Towards Decentralised Water Access, A Primer Solar Pumped Water Design Solution to Aid The COVID-19 Fight.

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Abstract

Hand hygiene has been shown to prevent respiratory illness COVID-19 and is recommended after coughing and sneezing and/or on entering the home having come from outside. Functioning handwashing facilities with water and soap are recommended to be available within 5m of all toilets, both public and private. This paper proposes a design of a piped water scheme for an identified rural centre to increase sustained access to safe water as a primer solution to the fight against COVID-19. For the identified borehole, the safe pumping yield is taken as 80 % of capacity test and is given as 1.2m^3/h. A special user defined excel simulation program was developed and employed that specified a 1.7kW motor pump, powered by a 1000 Wp solar array delivering a peak flow rate of 1.2m^3/hr (12m^3 of daily water yield) for the least insolation day at a TDH of 63m with overall pumping efficiency of 11l/Wp. The Hazen-Williams method was used to specify a 32mm Class 6 HDPE pipe that stretches for 530m as the pumping main. The mass balance curve gave a minimum balancing water storage of 30m^3 on considering the risk of water quality deterioration given the absence of a disinfection regime.

Keywords
capacity test, COVID-19, configurations, disinfection, efficiency, regime

1. Background

As global awareness of climate change increases, current energy generation and usage practices face growing scrutiny from governmental institutions and the general public (Pushak, N and Briceño-Garmendia 2011). More pressure is being placed on individual organizations to become more critical of their own energy sources and transition to cleaner technologies. While substantial progress has been made in increasing access to clean drinking water and sanitation, many people mostly in rural areas still lack these basic services. Worldwide, one in three people do not have access to safe drinking water, two out of five people do not have a basic hand washing facility with soap and water, and more than 673 million people still practice open defecation (AMCOW, 2011).

The COVID-19 pandemic has demonstrated the critical importance of sanitation, hygiene and adequate access to clean water for preventing and containing diseases. Hand hygiene saves lives. According to the World Health Organization, handwashing is one of the most effective actions you can take to reduce the spread of pathogens and prevent infections, including the COVID-19 virus (United Nations, 2020). Yet billions of people still lack safe water sanitation, and funding is inadequate. Availability and access to water, sanitation and hygiene (WASH) services is fundamental to fighting the virus and preserving the health and well-being of millions. COVID-19 will not be stopped without access to safe water for people living in vulnerability, UN experts said (AMCOW, 2011). The impacts of COVID-19 could be considerably higher on the urban poor living in slums, who don’t have access to clean water. There exists a need to urgently facilitate access to running water and handwashing in informal settlements. Young children are in need of urgent support in the form of with basic water, sanitation and hygiene facilities, especially those children who are cut off from safe water because they live in remote areas, or in places where water is untreated or polluted, or because they are without a home, living in a slum or on the street. In response to the COVID-19 outbreak, governments across the world are adjusting their WASH services to prevent the spread of the disease. This includes continued support to affected, at-risk, low-capacity and fragile areas to secure WASH services and infection prevention control in health facilities (United Nations, 2020). No one goes to a health care facility to get sick. People go to get better, to deliver babies or to get vaccinated. Yet hundreds of millions of people face an increased risk of infection by seeking care in health facilities that lack basic necessities, including water, sanitation, hygiene, health care waste management and cleaning (WASH) services. Not only does the lack of WASH services in health care facilities compromise patient safety and dignity, it also has the potential to exacerbate the spread of antimicrobial-resistant infections, COVID-19 and undermines efforts to improve child and maternal health. As part of these efforts to control the spread of COVID-19, this paper proposes a design of a piped water scheme for an identified rural centre to increase sustained access to safe water supply through a mini piped water schemes (PWS) targeting mainly the health facility. The rehabilitation and /or construction of piped water schemes is expected to increase access to safe water in the rural community, school and health centres and ensure increased impact for the borehole drilled with the aim of reaching a greater population and so enhancing water delivery efficiency and value for money.

The site for a proposed piped water scheme is located in the remote district of Zimbabwe and is accessible through a link dust road between to other moderately big growth points. The site has two boreholes, one borehole is fitted with a bush and is located close to the shops at the centre. This is the borehole chosen for the proposed scheme. While another borehole is located near a stream to the north of the site. Owing to the results of the capacity test conducted, the borehole closest to the shops was identified as the preferred water source and the one closer to the river may provide an alternative in times of shortages. There are two schools, a clinic, and shops at the business centre and surrounding households located near the business centre.

2. Methodology

The methodology followed a deliberate approach that evaluated the scheme's schematic layout, the water demand, water availability, solar resource and topographical parameters. The solar pumping system components are designed, and the PV generator array, a pump and a solar pump controller are dimensioned. The pumping mains is specified through an iterative process using the Hazen-Williams method together with the specification of the total dynamic head, related friction and abrupt losses as shown in the following sections.

2.1 Scheme layout and Water Analysis

Scheme layout and profiles of pipe routes were evaluated using survey analysis and drawings. Google earth was also adopted to determine differences in grown elevation profiles and also to show the relative location of water source (borehole) and proposed tank sites and distribution systems

The water demand of the scheme was accessed basing on field data and guidelines for rural water demand. Future demands were generally projected for 20years and a growth rate of 2.5% generally applied except at times for some projected small institutions for example were 1.25% was applied for schools. In the demand calculation generally 10% contingency was allowed for losses is the system.

The water availability for the scheme is based on the pump capacity test results. Borehole Safe pumping yield is taken as 80 % of Capacity Test Borehole Yield to avoid over draining of the borehole. Based on the available yield and demand from primary demand centres, the scheme water provision for supplying the communities in nearby villages was evaluated. Priority was given to the health centre owing to the critical nature of the services that requires water.

The water quality analysis was done on the samples obtained from the borehole. Parameters that were analysed and tested for include dissolved oxygen saturation, pH, turbidity, salinity, hardness and ionic compositions of calcium, chloride, magnesium, zinc, copper and sodium. However, owing to the variability nature of water quality parameters, these may need to be further re-evaluated just before the physical construction. The solar pumping system.

2.2 Solar Pumping Systems Design

The solar pumping system is composed of a PV generator array, a pump and a solar pump controller. Based on the design philosophy that it is more efficient to store water rather than energy, no energy storing device such as a storage battery are anticipated in the design. The solar pumping system consisted of the following sub-system components that were sized.

1. A pump-motor-controller subsystem (usually supplied as a complete unit). It consists of the solar controller, a variable frequency motor and a pump.
2. The pumping mains.
3. The PV module (or array- an assemble of modules)
4. The water or electricity storage system.

Due to the complex nature and multiple variables involved in calculating the solar system performance, the system was designed and planned using proprietary computer based tools; Win CAPS and Compass, and a home grown user defined excel calculator sheet that can closely model the irradiation, power generated from the solar array, ambient temperature, and typical pump performance. To easily manage and consider these different variables, a special simulation design approach was adopted for sizing and simulating the performance of the pumps systems with a deliberate bias to maximise pump yields at the least cost and the highest attainable pumping efficiency expressed in litres delivered per array size, (l/Wp).

2.3 Pump-Motor-Controller Sizing

To pump is selected basing the required peak flow rate and the required total dynamic head obtained from the site specific data and the capacity test results. The total dynamic head is determined as the sum of static head (the difference between the pump level and the tank inlet level), frictional losses (a function of pipe length, material type and diameter) and abrupt losses (strictly a function of fitting type, diameter and pipe material).

2.4 Peak Flow Rate

The peak flow rate is determined from the following equation:

$$Q = \frac{V}{PSH_e} \qquad (1)$$

$$PSH_e[hr/day] = \frac{H_T[kWh/m\text{^}2\ /day]}{[1\ kWh/m\text{^}2\ ]} \cdot F_c \qquad (2)$$

Where PSH_e is the effective Peak Sunshine Hours at the site, H_T is daily solar irradiation received on the tilted PV collector surface and F_C is a correction factor to account for the combined losses due to temperature, soiling, module mismatch, and inverter and controller efficiencies. A value of $F_C = 0.8$ can be used to cater for these losses at this site. The 1 kW/m^2 is solar irradiance received at Standard Test Conditions (1000 W/m^2 and PV cell temperature of 25 ºC). The value of H_T can be obtained from data of solar irradiation at the site together with a tilt factor, which is a function of the latitude of the location and the tilt angle of the collector. All over Zimbabwe all this data can be obtained from the data developed by Hove et al, (Hove & Manyumbu, 2014)

2.5 Total Dynamic Head

The total dynamic head is determined as the sum of *static head, frictional losses* (a function of pipe length, material type and diameter) and *abrupt losses* (strictly a function of fitting type, diameter and pipe material). Friction losses can be determined using the Hazen-Williams formula with C = 140 for PVC pipes.

$$h_f = 10.37L\left(\frac{Q}{C}\right)^{1.852} D^{-4.87} \qquad (3)$$

In Equation (3), C (dimensionless) is the Hazen-Williams coefficient and all other variables are expressed in SI units. The pipe diameter can be selected by using the continuity equation, given as;

$$D = \sqrt{\frac{4Q}{\pi v}} \qquad (4)$$

and limiting the flow velocity to $v < 2$ m/s for pumping mains. Velocity between 0.5 m/s – to avoid deposit and 1.5 m/s –to avoid erosion is acceptable. Abrupt losses can be accounted for as 10% of the friction losses for long pipe lines. The pump duty point can then be described according to a delivery of Q = flow rate (m^3/hr) at H = head (m). To select a suitable solar pump, an analysis of the different solar pump performance curves is instituted. Many solar pumps are feasible from the analysis of the difference pump curves. Care was taken to be careful not to over-pump the borehole and at the same time extract as much water as possible from the borehole. A solar PV array that cannot over-pump the borehole with the selected pump was also determined.

3. Results and Discussions

The water demand is made up of institutional water demand from the clinic and two schools and commercial buildings water demand. Based on the available yield and demand from primary demand centres, the scheme will not have provision for supply of communities in nearby villages. The scheme will be designed to only provide part of the current water demands and not future demand, hence future demand forecasting is not performed. Additional sources are recommended to meet future demands. Water availability is assessed in terms of water quantity and water quality as presented in the next sections. The water availability for the scheme is based on the pump test results shown in Table 1.

Table 1: Borehole and Pump Capacity Test Data for the Scheme

Parameter	Value
Total depth of borehole (m)	42
Static water level	20.39
Yield (l/s)	0.4
Drawdown(m)	10.11
Recovery time (min)	2
Depth of pump below ground (m)	39
Bore size(m)	6 "
Tank Surface (Elevation (m))	975
Lowest point (Elevation (m))	964
Tank Height(tank stand + tank)	9
Ground level pumping main distance (m)	485
Static head (m)	58

Borehole Safe pumping yield is taken as 80 % of Capacity Test Borehole Yield to avoid over draining of the borehole given as 1.2m^3/h. Based on the available yield and demand from primary demand centres, the scheme will not have provision for supply to communities in nearby villages. The safe yield of will only provide (about 80%) of the water to meet current demands. Additional sources will need to be considered to fully satisfy the demand and, also, to meet projected demands. The water quality from the borehole is shown in Table 2.

Table 2: Water Quality Results for the Borehole at the Scheme Site

Parameter	pH	Temperature	Turbidity	E.C.	DO	DO	TSS	TS	T.D.S. [mg/l]	COD
Unit		[ºc]	[NTU]	**[mS/cm]**	% Saturation	[mg/l]	[mg/l]	[mg/l]	[per 100ml]	[mg/l]
Value	6.463	25.5	21	501@25°C	0.86	9.42	27	559	432	10.6
Parameter	Bicabornate	Chloride	Calcium	Magnesium	Hardness	Zinc	Copper	Iron	Sodium	
Unit	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	
Value	268.4	77.99	78.57	43.74	376	1.4053	0.2746	0.1645	5.9862	

The water quality is fairly good based on the results at the time of sampling. However, some parameters including turbidity were elevated while salinity and hardness were moderate. However, water quality may need to be re-evaluated just before construction.

3.1 Site Meteo Profiling

The solar resource at the site is shown on Table 3. It comprises the radiation on a horizontal plane (global radiation), the diffuse radiation, the radiation received by a tilted plane, the average maximum ambient temperature and the minimum ambient temperature. The radiation on the tilted surface is the one "seen" by the PV modules and affect the performance of the solar pump. The efficiency of the solar modules is affected by the ambient temperature, i.e. higher ambient temperature results in lower PV efficiency. The modules are tilted towards the North at a tilt angle equal to the modulus of the location latitude plus 5 degrees. The PV site will be cleared of all obstructions, such as trees, that may cause shading of the PV modules. Other factors that may cause the reduction of effective radiation such as dust, and dirt from bird droppings and module mismatch, are taken account of in the design procedure. The site is clear from shading but due to dusty surroundings the system might be prone to dust and soiling. More radiation will be received by the solar arrays oriented to the North throughout the day. The modules were to be tilted at an angle of 24 degrees from the horizontal, facing north and are expected to be exposed to more radiation with a monthly average-daily value of 6.0 kWh/m^2 as given in Table 3 with December being the month with the least expected radiation of 5.2 kWh/m^2.

Table 3: Site Meteorological Parameters

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Global (kWh/m2)	6.2	6.1	6.1	5.6	4.9	4.5	4.6	5.6	6.2	6.8	6.4	5.9
Diffuse (kWh/m2)	2.9	2.9	2.5	2.1	2.0	2.0	2.1	1.8	2.0	2.2	2.8	3.2
Tilted (kWh/m2)	5.5	5.8	6.3	6.3	5.9	5.4	5.5	6.5	6.7	6.6	5.8	5.2
Min Temp (°C)	15.8	15.6	14.4	12.3	8.7	6.1	5.8	7.9	11.3	14.6	15.5	15.7
Max Temp (°C)	25.9	25.7	26.2	25.7	24	21.8	22.1	24.7	28	29.8	27.6	26.2

A value of $F_C = 0.8$ was used to cater for these losses at this site and 1 kW/m^2 was taken as solar irradiance received at Standard Test Conditions (1000 W/m^2 and PV cell temperature of 25 ^{o}C). Therefore, for the design month of December, $PSH_e = 0.8 \times 5.2 = 4.16$ hours. This gives a desired peak flow rate, Q of 2.88 m^3/hr. This value is slightly larger than the safe borehole yield, therefore the borehole safe yield of 1.152 m^3/hr was selected as the design flow rate.

3.2 Determination of Head

The total dynamic head was determined as the sum of *static head, frictional losses* (a function of pipe length, material type and diameter) and *abrupt* **losses** (strictly a function of fitting type, diameter and pipe material). Static Head = 39+11+8=58m

The Friction losses were determined using the Hazen-Williams formula with C = 140 for PVC pipes, substituting in Equation 3. The pipe diameter was selected by using the continuity equation, Equation (4), and limiting the flow velocity to between $v > 0.3$ m/s – to avoid deposit and $v < 1.5$ m/s –to avoid erosion and obviate water hammer impacts. For the pumping main, using v = 0.373m/s, the required pumping diameter is D = 0.0312 m, giving 32 mm as the nearest PVC standard size pipe diameter size.

3.3 PV-Pump-Motor-Controller Subsystem

To achieve the dual aim of extracting as much water as possible and avoiding over draining of the borehole, care is taken in selecting from amongst several capable pumps the most suitable Pump-PV combination that will not over-pump the borehole. For this case, Water will be pumped by 1.7kW motor pump driven by a 1000 Wp solar array delivering a peak flow rate of 1.2m^3 per hour translating to approximately 12m^3 of daily water yield for the least insolation day at a TDH of 63m for an efficiency of 11l/Wp. The pumping mains will be a 32mm Class 6 HDPE pipe that stretches for 530m. A Lorentz PS2-1800 HR-07-2 is specified or any other equivalent solar pump with the specified pumping characteristic that suits the design brief. The pumping curve of Lorentz PS2-1800 HR-07-2 under differing PV input characteristics is presented in Figure 1.

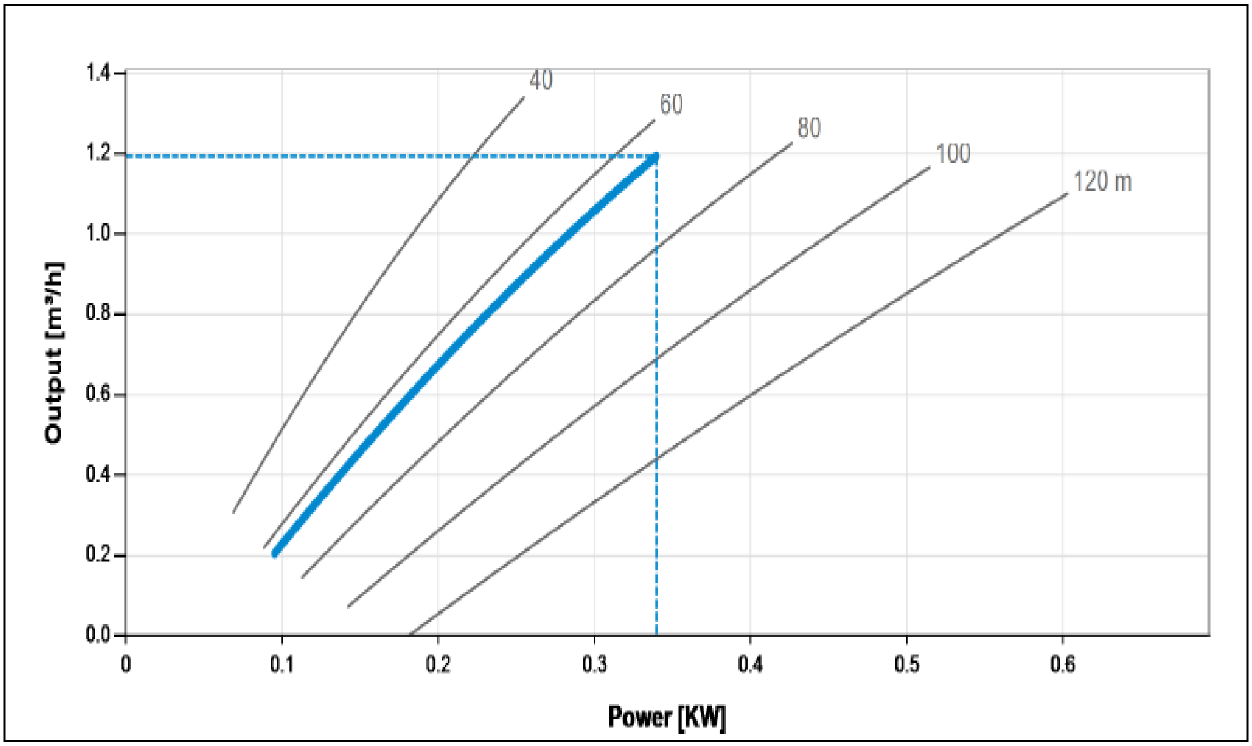

Figure 1: Pumping Curve for the selected PS2-1800 HR-07-2 Lorentz Pump

The PV array is configured such the voltage of the string of modules is equal to the voltage required by the pump. The modules were selected such that the total power is equal to about the power required for the selected pump as this determines the pumping rate (with regards to the safe yield of the borehole) and also determines the amount of water that can be salvaged from the borehole at the site.

3.4 System Water Output Parameters

Simulation and optimisation tools were adopted to determine pumped water outputs in line with the water requirements as shown in the Table 4.

Table 4: Pump hourly output for design month

Time (hrs)	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Temp (°C)	18	19	21	23	25	27	29	31	31	31	29	27
Flow rate (m^3/hr)	0	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.04	0

The PV power is varied until the maximum flow rate is just less than the safe pumping yield of the borehole. The PV power to achieve this is **1000 Wp**. The diurnal variation of flow rate and total dynamic head are shown on Figure 2.

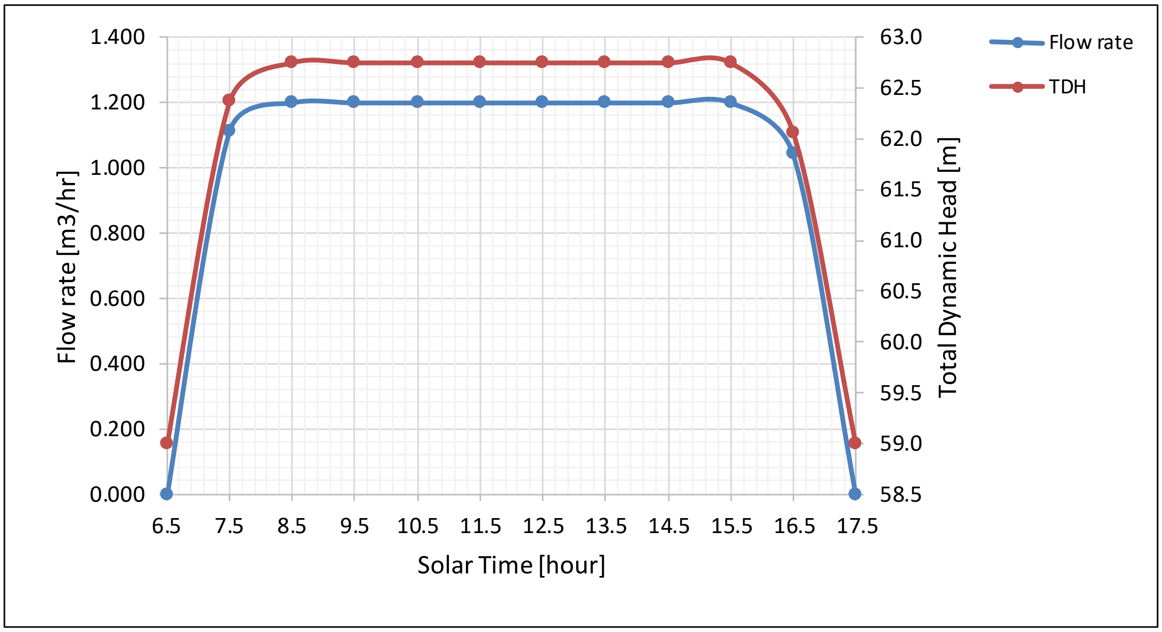

Figure 2: Diurnal variation of flow rate and total dynamic head for Lorentz PS2-1800 HR-07-2

Other important operating parameters of the pumping system for the designed system is the average daily solar-to-water efficiency which is shown in Figure 3.

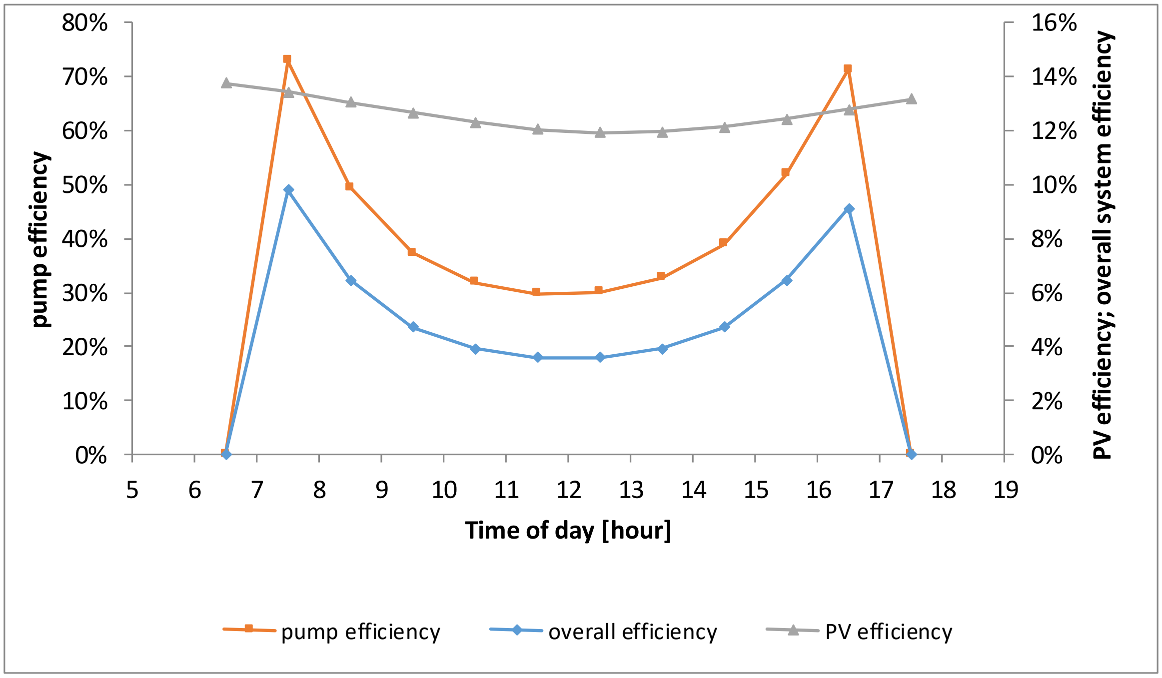

Figure 3: Average daily solar to water efficiency curves

3.4 Solar Pumping Main Design

The pipe diameter is selected by using the continuity equation, and limiting the flow velocity. The Hazen-Williams method is used iteratively for water flowing at ordinary temperatures of 4 to 25 °C through pressurized pipes. Major loss (h_f) is the energy (or head) loss due to friction between the moving fluid and the pipe wall. Hazen-Williams method is used to consider friction coefficient (C) as not a function of velocity or pipe diameter to solve for the pipe velocity and diameter.

- The Length of the pumping main is taken as the sum of the pumping borehole depth, the length of the ground profile from pumping point to the base of the storage and the height of the storage from ground to point of delivery and is given as 530m.
- Design flow in this case is taken as the maxim flow rate possible to extract as much water as possible from the borehole while avoiding over draining of the borehole and is taken as $0.0003m^3/s$ or $1.2m^3/hr$.
- Pipe Material identified due to its ease of availability, cost and properties is HDPE. Owing to the TDH of 61, a Class 6 HDPE pipe is identified.
- Diameters considered for this case are the 32mm, 40mm and 50mm
- Fittings and branches are accounted for through evaluation of the minor losses. A minor losses coefficient of 10% of frictional losses is factored in to represent abrupt losses which are strictly a function of fitting type, diameter and pipe material.
- Target velocity is taken to fall between 0.3 m/s – to avoid deposit and 2.0 m/s –to avoid abrasion.

Table 5: Summary of key design outputs for selecting pumping main pipe diameter at peak flow

Item	Length [m]	Diameter [mm]	Friction factor	Minor Losses (m)	Velocity [m/s]	Head loss per km (m)	Remark
1	530	32	140	0.65	0.3730	6.5	Acceptable
2	530	40	140	0.21	0.2387	2.176	Deposition
3	530	50	140	0.073	0.152	0.734	Deposition

Given the iteration in Table 5, the pipe diameter of 32mm is specified. The total dynamic head is determined as the sum of static head (59m), frictional losses (3.4m) (a function of pipe length, material type and diameter) and abrupt losses (0.34m) giving a rounded TDH of 63m. The summary of the pumping main details is as in Table 6.

Table 6: Summary of pumping main outputs

Parameter	Value
Pipe Diameter (mm)	32
Total dynamic head (m)	63
Total Equivalent Pumping Distance (m)	530

3.5 Determination of storage requirements

To determine the required storage volume, the mass balance curve is adopted. The diurnal rate of water withdrawal (which is such that the total daily withdrawal is equal to the daily volume pumped) is plotted together with the pump rate. The relative hourly withdrawal of water compared to the daily values are the same as those published by (Blokker, 2011). The cumulative respective volume is plotted in Figure 4. The required balancing storage is the sum of the maximum deficit and maximum surplus.

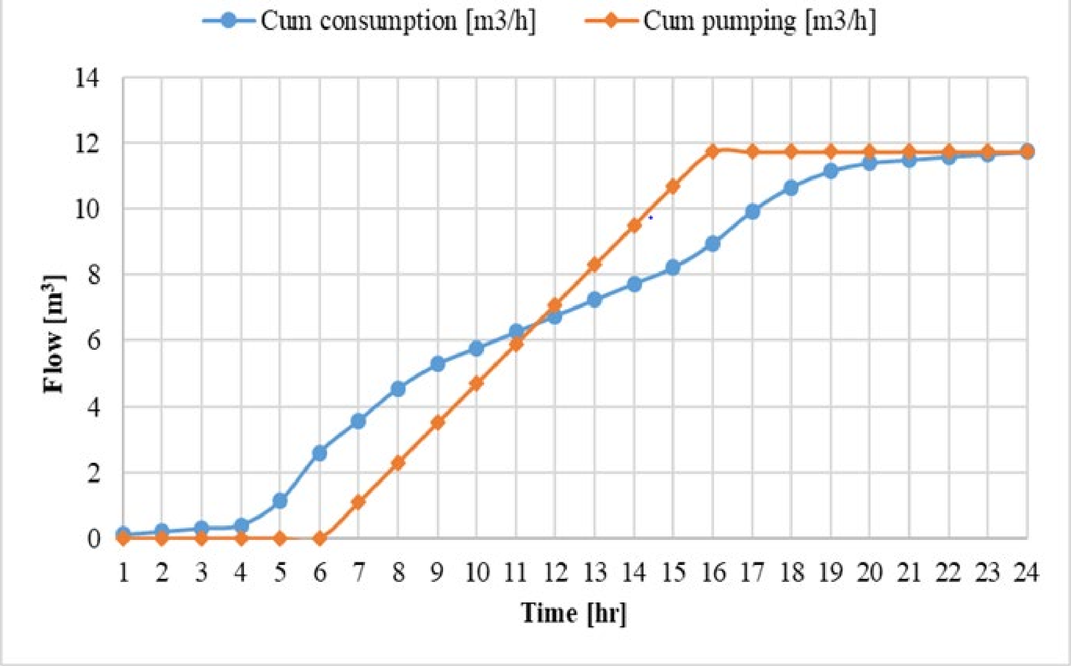

Figure 4: Flow balance analysis for Mushipe Scheme

Minimum balancing volume and storage basing on the above is determined as; The minimum volume = $|-2.59| + 2.79 = 5.38$ m^3

3.6 Storage Volume

As there are other sources of water and the level of service is not to match that of urban areas in Zimbabwe which requires 2 days' storage, and taking into consideration economic aspects, one (1) day storage is taken to be adequate. Considering that the water is not disinfected, long storage times may result in deterioration of water quality. In light of this, a storage volume of 30 m^3 is specified.

3.7 Pump-pipe Design Summary

Water will be pumped by 1.7kW motor pump driven by a 1000 Wp solar array delivering a peak flow rate of 1.2m^3 per hour translating to approximately 12m^3 of daily water yield for the least insolation day at a TDH of 63m for an efficiency of 11l/Wp. The pumping mains is a 32mm Class 6 HDPE pipe that stretches for 530m. A Lorentz PS2-1800 HR-07-2 is specified. The summary of the design described above is shown on Table 7.

Table 7: Summary of designed components

Component	Description
Solar pump	Lorentz PS2-1800 HR-07-2
Pumping main	HDPE 32 mm diameter, length 530 m
PV array	1000 W
Storage	30 m^3

Conclusion and Recommendations

WASH is a prerequisite for quality care, and is particularly important for the safe management of COVID-19. The provision of safe water conditions is essential for preventing and for protecting human health during all infectious disease outbreaks, including of coronavirus disease 2019 (COVID-19). Ensuring evidenced-based and consistently applied WASH practices in communities, homes, schools and healthcare facilities will help prevent human-to-human transmission of pathogens including SARS-CoV-2, the virus that causes COVID-19. The designed system is capable of supplying a daily water yield of 12m$^{3.}$ Ensuring universal access to WASH services in health care facilities is a solvable problem with a return on investment per day which is adequate to provide basic WASH services. The design was limited to sizing only the Solar Pumping systems and the related mains pipeline and storage. Further research can be developed to determine the distribution network distribution piping total length, spacing of the demand centres and the number of standpipes allocated for each demand centre. Key recommendations for Rural water supply (RWS) that can be adopted as priority actions in the fight against COVID-19 include developing a national program to repair and rehabilitate wells and boreholes. Placing responsibility and asset ownership of RWS with rural district councils, and build their sector capacity, whilst encouraging support from communities and the private sector and rethinking maintenance/spares policy and develop a regulated, competitive drilling industry.

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Biography

Hilton Chingosho is a professional Engineer, currently a Lecturer in the Department of Mechanical Engineering at the University of Zimbabwe, with research interests in Solar and Biomass Energy, Mini hydropower Plants, Energy Storage, Energy Efficiency, Management & Auditing and Energy Policy & Standards Development. He holds a Master's of Science Degree in Manufacturing Systems and Operations Management, a Master's of Science Degree in Renewable Energy Engineering both from the University of Zimbabwe and a Bachelors of Engineering (hons) in Fuels and Energy Engineering from Chinhoyi University of Technology. He is a Certified Energy Manager (CEM), an International Member of the Association of Energy Engineers (USA) and a professional member of the Zimbabwe Institution of Engineers. He currently seats as a Technical Committee member of Standards Associations of Zimbabwe's (SAZ) Energy Management and Energy Savings Technical Committee. Before joining UZ in 2017, he had worked in Energy Policy and Climate advocacy and lobbying programs. Has extensive experience in hydropower resource analysis, solar and biomass resource analysis and mapping and has also published in reputable journals on issues to do with Renewable Energy, Climate Change, Energy Access, Energy Management, Efficiency and Sustainable Engineering.