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DESIGN OF SOLAR WATER PUMP SYSTEM USING PUMPING AND GRAVITY METHODS TO IMPROVE HUMAN LIVING STANDARDS IN HATUERMERA - TIMOR LESTE

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Abstract

Access to water is a basic requirement for human life. However, currently there are still many small and remote communities that are relatively poor and still do not have access to better water sources. The absence of electricity and high fuel costs induce the need for pumping water to the community. The study designed a water supply system by using solar photovoltaic (PV) to generate power for water pump applications in Hatuermera village, Manatuto district, Timor Leste. The study used two methods, namely the pumping and the gravity system to take into account the geographical conditions and the location of the settlements. The solar water pumping system design needs several data such as information on water sources, water requirements, elevation differences, system components and local climate. The results showed that the water need to supply for 245 residents with a distance of 540 m and a height of 163 m between water sources and residential areas is 8.09 m^3/day. The design used a helical rotor submersible pump with DC current using a large total static head and small discharge to increase the efficiency, because electricity from solar panels is DC electricity. The total peak power of the PV array required is 2379.7 Wp which is supplied from 6 solar modules with a power rate of 400 Wp which are connected in series.

Keywords: Pumping system, solar energy, Photovoltaic (PV), Remote area

INTRODUCTION

The most basic condition for human life is access to water sources. For decades many organizations, both government and private companies and universities have tried to tackle this problem (Gualteros & Rousse, 2021). Many villages in Timor Leste, including those in Manatuto district, namely Hatuermera village, experience water shortages, especially during the dry season. To get water, people have to walk more than 1 Km to the nearest water source. Meanwhile, the electricity network is not yet available to use water pumps to deliver water from the springs to the villages. Therefore, an alternative is needed to use other energy as a pump driver, namely utilizing the abundant solar energy in that location (Da & Nci, 2019). Because the sources are easily available and abundant, then one of the best solutions to meet this energy need is the use of solar energy (Yadav et al., 2015)

The use of water pumps, especially in developing countries, relies heavily on conventional electricity or uses diesel as a power source. The application of a solar water pump is one solution to reduce the use of diesel fuel for diesel or coal-fired electricity. Water pump systems using diesel not only require expensive fuel but also cause noise and air pollution (Senthil Kumar et al., 2020).

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Solar water pumps (SWP) have the potential to significantly alter rural communities not only by providing a direct supply of water but also by offering opportunities for sociological and economic development. Solar water pumping systems reduce the need for electricity generated by burning fossil fuels (Salilh et al., 2020). Therefore, the best solution to break away from dependence on electrical energy sources is to use solar energy (Hameed Habeeb, 2018). Utilization of solar water pumps is generally in a place where it takes a long journey to fetch water or the well only provides water that can be used seasonally. The greatest benefit of a solar water pump system is in a community that can come together to organize, build, finance and manage the project (Ratterman et al., 2003). SWP projects are anticipated to raise beneficiaries' economic status through improved water supply and direct benefits from cheaper water services (Rahmani et al., 2022). Beyond the availability of fresh water, the impact of SWP can have both positive and negative effects (Short & Thompson, 2003). It is difficult to imagine how project designers, producers, and implementers can hope to provide sustainable solutions to water supply issues if they are unaware of these consequences. The sizing models of SWP for irrigation are based on estimates of daily water consumption and static models. In terms of economics, the capital cost of SWP is still higher than the traditional system driven by diesel engine, despite the fact that operating costs are much lower. These are the main technical barriers to the implementation of SWP (Chilundo et al., 2018).

The solar water pump system is the same as any other pumping system, except: the source of electricity is solar energy. Solar pumping technology covers the entire energy conversion process, from sunlight, into electrical energy and then into mechanical energy. Solar radiation is captured by solar electric panels, which then convert sunlight into electricity. Through the control box, whose main function is to condition electricity from the panel, the pump motor is powered to drive the pump and pump water into the reservoir. The water from the reservoir is then given to the user.

To build a solar-powered water pump at a spring location that can deliver water through pipes to the village, of course, it is necessary to plan and design a solar water pump system (SWP) beforehand so that the right capacity can be determined according to community needs, development costs as well as operating and maintenance costs. to support reliability and sustainability. This research was made with the hope that it can help the local government as a reference if they want to build a solar water pump in Hatuermera Village so that the availability of clean water that is close and easy to reach can improve the standard of living of the local community.

MATERIAL AND METHODS

The first step in this research is to study the total amount of water needed per day (Jenkis, 2014) and water sources closest to the village location and the resulting discharge. The study of water needs is carried out to find out how much water needs are in accordance with the population with the assumption that water needs per person are in accordance with WHO standards (Reed & Reed, 2013) **Error! Reference source not found.**namely for drinking, cooking and personal washing as shown in the Figure 2. Meanwhile, the study of discharge from water sources will

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be taken into consideration whether the standard needs per person can be fulfilled or must look for alternative water sources. Previous research literature related to the application of Solar Water Pumps (SWP) is also a reference in this study. Literature study is a reference material in the research method used in this study and is used as secondary data.

The next step is to calculate the total dynamic head (TDH) based on the length of the pipe from the pump to the storage tank, the height difference and the number of losses in the pipe. By knowing the TDH, the pump power can be determined and the type of pump selected according to the standards on the market. Selecting the accurate pump head has an important role in deciding the overall efficiency of the SWP (Verma et al., 2020). Solar water pumps are designed to use the direct current (DC) provided by a PV array, although some newer versions use a variable frequency AC motor and a three-phase AC pump controller that enables them to be powered directly by the solar modules (Raghav et al., 2013).The design of the system using simulation software helps to get the best result from available resources (Sharma et al., 2020). The software used to help with calculations is Compass lorentz and PVsyst.

The last is to determine the volume of the water storage tank. A water storage tank is an essential component especially in case of drinking water. A tank can be used to store enough water during peak solar energy to meet water needs in the event of cloudy weather or maintenance issues with the power system (Immadi et al., 2013). Considerable evaporation losses can occur if the water is stored in open tanks, while closed tanks big enough to store several days water supply can be expensive (Abu-Aligah, 2011). In general, storage tanks should be sized to store at least 2-3 days of daily water demand supply (m^3/day) x 3 days (Argaw et al., 2003). Field survey data show that many of the SWP storage tanks are too small, and experience overflows during the day and shortages at night. Optimal tank size must take into account hourly water demand patterns as well as possible variations in solar insolation in supplying water to the tank (World Bank, 2018) and determine the amount of costs needed to build SWP (cost budget plan) and the costs of operation and maintenance (O&M) as well as analysis of environmental impacts due to development (social risk).

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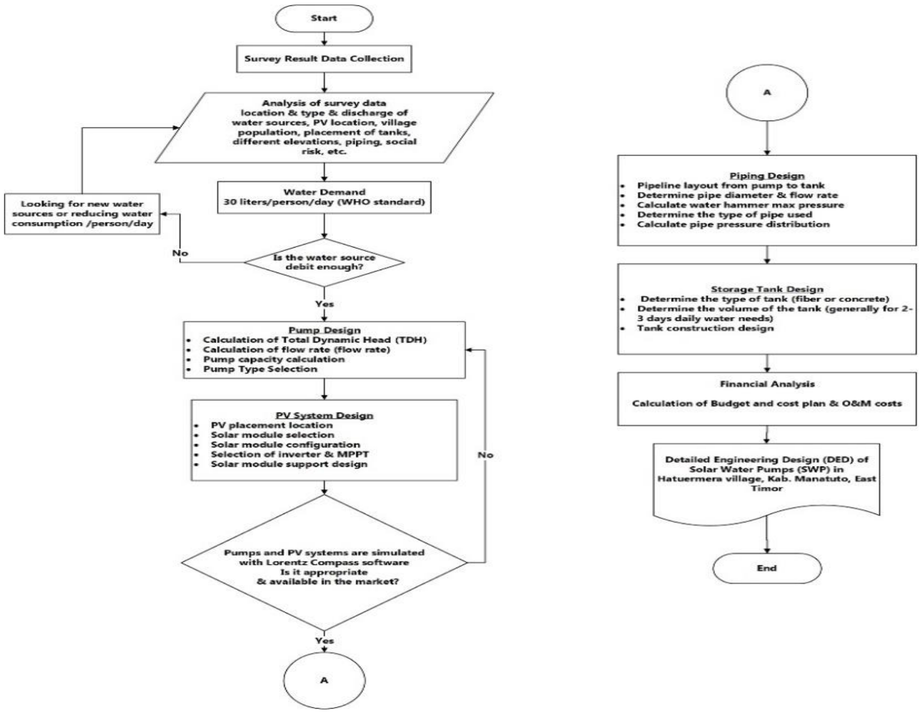

Fig. 1: Flowchart of the methods

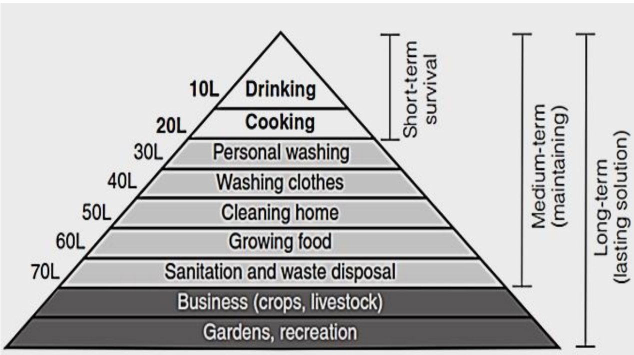

Fig. 2: Hierarchy of water requirements (after Maslow's hierarchy of needs)

Solar Water Pump Planning)

Solar water pumping systems generally consist of a PV array, a motor-pump subsystem, a controller and a tank Figure 3. The motor-pump subsystem includes a motor, a pump and a power converter (Ould-Amrouche et al., 2010). The SWP system configuration chosen for Hatuermera village is a PV-DC pumping system because the volume of water required is small. In this system the PV module is connected to a DC pump without a DC-DC converter. The configuration of this system is shown in Figure 3,

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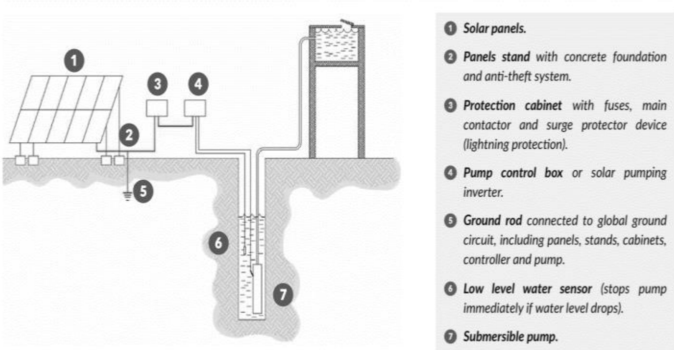

Fig. 1: Solar water pump configuration (Barlow et al., 1993)

The location of Solar Water Pump as shown in Figure 4.

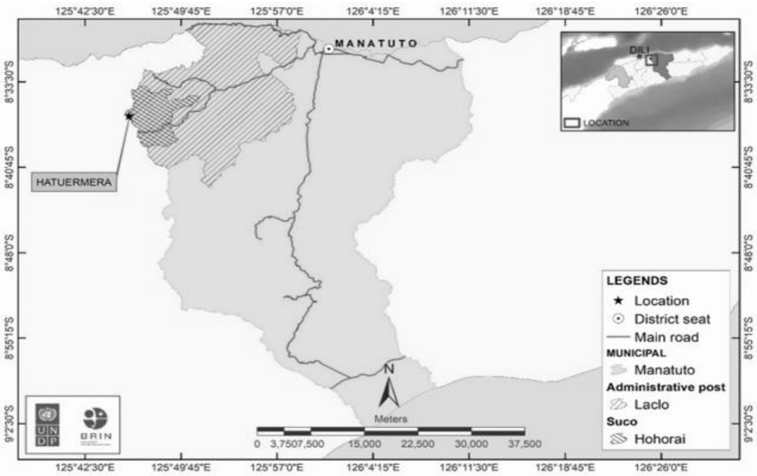

Fig. 2: Location solar water pump at Hatuermera village

Population and Water Resources

Based on the 2019 Manatuto City Statistics Document, the administrative area of Hatuermera is one of the 103 Aldeias in Manatuto, part of the administrative post Laclo and Suco Hororai. The population data of Hatuermera as a beneficiary of the PV Solar Water Pump System Project based on the results of the field survey in 2021 conducted by UNDP is shown in Table 1.

Table 1: Number of project beneficiaries in Hatuermera area (Da & Nci, 2019)

Suco/Village	Number of population (People)	Household
Hatuermera	245	84

Based on the results of the field survey in 2021, the number of beneficiaries of the solar water pump system project is 84 households consisting of 245 people. The difference in numbers should be further investigated to get more accurate data.

Access and Water Resources

Based on Document a Pre-Feasibility Study 29 Project Locations for the Implementation of a Solar Water Pump System in Timor Leste issued by UNDP in 2019, the water sources of Hatuermera Village is spring water. There are 2 (two) springs water in Hatuermara village, namely Aroen springs and Aimeta springs. However, for my Hatuermera area, people generally use Aroen springs.

Based on the information from the document, the current condition of the quantity of water sources is very sufficient, because the water sources are not dry even in the dry season. However, there is no public system in this area because the location of the water source is at the bottom of the mountain, while the community settlements are generally located on top of the mountain. Therefore, it is hoped that the pump facility will make it easier/assist the community in reaching water sources so that people can travel closer to getting water through public taps.

Fig. 3: Aroen Spring as a water source for the community of Hatuermera village (Da & Nci, 2019)

Water Demand Calculation

The quantity of water that will be consumed by all consumer groups is referred to as the water demand, and this definition assumes that there are no limiting factors such as a lack of resources, pressure, a negative perception of the quality of the water, inaccurate distribution, etc .

Table 2: Water demand calculation in Hatuermera (UNDP-TL, n.d.)

Municipal		Manatuto	
village		Hatuermera	
No	Water Spring	Total Discharge (m^3/d)	
1	Aroen Spring	22.12	
No	Water Demand Criteria	Total Demand (m^3/d)	Pumped Demand (m^3/d)
1	**WHO Criteria (30L/Person/Day) +10% Growth**	**8.09**	**8.09**
2	WHO Criteria (30L/Person/Day)	7.35	7.35
3	Survey +10% Growth	5.39	5.39
4	Survey	4.90	4.90

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Water Supply Scheme in Hatuermera Village

To supply the water needs of Hatuermera village, it is obtained from the Aroen spring located at latitude 8.6, longitude 918.8 with elevation 918.7 m. This source has 10.7 m^3/day. Then the spring is made a water reservoir with a capacity of 2 times the total water demand per day to ensure the adequacy of water needs per day. The water reservoir is placed at a height below the location of the water source. The water in the reservoir is pumped into the reservoir/distribution tank with a distance of 540 meters with an elevation difference of 163 meters using a solar water pump. From the reservoir, water is flowed by gravity to 11 faucets in the village of Hatuermera. To distribute water as needed, a water flow control valve is installed in each tap.

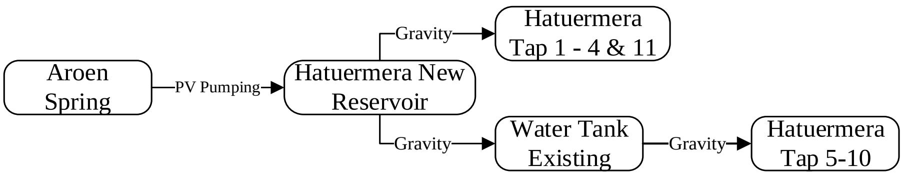

Fig. 4: Overall water supply system topology in Hatuermera village

Solar resources

For the calculation of photovoltaic capacity, radiation data is needed. For this purpose, secondary data is taken from Meteonorm 8.0 satellite data, for each location. For the Hatuermera location, data on global radiation, diffuse, are obtained, as shown in Table 3.

Table 3: Solar Resources at Hatuermera Village

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	183.2	147.4	154.3	183.6	155.1	155.7	168.1	184.1	187.5	207.5	195.5	184.5	2106.5	kWh/m²
Horizontal diffuse	77.7	81.7	83.9	66.0	70.5	55.4	54.6	61.3	63.4	80.6	76.6	78.8	850.5	kWh/m²
Extraterrestrial	336.8	303.7	325.4	290.7	272.9	248.7	262.0	285.2	302.4	330.0	324.5	335.0	3617.3	kWh/m²
Clearness Index	0.544	0.485	0.474	0.632	0.568	0.626	0.642	0.646	0.620	0.629	0.602	0.551	0.582	ratio

RESULT AND DISCUSSION

Total dynamic Head (TDH)

The Total Dynamic Head (TDH) is the total vertical height that the pump has to push water that takes into account all losses. The TDH of any system is given by: Vertical head + Major Loss + Minor Loss.

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Table 4.:Total Pumping Head and Transmission Line Sizing (Nath Shrestha et al., 2014)

Distance of pumping main, L	=	**540,00**	m
Total level difference between source and proposed reservoir	=	**163,00**	m
Total discharge to be pumped, Q	=	2022,50	L/h
	=	0,0006	m3/s
By Lea's formula, economic size of pumping main D is given then:			
D = 1,22 x sqrt (Q)	where, Q is in m3/sec		
Hence, D	=	28,92	mm
However available size of HDPE pipe nearest to this size is:	=	40	mm
Hence, use 40 mmØ HDPE pipe having bore Calculation of head loss:	=	40	mm
Here, discharge, Q	=	0,56180556	Lps
For 40 mmØ HDPE pipe			
Pipe bore, D	=	40	mm
For length, L	=	540	m
Pipe material being used		HDPE	
Velocity of flow, $V = Q/A = 4Q/\pi D^2$	=	0,45	m/s
Absolute roughness	=	0,0015	mm
Coeficient of friction, f	=	0,0507	
Using Darcy-Weisbach equation			
Headloss, $H1=f.L/D.v^2/2g$	=	6,97	
Total Headloss	=	6,97	
Total head for pumping = Level difference + headloss + suction head			
Depth of sump-well	=	2	m
However take the dynamic level of water for submersible pump as 1,2 m below the sumpwell dynamic level of water below the sumpwell for submersible pump as	=	1,2	m
Total dynamic head, H	=	**172,15**	m

The head of operation, total daily water output, flow rate, and subsystem efficiency at the head of operation all play a significant role in pump selection .The majority of pumps are using an average subsystem efficiency of 40-50% (Renu et al., 2017). DC motors are used in many solar water pumping systems because they can be directly connected to PV arrays and simplify the system (Taufik et al., 2009). Brushless dc motors are now available and provide low maintenance on shallow submersible pumps (Nyein & Ya, 2019).

The Solar water pumping system (SWP) in Hatuermera used to pump water from the Water Spring to main reservoir. The SWP for 245 people with pumped water demand of 8.09 m^3/day, the total dynamic head of 172.15 m, and the lowest peak-sun-hour (PSH) of 4.42 h in May, can be estimated using the equation (1) – (3) below:

The daily electrical energy to be supplied to the motor pump with water demand (Q) of 8.09 m^3/day, Total dynamic head (TDH) of 172.15 m, and pump efficiency of 0.6, can be calculated using formula (1) in Watt hours per day (Wh/day):

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Total hydraulic energy required =

$$8.09\ m^3/day \times 172.15\ m \times 1{,}000 \times 9.8 / 3{,}600{,}000 = 3.795\ kWh \quad (1)$$

Assume that pump motor is optimally sized at its operating point of 60% wire-to-water efficiency

$$E(Wh/day) = \frac{3.795}{0.6} = 6.325\ kWh/day \quad (2)$$

The rated water pump for the daily electrical need of 6325 Wh/day or 6.325 kWh/day, and the daily solar irradiation 0f 4.42 kWh/m2.day or PSH (4.42 h) at the site, can be estimated with the equation (2) about 1.4278 kW or 1427.8 Watt.

$$P\ (W) = \frac{6.325}{4.42} = 1.4278\ kW \quad (3)$$

Solar PV Module and Array Support

The pumping system will be unable to meet the water demand if the PV array is not properly sized, resulting in the project's failure (Almarshoud, 2016). To reduce the voltage, drop in the cables, a minimum distance should be maintained between the pump and the PV panels. Harmonics are produced when distance is increased, and in order to prevent damage to the pump and inverter/control, a harmonics filter would be required (Solar & Initiative, 2017). The arrangement of the PV array has a significant impact on the efficiency of water pumping systems powered by solar PV (Aliyu et al., 2018). To simplify and minimize error possibility in construction process, PV module used is limited to only one type of PV module for all villages with specifications as Table.5:

Table 5: Proposed PV module specification used for design reference

Peak Power (P_{MAX})	400 Wp
Open Circuit Voltage (V_{OC})	41.20 V
Maximum Power Voltage (V_{MPP})	34.20 V
Short Circuit Current (I_{SC})	12.28 A
Maximum Power Current (I_{MP})	11.70 A
Module Efficiency (η)	20.80%
Number of Cell	120 (2x60)
Dimensions	1754×1096×30 mm
Weight	21 kg
Maximum System Voltage	1500 V (IEC)
Warranty	min. 15 years
Certifications	IEC61215, IEC61730, IEC61701, IEC62716

Total peak power of PV array with no tracking system, and in the clean environment (PR=0.6) required to run the motor-pump of 1427.8 W is calculated using equation (4) about 2379.7 Wp.

$$P\ (Wp) = \frac{1427.8\ (W)}{0.6} = 2379.7\ WP \quad (4)$$

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The SWP at the site requires 6 pieces of PV module with power rate of 400 Wp, type poly/mono crystalline (see Table 6).

PV module support is aim to mount the solar module array to optimize them in receiving sunlight. Ideally for tropical area, PV module support installation tilts 10^{o} to the north. For optimal results, the solar module supports can be made permanently or movable following sun direction, day and night. PV module supports sit on a solid foundation, so they don't slide over against wind gusts or other disturbances. They can be made higher, for shadow-free purpose that blocking the solar array from receiving sunlight.

Controller

Fig. 7: Pump controller technical specification of PS2-4000 from Lorentz

Piping Distribution Design

Water from Aroen spring with a height of 899 m is streamed with a Solar Water Pump to the reservoir in Hatuermera village with a height of 1062 m as far as 540 m. The pump discharge is 2.0225 m^3/hr (If Sun Peak Hour = 4). Then it goes gravitationally to 5 water taps around the reservoir as well as the water tank with a distance of 318 m, then the water is distributed into 6 other taps using gravity system. The water flow in each tap is equalized using the Flow Control Valve, of 0.184 m^3/hr/tap.

Table 6: Water Tap Distribution

Water Source	Water Source Elevation (m)	Number of taps/ public hydrants	Nearest Tap		Farthest Tap	
			Elevation (m)	Pipe Length (m)	Elevation (m)	Pipe Length (m)
Hatuermera Reservoir	1062	11	1054	74	840	1506

The water distribution system of Hatuermera is described in the following block diagram:

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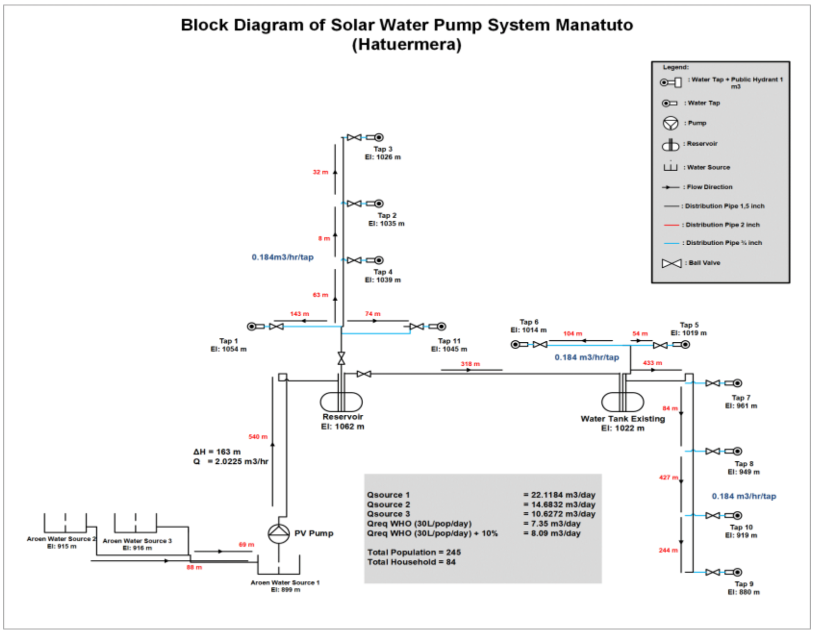

Fig. 8: Block diagram of Hatuermera village

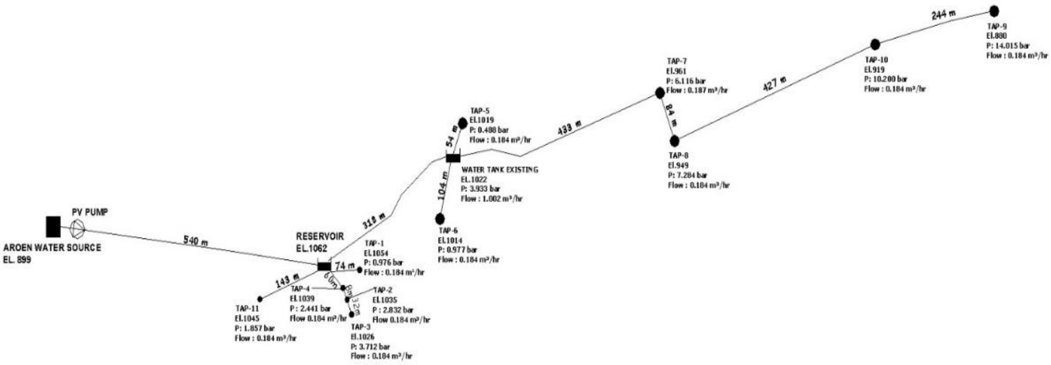

Fig. 9: Pressure distribution in water taps of Hatuermera

Simulation

Solar Water Pump in Hatuermera will be used to pump water from Aroen Water Spring to Hatuermera main reservoir. Pump rating and required PV capacity is calculated with software assistance which consider required flow, head (static/dynamic), location of the Solar Water Pumping system (irradiation and rainfall).

Table 7: Summary of solar water pumping system for Hatuermera village

Pump Designation	Pump Type	Pump Motor Rating (W)	PV Size (WP)	PV Conf (WP)	Pump Head (m)	Pump Output (m^3/d)	Putput (L/WP)
Aroen Spring to Hatuermera Reservoir	PS2-4000 HRE-05HHL	4000	2400	6x400	150-450	8.8	3.7

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Figure 10, is the daily water output average in each month for the Hatuermera Village Solar Water Pumping system, with the lowest daily output in June is 8.8 m^3. The software iteration resulted in the use of a pump with a motor rating of 4000W which means the manufacturer has recommended the pump available on the market. Because the pump is a permanent magnet DC pump, the pump can work normally on a variable basis, even with a PV input of only 2400Wp. The amount of variable power supplied to the pump will be directly proportional to the amount of water output/discharge issued by the pump. Assuming a PV system power loss of 15% (typical), the PV system will be able to supply power in the range of 0 - 2040W. So with the sun sensor switch set at a minimum of 100W/m^2, the pump will work in a variable manner with an operating power range between 204 - 2040W depending on the level of solar irradiation, ambient temperature and wind speed.

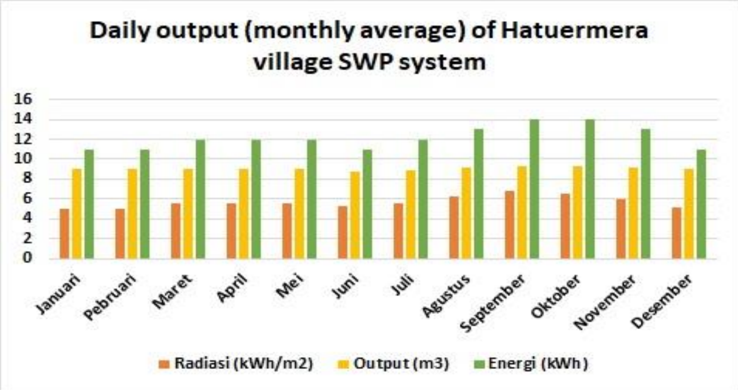

Fig. 10: Daily output (monthly average) of Hatuermera village SWP system

Below is the specification of the pump and motor for Hatuermera Village Solar Water Pumping system.

Table 8: Specification of proposed pump for Hatuermera village SWP system

Pump Type	**PS2-4000 HRE-05HHL**
Head	Max. 450m
Flow rate	Max. 0.92m^3/h
Motor Power	4000 W
Motor Type	Brushless DC
Input voltage	max.375 V
Optimum Vmp	> 238 V
Motor current	Max. 14 A
Motor speed	900 - 3300 rpm
Pump Type	Helical rotor
Pump Material	Stainless steel: AISI 304/316
Borehole Diameter	min. 4.0 inch

The pump will be powered by 6 pieces of 400 Wp PV modules connected in series into the pump controller as shown in the figure below. The support and frame of PV modules shall be

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grounded to a grounding system with grounding resistance < 5Ω or as suggested by PV module manufacturer.

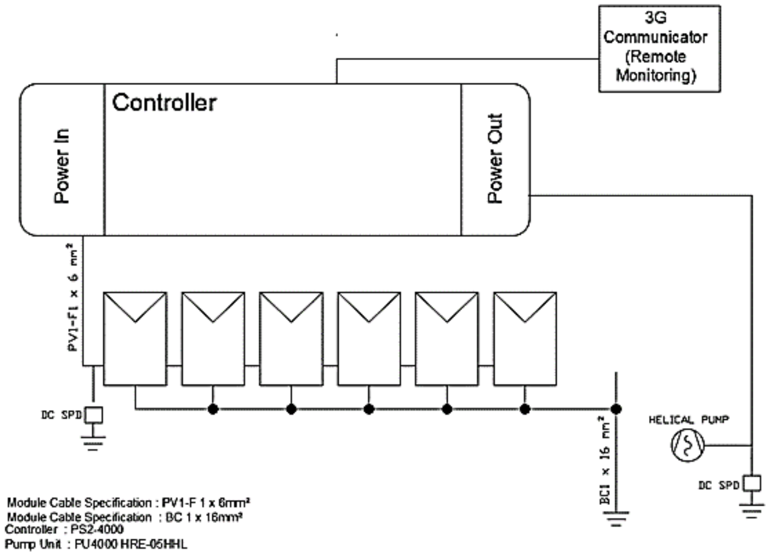

Fig. 11: Wiring of PV modules to pump controller in Hatuermera village SWP system

With 400 Wp PV system connected to the pump controller, the expected power output on average sunny day will be around 1200 - 1700 W, therefore pump output at 163 m static head and 540 m piping length will be approximately 0.9 m^3/h as shown in pump output-power characteristic below.

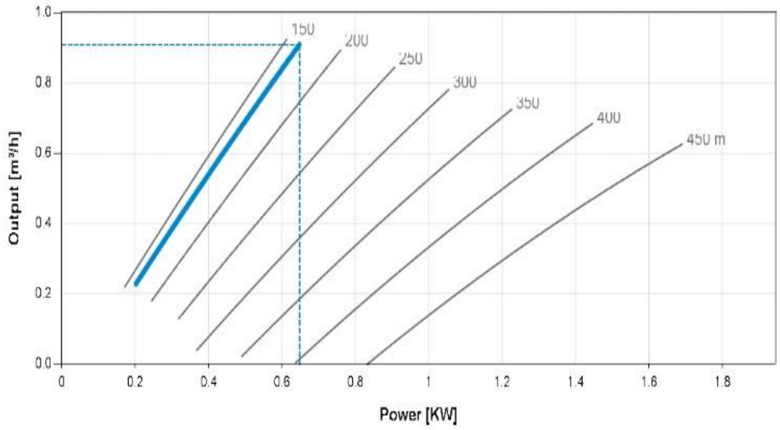

Fig. 52: Output characteristic of SWP system with installed PV in Hatuermera village

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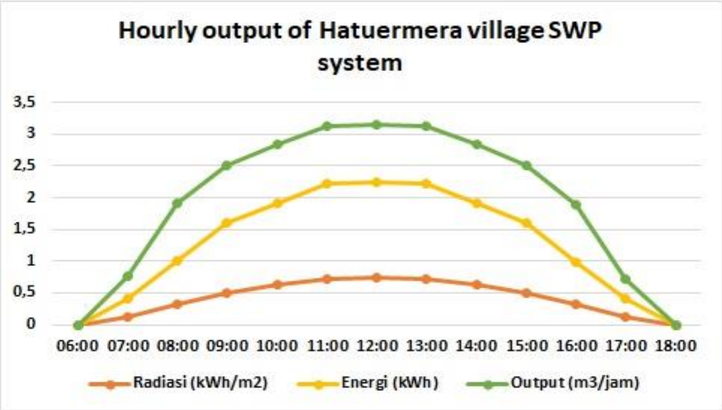

Fig. 63: Hourly output of Hatuermera village SWP system

CONCLUSION

From the results of calculations and simulations, to meet the water needs of 245 inhabitants of the village of Hatuermera, Manatuto Regency, Timor Leste, a solar water pump is needed at Aroen spring with a capacity of 8.09 m^3/day with a static head of 163 m. which is located 540 m from the village of Hatuermera. The total peak power of the PV array required is 2379.7 Wp which is supplied from 6 solar modules with a power rate of 400 Wp which are connected in series.

The type of pump selected is a helical rotor submersible pump with DC current. This is because electricity from solar panels is DC electricity so it will be more efficient if you use a DC pump. In addition, DC pumps have the advantage of being more efficient because they provide maximum output with fewer solar panels.

DC pumps do require more difficult maintenance, but because DC pumps have a motor with copper coils inside they are more durable, increasing the life of the pumping system. AC solar pumps, on the other hand, have solar motor coils made of aluminum, making them susceptible to damage. As a result, it requires more frequent maintenance compared to DC pumps.

From a social and environmental perspective, the construction of a clean water supply system will make it easier for residents to get water and improve people's lives, but with a limited quota. This has the potential to cause social conflict. Therefore, it is necessary to socialize the management of the Water Pump System and the use of water for the community.

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