

The feasibility of Solar Water-Pumping in a Rural Village of Malawi

Authors: Esther Phiri^{1,2}; Paul Rowley¹; Richard Blanchard¹

¹ Center for Renewable Energy Systems Technology (CREST), Loughborough University
Loughborough, United Kingdom

² Corresponding author: e.phiri@lboro.ac.uk or ephiri@poly.ac.mw

Abstract

Though Malawi has achieved and exceeded the Millennium Development Goals (MDGs) water target, over half of the people in the rural areas collect water from boreholes or rivers. In spite of boreholes qualifying as improved water sources, studies show that the drinking water from these sources was contaminated and likely to cause disease. Other potable water problems include long distance to collect water and gender disparity in that the majority who collect water are women. As for hand-pumps, they are manually straining and most of them break and are not repaired sometimes even for minor faults; which makes the people resort to collect water from their previous contaminated water sources. Electric-powered pumps can play a significant role in the provision of potable water either by increasing the depth of well or by purifying water obtained from shallow wells or rivers. With no grid electricity in most of the rural areas, vulnerability to oil prices, depletion of fossil fuels, and high maintenance cost of diesel systems; Renewable Energy Technologies provide a viable option. A techno-economic feasibility study was carried out for a case study village: Nlukla Village, Chiradzulu District in Malawi. Results show that with the favourable sunlight conditions a solar water pumping system is a viable option for the area. The study is ongoing and future studies include working towards addressing the issue of high initial costs and how to make the system sustainable.

Keywords: Potable Water, Solar Water-pumping, Malawi, Techno-economic Analysis, Renewable Energy

1 Introduction

In 2000 the United Nations put forward eight goals called the Millennium Development Goals (MDGs) to be achieved by 2015. Target 10 of goal 7 of the MDGs was to halve by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation. Though the global MDG drinking water target was met five years ahead of the target date, 768 million people still drew water from an unimproved source in 2011 and 636 million of these lived in rural areas [1]. Malawi also achieved and exceeded the water target and the Government of Malawi reported that by 2015, about 94 percent of population was likely to have sustainable access to improved water source [2]. However, just like on the global scene the rural-urban divide persists; with a majority of the people in the rural areas still collecting

water from boreholes or surface water. In spite of boreholes qualifying as improved water sources, the quality and safety for many of them is questionable and also many of the boreholes break. Electric pumping can make a difference by making the boreholes deeper for safer water. Lack of grid electricity in the rural areas and high cost of fossil fuels make renewable energy technologies (RETs) the best option for water pumping. At the same time RETs can provide mitigation and adaptation to climate change. Hence the objective of this study is to determine the feasibility of solar water pumping using renewable energy. The study will focus in the rural areas where the majority of the population (85 %) live and have less access to services such as water, health, education, and telecommunications as compared to those living in the urban areas.

Background of Drinking Water Situation in the Rural Areas of Malawi

The Malawi Demographic and Health Survey Report [3] found that the rural population with access to an improved sources of drinking water is 77.1 % whereas 22.6 % of the rural population still access water from non-improved sources and the rest 0.3 % from other sources. The World Health Organisation [4], defines improved water sources to include household connections, public standpipes, boreholes, protected dug wells, protected springs, and rainwater collection; which must be within 'reasonable access' [5].

For rural water supply systems, groundwater is generally preferred as a drinking water source because the cost of extracting groundwater is less than that of treating surface water. Also water pumped from shallow wells can easily be contaminated from human and animal activities. Thirdly, the shallow wells have limited yield because they are dependent on seasonal rainfall unlike the deep wells that are less affected by seasonal rainfall. Several other factors such as latrines, septic tanks, refuse dumps, cattle kraals, dip tanks and cemeteries have a great impact on the quality of the groundwater, and hence consideration of these has to be taken [6], [7]

In Malawi studies on water resources and water quality in particular are limited [8], [9]. Early studies of groundwater were done by [10] who recorded that the availability of groundwater resources in Malawi is associated with two major aquifer types: the Precambrian crystalline weathered basement complex aquifer which makes up approximately 70 % of Malawi's landscape and the Quaternary alluvial deposits. Groundwater levels in the basement aquifers are in most cases less than 15 m below surface, with seasonal fluctuations of typically 1 to 5 m.

[11] showed that the shallow wells of Chiradzulu yielded water of unacceptable microbiological quality and that the situation was significantly worse in the wet season because the form of construction and method of water extraction for these wells was insufficient to yield potable water. On the other hand, the physical and chemical parameters were generally close to or within the WHO or National guidelines standards and did not

change significantly with season. Conventional water treatment technologies such as chlorine were unaffordable and unsustainable for rural livelihoods. It was also noted that a number of wells dry up during the dry season, which in turn forces people to use open water sources such as rivers which are even more contaminated. On the other hand the hand-pumps are a physical burden to women who usually collect water and at the same time are involved in other domestic chores. Cholera and diarrhoea are the common water-related diseases prevalent in the country. The major likely cause of these diseases is drinking contaminated water collected from shallow wells, lakes, rivers and other unprotected sources [12]–[16].

Water-pumping Using Renewable Energy

The availability of abundant renewable resources makes RETs very competitive for water pumping in rural areas of developing countries, where fossil fuels are expensive and it is usually challenging to extend the grid. [17] reviewed and summarised over a hundred renewable energy water pumping systems used for both irrigation and domestic use and found that solar photovoltaic followed by wind energy are the mostly widely used RETs for water pumping. They concluded that RETs play a vital role in reducing consumption of conventional energy sources and their environmental impacts are negligible. For storage methods they recommended water tanks and/or battery. [18] found that it could be more cost effective to use the photovoltaic water pumping systems than diesel engines to energize pumping systems in Jordan Badia. For Nigeria, [19] recommend solar and wind based systems over petrol, and wind was less favoured because of less resource availability and lack of suppliers. In widely distributed populations they recommended hand pumps and batteries and/ or pump storage tank for storage. Other authors who recommended solar PV include [20]–[22]. In high wind regions, wind was generally recommended over solar and diesel, and because wind is intermittent, use of a reservoir tank for storage was advised [23]–[26]. Solar PV was cited as the most advantages system despite the high capital costs with being environmentally friendly and low O&M requirements topping the list of advantages. Wind came second with advantages of minimal maintenance as compared to the diesel ones and also that unlike solar PV, it is not prone to theft. Diesel systems' main disadvantages were high fuel costs and need for maintenance though the capital costs are comparatively low.

In Malawi, the existing renewable energy potential (apart from large hydro) is very poorly utilised. With less than 10 % of the population connected to the electricity grid, RETs are a viable option for water pumping in the rural areas [27].

Case study

Nlukla is a village in Chiradzulu district in the Southern Region of Malawi. The district is the second highly populated district whilst at the same time it is one of the poorest districts despite the district being only 25 km from the commercial city of Blantyre [28]. The area has no access to the grid power and with low wind speeds solar was chosen over wind. The

current water supply is a 6 m deep elephant pump with maximum total faecal coliforms of 5, 820 Total Coliforms /100 ml in the wet season [11].

System Design

A 50 m deep borehole with storage tanks and public taps fed by gravity was proposed and designed for a population of 820 people. The daily usage was calculated from WHO/UNICEF recommendation of 20 litres per person per day. The monthly averaged sunlight hours for the study area as obtained from NASA Website and are given in Table 1. The least month which for the study area is June with a radiation of 4.34kWh/m²/day was used.

Table 1: Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m²/day) for Chiradzulu positioned at Lat -15.676 and Lon 35.141 [29]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann Avg
22 yr avg	5.32	5.46	5.43	5.19	4.84	4.34	4.48	5.26	6.21	6.49	6.12	5.43	5.38

The estimated dynamic Head (h) was estimated to be 70 m. The sizing of PV array in terms of hydraulic power and solar irradiation is given by [30]:

$$P = 1000 \frac{\rho g h V \eta_r}{G_T \eta_{pv} \eta_s}$$

where P is the electric power of the PV array , ρ is the density of water, g is the acceleration due to gravity, h is the total pumping head (m), G_T is the daily solar radiation on the PV array surface(kWh/m²), η_r is the array efficiency at the reference temperature (T_r = 25 °C), η_{pv} the PV array efficiency under the operations conditions, and η_s the subsystem efficiency.

From the calculated results the following components were selected: 10 solar modules of 100 Wp each, 1 Grundfos SQF 2.5-2 Submersible Pump and 4 storage tanks of 10,000 litres each. The cost of the system is given in Malawi Kwacha as shown in in Table 2 (as of 31 August 2015, US\$ 1= MWK 561).

Economic Analysis

Simple Payback

Simple Payback was calculated as:

$$\text{Simple Payback (yrs)} = \frac{\text{Cost of installed system}}{\text{Net annual cash inflow}}$$

Table 2: Solar Water Pumping System Costs and Results

Capital Costs	Cost (MWK)
Solar Modules	1,170,000.00
Pump	1,196,715.00
Accessories & Labour	442,843.48
Well Drilling	2,500,000.00
Pipework & Taps	250,000.00
Tanks and tank stands	4,000,000.00
Labour & Administration	300,000.00
Total	8,689,558.48
Operation & Maintenance	
Pump Replacement (10yrs)	1,196,715.00
Annual Maintenance	120,000.00
Results	
Simple Payback	9.56 years
Net Present Value	-MWK 4,989,131.69

Net Present Value

Using Microsoft Excel, the life cycle costs (LCC) was calculated for an assumed 20-year period taking into account capital cost, operating and maintenance costs, and replacement costs. The Net Present Value (NPV) was calculated by selecting a discount rate of 35 % in line with the borrowing interest rate in Malawi. The net present value is given as:

$$NPV(i, N) = \sum_{t=0}^N \frac{R_t}{(1+i)^t}$$

Where t is the time of the cash flow, R_t is the net cash flow at time t , N is the total number of years. The results obtained for simple payback, net present value and cost of water are presented in Table 2.

Conclusions

The simple payback period is 9.6 years which is shorter than the useful life (20 years). This suggests the solar pumping system will pay for itself before it stops working. The NPV, however, is negative suggesting that, accounting for the time value of money, there will be a loss. With high interest rate used in the country, this should be expected. For the people living in rural areas of Malawi these costs are exorbitantly high, hence a system has to be devised on how to cover these costs, which is recommended as future area of research for this study.

Apart from designing a solar water pumping system for irrigation; the other recommended future area of research for this study is to design a financing mechanism to cover for the high capital costs bearing in mind that for the people living in rural areas of Malawi the capital costs are exorbitantly high.

References

- [1] United Nations, "The Millennium Development Goals Report 2013," 2013. [Online]. Available: <http://www.un.org/millenniumgoals/pdf/report-2013/mdg-report-2013-english.pdf>. [Accessed: 01-Dec-2014].
- [2] Malawi Government, "2010 MALAWI MILLENNIUM DEVELOPMENT GOALS REPORT," 2010. [Online]. Available: <http://planipolis.iiep.unesco.org/upload/Malawi/MalawiMDGs2010Report.pdf>. [Accessed: 01-Dec-2014].
- [3] National Statistical Office, "Malawi Demographic and Health Survey," 2011.
- [4] WHO, "Guidelines for Drinking-water Quality," 2006. [Online]. Available: http://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf. [Accessed: 01-Dec-2014].
- [5] WHO & UNICEF, "Global Water Supply and Sanitation Assessment 2000 Report," 2000.
- [6] T. Kanyerere, J. Levy, Y. Xu, and J. Saka, "Assessment of microbial contamination of groundwater in upper Limphasa River catchment , located in a rural area of northern Malawi," vol. 38, no. 4, pp. 581–596, 2012.
- [7] H. Taylor, G. Chavula, J. Ebdon, R. Phillips, and O. Kapudzama, "Assessment of Drinking Water Quality for Low-cost Water Options in Rural Malawi Technical annex November 2012," no. November, 2012.
- [8] H. W. T. Mapoma and X. Xie, "Basement and alluvial aquifers of Malawi: An overview of groundwater quality and policies," *African Journal of Environmental Science and Technology*, 2014. [Online]. Available: [http://www.academicjournals.org/article/article1394534763_Mapoma and Xie.pdf](http://www.academicjournals.org/article/article1394534763_Mapoma%20and%20Xie.pdf). [Accessed: 01-Dec-2014].
- [9] N. Robins, J. Davies, and J. Farr, "Groundwater supply and demand from southern Africa's crystalline basement aquifer: evidence from Malawi," *Hydrogeol. J.*, vol. 21, no. 4, pp. 905–917, Feb. 2013.
- [10] P. J. CHILTON and SMITH-CARINGTON A. K., "Characteristics of the weathered basement aquifer in Malawi in relation to rural water supplies," in *Challenges in African Hydrology and Water Resources*, 1984.
- [11] M. Pritchard, T. Mkandawire, and J. G. O'Neill, "Biological, chemical and physical drinking water quality from shallow wells in Malawi: Case study of Blantyre, Chiradzulu and Mulanje," *Phys. Chem. Earth, Parts A/B/C*, vol. 32, no. 15–18, pp. 1167–1177, Jan. 2007.

- [12] J. F. Kamanula, O. J. Zambasa, and W. R. L. Masamba, "Quality of drinking water and cholera prevalence in Ndirande Township, City of Blantyre, Malawi," *Phys. Chem. Earth, Parts A/B/C*, Sep. 2014.
- [13] D. L. SWERDLOW, G. MALENGA, G. BEGKOYIAN, D. NYANGULU, M. TOOLE, R. J. WALDMAN, D. N. D. PUHR, and R. V. TAUXE, "Epidemic cholera among refugees in Malawi, Africa: treatment and transmission," *Epidemiol. Infect.*, vol. 118, no. 03, pp. 207–214, Jun. 1997.
- [14] A. Khonje, C. A. Metcalf, D. D. Mlozowa, A. Akesson, and T. Corbet, "Cholera outbreak in districts around Lake Chilwa , Malawi : Lessons learned," vol. 24, no. March 2010, pp. 29–33, 2012.
- [15] A. M. MOREN, D. BITAR, I. Navarre, M. G. ETCHEGORRY, A. BRODEL, G. LUNGU, and P. HAKEWILL, "Epidemiological Surveillance Among Mozambican Refugees in Malawi, 1987-89," *Disasters*, vol. 15, no. 4, pp. 363–372, Dec. 1991.
- [16] S. J. Masangwi, T. D. Morse, N. S. Ferguson, G. Zawdie, A. M. Grimason, and J. J. Namangale, "Behavioural and environmental determinants of childhood diarrhoea in Chikwawa, Malawi," *Desalination*, vol. 248, no. 1–3, pp. 684–691, Nov. 2009.
- [17] C. Gopal, M. Mohanraj, P. Chandramohan, and P. Chandrasekar, "Renewable energy source water pumping systems—A literature review," *Renew. Sustain. Energy Rev.*, vol. 25, no. 25, pp. 351–370, Sep. 2013.
- [18] M. Al-Smairan, "Application of photovoltaic array for pumping water as an alternative to diesel engines in Jordan Badia, Tall Hassan station: Case study," *Renew. Sustain. Energy Rev.*, vol. 16, no. 7, pp. 4500–4507, Sep. 2012.
- [19] M. Cloutier and P. Rowley, "The feasibility of renewable energy sources for pumping clean water in sub-Saharan Africa: A case study for Central Nigeria," *Renew. Energy*, vol. 36, no. 8, pp. 2220–2226, Aug. 2011.
- [20] J. K. Kaldellis, E. Meidanis, and D. Zafirakis, "Experimental energy analysis of a stand-alone photovoltaic-based water pumping installation," *Appl. Energy*, vol. 88, no. 12, pp. 4556–4562, Dec. 2011.
- [21] S. Ould-Amrouche, D. Rekioua, and A. Hamidat, "Modelling photovoltaic water pumping systems and evaluation of their CO2 emissions mitigation potential," *Appl. Energy*, vol. 87, no. 11, pp. 3451–3459, 2010.
- [22] K. MEAH, S. ULA, and S. BARRETT, "Solar photovoltaic water pumping—opportunities and challenges," *Renew. Sustain. Energy Rev.*, vol. 12, no. 4, pp. 1162–1175, May 2008.

- [23] B. Bouzidi, "Viability of solar or wind for water pumping systems in the Algerian Sahara regions – case study Adrar," *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4436–4442, Dec. 2011.
- [24] A. M. Omer, "Wind energy in Sudan: Water pumping in rural areas," *Refocus*, vol. 2, no. 8, pp. 34–37, Oct. 2001.
- [25] W. K. Biswas, "Application of renewable energy to provide safe water from deep tubewells in rural Bangladesh," *Energy Sustain. Dev.*, vol. 15, no. 1, pp. 55–60, Mar. 2011.
- [26] Z. Al Suleimani and N. R. Rao, "Wind-powered electric water-pumping system installed in a remote location," *Appl. Energy*, vol. 65, no. 1–4, pp. 339–347, Apr. 2000.
- [27] G. E. T. Gamula, L. Hui, and W. Peng, "Development of Renewable Energy Technologies in Malawi," *Int. J. Renew. Energy Technol. Res.*, vol. 2, no. 2, pp. 44–52, 2013.
- [28] National Statistical Office, "Population and Housing Census 2008," Zomba, 2010.
- [29] NASA, "NASA Surface meteorology and Solar Energy - Choices," 2014. [Online]. Available: <https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?&email=skip@larc.nasa.gov&step=1&p=&lat=-15.676&submit=Submit&lon=35.141>. [Accessed: 02-Dec-2014].
- [30] N. Argaw, "Renewable Energy Water Pumping Systems Handbook," Denver, 2004.