A Draft report

Solar PV based Drinking Water Pumping Systems

Case Studies from Jawhar and Mokhada

Technology and Development Solutions Cell (TDSC)
Center for Technology Alternatives for Rural Areas (CTARA)

Indian Institute of Technology Bombay

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A Case Study of Solar PV based Drinking Water Systems

Mokhada taluka acquires adequate rainfall but due to hilly terrain and lack of water recharge systems, several habitations of the recharge systems, several habitations of the region experience water scarcity leading to high degree of drinking water stress after monsoon. Water supply system must provide sufficient quantity of quality water with reliable access throughout the year. Availability, quality and accessibility are the important dimensions for water security. Accessibility is important factor as it affects the health of women who fetch water from long distance. Accessibility is not only measured in terms of distance but also the condition and slope of the road. Pumping drinking water near habitation can reduce accessibility stress. Pumping and transporting water from source to end user requires energy. For remote villages far from power grid or where grid power is not available and good solar condition exists, solar powered pumping is good solution.

Pragati Pratishthan is an NGO based in Jawhar that works in sectors like agriculture development, school, water and solar energy. Solar powered drinking water pumping systems is one such project of the NGO. To get basic idea about the existing solar powered drinking water pumping systems, field visits were made to three solar powered drinking water pumping systems installed by the Pragati Pratishthan in Jawhar and Mokhada region, as shown in the Table 1.

Table 1: Solar Powered Drinking Water Pumping Systems installed by Pragati Pratishthan

System	Habitation	Village	Taluka/Block	Pump Capacity	PV Capacity
1	Pardhipada	Aine	Jawhar	1 HP	0.25 kW
2	Umberpada	Beriste	Mokhada	2 HP	1.92 kW
3	Bramhangaon	Aase	Mokhada	5 HP	5.44 kW

People's participation is involved in the process of implementation of these projects. During the visit to the system in Umberpada, it was found that village survey is carried out by Pragati Pratishthan to identify the requirement of drinking water pumping system. Once requirement of water pumping system is identified, it is communicated to villagers at habitation level meeting/sabha. Upon receiving the approval of villagers, the process of implementation of drinking water pumping system is initiated. Source of funding is in the form of donations or CSR funding.

In case of Umberpada, villagers participated in the process of construction of system while wages were paid by Pragati Pratishthan. Cost required for the construction of system in Bramhangaon was more compared to that in Umberpada since the location of water source was located further away. As a result, villagers of the Bramhangaon had to wait for one year from the time of decision to implement this project. As per villagers of Bramhangaon, villagers voluntarily participated in the process of construction of system and a contribution of Rs. 200 from each family was collected for the construction of the system.

Details of the study of three solar powered drinking water pumping systems installed by the Pragati Pratishthan in Jawhar and Mokhada region are given in the following sections.

1. Solar powered drinking water pumping system: Pardhipada, Aine, Jawhar

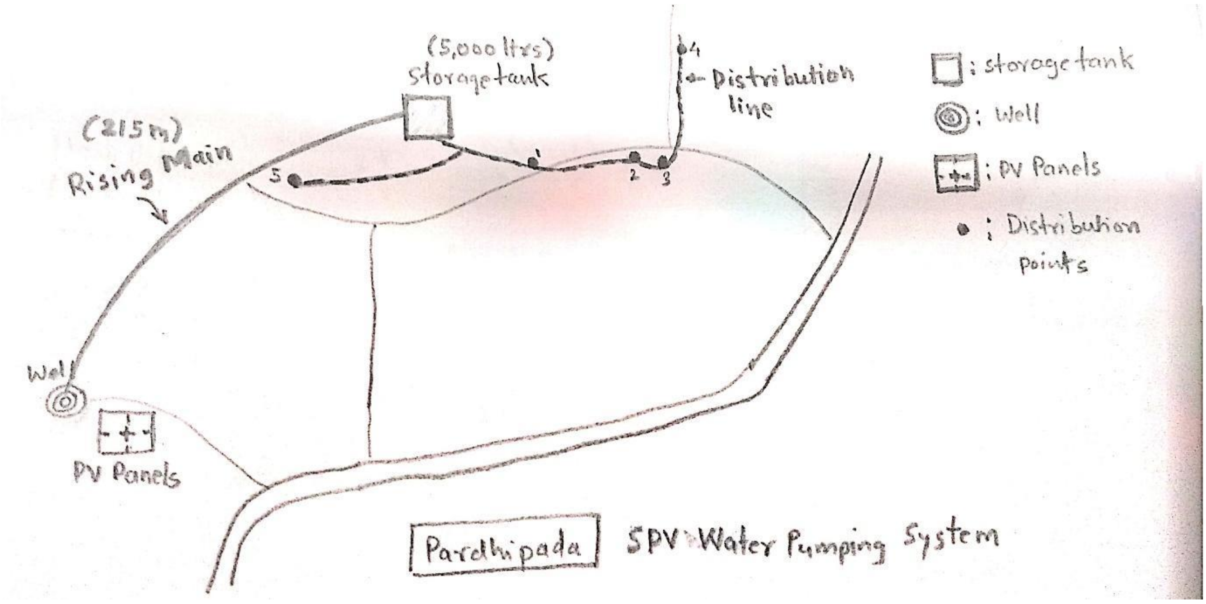


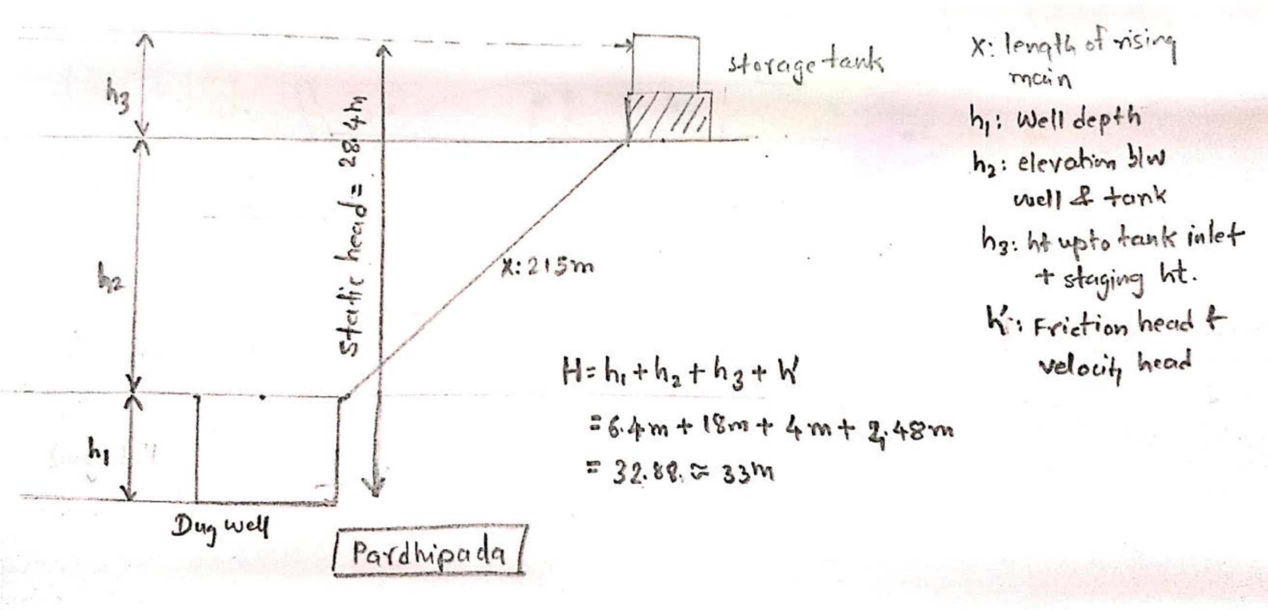
Figure 1: Map showing location of well, PV panels, storage tank & distribution points (Pardhipada)

This solar powered drinking water pumping system was installed in Pardhipada, Aine, Jawhar in the year 2012. The total population of the habitation is 202 (Source: NRDWP, 2018).

Details of water pumping system

- Source: The source of water is dug well near habitation. The depth of dug well is 6.4 m and diameter is 6.73 m. Water column, at the time of visit, was found to be 2.8 m. Water is available for 12 months in the dug well.
- PV Panels: No. of Panels: 1 (2 m x 1 m), Capacity of Panel (Wp): 240 W
- Pump: Pump Capacity: 1 HP (Pump make: Lorentz)
- Storage Tank: The staging height of the storage tank is 2 m and the capacity of the storage tank is 5,000 litres.
- Rising Main: The diameter of the rising main is 40 mm. Length of rising main is 215 m.
- Distribution Points: The number of distribution points/stand posts is 5. Water is supplied daily while in the rainy season, water is supplied on alternate days.
- As shown in Figure *8*, Solar PV panels are covered with wired mesh protecting it from any kind of damage.

Design Analysis



Demand Estimation

Population of habitation : 202 Souls

Total daily demand : 8080 litres (202 * 40 lpcd)

(Considering NRDWP guidelines of providing drinking water of 40 litres per capita per day)

Installed Storage Tank Capacity : 5,000 litres

Estimation of Pump Capacity

Water quantity to be pumped : 5,000 litres

Pumping hours per day : 2 hours

Rate of pumping, Q : 5000/2: 2500 litres/hr: 2.5 m^3/hr: 0.7 lit/sec

Velocity, v : 0.557 m/s

$$v = \frac{Q}{1000 \; x \; 0.7855 \; x \; d^2}$$

where Q in lit/sec; diameter of rising main, d in meters

Static head, h1+h2+h3 : 28.4 m

[(static head: well depth, h1) + (elevation difference b/w well & tank, h2) + (height up to tank inlet + staging height, h3)]

Frictional Head

Length of rising main, L : 215 m

Diameter of rising main, d : 40 mm

Roughness coefficient, c' : 140

Frictional head loss, h_f : 10.47 m/Km

$$hf = 1000\ x (\frac{v}{4.567\ x\ 0.001\ x\ c'x\ d^{0.63}})^{1/0.54}$$

(Hazen Williams Friction Loss Eqn: Refer Annexure A)

Total frictional loss : (L x h_f/1000): 2.251 m
Add 10% for losses in bends, valves : 0.225 m (2.251 x 0.1)
Total frictional head : 2.48 m (2.251+0.225 = 2.746)

Velocity head : 2 m

Friction head + velocity head, **h'** : 4.48 m

Total head on pump, H : 33 m
(H = h1 + h2 + h3 + h')

$$P = \frac{Q\ x\ \rho\ x\ g\ x\ H}{746\ x\ 3600\ x\ \eta}$$

$$Q = 2.5\ \frac{m3}{hr}; \quad \rho = 1000 \frac{kg}{m3}; \quad g = 9.81 \frac{m}{s2}; \quad H = 33\ m; \quad Efficiency, \eta = 0.6$$

$$P = \frac{2.5\ x\ 1000\ x\ 9.81\ x\ 33}{746\ x\ 3600\ x\ 0.6}$$

P = 0.502 HP
Say, P = 1 HP

Required Pump Capacity : 1 HP
Installed Pump Capacity : 1 HP

Average daily sun hours is 5.5 hours for Mumbai location, assuming similar average daily sun hours for Mokhada location.
Power required by pump: 0.75 kW
Energy used by pump running for 2 hrs: 1.5 kWh
Assuming avg. daily sun hours of 5.5, peak watt rating of modules required: 1500/5.5 = 272 Wp ~ 300 Wp

One panel of 240 W capacity is installed. Total system capacity: 240 W which is less than required. This could be a reason why in the rainy season, water is required to be supplied on the alternate days.

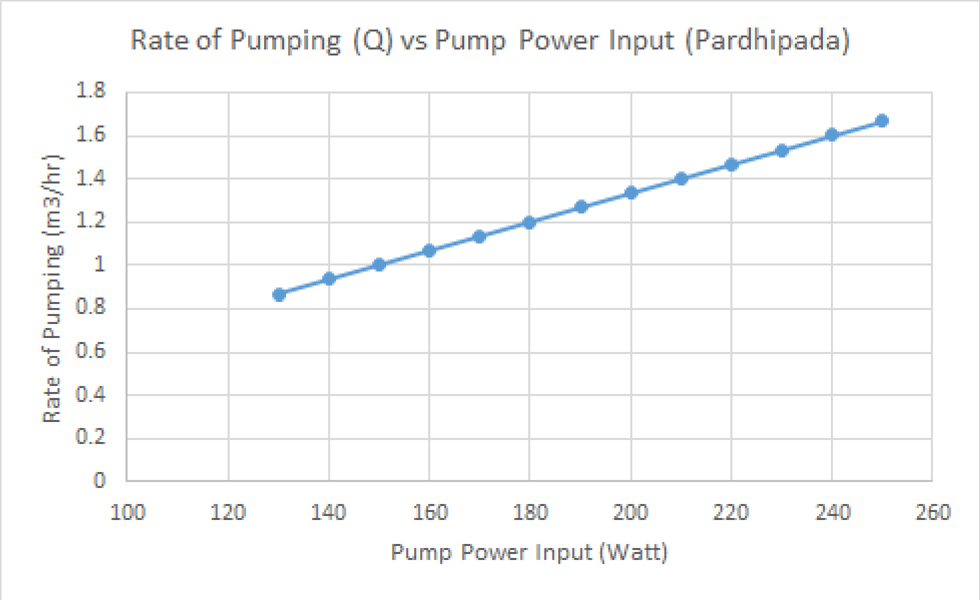
Operation and Maintenance

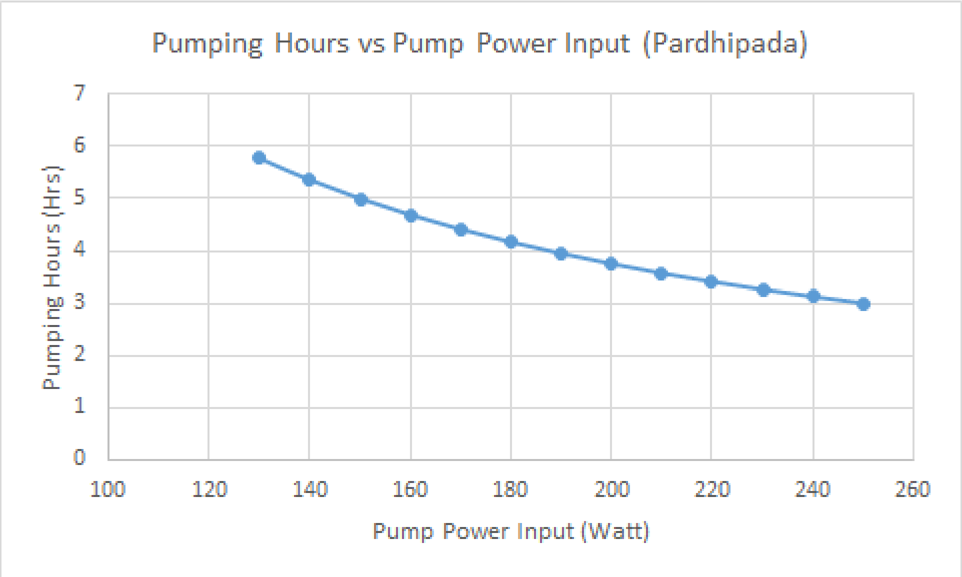
Rs. 50/month are collected from every family. The group is formed in the Pardhipada that looks after the system. System is functional in the rainy season too. No significant repair work has been carried out. Only desilting was carried out in the summer of 2018.

Challenges

System is functional in the rainy season too. In the rainy season, due to low solar radiation, water is supplied on the alternate days.

Following two graphs are plotted for change in rate of pumping and pumping hours with change in pump power input. Total head on pump, H = 33 m. If power input to the pump is increased by 50%, rate of pumping is increased by about 40% decreasing pumping hours by about 2 hours.





2. Solar based drinking water pumping system: Umberpada, Beriste, Mokhada

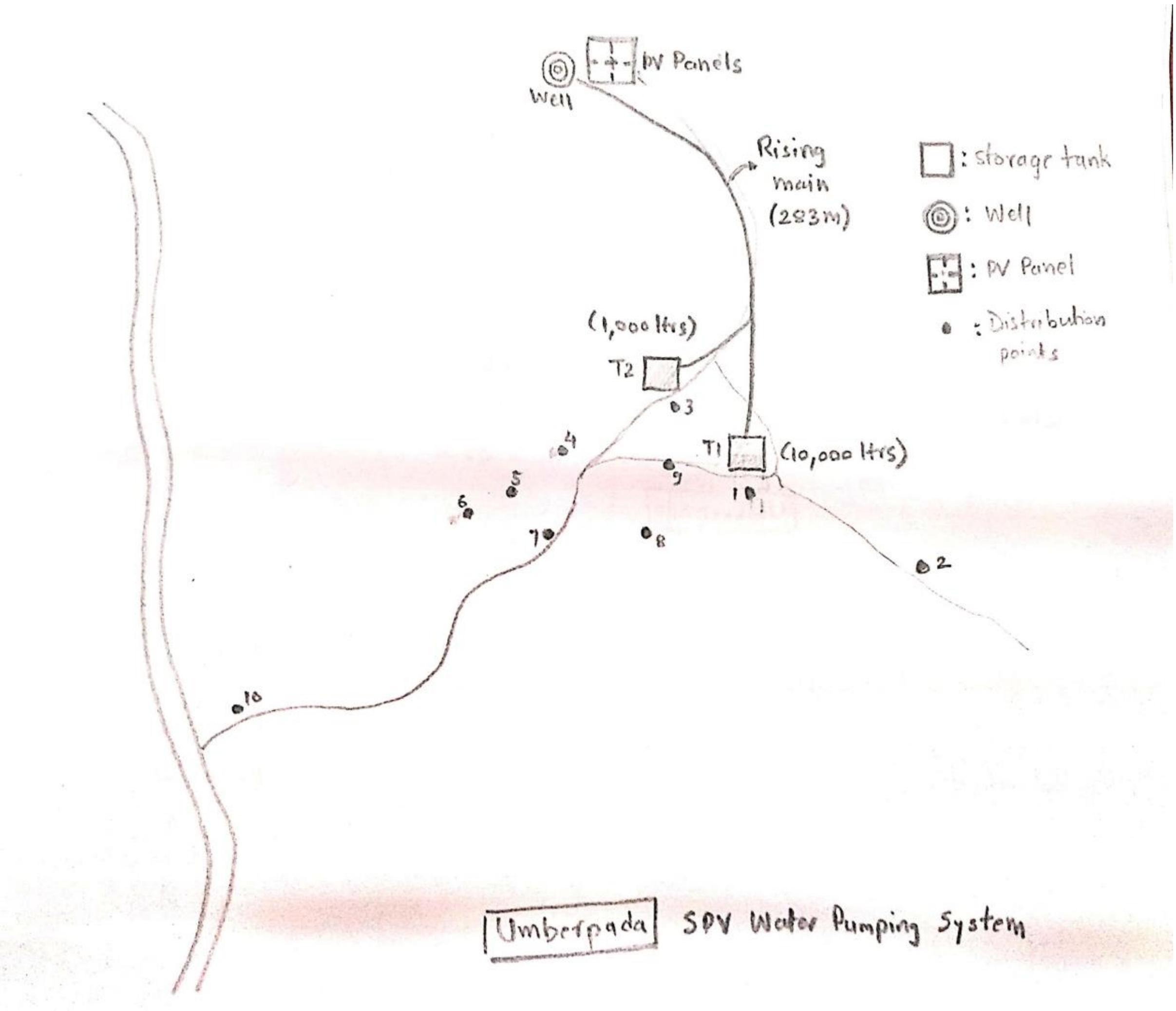


Figure 2: Map showing location of well, PV panels, storage tank & distribution points (Umberpada)

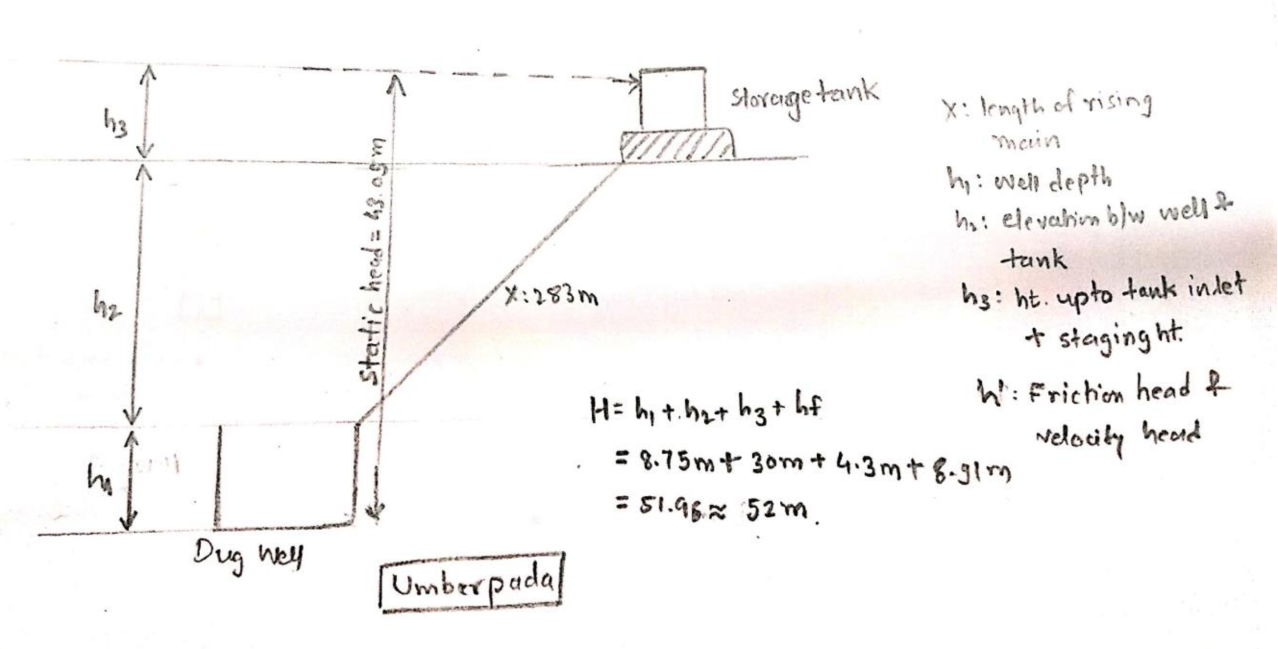
This solar powered drinking water pumping system is installed in Umberpada, Beriste, Mokhada in the year 2015-16. The total population of the habitation is 281 (Source: NRDWP, 2018).

Details of water pumping system

- Source: Dug well near habitation is the source of water. This dug well is constructed in the year 2000 from Jal Swarajya scheme. The depth of dug well is 8.75 m and diameter is 6 m. Water column, at the time of visit, was found to be 2.75 m. In rainy season water column is usually about 7.5 m, it starts decreasing after rainy season reaching up to 1 m. Water is available for 12 months in the dug well. Dug well is covered with wired mesh which is added by Pragati Pratishthan. Cost of wired mesh is about Rs. 30,000/-.
- PV Panels: No. of Panels: 8 (1.65 m x 1 m), Capacity of each Panel (Wp): 240 W
- Pump: Pump Capacity: Submersible DC Pump of 2 HP (Pump make: Grundfos), Pump runs for about 4.5 hours

- Storage Tank: There are two storage tanks as shown in, one of capacity 10,000 litres and other of capacity 1,000 litres. The storage tank of capacity 1,000 litres is used by school. Tanks are filled once in a day, and it takes about 4 - 4.5 hours in the rainy season while it takes 2 – 3 hours in the summer season for the tank to fill. The dimensions of 10,000 litres capacity tank are: about 3.15 m height and 2.1 m diameter.
- Rising Main: The diameter of the rising main is 40 mm. Length of rising main is 283 m.
- Distribution Points: The number of distribution points/stand posts is 10.

Design Analysis



Demand Estimation

Population of habitation : 281 Souls
Total daily demand : 11240 litres (281 * 40 lpcd)
(Considering NRDWP guidelines of providing drinking water of 40 litres per capita per day)
Installed Storage Tank Capacity : 11,000 litres
(There are two separate tanks of 10,000 litres and 1,000 litres capacity. For calculations, one single tank of 11,000 litres is considered.)

Estimation of Pump Capacity

Water quantity to be pumped : 11,000 litres
Pumping hours per day : 3 hours
Rate of pumping, Q : 11000/3: 3667 litres/hr: 3.667 m^3/hr: 1.02 lit/sec

Velocity, v : 0.812 m/s

$$v = \frac{Q}{1000 \; x \; 0.7855 \; x \; d^2}$$

where Q in lit/sec; diameter of rising main, d in meters

Static head, h1+h2+h3 : 43.05 m

[(static head: well depth, h1) + (elevation difference b/w well & tank, h2) + (height up to tank inlet +staging height, h3)]

Frictional Head

Length of rising main, L : 283 m
Diameter of rising main : 40 mm
Roughness coefficient, c' : 140
Frictional head loss, hf : 21.025 m/Km

$$hf = 1000\ x\left(\frac{v}{4.567\ x\ 0.001\ x\ c'x\ d^{0.63}}\right)^{1/0.54}$$

(Hazen Williams Friction Loss Eqn: Refer Annexure A)

Total frictional loss : (L x h_f/1000): 5.95 m
Add 10% for losses in bends, valves : 0.595 m (5.95 x 0.1)
Total frictional head : 6.55 m (5.95 + 0.595 = 6.545)
Velocity head : 2 m

Friction head + velocity head, h' : 8.55 m

Total head on pump, H : 52 m
(H = h1 + h2 + h3 + h')

Pump Capacity

$$P = \frac{Q\ x\ \rho\ x\ g\ x\ H}{746\ x\ 3600\ x\ \eta}$$

$$Q = 3.667\ \frac{m3}{hr};\quad \rho = 1000\frac{kg}{m3};\quad g = 9.81\frac{m}{s2};\quad H = 52\ m;\quad Efficiency, \eta = 0.6$$

$$P = \frac{3.667\ x\ 1000\ x\ 9.81\ x\ 52}{746\ x\ 3600\ x\ 0.6}$$

P = 1.16 HP
Say, P = 2 HP

Required Pump Capacity : 2 HP
Installed Pump Capacity : 2 HP

Average daily sun hours is 5.5 hours for Mumbai location, assuming similar average daily sun hours for Mokhada location.
Power required by pump: 1.5 kW
Energy used by pump running for 3 hrs: 4.5 kWh

Assuming avg. daily sun hours of 5.5, peak watt rating of modules required: 4.5/5.5 = 0.818 kWp ~ 1 kWp.
8 panels each of 240 W capacity are installed. Total installed system capacity: 1.92 kW which is more than required. One of the panels, as shown in Figure 6, is in damaged condition. And, the system is in working condition. Since one of the panels of the system is damaged, system seems to be functioning at lower output than that it is designed for.

Operation and Maintenance

One stand post is in not working condition. At the time of construction, 7 stand posts were constructed, later 3 more were added. Water is supplied daily once in the morning for about 1 to 1.5 hours throughout the year. Whenever there is function in the village, water is supplied for more duration. Water is supplied to Umberpada habitation only, that is, about 52 families. Rs. 50/month are collected from every family. Operator is appointed who looks after the system (Name of the operator: Deepak Raut). The operator is paid Rs.700/month. System is functional in the rainy season too. No significant repair work has been carried out. Only addition of three stand posts. The TCL is added to the water (about 250 grams). TCL is added once in 6 days in summers while it is added once is 2 days in the rainy season. The responsibility of the same is with Arogya Rakshak from gram panchayat.

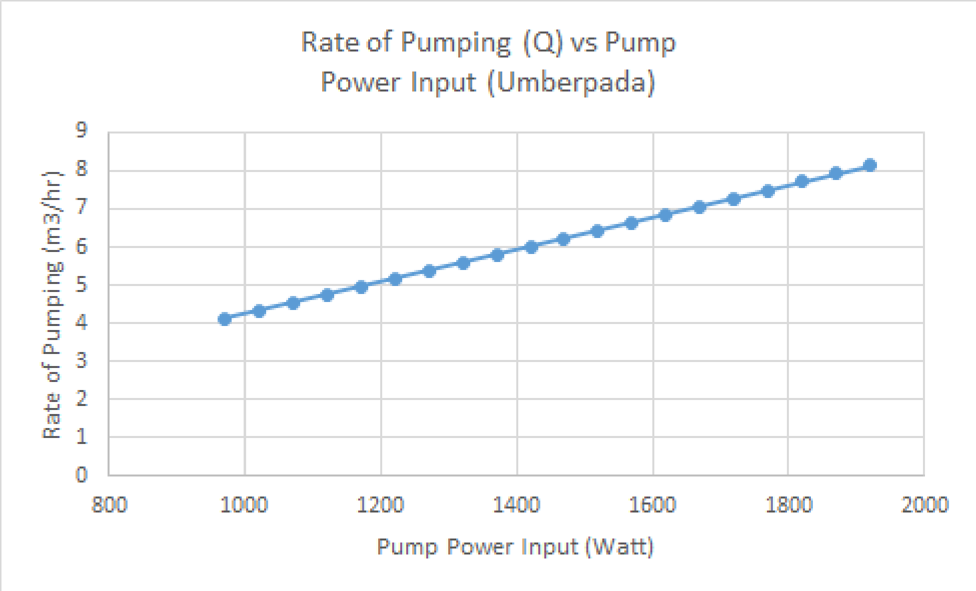
Household Water Usage

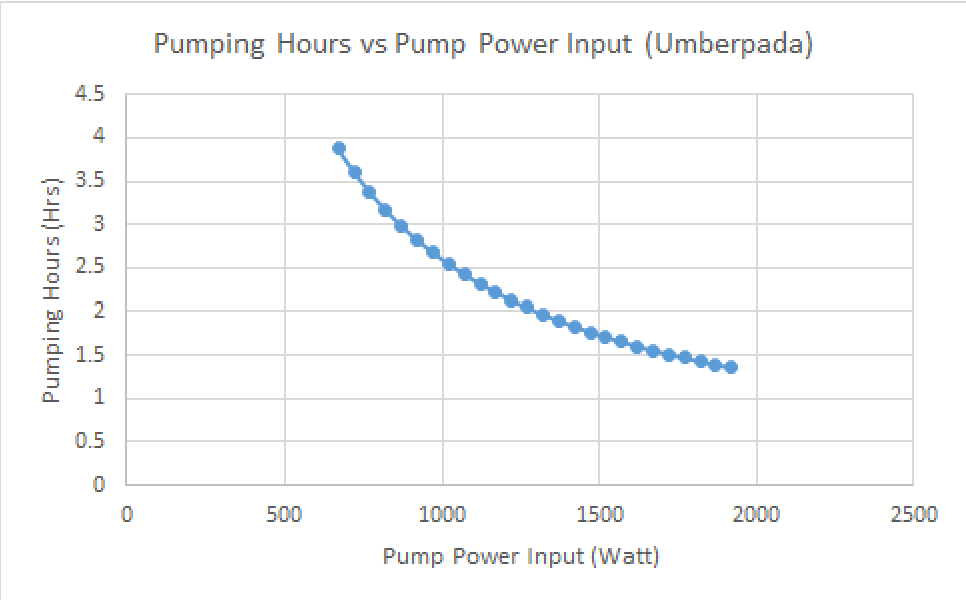
In order to get some idea about the quantity of water used/available per capita, sample of villagers were asked about number of *hundas* water used and number of household members. Details of which are shown in the Table 2. From the Table 2, it can be said that water usage is approximately 9 lpcd.

Table 2: Number of household members and approximate usage of water

Sr. No.	Villager Name	No. of household members	Number of *Hundas* *(~10 litres/hunda)*	Approx. Water Usage (litres)
1	Prameela Sharad Raut	3	12-15	135
2	Dwarka Atmaram Maule	4	12	120
3	Malti Chanda Raut	1	5-6	55
4	Changuna Krishna Ghune	5	10-12	110
5	P Ashok Patil	6	7-8	75
6	Jitendra Raut	2	8-10	90
7	Pandurang Patil	4	10-15	125

Following two graphs are plotted for change in rate of pumping and pumping hours with change in pump power input. Total head on pump, H = 52 m. If power input to the pump is increased by about 78%, rate of pumping is increased by about 78% decreasing pumping hours by about 1 hours.





3. Solar based drinking water pumping system: Bramhangaon, Aase, Mokhada

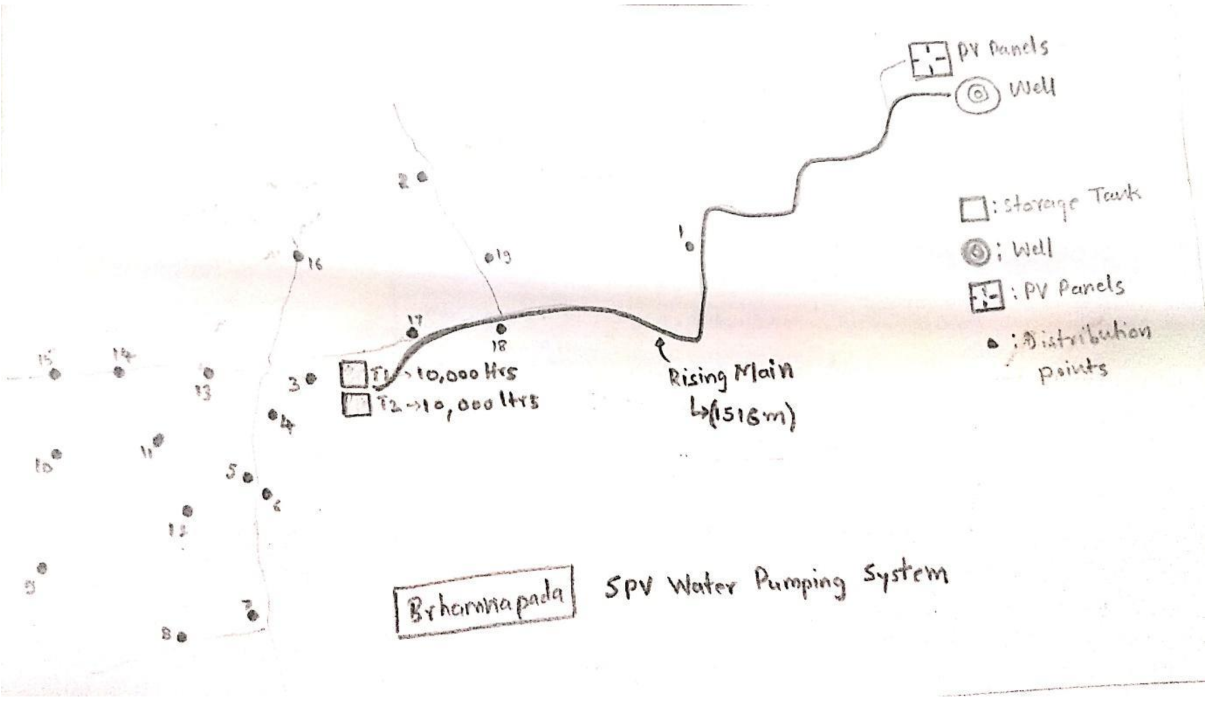


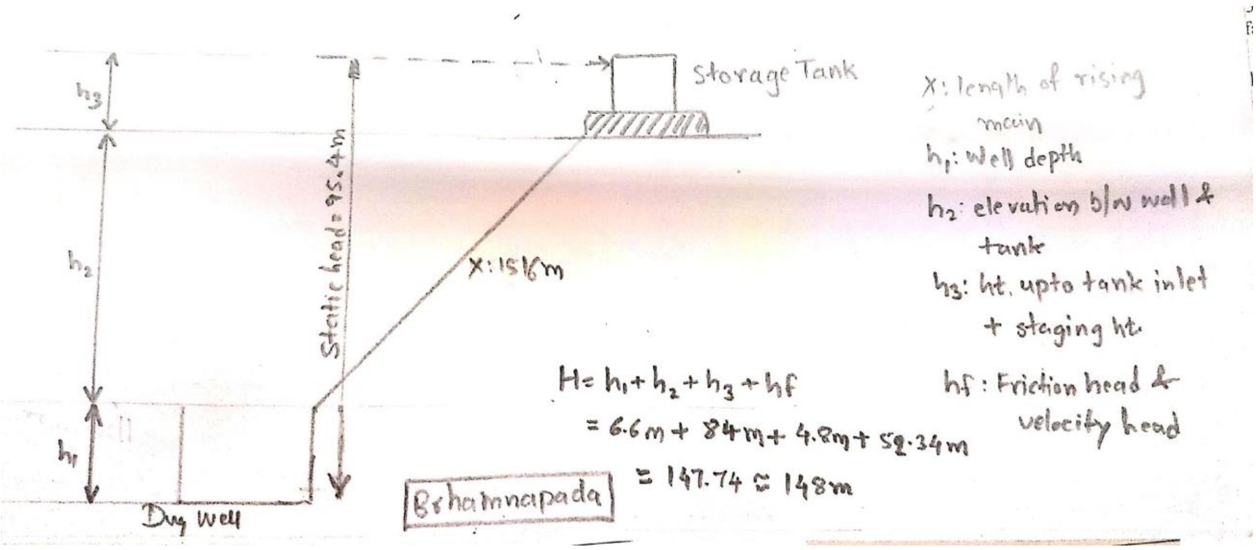
Figure 3: Map showing location of well, PV panels, storage tank & distribution points (Bramhangaon)

This solar powered drinking water pumping system is installed in Bramhangaon, Aase, Mokhada in the year 2018-19. The total population of the habitation is 860 (Source: NRDWP, 2018).

Details of water pumping system

- Source: Dug well near habitation is the source of water. The depth of dug well is 6.6 m and diameter is 7.75 m. Water column, at the time of visit, was found to be 1.6 m. In rainy season, water column is usually about 4.5 m, which decreases up to 3.6 m by the month of December. It further decreases in the summer season. Water is available for 12 months in the dug well.
- PV Panels: No. of Panels: 17 (1.95 m x 1 m), Capacity of each Panel (Wp): 320 W
- Pump: Pump Capacity: Submersible DC Pump of 5 HP (Pump make: Grundfos), Pump runs for about 4-5 hours.
- Storage Tank: There are two storage tanks, as shown in, of capacity 10,000 litres each. Tanks are filled once in a day, and it takes about 4 - 5 hours in the rainy season for the tanks to fill. The dimensions of 10,000 litres capacity tank are: about 3.15 m height and 2.1 m diameter.
- Rising Main: The diameter of the rising main is 40 mm. Length of rising main is 1516m.
- Distribution Points: The number of distribution points/stand posts is 19.

Design Analysis



Demand Estimation

Population of habitation : 860 Souls

Total daily demand : 34,400 litres (860 * 40 lpcd)

(Considering NRDWP guidelines of providing drinking water of 40 litres per capita per day)

Installed Storage Tank Capacity : 20,000 litres

Estimation of Pump Capacity

Water quantity to be pumped : 20,000 litres

Pumping hours per day : 4.5 hours

Rate of pumping, Q : 20000/4.5: 4444 litres/hr: 4.444 m^3/hr: 1.24 litres/sec

Velocity, v : 0.987 m/s

$$v = \frac{Q}{1000\ x\ 0.7855\ x\ d^2}$$

where Q in lit/sec; diameter of rising main, d in meters

Static head, h1+h2+h3 : 95.4 m

[(static head: well depth, h1) + (elevation difference b/w well & tank, h2) + (height up to tank inlet + staging height, h3)]

Frictional Head

Length of rising main, L : 1516 m

Diameter of rising main, d : 40 mm

Roughness coefficient, c’ : 140

Frictional head loss, hf : 30.186 m/Km

$$hf = 1000\ x\ (\frac{v}{4.567\ x\ 0.001\ x\ c' x\ d^{0.63}})^{1/0.54}$$

(Hazen Williams Friction Loss Eqn: Refer Annexure A)

Total frictional loss	: (L x h_f/1000): 45.763 m
Add 10% for losses in bends, valves	: 4.576 m (45.763 x 0.1)
Total frictional head	: 50.34 m (45.763 + 4.576)
Velocity head	: 2 m
Friction head + velocity head, h'	: 52.34 m
Total head on pump, H (H = h1 + h2 + h3 + h')	: 148 m

$$P = \frac{Q\ x\ \rho\ x\ g\ x\ H}{746\ x\ 3600\ x\ \eta}$$

$$Q = 4.444\frac{m3}{hr};\quad \rho = 1000\frac{kg}{m3};\quad g = 9.81\frac{m}{s2};\quad H = 148\ m;\quad Efficiency, \eta = 0.6$$

$$P = \frac{4.444\ x\ 1000\ x\ 9.81\ x\ 148}{746\ x\ 3600\ x\ 0.6}$$

P = 4.02 HP

Say, P = 5 HP

Required Pump Capacity	: 5 HP
Installed Pump Capacity	: 5 HP

Average daily sun hours is 5.5 hours for Mumbai location, assuming similar average daily sun hours for Mokhada location.
Power required by pump: 3.75 kW
Energy used by pump running for 4.5 hrs: 16.875 kWh
Assuming avg. daily sun hours of 5.5, peak watt rating of modules required: 16.875/5.5 = 3.068 kWp ~ 3.20 kWp.
17 panels each of 320W capacity are installed. Total installed system capacity: 5.44 kW which is more than required.

Operation and Maintenance

Water is supplied daily once in the morning for about 1 to 1.5 hours. Water is supplied to only Bramhangaon, that is, more than 150 families. In general, one stand post is being used by 8-10 households. One of the 19 stand posts is being used by 8-10 households, school and anganwadi. Rs. 50/month are collected from every family. Operator is appointed who looks after the system (Name of the operator: Narayan Mahale). The operator is paid Rs.2000/month. System is constructed in summer 2018. It was not in use for about two months in the rainy season. No significant repair work has been carried out. TCL is added to the well by the operator but there is no fixed schedule for the same.

A group is formed in the village called *'Naalpaani Yojana Samitee, Bramhangaon'*. President of the committee is Indira Maule. The committee has special account in the bank associated with the group. Monthly money collected from families goes into this account. Additionally, two other wells near the habitation are used as the source of water. In case of water scarcity, two water tankers daily are required. These two wells are not part of the solar powered drinking water pumping system.

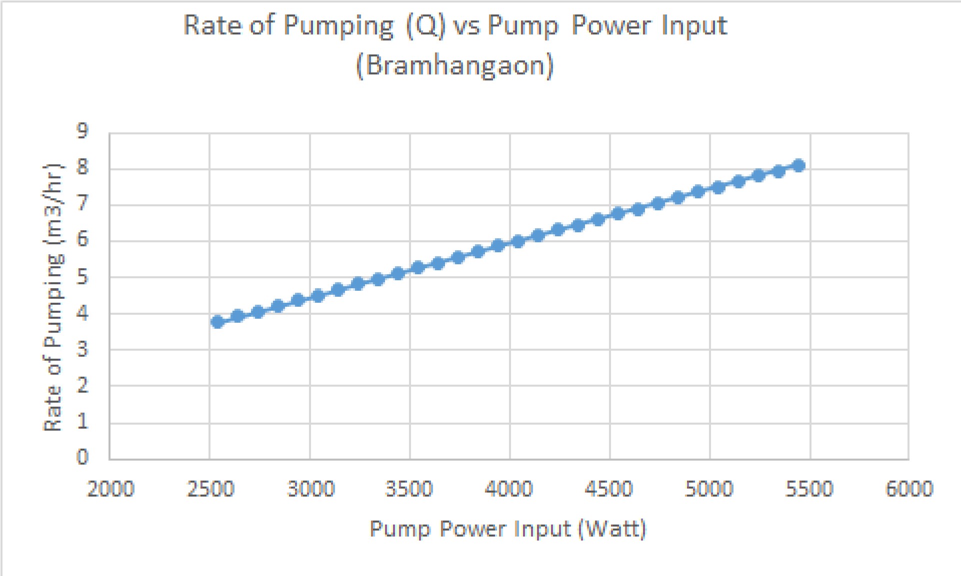
Household Water Usage

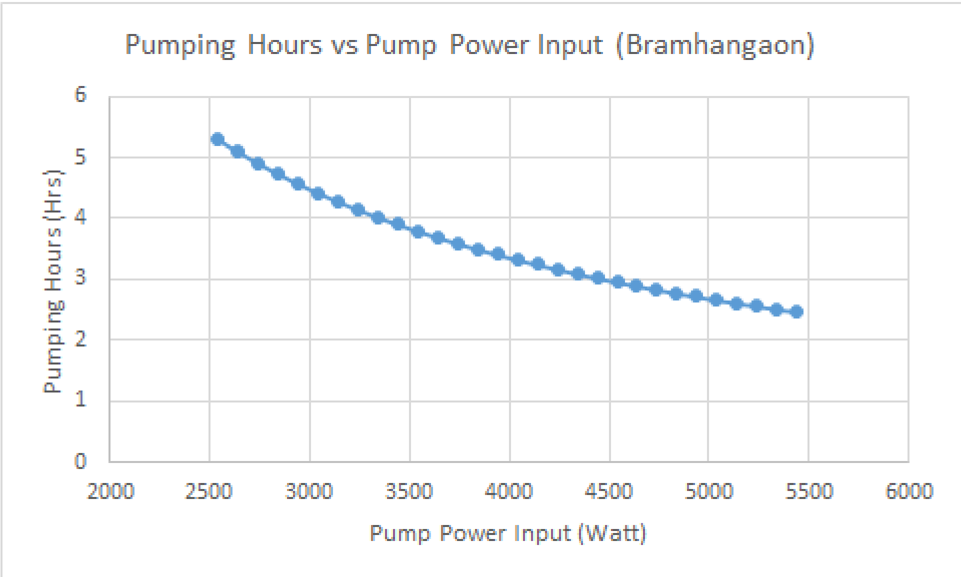
In order to get some idea about the quantity of water used/available per capita, sample of villagers were asked about number of *hundas* water used and number of household members. Details of which are shown in the Table 3. From the Table 3, it can be said that water usage is approximately 9 lpcd.

Table 3: Number of household members and approximate water usage

Sr. No.	**Villager Name**	**No. of household members**	**Number of *Hundas* *(~10 litres/hunda)***	**Approx. Water Usage (litres)**
1	Anusaya Ananta Mahale	3	5-6	48
2	Prameela Maule	2	7-8	56
3	Kashi	4-5	4-5	30
4	Yashoda Mahale	4-5	4	32
5	Ramu Mahale	4-5	4	32
6	Taiba Mahale	5	4-5	40
7	Janardhan Maule	5	4	32
8	Yashoda Bhabhole	7	4	32
9	Harishchnadra Maule	5	4	32

Following two graphs are plotted for change in rate of pumping and pumping hours with change in pump power input. Total head on pump, H = 148 m. If power input to the pump is increased by about 50%, rate of pumping is doubled decreasing pumping hours by about 2.5 hours.


Rate of Pumping (Q) vs Pump Power Input (Bramhangaon)
Rate of Pumping (m3/hr)
0
1
2
3
4
5
6
7
8
9
2000
2500
3000
3500
4000
4500
5000
5500
6000
Pump Power Input (Watt)


Pumping Hours vs Pump Power Input (Bramhangaon)
Pumping Hours (Hrs)
0
1
2
3
4
5
6
2000
2500
3000
3500
4000
4500
5000
5500
6000
Pump Power Input (Watt)

Annexure A: Solar PV Water Pumping System Installation Details

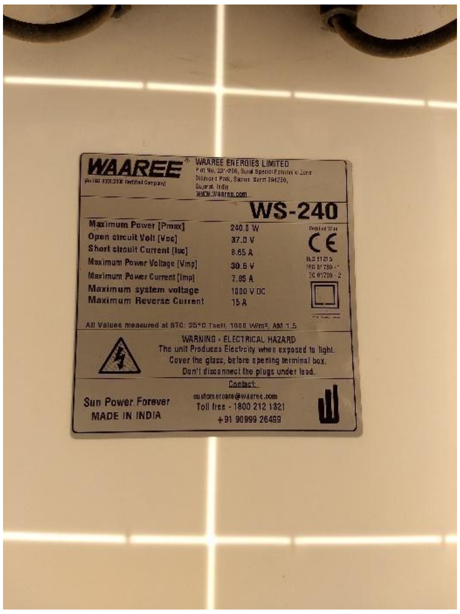


Figure 4: Umberpada PV Panel Specification

Figure 5: Brahamanapada PV Panel Specification

Figure 6: PV Panels at Umberpada

Figure 7: PV Panels at Brahamanapada

Figure 8: PV Panel and Well Pardhipada

Figure 9: Storage Tank at Brahamanapada

Annexure B: Details of the Hazen-Williams Friction Loss Equation

Hazen-Williams Equation:

$V = k\ C\ (D/4)^{0.63}\ S^{0.54}$
(Refer formula 8.3 from Water Supply and Sanitary Engineering by G.S. Birdie & J.S. Birdie, 8th Edition)

$S = h_f / L$ (m/m) and $Q = V\ (\pi\ D^2)/ 4$

Where,
k is a unit conversion factor
k=1.318 for English units (feet and seconds)
k=0.85 for SI units (meters and seconds)

L is length of pipe (meters)
C is Hazen-Williams Coefficient/Roughness Coefficient of the pipe
D is pipe inside diameter (meters)
V is the velocity of water flowing through the pipe (m/s)
Q is the net flow rate expected from a pipe (m^3/sec)

$$\frac{v\ x\ 4^{0.63}}{0.85\ x\ c\ x\ D^{0.63}} = S^{0.54}$$

$$\frac{v}{0.3549\ x\ c\ x\ D^{0.63}} = S^{0.54}$$

$$\frac{v}{0.3549\ x\ c\ x\ 0.001^{0.63}\ x\ D^{0.63}} = S^{0.54}$$

$$\frac{v}{0.3549\ x\ c\ x\ 0.001^{0.63}\ x\ D^{0.63}} = \left(\frac{h_f}{L}\right)^{0.54}$$

$$\frac{v}{0.3549\ x\ c\ x\ 0.001^{0.63}\ x\ D^{0.63}} = \left(\frac{h_f}{L}\right)^{0.54}$$

$$h_f\ (m/km) = 1000\ x\ \left(\frac{v}{4.567x\ 0.001\ x\ c\ x\ D^{0.63}}\right)^{1/0.54}$$

where v is in meter/sec, c is roughness coefficient and D is pipe diameter in mm

h_f is the friction head resulting from the pipe type, its length and the expected flow rate.

Hazen-Williams coefficients are used in the Hazen-Williams equation to calculate friction loss.. Coefficients for some common materials used are stated below in Table 4.

Table 4: Pipe material and Hazen-Williams coefficient

Pipe Material	**Hazen-Williams coefficient, c (design purpose)**
Cast Iron, Ductile Iron	100
Mild Steel	100
Galvanised Iron (above 55 mm dia)	100
Galvanised Iron (below 55 mm dia)	55
RCC-spun concrete, Prestressed concrete (up to 1200 mm dia)	140
RCC-spun concrete, Prestressed concrete (above 1200 mm dia)	145
PVC, GRP and other plastic pipes	145

[Source:Page No. 87, Technical Data Book (4th Edition, 2007), India Water Works Association]

Annexure C: Design Procedure of a Solar PV Water Pumping System

Step 1: Demand estimation and storage tank sizing

The first step in designing a solar powered water pumping system is to determine the overall water requirement. As per NRDWP guidelines, 40 litres per capita per day of water should be the provisioning and service norm. Typically, a tank is used to store the required amount of water during peak energy production. The tank is sized to store water to meet the daily water demand. In cases where cost is constraining, a storage tank of lesser capacity can be installed to reduce the overall system cost, but may require multiple supply rounds to meet the demand. Appropriate staging height and location of the storage tank needs to be determined.

Step 2: Identify the water source

The water source may be either subsurface (a well) or surface (a pond, stream, or spring). Once the source is identified, the water availability and water quality needs to be determined. If the identified water source is unable to meet the required water demand, alternate source of water needs to be identified.

Step 3: System Layout

Once the water source and water requirement or demand is determined, the next step is to determine the *locations* and *elevation* of the following system components,

1. Water source
2. Storage tanks
3. Pump(either submersible or surface mounted)
4. PV panels
5. Distribution points of use and pipeline routes (network layout)

Step 4: Solar insolation and PV panel location

Appropriate data should be used to determine the amount of solar insolation (peak sun hours) available at site. In the Northern Hemisphere, the best direction to face solar panels is south, since that is generally where they receive the most sunlight. The solar array should be placed as close to the pump as possible to minimize the electric wire length (and thus any energy loss), as well as installation costs. In addition, it needs to be considered that there is no significant shading in the vicinity of the panels.

Step 5: Pump selection

The design flow rate for the pump is calculated by dividing the daily water needs of the operation by the no. of peak sun hours. The total dynamic head of the pump is the sum of the static head, velocity head and friction head. Static head is sum of suction head and discharge head. Friction loss depends upon the diameter and material of the pipe. Once the desired flow rate and total head on the pump is determined, a water pump can be selected using pump performance curves that show the operating characteristics for the solar-powered pump. Where AC powered pump is used, an additional component – inverter needs to be used to convert DC power output of the PV panels to AC power.

Step 6: Solar PV panel selection and array layout

Once the pump is selected and power required for selected pump is known, the next step would be to select PV panel or array of PV panels to supply that power. When multiple panels are required, they must be wired in series, parallel, or a combination of series-parallel to meet both the voltage and amperage requirements of the pump. The power output of the individual panels can be added together to determine the total power they produce. Solar panel specification includes rated max power (Pmax), current at Pmax (Imp), voltage at Pmax (Vmp), short-circuit current (Isc), open-circuit voltage (Voc) and panel dimensions.

Step 7: Setting up of distribution points

The purpose of a distribution system is to deliver water to households with appropriate quality, quantity and pressure. The system should be analysed so that the design flow rates can be delivered to the delivery point(s) at the required pressure. Distribution points for small water systems are typically stand posts serving clusters of houses in the vicinity.

Step 8: Cost of system

The total capital cost of the system includes cost of different components of the system listed below,

1. Pump
2. PV panels, civil support structure and electrical components and wiring
3. Pipes and valves
4. Water storage tank and associated civil structure
5. Water filtering system

Step 9: Decide operating schedule

Considering available amount of water at source, installed PV system capacity and water storage tank capacity, system can be operated to,
(i) To fill the water tank and supply water simultaneously to households, or
(ii) To fill the water storage tank and then supply water to households based on a supply schedule

In either case, an operating schedule is to be determined for pump and supply operations.

Step 10: Maintenance and monitoring tasks

The system will require maintenance and monitoring for proper functioning. Periodic inspection of the various components of the system could be carried to identify any problems in the system---leakages in pipes, damage to PV panels, accumulation of dust on the panels, breakage of valves etc. An operator should be assigned to look after the system operations and maintenance. Operation and maintenance would incur cost which can be collected from the villagers. Further, an annual budget will be required for routine maintenance and upgradation tasks. A monthly collection from households can decided on towards creation of this fund.

Annexure D: Schedule of rates for different pipe types

For schedule of rates for different pipe types, refer Maharashtra Jeevan Pradhikaran (Kokan Region) schedule of rates for the year 2018-19. Example of HDPE pipes is provided in the following Table 5:

Table 5: Schedule of rates for HDPE pipes

Pipe type	**Pressure rating**	**Pipe diameter**	**Rate (Rs/m)**
PE-100	6 kg/sq.cm	75 mm	111
		90 mm	157
	8 kg/sq.cm	75 mm	134
		90 mm	191
	10 kg/sq.cm	75 mm	174
		90 mm	250
	12.5 kg/sq.cm	75 mm	205
		90 mm	295

[Source: Maharashtra Jeevan Pradhikaran (Kokan Region) schedule of rates for the year 2018-19]

According to ISO 4427, PE-100 is a polyethylene pipe with minimum required strength (at 50 years and 20^{o}C) of 10 MPa (MegaPascal).