, the villagers do not make any attempt at repairs as it is not perceived to be their responsibility (Hysome 2006).

The pipes were laid at a depth of 1 m below ground to pave the way for ground surface activities such as farming to continue alongside the project. WM made an agreement with the community that they will commit land to the project at no cost to enhance the spirit of ownership. The community was requested to nominate three people to work alongside WM's technicians as part of hands on training. Amongst these trainees, two who performed best were selected to become system operators as qualified by an examining Technician. Satellite water meters were installed in all the systems to monitor production from the boreholes remotely while every tap stand was fitted with a mechanical meter to monitor consumption, which could also be used for accountability for the volumes of water sold versus the money collected by designated tap operators. To ensure quality control, the Engineers supervised the entire installation process until water was in the taps with best quality levels.

PROJECT SUSTAINABILITY

The beneficiary communities were taken through a series of trainings to build capacity management of the systems in terms of administration, operation, maintenance and accountability to the general assembly. A Safe Water Committee (SWC) was elected in the projects, which was a focal point for the trainings. To ensure that the interventions were reinforced, WM's Community Development Department carried out the following trainings:

SWC training

Formalized training programs were put in place in order to build the capacity for administration as well as technical operation and maintenance of the system. The committee was trained in administrative and financial reporting, financial management, leadership skills and constitutional development and application. Technically, emphasis was put on training on the system and tap operators on how to troubleshoot and come up with simple maintenance procedure. A financial sustainability plan was drafted jointly with the committee regarding management of funds and alternative income-generating activities for the projects.

Water pricing

The Community Development Officers engaged the project communities to determine the sustainable price for the water while making it accessible and affordable to all. This process took into account the project investment in terms of physical infrastructure and their rate of depreciation. The training centred on ensuring that a project must meet the present operations and be able to make savings for the future maintenance or replacement costs. To ensure that this was done, WM developed a Financial Sustainability Worksheet using the data generated from the assessment report: households, population, monthly household income, anticipated household penetration and inflation rate.

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

The operational costs were determined by listing the needs required on a daily or monthly basis to run the project and create an estimated budget, while replacement costs looked at the (capital investment + inflation rate)/life span) of each equipment. The significance of this tool was to summarize the anticipated operational costs, replacement costs, recommended maximum water price and the breakeven water price.

Monitoring and evaluation

The WM model has a monitoring and evaluation tool, which was applied to these projects to determine whether they had qualified for transitioning, needed more training or monitoring. The monitoring looked at the projects at three levels, namely management capacity, relational awareness and overall success standards. The follow up, monitoring and support was done for one year before a final decision was made to transition them for management to the communities or not.

Management capacity index

This indicator was designed and effected with the intention of providing a collective measurement of all management personnel's perceived capacity to oversee and/or respond to financial, technical, and social elements that are critical to ongoing safe water service delivery. The management capacity was evaluated three times at least once a quarter, during follow-up visits. Data collection involved focus group discussion during which management personnel collectively determined the extent to which they have or do not have capacity as well as whether or not they rely on external support. Responses were analysed by the Community Development Officers and all capacity areas were equally weighted and contribute to an overall percentage-based index score.

Relational awareness index

This indicator was designed and applied to provide a collective measurement of the perceptions that people within the service area hold regarding transformational opportunities and practices in water, sanitation and hygiene. Such awareness was evaluated at least once a quarter, during follow-up visits. Data collection involved focus group discussion with community leaders (management personnel, institutional and local government representatives, church leaders and elders) during which participants collectively determined the extent to which their community was or was not aware of different opportunities and practices as well as whether or not they believed it was possible to increase awareness. Responses were analysed and equally weighted and contributed to an overall percentage-based index score.

Safe water project support evaluation

Evaluation was done and compared to the pre-designed success standards, which go along with the follow ups of projects. The success standards were put in place and relayed to the project committees at the onset of the projects in order to make them aware that they could be evaluated against them as a measure of success. The standards comprised four components, as follows:

i. **The Accessibility Standard** ensured that all people in the service area had access to water and sanitation services that had proven capable of meeting their stated needs daily. Also considered were water quantity, distance, affordability, end user satisfaction and overall reliability for safe water supply.
ii. **The Safety Standard** ensured that water and sanitation solutions were capable of providing a level of service that did not pose a significant risk to human health over a lifetime of consumption or

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

use. In terms of water quality, turbidity, residual chlorine and microbiological properties of water were considered.

iii. **The Sustainability Standard** covered three dimensions of sustainability: management capacity, financial sustainability and relational awareness. The sustainability standard ensured that the management structure had proven capability of functioning for an indefinite period of time. Specific indicators which were considered included management capacity indices, operational cost, replacement cost recovery and banking compliance.

RESULTS AND DISCUSSION

Technical output

Ten projects were designed and installed with respect to the methodology and approach highlighted above. All the projects had a borehole drilled as a water source and fitted with Grundfos 11SQF-2 submersible pumps except Chikavumbwa, which had a 16SQF-10 pump. The pumps were all powered by 235 watt rated solar panels according to the electrical design. For treatment, all systems were installed with WM portable chlorinators. Table 3 below summarizes the system details:

Table 3 | Project specific technical installations and results

Name of project	Number of solar panels	System power requirement (Watt)	Total power provision (Watt)	Number of tap points	Average daily water production (litres)
Chamatete	6	880	1,410	5	12,500
Mangwazu	4	588	940	6	15,000
Chimbayo	8	1,175	1,880	6	20,000
Dickson	6	880	1,410	7	14,820
Ukwe	4	588	940	7	16,300
Kalumbu	6	880	1,410	10	18,330
Muonekera	6	880	1,410	6	14,820
Namaela	5	735	1,175	5	14,820
Andiseni	4	588	940	7	17,160
Chikavumbwa	8	1,175	1,880	11	20,000

Silderberg (2003) stated that contamination of water bodies has increasingly become an issue of serious environmental concern. Clean water is a priceless and limited resource that man has begun to treasure only recently after decades of pollution and waste. Potable water is an essential ingredient for good health and the socio-economic development of man (Udom *et al.* 2002), but it is lacking in many societies. This was substantiated by Singh & Mosley 2003, who argued that all natural waters contain many dissolved substances. Contaminants such as bacteria, viruses, heavy metals, nitrates and salt have polluted water supplies as a result of inadequate treatment and disposal of waste from humans and livestock, industrial discharges, and over-use of limited water resources.

The major sources of pollution in streams, rivers and underground water arises from anthropogenic activities largely caused by the poor and uncultured living habits of people as well as the unhealthy practices of factories, industries and corporate bodies, resulting in the discharge of effluents and untreated wastes. Ground water pollution could be avoided when borehole wells are located far

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

from any source of potential pollution. Good well design is also important in the prevention of underground water pollution. During the construction process of a borehole, drilling fluids, chemical casings and other materials may find their way into the well thereby polluting the water. An open hole during the construction stage can also be a direct route for contaminants from the surface to the aquifer, thereby providing an ideal opportunity for chemical and bacteriological pollution to occur. Lasting damage can be avoided if the well is completed, disinfected and piped within a short space of time. The possibility of contamination increases if there is a lengthy delay in completing the well (Akpoveta *et al.* 2011).

In the interest of water safety for the consumer, quality was therefore monitored and tested for each borehole in the project and were found to have bacteria contamination, but after treatment the tests produced clean samples as in Figure 2.

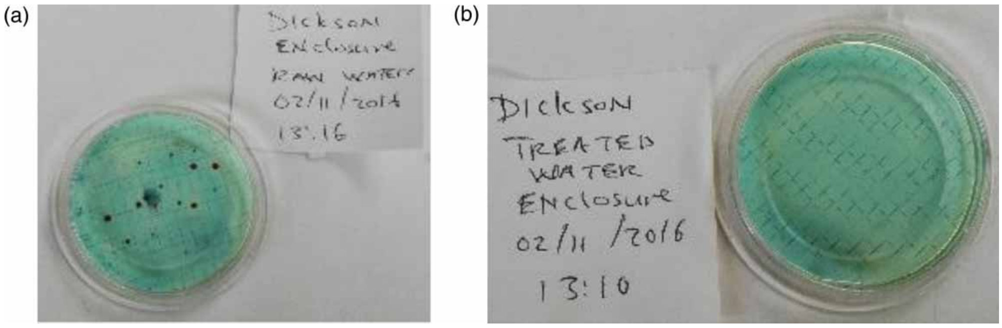

Figure 2 | Water samples before and after treatment for Dickson project. Sample (a): Untreated water. Sample (b): Treated water.

Each project was installed with an enclosure, which served three main purposes, namely water treatment, power unit on the roof top and water production monitoring using a satellite water meter. Figure 3 below is a sample of an enclosure constructed at Andiseni project in Blantyre as a standard treatment house constructed in the projects under review while Figure 4 shows a satellite water meter communicator (transmitter) being installed on the roof top and a Solar Control Unit (CU200 model) as installed in the enclosure.

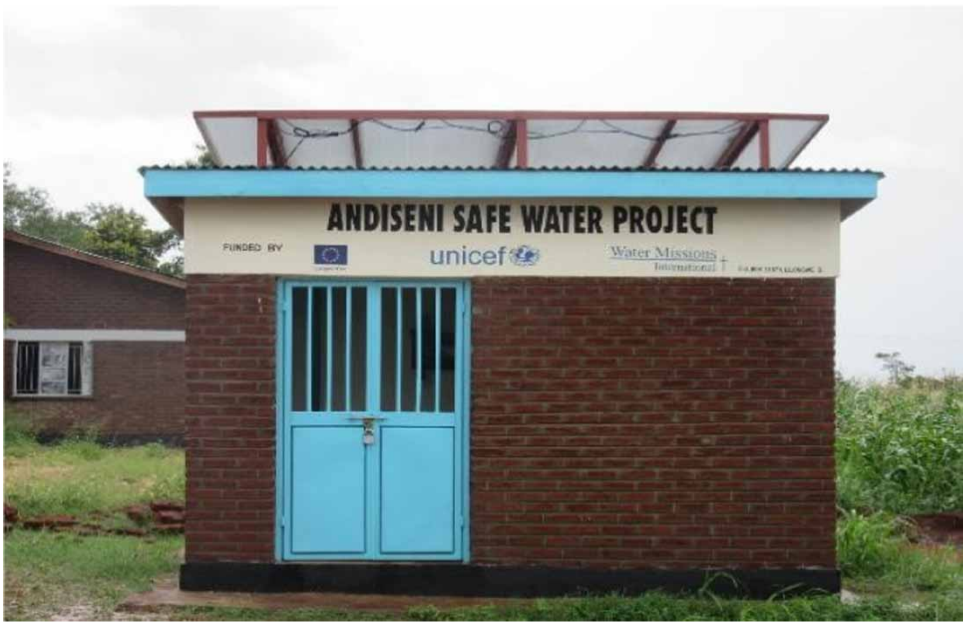

Figure 3 | A sample of a treatment and solar power house at Andiseni in Blantyre.

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

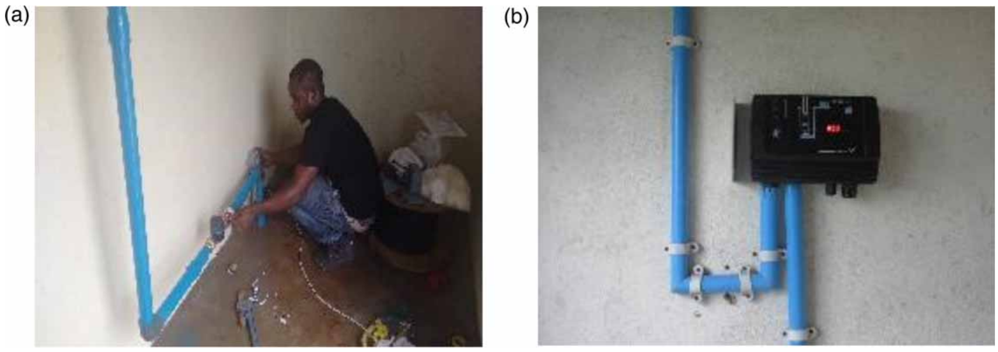

Figure 4 | (a) Satellite water meter and communicator installation (b) CU200 as installed in the enclosure.

Financial performance

The projects were also subjected to financial performance analysis to find the best working figures for buying the water at tap points. This data was fed into the sustainability analysis in order to qualify the projects as being self-reliant financially or not in the medium and long term. The following results in Table 4 were obtained.

Table 4 | Water price paid by the community member in each project as a contribution towards sustainability

Name of project	Working price on the ground (Kwacha per 20 litre container)
Chamatete	20
Mangwazu	15
Chimbayo	15
Dickson	10
Ukwe	10
Kalumbu	10
Muonekera	10
Namaela	10
Andiseni	10
Chikabvumbwa	10

The financial performance was also analysed on the basis of income, expenditure and savings for each project. Income in this case entails the total amount of money raised from the time the project started making sales to the time the financial analysis was done. Expenditure on the other hand is the total amount of money used within a project from the revenue collected, while savings entails the total amount of money a project had in the bank account at the time the financial analysis was conducted. Table 5 below presents the financial status of the projects just before the final evaluation for a possible handover to the communities, while Table 6 summarises the evaluation criteria that Water Mission uses to decide on the fate of projects for hand over consideration.

After full evaluation, the following were the results with respect to transitioning for sustainability as given in Table 7. Table 7 give a detailed explanation of what the evaluation matrix in Table 6 entails. A project is set to be transitioned if it has attained excellent or good status during evaluation. WM staff are tasked to examine data from given projects (for a period of 3 months) through reports given and general observations. There are specific parameters that apply across all the projects and in the final analysis a grade is given that determine whether a project should be transitioned or not. As stated

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

Table 5 | Financial status (in Malawi Kwacha) of the projects just before handover evaluation

NAME OF PROJECT	INCOME	EXPENDITURE	SAVINGS
Chamatete	778,835.00	484,179.00	371,078.00
Mangwazu	752,665.00	533,247.00	251,040.00
Chimbayo	591,580.00	262,524.00	304,931.00
Dickson	1,184,738.00	536,643.00	658,830.00
Ukwe	1,498,753.00	969,013.00	512,821.00
Kalumbu	797,894.00	638,300.00	196,704.00
Muonekera	888,849.00	641,145.00	250,000.00
Namaela	690,790.00	438,930.00	254,672.00
Andiseni	589,670.00	452,481.00	148,350.00
Chikavumbwa	737,114.00	559,239.00	223,006.00

earlier; Table 7 outlines projects that were transitioned and those that were put on hold for failure to meet the standards required.

The installation process went very well in all the projects and the community responded so well by offering their support in terms of labour and construction materials that were locally found, such as quarry stone, sand and bricks. Ten systems were installed and commissioned with funding from UNICEF and Water Mission. Solar powered boreholes were found to be a reliable source of water in the rural community as they helped to calculate or determine distances for electrical cabling, piping and siting of treatment, storage structures and consequently the tap points to solve the accessibility issue. The position of the boreholes was also important as this determined the level of risk associated with the safety of the pump against theft.

A direct connection between the PV panel and the motor (without inverter and batteries) reduces the efficiency of the overall system but increases its reliability. In many places, the reliability of the safe water source can be a key health issue as it exposes consumers to searching for alternative water sources, which most of the time tend to be unprotected (Short & Thompson 2003).

The WM models adopt this approach and instead of keeping power in batteries, the designs maximize pumping during the day and keep the water in the tanks instead. The batteries have been found to be expensive on the market and as such would end up increasing the cost for sustainability; that is not the case with the tanks, hence their adoption. The engineering design process has traditionally been linked with trade-offs, such as between price and functionality, safety and aesthetics, life span and maintenance. In recent years, however, a further constraint has been introduced – that of 'sustainability' or 'sustainable development' (Luttropp & Lagerstedt 1999).

Training was conducted at all the sites to build enough capacity for the communities to run the projects by themselves after a period of one year. The evaluation that was conducted and analysed was weighed in terms of three major parameters, namely reliability, the safety of the water, and sustainability. It has been suggested that 'beneficiary participation is the single most important factor contributing to project effectiveness' (Narayan 1994). Without participation, it has been claimed that systems are unlikely to be sustainable even if spare parts and repair technicians are available. Participation can take different forms, including the initial expression of the demand for water, the selection of technology and its siting, the provision of labour and local materials, a cash contribution to the project costs, the selection of the management type and even the water tariff (Harvey & Reed 2007). It is thus the process through which demand-responsiveness is exercised, and empowerment achieved.

All projects qualified on reliability and safety standards as a basis for handover except Muonekera. This took into consideration reliability of the system with regards to water availability

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

Table 6 | Summarised evaluation matrix used by water mission to recommend projects for transitioning to communities

Project name	Commission date	Transition date	Months active	Reliability	Overall accessibility	Microbiological quality	Turbidity	Chlorine residual	Overall safety	Management capacity	Relational awareness	Operational cost recovery	Replacement cost recovery	Banking compliance	Overall sustainability	Overall performance
Chamatete	27/01/2016	26/12/2016	15	E	G	E	E	G	G	G	G	E	P	E	G	G
Mangwazu	26/01/2016	25/12/2016	15	E	G	E	E	E	E	A	G	P	P	P	A	A
Chimbayo	19/02/2016	18/02/2017	15	E	G	E	E	E	E	A	A	G	P	G	A	A
Dickson	13/01/2016	12/02/2017	15	E	E	E	E	E	E	E	A	E	E	E	E	E
Ukwe	19/01/2016	18/01/2017	15	E	E	E	E	E	E	E	E	E	G	E	E	E
Kalumbu	16/02/2016	15/02/2017	14	E	G	E	E	E	E	A	A	A	A	A	A	A
Muonekera	02/12/2015	01/12/2017	17	A	G	E	G	G	G	E	G	G	A	A	G	A
Namaela	13/07/2015	12/07/2016	23	E	G	E	G	A	G	G	G	E	A	E	G	G
Andiseni	14/02/2015	13/02/2016	28	E	G	E	E	A	G	E	G	E	A	E	E	G
Chikabvumbwa	30/11/2017	29/11/2016	19	E	G	E	E	G	E	E	G	E	A	E	E	G

Note: E = Excellent; G = Good; P = Poor; A = Average.

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

Table 7 | Final evaluation results of the projects based on sustainability test

Name of project	Status	Reasons	Remarks
Chamatete	Transitioned	Met all conditions for sustainability	No issues both technically and socially since transitioned
Mangwazu	Pending	Failed on sustainability grounds	Retraining of the communities' capacity to manage
Chimbayo	Pending	Failed on sustainability grounds	Retraining of the communities' capacity to manage
Dickson	Transitioned	Met all conditions for sustainability	No issues both technically and socially since transitioned
Ukwe	Transitioned	Met all conditions for sustainability	No issues both technically and socially since transitioned
Kalumbu	Pending	Failed on sustainability grounds	Retraining of the communities' capacity to manage
Muonekera	Pending	Failed on reliability grounds	WM mobilizing resources for new water source
Namaela	Transitioned	Met all conditions for sustainability	No issues both technically and socially since transitioned
Andiseni	Transitioned	Met all conditions for sustainability	No issues both technically and socially since transitioned
Chikavumbwa	Transitioned	Met all conditions for sustainability	No issues both technically and socially since transitioned

at any time people wanted to have it; the capacity of the communities to manage water quality analysis in regard to biological, physical and chemical safety measures by themselves. Water provided to the communities should be water that does not pose a threat to human health when consumed; these projects had understood about the procedure for water quality monitoring as taught by WM's staff and reported accordingly for approval. The Muonekera project did meet the overall sustainability threshold following its borehole not providing sufficient water for the population, even though financially the community were able to buy the water for sustainability. The project was therefore not handed over pending WM re development of a reliable water source.

Kalumbu, Dickson and Chimbayo projects failed to meet the overall sustainability test on the basis of under performance on the financial management capacity but also the ability to operate and maintain the system. WM approach to solar powered water supply projects does not compromise on the standards and evaluation criteria set. The organization values the cost of investment and is not prepared to put in to the worst, so much so that all the projects that have failed the sustainability test have been put back to the monitoring phase for another six months to redress the issues that were identified, such as helping the communities that failed on finance generation to consider new income generation ideas in order to pass the next evaluation. The approach taken by WM proved that out of the ten targeted projects, only four failed to make it for transitioning under the criteria and they are being followed up to address the bottlenecks.

The experience that WM has had in the design, installation and community capacity building in sustainability gave lessons that need to be shared further as follows through further research to quantify solar powered systems in Malawi that have been implemented by various stakeholders and their state of sustainability and the factors that have contributed to their success, if any, and to failure. It should also be put to implementing agents who could be interested in adopting the WM model for sustainability to come forward and share their experience so that a common ground for sustainability could be established. It should be noted that installation of solar powered water supply systems for rural communities should not just be a technical issue but blend with social and financial aspects in the interest of sustainability. Finally, a solar powered system should satisfy reliability, safety, financial and sustainability requirements before being handed over to communities if it's to remain beneficial.

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

CONCLUSION

A systematic step by step design approach of solar powered safe water supply projects by WM has been illustrated with respect to technical, financial and sustainability elements to the effect that following the evaluation criteria, no compromise should be taken to hand over the project to the communities as doing so would drain away all the gains made by the project. The non-compromise approach assists in delivering best service to the rural communities as their project is reliable, safe and sustainable.

The sustainability approach used by water mission recognizes that water supply systems do not just survive as a result of best technical installation but counts on how strong communities are with respect to managerial, financial and technical capacity combined into one strategy. The WM's approach reaffirms that renewable energy is a solution for water generation and supply and there is room for sustainability if communities are well trained and monitored before a project is handed over to them.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the following people for the various roles they played in the development of these projects and the writing of this paper.

- Wongani Msiska – Community Development Coordinator
- Charity Mithi – Community Development Officer
- Charles Ryan Njikho and Ernest Chilalika – Project Engineers
- Plumbing and Welding Technicians for Water Mission Malawi
- Evelyn Itimu and all Administrative staff
- The project beneficiary communities
- UNICEF Malawi for provision of funding for the projects
- Water Mission staff at headquarters in Charleston, USA for funding and technical support

REFERENCES

Abrams, L. 1998 *Understanding Sustainability of Local Water Services*. http://www.africanwater.org/sustainability.htm (accessed 10th August 2019).

Akpoveta, O. V., Okoh, B. E. & Osakwe, S. A. 2011 Quality assessment of borehole water used in the vicinities of Benin, edo state and agbor. *Delta State of Nigeria. Current Research in Chemistry* **3**, 62–69.

Boulenouar, J., Byrns, S. & Hughes, G. 2018 Supporting institutional sustainability to deliver permanent WASH services in Malawi [Internet]. (accessed 5 August 2019).

Bovolo, I., Parkin, G. & Sophocleous, M. 2009 Groundwater resources, climate and vulnerability. *Environmental Research Letters* **4**(3), 1–4.

Harvey, P. A. & Reed, R. A. 2007 Community-managed water supplies in Africa: sustainable or dispensable. *Community Development Journal* **42**(3), 365–378.

Hysome, A. 2006 *A Study of the Factors Affecting Sustainability of Rural Water Supplies in Tanzania*. Cranfield University, Silsoe Institute of Water And The Environment, Oxford, UK.

Lockwood, H. & Mansour, G. 2017 Global Study on Sustainable Service Delivery Models for Rural Water: evidence from 16 countries. In: *40th WEDC International Conference*, Loughborough, UK.

Luttropp, C. & Lagerstedt, J. 1999 Customer Benefits in the Context of Life Cycle Design. In: *Eco Design´99:1st Int. Symposium on Environmentally Conscious Design and Inverse Manufacturing*, Tokyo, Japan.

Moriarty, P., Smits, S., Butterworth, J. & Franceys, R. 2013 Trends in rural water supply: towards a service delivery approach. *Water Alternatives* **6**(3), 329–349.

Mwangi, K. F. & Daniel, W. 2012 *Assessment of Factors Affecting Sustainability of Rural Water Supply Schemes in Nyandarua County, Kenya: A Case of Kangui Water Scheme*. International Journal of Science and Research (IJSR).

Narayan, D. 1994 *Contribution of People's Participation: Evidence From 121 Rural Water Supply Projects*. Environmentally sustainable development occasional paper series, No 1. World Bank, Washington, DC.

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest

Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.079

Short, T. D. & Thompson, P. 2003 Breaking the mould: solar water pumping – the challenges and the 30 reality. *Solar Energy* **75**(1), 1–9.

Silderberg, M. S. 2003 *Higher Education Chemistry. The Molecular Nature of Matter and Change*. Mc Graw Hill.

Singh, S. & Mosley, L. M. 2003 Trace metal levels in drinking water on Viti Levu, Fiji Islands. *South Pacific Journal of Natural Science* **21**, 31–34.

Udom, G. J., Ushie, F. A. & Esu, E. O. 2002 A geochemical survey of groundwater in Khana and Gokana local government area of Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management* **6**, 53–59.

UNICEF 1999 *Water Environment and Sanitation Technical Guidelines*. Towards better programming, a handbook ID No. PD/WES/99/1, New York.

Downloaded from http://iwaponline.com/wpt/article-pdf/14/4/749/759940/wpt0140749.pdf
by guest