

Article

Design and Analysis of Solar Water Pumping System to Supply Water for Shambu Town, Horro Guduru Wollega Zone, Oromia Regional State, Ethiopia

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Abstract: Due to the fact that the price of fossil fuel is increasing in developing countries, many researchers are investigating the scientific research to overcome the challenges day to day. This research was focused to Design solar water pumping for supplying water for multipurpose utilization in Shambu town. Normally water pumping needs generator driven pumps, which requires fuel and human labor but the diesel generator is operated through the man power by using fuel diesel and also needs maintenance. The design and Evaluation of the system was done by using Ethiopian Excel Toolkit through fitting Locations, The results found by design for Total daily water requirement, Maximum (Design flow rate), Storage thank size, Net positive suction Head (NPSH) available, NPSHrequired, PV array size needed, most Economical module size and Actual size PV Array, recorded values from the toolkit were 4,750.9m³/day, 261.7L/s, 9,501.8m³, 14.28m, 5.00m, 8896wp, 150wp and 9000wp respectively, considering design month of July (5.0kwh/m²/day) of solar irradiance. The Design for solar water pumping system contributes basic knowledge for local community by creating awareness and assists them, to use the design sample as starting point to install solar water pumping system and for cultivations of crops via familiarizing themselves with new technologies.

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Keywords: Excel Toolkit, Net Positive Suction Head, Actual PV Array Size, Economical Module Size, Water Pumping System

1. Introduction

In developing countries like Ethiopia, which have scarcity of fuel resources and composed many rural area, it is very difficult to cover all places by electric power to the locations and supplying of water to rural areas as well as to town is very difficult [1]. Majority of water resources for rural, town and for irrigation of crops and watering animals, the sources are deep wells, shallow wells, Rivers, and ponds. Diesel and petrol driven pumps for supplying water have many problems like running cost, maintenance cost, and high consumptions of fuels and lack of availability of parts to replace the generator during breakage time [2]. Thus Solar water pumping, which is driven by photovoltaic energy can solve the diesel generator problem that utilized for pumping water.

Solar generator, which is a solar module made up of silicon cells is the best options for water pumping in fulfilling water demand for town and remote areas [3]. The availability of solar irradiance in the site, where PV module or generator installed ad

shading, climatic conditions can affect the locus maximum power output. Additionally, there are other huge problems for which the use of solar energy is the best option. Scarcity of the nonrenewable energy resources like coal is mostly used for the generation and supply of electrical energy which demands in the world [4]. This generation of electricity will increase carbon content in the climate, which lead to increase the pollution environment and global warming. So in developing countries, solar photovoltaic water pumping system can be used for the supply of water for multipurpose can be the best alternative solution to tickle the problem today and in the future.

2. Materials and Methods

2.1. Site description

Shambu is a town and separate woreda, in western Ethiopia, see Figure 1. Located in the Horro Guduru Wollega Zone of Oromia Region west of Lake Fincha'a, this town has an elevation of 2,503 meters above sea level. It was previously the administrative center of Horro woreda.

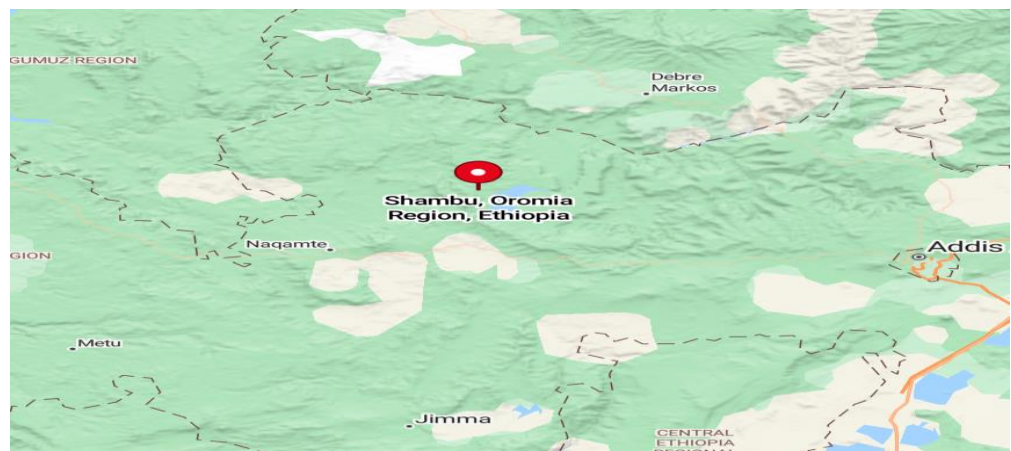


Figure 1. Map of Shambu town.

The design was carried out using different soft wares like Ethiopian excel toolkit and Lorentz Compass.

2.2. Data need for Design using the toolkit and Procedures

2.2.1. Data needed for PV sizing and determining the water requirement demands

- a. Population size of the town
- b. Number of cattle
- c. Number of equine
- d. Number of pigs
- e. Number of Goats/ Sheeps
- f. Number of camels
- g. Number of chickens

2.2.2. The procedures followed for using the soft wares were

- a. Determination of the location by the software's through providing
- b. Latitude(N) and
- c. Longitude (E)
- d. Determination of daily water requirements
- e. Determination of hydraulic power requirement
- f. Estimation of solar resources(Solar irradiances) in the site
- g. Financial analysis
- h. Summarizing the Design and Recommending the data users

The Ethiopian solar toolkit Excel developed by The Ethio-Resource Group was used for the design and analysis.

The data used for population of Shambu town was taken by estimating population size for Designing sample analysis to create awareness among our community towards adapting new technologies.

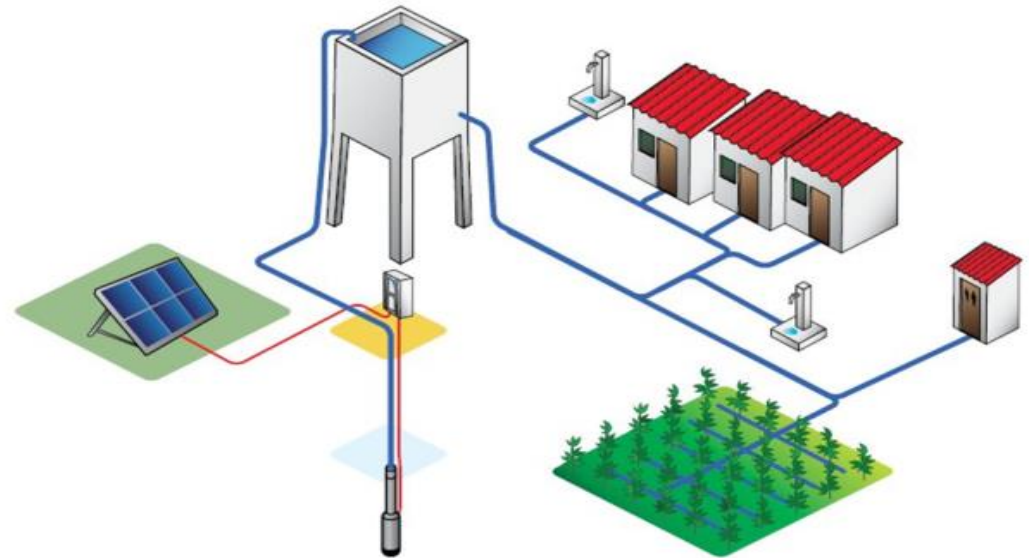


Figure 2. Solar water pumping figure demonstrating multipurpose utilization.

Source: Lorentz Compass

The Figure 2 above illustrates as solar water pumping have the capacity of supplying water for multipurpose utilization, especially for home water supply, irrigating orchards, supplying water for swimming pool, Drinking for animals and for irrigating different crops, By having this concept in mind, the design was carried out for Shambu town.

3. Results and Discussion

3.1. Determination of Daily water requirements

The toolkit was used location details of the Shambu town for determination of daily water requirement and this location information were illustrated in the summary sheet of the excel toolkit used for the design .

Thus the Community water supply was estimated from population size and from the daily per capital water consumption. Water demand estimation also considers the future demand from the growing population. Livestock water supply was estimated from the number of animals using the system multiplied by the per capital water consumption [5]. The design also considered, livestock population growth rate.

Usually, water demand estimation considers the life time of the water lifting system or the major cost item of the system components. A properly sized system would suffice the existing and growing demand for water during its life time. The user has to forecasted and entered the population size of the community and/or livestock number anticipating the life time of the water pumping system [6]. The toolkit does not forecast future demand.

The Ethiopian standard for water supply is 15 and 20 liter per person per day in rural and urban settlements respectively [7].

Livestock water supply depends on the type of animal of daily water requirement illustrated in Table 2 below as per the standard unit for categorization of livestock by type in tropical areas. According to International Livestock Research Institute (ILRI), per capita water demand is 25 liters per TLU per day, Extremely hot heat-stress weather could

increase the daily requirement by 20 to 30% [8]. The flow rate is calculated based on the peak sunshine hours of the design month.

Table 1. Determination of Daily water requirement.

STEP 1 - Determine Daily Water Requirement

1. Village/community water supply
Community water supply can be estimated from population size and from the daily per capita water consumption. Water demand estimation also considers the future demand from the growing population. Usually water demand estimation considers the life time of the water lifting system or the major cost item of the system components.

2. Water for livestock
Livestock water supply is estimated from the number of animals using the system multiplied by the per capita water consumption. It also considers livestock population growth rate.

Please enter daily water demands for the predicted period in gray shaded cells:

3. Location Name: Region Zone Horro
Kebele Site Name

4. Community water supply
Per capita water demand liters/day (ranges from 15 to 50 liters/day)

5. Water for livestock

Livestock Type	Water demand (L/day)	Typical values (L/day)
Cattle	100	25 - 60
Camel	0	40 - 70
Equine	40	30 - 45
Sheep/goat	10	4 - 15
Pigs	20	10 - 20
Chicken	300	0.1

Values in **Green Shaded Cells** are typical values for livestock water requirement. These values may vary depending on livestock breed and also seasonally. Users are required to enter appropriate values in **Gray shaded cells**.

Note: Water demand for humans and livestock may vary depending on local climatic conditions.

Daily Water Requirements: Enter population value for the predicted period.

	Quantity	L/day
6 Population size	<input type="text" value="100,000"/>	<input type="text" value="4,500,000"/>
7 Cattle	<input type="text" value="100"/>	<input type="text" value="10,000"/>
Camel	<input type="text" value="0"/>	<input type="text" value="0"/>
Equine	<input type="text" value="40"/>	<input type="text" value="1,600"/>
Sheep/goat	<input type="text" value="100"/>	<input type="text" value="1,000"/>
Pigs	<input type="text" value="20"/>	<input type="text" value="400"/>
Chicken	<input type="text" value="300"/>	<input type="text" value="90,000"/>
8 Other water demand (L/day)	<input type="text" value="600"/>	<input type="text" value="600"/>
9 Enter additional percentage of daily water supply that you want to account for storage or compensate for losses due to spillage.	<input type="text" value="3.2%"/>	
10 Storage Tank Required - days of storage	<input type="text" value="2.0"/>	days
11 Total Daily Water Requirement		4,750.9 m³/day
12 Maximum/Design flow rate		261.7 L/s
<i>It should not exceed safe yield of the well</i>		942.0 m³/h
13 Storage Tank size		9,501.8 m³

From table 1 above, total daily water requirement was recorded automatically 4,750.9m³/day, Maximum Design flow rate was 261.7 L/s and the storage Tank size was 9,501.8m³.

According to, table 2 below, the recommended typical values of water demand per animals and types were demonstrated in the software toolkit for the design purpose, tabulated in the following table but the water demand varies based on the climatic conditions of the area for humans and live stocks.

Table 2. Sater demand recommended for livestock's.

No	Livestock type	Typical values(L/day)
1	Cattle	25-60
2	Camel	40-70
3	Equine	30-45
4	Sheep/Goat	4-15
5	Pigs	10-20
6	Chicken	0.10

Source: International Livestock Research Institute (ILRI)

3.2. Determination of Hydraulic Power requirement for the Design

The second step of the design process was determination of the Hydraulic Power Requirement. In the Toolkit the designer entered the type of water source, type of pump, dynamic and static heads, and type and size of pipe network including fittings. The user had the possibility of choosing types and sizes of pipes from drop-down menus and calculates head losses in the pipes and fittings. The toolkit calculates the total dynamic head and the total hydraulic power requirement of the system, when appropriate value feed to it. The Net Positive Suction Head Required (NPSHrequired) was found 5.00m and

it should be compared to solar pump manufacturers manual and the system calculates the (NPSH Available =14.28m) and the minimum depth of the Pump position from the dynamic water level was illustrated in the tool kit. The ‘-’ sign on the ‘-15.72m, Minimum depth from the dynamic water level’ indicates that the pump must be below this level. From figure 3 below, the results obtained by consideration of Bore hole and submersible pump the total hydraulic head was 39.406m4/static water level below the ground(hg) at 80m,Draw down(hd) of 20m,pump position from dynamic water level(hp) at 25m,Vertical lift above the well head(hv) was at 41.4m,The total static head from the toolkit calculated immediately,141.4m and From the design again considering the head losses in the pipe ,results found were by taking into account the required data must be feed by the designer, Thus riser diameter pipe was considered 12inch,riser pipe type was selected from the drop down menu, as Galvanized steel, Delivery pipe length of 300m,delivery pipe diameter of 18inch,delivery pipe type of Galvanized steel by taking into account the Friction losses for pipe aging of 5%(0-15), friction losses in the pipe, total friction losses in the pipes and fittings was calculated 7.2m.the residual reservoir exit was 2m,the Total dynamic head obtained was150.6m,the percentage of friction losses of 5% and Then finally, the overall total hydraulic Power requirement, for solar water pumping of submersible pump type was obtained, 386,180.1 watt, from the design data’s. The Figure 3,below illustrates the layout of the Hydraulic Power Requirement sheet from the excel toolkit.

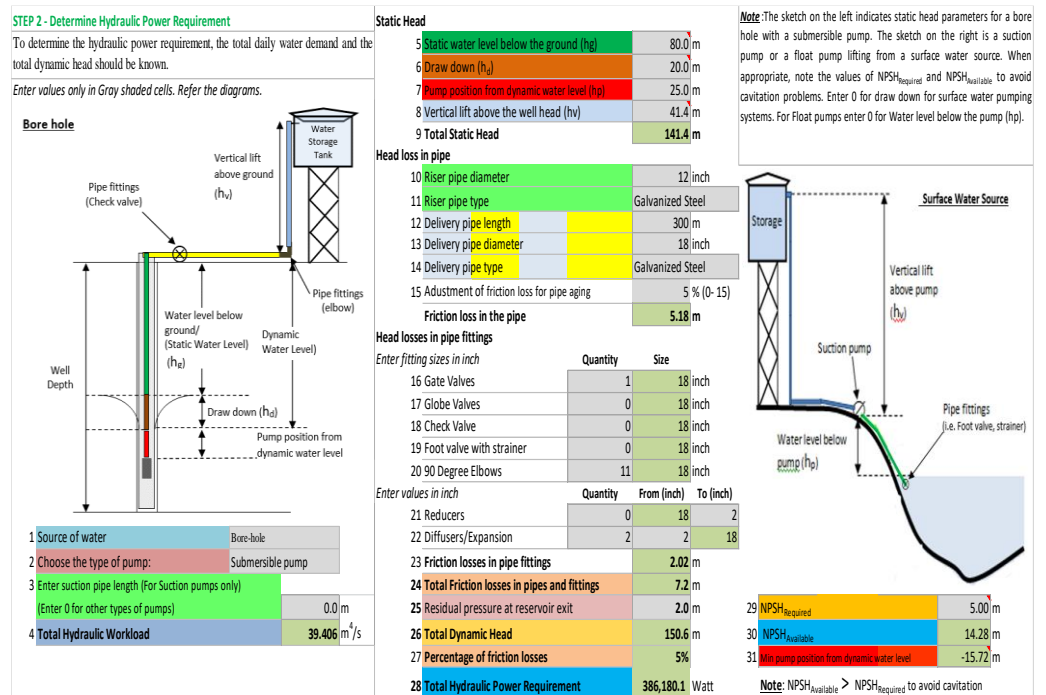


Figure 3. Determination of Hydraulic Power requirement.

The toolkit accommodates designing of systems for bore-holes and surface water sources, 0 (zero) was entered for other type of pumps.

Note the changes in the labels indicated by bullet number 5 to 10 for different types of pumps. The correct type of pump appropriate to the type of water source was selected, so that the labels that describe the type of data in subsequent cells were correctly displayed. The schematics on the left and right side of the worksheet guide the user which data are referred in the cells provided.

The diameter and type of suction pipe (in the case of suction pump), riser pipe (in the case of submersible pumps or positive displacement pumps[9] and delivery pipes was entered from the drop-down menus.

Pipe length was entered in meters. Since “Inch” is the standard unit of measurement for pipe sizes, the designer must choose the appropriate size of pipes from the drop-down

menu. Similarly, the pipe material whether galvanized steel, PVC or polyethylene, must also be selected from the drop-down menu.

Head lose in the pipes due to friction is pretty much accurately estimated using Moody's equation for the first estimation. Then, Colebrook's equation to the tenth iteration was used to determine friction losses in pipes to high precision. Note that the widely used Moody's Diagram for estimation of friction losses in pipes during fluid flow was generated from Colebrook's equation [9] as illustrated in equation 1 and 2 below.

Equation 1 : Moody's equation calculating friction losses in pipes

$$f = 0.0055 \left[1 + \left(20000 \frac{e}{D} + \frac{10^6}{Re} \right)^{1/3} \right]$$

Where:

- f - friction factor
- e - effective surface roughness
- D - diameter of the pipe
- Re – Reynold's Number

Equation 2: Colebrook's equation to the tenth iteration was used to determine friction losses in pipes to high precision

$$f = \left[1.14 - 2 \log_{10} \left(\frac{e}{D} + \frac{9.28}{Re \sqrt{f}} \right) \right]^{-2}$$

The toolkit is primarily intended for designing a new water supply system. However, it also allows the user to determine the total dynamic head in aged pipes in an existing water supply system provided that the user has sufficient knowledge about the effect of age on the pipes. Effect of aging is prominent in iron-based pipes as the main source of aging is the building up of corrosive materials which increase the surface roughness and also allow suspended particles to accumulate.

3.2.1. Age effects in iron-based pipes in water distribution system

Hydraulic properties of iron-based pipes may change due to aging. Accumulation of corrosive materials and suspended particles in the inside surface of aged pipes increase pipe roughness and reduce pipe diameter [10]. In both cases, the changes in the pipe surface profile increase head loss due to friction as a result of increased surface roughness and increased flow velocity due to reduced pipe diameter [11]. The rate of accumulation of corrosive and suspended materials in pipes depends on the nature of the fluid in terms of its chemical composition and suspended materials, the age of the pipe and the type of iron-based material such as galvanized steel, thin-walled steel, and bituminous coal lined cast iron.

A knowledgeable user can estimate the increase in the roughness of the pipe surface and the reduction of pipe diameter due to water age effect in percentage terms relative to a new pipe. To consider aging effect on pipes, the user can calculate ageing effect adjusted pipe size and selected the nearest pipe size available from the drop-down menu.

Number and type of pipe fittings must also be entered in cells indicated by bullet numbers 16 to 22 to calculate the corresponding head loses. Residual pressure at the reservoir exit must also be entered by the Designer. Once all the necessary values are correctly entered, the Toolkit calculates the Total Dynamic Head, the percentage of friction losses and the total hydraulic power requirement of the water supply system. Observing the percentage of the total head loses, the user can play paramount role by selecting different pipe sizes and types until an acceptable percentage of head loss is obtained. To avoid problems of cavitation, the Toolkit helps determine the Net Positive Suction Head available (NPSHAavailable) and calculates the maximum height of the pump position from

the source water level. User needs to enter the value for NPSH required (NPSHRequired) from the manufacturer's manual.

3.3. Determination of solar irradiances in the site

The third step in the solar water pumping system design Toolkit is estimation of the solar resource in the area of interest. The user needs to fill in necessary data in the spaces provided in the tap labeled as Solar Resource. This part of the Toolkit helps to determine the design month and mean solar irradiance based on solar resource data entered by the user. Solar resource data can be available from various sources including own measurement, national solar resource atlas, online data sources[9] Table 3 below shows the layout of the Solar Resource estimation component using the toolkit excel.

The user enters geo-referenced data to locate the specific location of the pump site. This will appear in the description of the project in the summary part. Altitude of the site should also be entered. The altitude value was used to modify the performance of a generator when comparison is made in the feasibility assessment section of the Toolkit.

Table 3. Determination of solar irradiances.

Step 3 - Estimate the Solar Resource in the site

Determine the mean monthly global solar irradiance in kWh/m²/day for every month of the year. This can be obtained from several sources. Solar irradiance data can be obtained from the nearest meteorology station, national solar resource maps or own data for the site.

1 Enter the GPS coordinates of the site in Decimal Degrees
(Eg. 7.9549999 E, 34.31399917N)

Latitude: °N Longitude: °E
Altitude: m

2 Enter the tilt angle for the solar array °
(Tilt angle between 15° to 18° for site in Ethiopia)

3 Populate the table with the mean monthly daily solar irradiance data for the site (kWh/m²/day)

Month	Irradiance on Horizontal surface	Tilt	Irradiance on Array
January	6	15	6.6
February	6	15	6.3
March	6	15	6.1
April	6	15	5.8
May	6	15	5.7
June	6	15	5.6
July	5.4	15	5.0
August	6	15	5.8
September	6	15	6.0
October	6	15	6.3
Novemebr	6	15	6.5
December	6	15	6.6

(Note: For inhabited areas, the solar radiation flux varies from about 3 to 30MJ per m² per day (0.8 to 8.3 kWh per m² per day), depending on the place, time and weather conditions).

4 Design month is the month for which the solar pumping system is sized to ensure sufficient water supply when the solar irradiance is the minimum while the corresponding hydraulic power is the maximum. This is the month where the Reference Area is the maximum.

Month	Average hydraulic power (kWh/day)	Solar Irradiance on Array (kWh/m ² /day)	Ratio P _{hy} /Irrad
January	1947.7	6.6	296.85
February	1947.7	6.3	306.94
March	1947.7	6.1	318.86
April	1947.7	5.8	332.96
May	1947.7	5.7	344.17
June	1947.7	5.6	349.85
July	1947.7	5.0	386.18
August	1947.7	5.8	338.12
September	1947.7	6.0	324.54
October	1947.7	6.3	311.26
Novemebr	1947.7	6.5	299.66
December	1947.7	6.6	294.02

Design month is the month for which the solar PV system is sized to ensure sufficient water supply when the solar resource is the minimum.

5 Design month is the month of with mean solar irradiance of kWh/m²/d

The tilt angle is the angle of inclination of the solar array. In regions near the equator, this is mainly useful to maintain sufficient slop to drain rain water or other to wash away dusts from the solar array. Inclination level between 10 to 15 degrees is sufficient, for regions further away from the equator [12] the inclination helps to maximize the intercepted solar irradiance by the solar array for winter. In this case, the inclination usually is equal to the latitude of the location.

Monthly average Global solar irradiance on horizontal surface data must be entered in gray and white cells under the instruction labeled by bullet number 3. Design month is determined to ensure maximum water demand during the month where the solar irradiance is the minimum. If the Designer prefers to use annual mean solar irradiance for sizing the system, then in all months the annual mean value of the solar irradiance must be entered.

3.4 .Pump selection and solar array sizing

The fourth step in the Toolkit is about solar PV array sizing and to complete this part of the design process the user needs to refer to manufacturers’ manual for pumps. Input values required in this section are pumps-motor performance efficiency which is referred to as subsystem efficiency. It combines the pump and motor efficiencies together. Another value needed from the user is about the pump or inverter/controller unit voltage and current requirement. Table 3 below shows the layout for the Solar PV Array Sizing sheet of the Toolkit.

Pumps technology has improved over the years and it is possible to obtain some pumps that perform at 70% or higher efficiency at the design point of operation [13]. However, the average performance could be lower by 10% or more. User needs to refer to the efficiency graph provided by pump manufacturers and determine the average efficiency which usually ranges between 50% and 60%. The Toolkit uses the average subsystem efficiency to calculate the solar PV size needed for the water pumping system.

With the subsystem efficiency value entered, the electrical energy and the corresponding solar PV array size required was calculated[6]. Selection of appropriate solar panel size and arrangement of the panels, series and parallel combinations, depend on the operating voltage and current ranges of the pump or inverter/controller. Solar panels must be arranged in series and parallel combinations so that the minimum voltage and current required to keep the pump working are ensured and also that the supply voltage and current do not exceed the maximum allowable amount to the pump. Thus from the design 15 modules combined in series and 4 module strings combined in the parallel ,indicates effective design selection .Voltage losses from the solar array should be kept between 5% and 10% [14] . Long wire runs from the solar array to the pump/controller/inverter should be avoided as much as possible by installing the array near the pump location or using appropriate wire sizes. The wire lose factor should be entered to account the loss into the solar array size.

The actual array size with parallel and series arrangement of the panels are also determined by the Toolkit as indicated in table 4 below and Fig 3 and 4 illustrates solar water pumped monthly and hourly by using solar water pumping. The Toolkit also provides options for selection of panel sizes and the corresponding configurations.

Table 4. Solar PV array sizing.

Solar PV Array Sizing																																																													
Step 4 - Determine PV Array Size																																																													
When determining the PV array size, derate factors for the array performance due to power mismatch and cell temperaturing increase are considered. In this worksheet a derate factor of 20% is considered.																																																													
Required electrical energy and the corresponding solar PV power																																																													
1 Average subsystem energy efficiency	44% (Typical values 30% to 50%)																																																												
2 Peak subsystem power efficiency:	50% (Typical values 40% to 60%)																																																												
3 Required electrical energy:	36.6 kWh 7.29 kW																																																												
4 PV Array Size Needed:	8,896 Wp																																																												
Note: Use manufacturers manual for pumps to determine the appropriate type and size of motor-pump unit at the <i>Maximum Flow Rate</i> (shown in 'Daily Water Requirement' sheet) and at the <i>Total Dynamic Head</i> (shown in 'Hydraulic Power Requirement' sheet). Read the pump efficiency from the manufacturers' manual at the system's operating head and discharge. Also determine the minimum and maximum input voltage, and maximum input current to the motor-pump unit directly or to the inverter. Enter these values in the gray shaded cells.																																																													
Selection of module size and PV array arrangement (Selection of modules is made from size that range from 50 Wp to 250Wp)																																																													
5 Minimum operating input voltage to pump/inverter	400 Volt																																																												
6 Maximum input voltage of pump/ inverter	620 Volt																																																												
7 Maximum input current of pump/ inverter	20.0 A																																																												
8 Wire loss factor	0.95 (Typical values 0.8 to 0.95)																																																												
9 Most economical module size	150 Wp																																																												
10 Number of modules connected in series	15																																																												
11 Number of module strings in parallel	4																																																												
12 Actual Size of PV Array	9,000 Wp																																																												
Other Possible Configurations																																																													
	<table border="1"> <thead> <tr> <th>A</th> <th>B</th> <th>C</th> <th>Total Wp</th> <th>$I_{mp,max}$</th> <th>V_{max}</th> </tr> </thead> <tbody> <tr> <td>50</td> <td>31</td> <td>6</td> <td>9,300</td> <td>17.9</td> <td>603</td> </tr> <tr> <td>75</td> <td>31</td> <td>4</td> <td>9,300</td> <td>18.4</td> <td>595</td> </tr> <tr> <td>80</td> <td>29</td> <td>4</td> <td>9,280</td> <td>18.3</td> <td>580</td> </tr> <tr> <td>90</td> <td>31</td> <td>3</td> <td>8,370</td> <td>15.8</td> <td>615</td> </tr> <tr> <td>100</td> <td>31</td> <td>3</td> <td>9,300</td> <td>18.9</td> <td>606</td> </tr> <tr> <td>120</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>150</td> <td>15</td> <td>4</td> <td>9,000</td> <td>18.4</td> <td>576</td> </tr> <tr> <td>170</td> <td>14</td> <td>4</td> <td>9,520</td> <td>19.4</td> <td>561</td> </tr> <tr> <td>250</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>	A	B	C	Total Wp	$I_{mp,max}$	V_{max}	50	31	6	9,300	17.9	603	75	31	4	9,300	18.4	595	80	29	4	9,280	18.3	580	90	31	3	8,370	15.8	615	100	31	3	9,300	18.9	606	120						150	15	4	9,000	18.4	576	170	14	4	9,520	19.4	561	250					
A	B	C	Total Wp	$I_{mp,max}$	V_{max}																																																								
50	31	6	9,300	17.9	603																																																								
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250																																																													
Warning: System voltage and current must not exceed the maximum Voltage and maximum Current of the pump or inverter.																																																													
In such cases, user may need to look for a different array configuration or another motor-pump unit or inverter with higher maximum input voltage and current.																																																													
A - Single PV module size in Wp B - Number of modules in series C - Number of parallel module strings																																																													

The above table 4, illustrates the PV array size needed is 8,896Wp, considering peak subsystem power efficiency of 50%, while required electrical energy was 36.6KWh, the maximum input voltage of pump/inverter was 620volt for the actual size pv array of 9000Wp and the most economical module size was displayed by the toolkit was 150Wp through considering wire loss factor of 0.95. From the design the pv array sizing demonstrated that the designed solar water pumping can be through considering the outcome of the possible configurations of module arrangements, thus the design illustrated for 150Wp of module size, 15 number of modules connected in series, 4 module strings connected in parallel, the required I_{max} (Maximum current input) was 18.4A and V_{max} of 576Volt needed to obtain the desired result

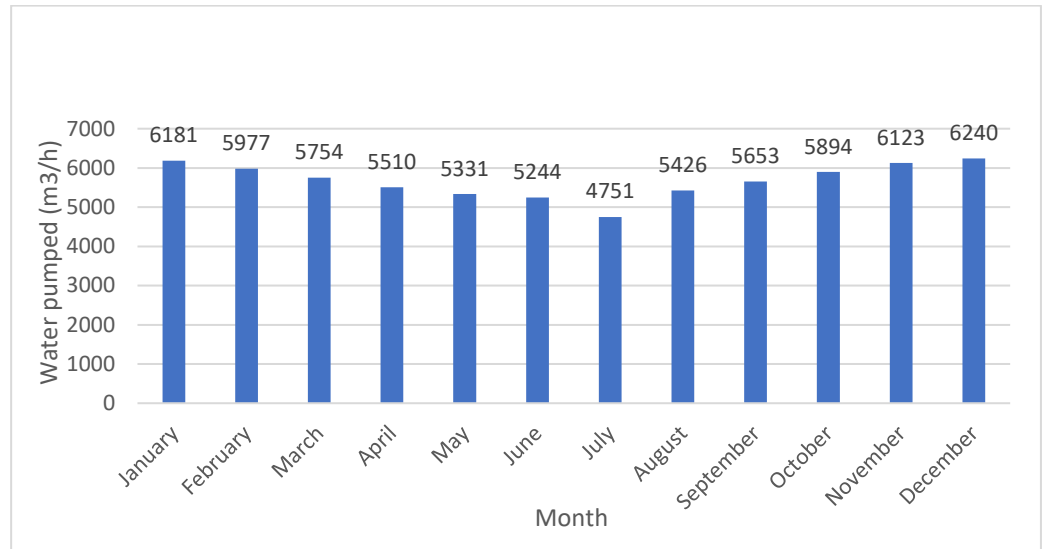


Figure 4. Daily Volume of Water Pumped in a Specific Month (m³/day).

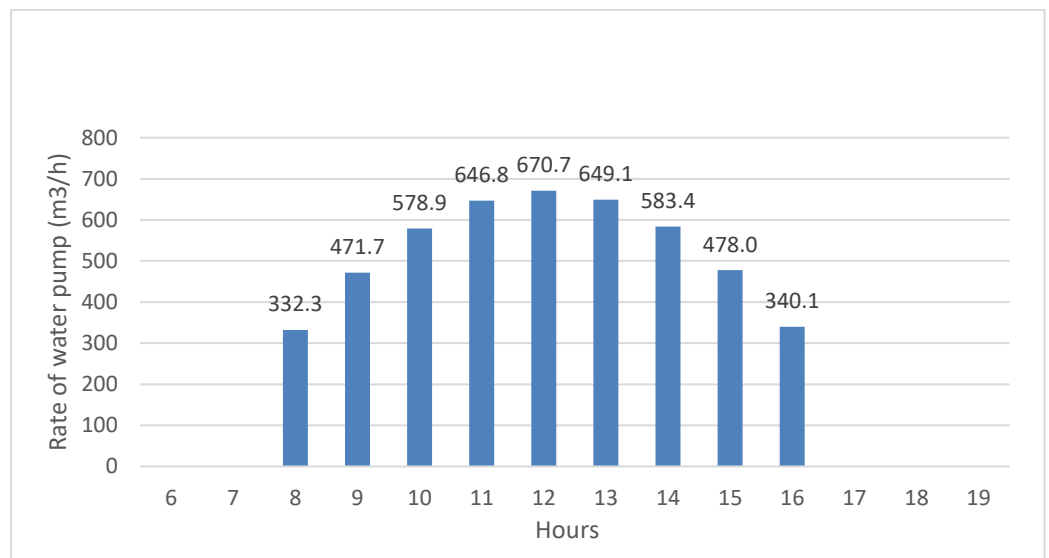


Figure 5. Hourly rate of water pumping in a typical day of the month with Minimum Irradiance.

From the figure 4 and 5 above, the daily volume of water pumped in specific month in m³/day at the design month of July, with irradiance of the months in the year at Shambu town was 4751m³/month and hourly rate of water pumping in a typical day at this month resulted 332.3m³ of water.

4. Conclusion

It was concluded that, Solar water pumping system design Toolkit is used for estimation of the solar resource in the area of interest. This part of the Toolkit helps to determine the design month and mean solar irradiance based on solar resource data entered by the Designer. Solar resource data can be available from various sources including own measurement, national solar resource atlas, According to the design the results found were,

- a. Total daily water requirement was recorded as 4,750.9m³/day for the town, it can also help full for cattle, sheep, goat and other uses
- b. Storage tank size was 9,501.8m³ as per the design
- c. NPSH required was 5.00m³
- d. NPSH available was 14.28m³
- e. Required Electrical energy 36.6kwh
- f. Minimum Operating input voltage of pump/inverter was 400volt
- g. Maximum Operating input voltage of pump/inverter was 620volt
- h. Maximum input current of pump/inverter 20A

Generally, the design illustrated for 150Wp of module size, 15 number of modules must be connected in series, 4 module strings connected in parallel, the required I_{max} (Maximum current input) was 18.4A and V_{max} of 576Volt needed to obtain the desired result by considering Wire loss factor 0.95 its Most Economical module size found was 150wp, Actual size PV Array 9000WP.

4.1 List of abbreviations

A=Ampere
 I_{max} =maximum current
 W_p = Watt peak
 NPSH = Net Suction Head
 V_{max} = maximum voltage
 KWh = Kilowatt hour
 L/s = litre per second

4.2 Recommendations

The authors recommended the following points based on the design

- a. The design is very helpful for delivering courses related to practical solar application in any area
- b. The community of Shambu town can utilize the design as in put data
- c. Students and instructors can use the design as raw data for other designs
- d. It adds knowledge for the scientific community in the globe

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REFERENCES

- [1] M. B. Raghav, K. Naga Bhavya, Y. Suchitra, G. S. Rao, -B Tech, and - Asst Professor, "Design of Solar Power Based Water Pumping System," [Online]. Available: www.ijert.org.
- [2] P. Nisha and S. Joseph, "Design and implementation of solar powered water pumping system," *Int. J. Adv. Trends Comput. Sci. Eng.*, vol. 2, no. 2, pp. 272–278, 2013.
- [3] M. Silwal and R. R. Shrestha, "Project proposal," 2013.
- [4] B. Charjan and S. Wadhankar, "Design of solar powered based water pumping system," 2018.

- [5] A. Saleem, I. Mahmood, H. Sarjoughian, H. A. Nasir, and A. W. Malik, "A water evaluation and planning-based framework for the long-term prediction of urban water demand and supply," *Simulation*, vol. 97, no. 5, pp. 323–345, 2021, doi: 10.1177/0037549720984250.
- [6] D. S. Falconer, "Selection in different environments: Effects on environmental sensitivity (reaction norm) and on mean performance," *Genet. Res.*, vol. 56, no. 1, pp. 57–70, 1990, doi: 10.1017/S0016672300028883.
- [7] A. Tadesse, T. Bosona, and G. Gebresenbet, "Rural water supply management and sustainability: The case of Adama area, Ethiopia," *J. Water Resour. Prot.*, vol. 5, no. 2, pp. 208–221, 2013, doi: 10.4236/jwarp.2013.52022.
- [8] D. Peden, G. Tadesse, and M. Mammo, "Improving the water productivity of livestock: an opportunity for poverty reduction," in *Integr. Water L. Manag. Res. Capacit. Build. Priorities Ethiop.*, pp. 57–65, 2003. [Online]. Available: <http://mahider.ilri.org/handle/10568/274> on 23/08/2016.
- [9] M. Yazdi and A. Bardi, "Estimation of friction factor in pipe flow using artificial neural networks," *Can. J. Autom. Control Intell. Syst.*, vol. 2, no. 4, p. 52, 2011, [Online]. Available: <https://www.researchgate.net/publication/265939967>.
- [10] L. T. Leonard et al., "Disinfection byproducts formed during drinking water treatment reveal an export control point for dissolved organic matter in a subalpine headwater stream," *Water Res. X*, vol. 15, no. Jan., p. 100144, 2022, doi: 10.1016/j.wroa.2022.100144.
- [11] S. Al-Ajeel, E. Spasov, L. A. Sauder, M. M. McKnight, and J. D. Neufeld, "Ammonia-oxidizing archaea and complete ammonia-oxidizing Nitrospira in water treatment systems," *Water Res. X*, vol. 15, no. Mar., p. 100131, 2022, doi: 10.1016/j.wroa.2022.100131.
- [12] X. Li, Y. Zhao, W. Zhang, F. Wang, W. Yin, and K. Liu, "Photovoltaic potential prediction and techno-economic analysis of China railway stations," *Energy Rep.*, vol. 10, no. May, pp. 3696–3710, 2023, doi: 10.1016/j.egy.2023.10.040.
- [13] N. Yadav et al., "Toward improving water-energy-food nexus through dynamic energy management of solar powered automated irrigation system," *Heliyon*, vol. 10, no. 4, p. e25359, 2024, doi: 10.1016/j.heliyon.2024.e25359.
- [14] H. K. Pathak and R. Rodríguez-López, "Existence and approximation of solutions to nonlinear hybrid ordinary differential equations," *Appl. Math. Lett.*, vol. 39, pp. 101–106, 2015, doi: 10.1016/j.aml.2014.08.018.