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SOLAR WATER SUPPLY FOR RURAL COMMUNITIES IN RIVERS STATE, NIGER DELTA OF NIGERIA

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ABSTRACT: *Several communities in the Niger Delta region of Nigeria are without electricity to pump water. Hospitals, health centers and schools that served a sizable population of the rural dwellers in the Niger Delta region are also affected. The used of solar energy for providing drinking water for rural areas of Niger Delta region of Nigeria has been presented. Data analysis and mathematical computations showed that Rivers State has monthly solar radiations up to 4kWh/m^2/day, which is capable of pumping water from boreholes for communities with population more than 500 people. A systematic design process of an integrated solar-based water pumping system is presented. A method of solar water pumping design and sizing under Niger Delta environmental and meteorological conditions is presented. Evaluation of selected water installations in Rivers State indicated that solar water system is technologically viable in the region. Solar water pumping proved to offer sustainable solution to the challenge of drinking water supply in Rivers State and the entire Niger delta region. Policy makers and decision makers, in Rivers State should therefore decide in favor of solar water pumping systems when providing drinking water for the rural communities of the State.*

KEYWORDS: Rivers State, Niger Delta, Rural Communities, Solar Water pumping

INTRODUCTION

The provision of sustainable water supply scheme in Rivers State, Niger Delta region of Nigeria remains a major concern to various levels of government in the region. Water is a precious natural resource that sustains all forms of life. It is a common saying that there is no life without water. However, where water is available (surface water, hand dug wells) but of poor quality, it will result in adverse health effect. Problems related to the availability of potable drinking water are being faced in several parts of Niger Delta of Nigeria with the people having to drink from polluted streams and rivers (Horizon Concept, 2000). Significantly, majority of the rural communities in the Niger Delta have no access to good drinking water source with greater number of their water sources exceeding WHO water quality guidelines (WHO, 1993) and Federal Environmental Protection Agency standards and guidelines for drinking water quality in Nigeria (FEPA, 1991).

The deleterious health effects associated with prolonged consumption of highly contaminated stream water and hand dug wells are well documented and include kidney and gastric disorder, typhoid, diarrheas cholera (Mezie-Okoye, 2003). Water related diseases are the most critical health problems among the rural people of Niger Delta of Nigeria and represents 80% of all illness in rural communities (Mezie-Okoye, 2003). The greatest problem affecting the supply of good

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drinking water in the rural areas of Rivers State is lack of electricity to pump water for the people. Few of the communities that are connected to the national power supply continue to experience epileptic power supply. There are several water boreholes in almost all the communities in the State but majority of them have stopped functioning due to lack of electricity to power the pumps (Horizon Concept, 2000). The generating plants donated by the government and other corporate organizations are there with their numerous attendant problems ranging from constant breakdown to servicing and replacement of parts as well as fueling. The rural people are peasant farmers and fishermen and are impoverish. Equally, they cannot afford the cost of running generating plants. There is therefore an urgent need to find alternative technology that will not only address the ever worsening water delivery situation in the rural areas of the State but will also have a sustainable outcome on the lives of the people. Solar water pumps based on Solar Energy Technology offers the best option.

Rivers state has been shown to have adequate solar energy (IITA, 2005) and what is needed or required is an appropriate technology to tap it to power borehole pumps for the people. However, solar water systems remain largely ignored in Rivers State, particularly in the area of rural community water supply due to lack of awareness on its applicability for rural water supply and absence of precise technical data. This study therefor investigates and evaluates solar water system as a sustainably viable option for rural water supply application. Access to good potable and reliable water supply through solar power can improve the quality of life in rural communities and will form the bedrock for a sustainable water supply that will enhance the quality of life of the rural dwellers.

LITERATURE REVIEW

Solar water pumping is one of the most widely used solar energy applications all over the world today, with thousands of solar-powered water pumping systems installed both in developed and developing countries ((Kavitha and Others, 2014; Abdourraziq and others, 2013; Nang and Wunna, 2011; Abu-Aligah, 2011; Hamidat and Benyoucef, 2007; RETScreen, 2004). Solar water pumping applications include domestic water, livestock watering, rural water supplies and irrigation. Solar water pumping is a technology that uses photovoltaic to convert sunlight into electrical energy that powers water pumps for water supply. In solar water pumping applications, water is pumped during periods of sunshine and stored in a storage tank; however, period of overcast may exist for some days making the use of back-up batteries often necessary (Nang and Wunna, 2011). Solar water pumping systems are relatively simple, require little maintenance, and provide independent water pumping schemes. Solar water systems are suitable for rural and remote water supply where the electricity is not available (Abu-Aligah, 2011).

A typical solar water pumping system consists of array of solar modules, a direct current (DC) controller, motor-pump subsystem and a water tank (Hamidat and Benyoucef, 2007). The array modules are connected in series–parallel combinations to provide the required electrical power needed to drive the motor-pump subsystem. The controller is a DC-DC power booster that supplies the motor-pump subsystem with maximum power. Systems configuration is the solar array coupled to a controller which is then coupled to a DC motor and a pump.

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METHOD OF DATA COLLECTION

Data on borehole depths and borehole diameters were obtained from some rural water installations in Rivers State. A ten year meteorological data was obtained from the International Institute of Tropical Agriculture (IITA, 2005) Onne, Rivers State. These data include monthly solar irradiation, monthly minimum and maximum temperatures and amount of rainfall. Data on solar energy technology and application in rural water supply were obtained from local and international manufacturers and distributors of solar products. Data on different capacities of solar panels and solar water pumps were obtained from Kyocera Solar, Inc (Kyocera, 2004) and African Energy Source (2004). Also data on controllers, inverters and batteries were obtained from Xatrex and African Energy Source. These data were used for the selection of the right size of panels, motor-pumps and controllers/inverters for water requirement in different communities in the State. Solar water data were collected on existing solar water installation in Edo State (Solarmate, 2005) shown in Figure 12.

Area of Study

Rivers State occupies the coastal plain of the Niger delta region of the South-South zone of Nigeria. It is located on latitude 4.839124° N, and longitude 6.912407° E. The State consists of 23 Local Government Areas (Figure 1). Farming and fishing are the main occupations of the rural communities of the State. Rivers State is also one of the major oil producing States in the Niger delta region of Nigeria. Oil is found in most communities in the State. A large proportion of the people of Rivers State lived in remote rural and island areas where there is no availability of national electricity supply.

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Figure 1: Map of Rivers State

Modeling of Solar Water Pumping System

The modeling steps for a typical solar water pumping system are presented in Figure 2.

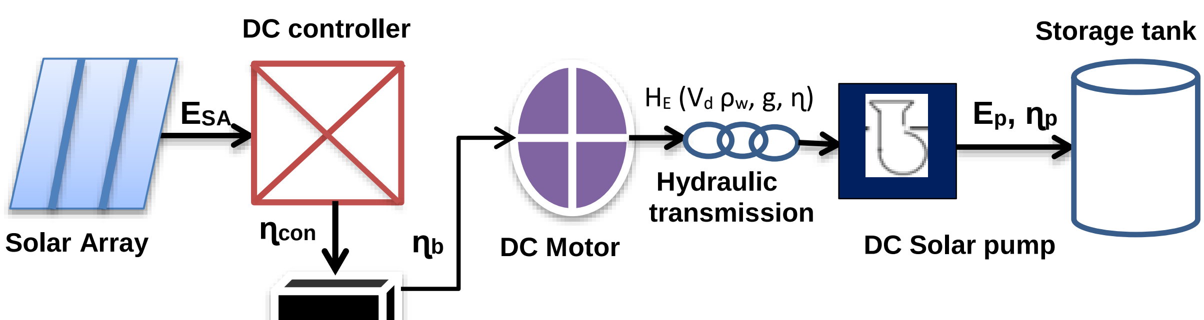

Figure 2: Modeling Steps of a Solar Water Pumping System

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Mathematical modeling of solar water pumping has been developed by RETScreen (2004) based on some equations found in Royer and Others (1998). The daily hydraulic energy required to pump water to a height, H with a daily volume of V_d is computed as:

$$H_E = \rho_w g V_d H(1 + h_f) \qquad (1)$$

Where H_E is the hydraulic energy per day, H is the total lifting or dynamic height (meter, m), V_d is the daily volume water demand (m^3/day), g is acceleration of gravity (9.81m/s^2), ρ_w is the density of water (1000kg/m^3) and h_f is the frictional loss on lifting pipes.

The electrical energy required for solar pump is computed from Equation (1) as:

$$P_E = \frac{H_E}{\eta_P} \qquad (2)$$

Where P_E is the pump energy, and η_P is the pump system efficiency. Equation (2) is modified to account for controller and batteries efficiencies.

$$P_E = \frac{H_E}{\eta_P \eta_c \eta_b} \quad \text{or} \quad P_E = \frac{H_E}{\eta_P \eta_{bc}} \qquad (3)$$

Where η_c is controller efficiency and η_b is battery efficiency

Also, $\eta_{bc} = \eta_c \times \eta_b$

Energy delivered is given as

$$E_d = \eta_p (P_E, E_{SA}) \qquad (4)$$

Where E_{SA} is the energy available from solar module array

E_{SA} is further decreased by the energy delivered directly to the load, E_d, charge controller and battery efficiencies (η_c and η_b) as follows.

$$\hat{E}_{SA} = \eta_{bc}(E_{SA} - E_d)$$

The daily volume of water delivered, V_d is computed as:

$$V_d = \frac{\hat{E}_{SA}}{\rho_w g H (1 + h_f)} \qquad (5)$$

The total solar array power is calculated from Equations (1), (2) and (5) as:

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$$P_{SA} = \frac{P_E}{\eta_{SA}\eta_{bc}} \qquad (6)$$

Where η_{SA} is the overall solar array efficiency

$$P_{SA} = \frac{H_E}{\eta_P \eta_{SA}\eta_{bc}} \qquad (7)$$

Equations (6) and (7) are used to calculate the required solar array size. The overall pump efficiency is computed from Equation (7) as

$$\eta_P = \frac{H_E}{P_{SA}\eta_{SA}\eta_{bc}} \qquad (8)$$

System Design and Sizing

Daily hydraulic energy, H_E in joules

Pump head or lifting height, H

Daily pumping volume, V_d

g = Acceleration due to gravity (9.81m/s)

η = overall system efficiency

η_s = Total solar array efficiency

ρ_w = water density is assumed to be 1000 kg/m^3

Power required to pump water

The load on pump is calculated using the relationship between lift and pressure (Kyocera, 2004)
$\text{Vertical height (meter)} = \text{Pressure x } 2.31$ or

$$\text{Pr}essure = \frac{Vertixcal\,\text{height (meter)}}{2.31} \qquad (9)$$

Power required in Watts to pump a liter of water per minute is given as:

$$P_{Watts} = \frac{\text{Vertical height (meters) x q x 16}}{\text{pump efficiency, \%}} \qquad (10)$$

Where q is quantity of water pumped in liter per minute.
From equation (10), the efficiency of any solar pump is given as:

(11)

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$$\text{Pump Efficiency, \%} = \frac{16qH}{P_{watt}}$$

Where H is the vertical height in meters, q is the quantity of water pumped per minute, and P_{watt} is the power in Watt.

Sizing Solar Water Pumping Systems

The sizing of solar water systems as contained in Barlow and others (1993) depends on the hydraulic energy required $H_{E,}$ (kWh/day), the volume of water required per day (m^3/d), the lift head or total dynamic head (m) x water density x gravity. This is expressed as:

$$H_e = \frac{\rho_w g V_d H}{3.6 \times 10^6} \qquad (12)$$

Where H_e is hydraulic energy required per day, kWh/d;
V_d is the volume of water required per day, m^3/d;
H is the vertical lift, m; ρ_w is the density of water, kg/m^3; and g is the gravity m/s^2.

Given the density of water, ρ_w as 1000kg/m^3 and gravity, g as 9.81m/s, equation (12) can be written as:

$$H_E = 2.725 V_d H \qquad (13)$$

Equation (13) is used to calculate the required solar array power, kW_p (Barlow and others, 1993) as follows:

$$\text{Required solar array power, kWp} = \frac{\text{Hydraulic energy required}}{\text{Average daily solar irradiance x F x E}} \qquad (14)$$

Where F = solar array mismatch factor = 0.85 on average, and
E = daily subsystem efficiency = 0.25 – 0.4 typically.
Equation (14) can be written as:

$$P_{SA} = \frac{H_E}{S_R F E} \qquad (15)$$

Where P_{SA} = solar array power required, KW_p; and

S_R = Solar irradiance (insolation), KWh/m^2/d

Given F as 0.85 and taking E as 0.275 Equation (15) can be written as:

$$P_{SA} = \frac{11.6578 V_d H}{S_R} \qquad (16)$$

This is the general solar water pumping design equation as contained in Hahn (2002).

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Design of an Integrated Solar based Water Supply System for Rural Areas

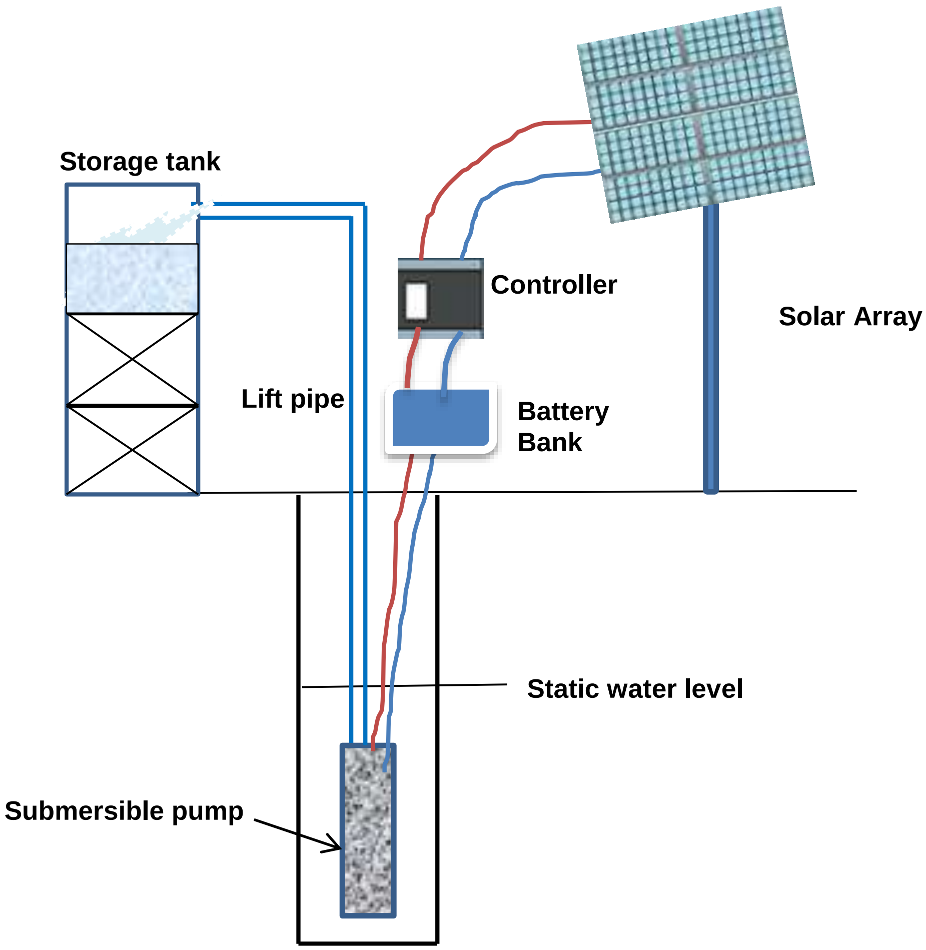

Figure 3: Schematic Diagram of a Solar Water Pumping System

The total dynamic head is the effective pressure the pump must operate against. From Figure 3 above, the total dynamic head is calculated as: The total dynamic head or total vertical lift is calculated by adding the standing water level, the drawdown and the elevation.

$$\text{Total dynamic head (TDH), H} = A + B + \text{pipe friction loss} = \text{Static head } (H_s) + \text{pipe friction loss } (h_f)$$

Total vertical lift is the sum of the Static water level, and elevation. As shown in Figure 4, the vertical lift is equal to A + B. The size of wells or boreholes is dependent on the size of pump and expected volume of water to be pumped.

In this design, a tank height of 12 meters and a storage tank capacity of 20,000 liters ($20m^3$) were used. Storage tank is used to store water for use during the night or periods of cloudy weather. The population of the community was estimated to be up to 500 people with water consumption of about $20m^3$ per day (40litre per capita per day).

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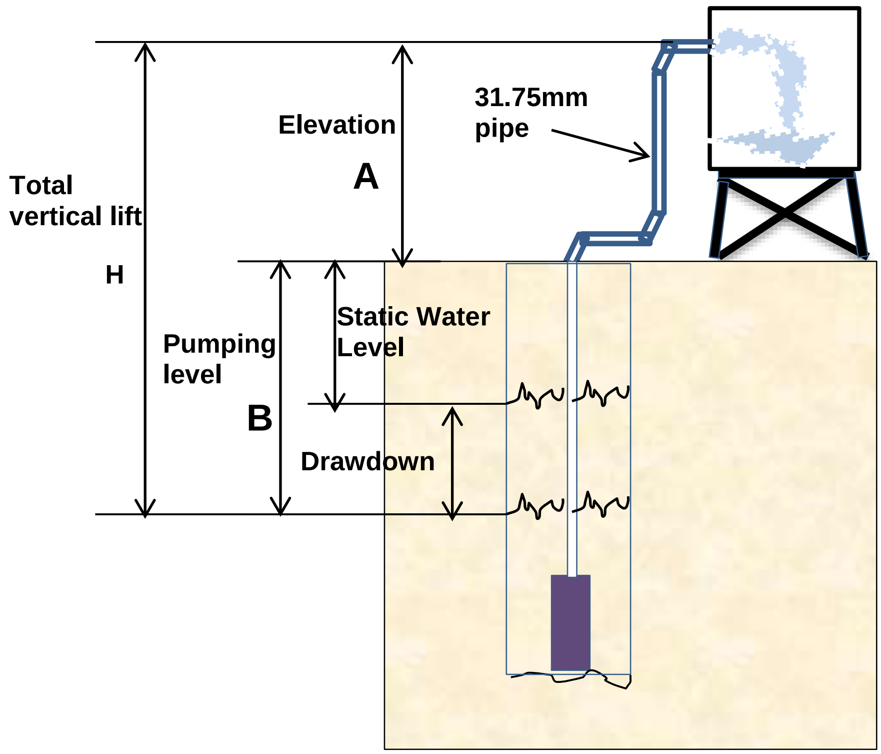

Figure 4: Solar water system showing Total Dynamic Head

TOTAL DYNAMIC HEAD = TOTAL *VERTICAL LIFT + FRICTION LOSS*

Friction loss is estimated at 2% of the TOTAL VERTICAL LIFT to allow for a few straight runs of pipe and a few fittings.

To estimate the flow rate

Flow rate = Vd/(24 x 60) = 20m^3/d/1440 = 0.014m^3/min

Calculate the friction loss by adding the length of all piping in the system

All Kyocera SC series pumps use the CC 2000 controller (Kyocera, 2004).

SC series pumps offer much higher volumes of water, and will pump from greater depth

These pumps are usually used for community water supply

The following parameters were therefore used in the solar water design:

Borehole total depth = 50m,

Borehole diameter =15.24cm (6inch),

Storage tank height = 12m and

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Storage tank capacity = 20,000l ($20m^3$)

A suitable solar pump that would deliver the above water requirement was selected from solar Kyocera products catalog (Kyocera, 2004). This was done by consulting manufacturer's product charts to select the pump that will meet the above water volume and total depth requirements. In this project a Kyocera SC1000 60 – 45 pump rated at 1050 Watts was used.

This pump can actually deliver up to $30m^3$ of water per day. The daily average insulation or solar radiation for the region is $4kW/m^2$/day (IITA, 2005).

Total static head $H_s = 50 + 12 = 62m$

Pipe friction loss, h_f = 2% of H_s = 1.24

Total Dynamic Head, TDH= 62 + 1.24 = 63.24m

The Hydraulic energy required H_E, kWh/d using Equation (13) is calculated as follows:

$H_E = 2.725 V_d H$

Substituting for values of V_d and H,

H_E = 2.725 x 20 x 63.24; H_E = 3.45kWh/day

The solar power required P_{SA} in kW_p is calculated using Equation (15) as follows:

For a solar array mismatch factor, F, of 85%; a daily subsystem efficiency, E, of 0.275 as given by (Barlow and others, 1993); and daily insolation, S_R, of $4kWh/m^2$/day, required solar power,

P_{SA} = 3.45/ (4 x 0.85 x 0.275) = 3.69kWp rounding up to 3.7kW_p or alternatively, using equation derived by Hahn (2002)

P_{SA} = 11.6578 x H x V/S_R

Substituting values we have

P_{SA} = 11.6578 x 63.24 x 20/4000 = 3.69kW_p rounding up to 3.7kW_p

This result shows that it will take a 3.7kW_p solar power array to deliver $20m^3$/day of water at a total head of 63.24m, for a daily insolation of $4kWh/m^2$/d.

The number of Kyocera, KC167W solar panels or solar array that can deliver the above power requirements was calculated as follows:

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For a 60 Volt DC pump using 167W panel,

The rated output Power, P = 167W and Voltage V = 23.2V

Current, $I = P/V$ = 167/23.2 = 7.2 A

P_{SA} = 3.7kW_p,

Maximum current I_{max} = 3700/60 = 62A@60V

Number of panels = 62/7.2 = 9

The output voltage of the solar panel is 23.2 volt, while the pump operating voltage is 60 volt, which is three times the panel's output voltage. Therefore the total number of panels required is 3 x 9 = 27, 3 connected in series and 9 connected in parallel.

Cloudy weather affects solar array power output therefore solar tracker is required in the system.

Battery Sizing

The sizing battery bank was based on the desired number of days of autonomy. The usable battery capacity was determined using the Equation (RETScreen, 2004):

$$Q_B = \frac{NL_{dc}}{h_{Bd}\eta_b} \quad (17)$$

Where Q_B is the battery capacity, N is the number of days of autonomy, L_{dc} is the equivalent DC load, h_{Bd} *is* the battery depth of discharge and η_b is the battery efficiency.

A 2 day of autonomy is assumed based on the climatic conditions of the Niger Delta.

N = 2 days, Ldc = 3400W, h_{Bd} = 80% and η_b = 85%

$$Q_B = \frac{2 \text{ x } 3400}{0.8 \text{ x } 0.85} = 10{,}000\text{Ah}$$

A deep cycle battery of 12volts 200Ah is chosen

Number of batteries required = 50

Cable Size and Overcurrent Protective Calculation

The solar water pumping system was designed based on the National Electric Code (NEC) suggested practice on Photovoltaic Power Systems (Wiles, 2001).

System Characteristics:

Solar array size = 27,

Panel Voltage = 23.2volt,

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Panel power = 167 Watt

Short circuit current, I_{sc} = 3.8amps,

Open circuit voltage, V_{oc} = 21.7volts

Controller current output = 90amps

Load: 60volt, 40amps motor pump

Calculations

The array short circuit current is 27 x 3.8 = 102.6amps

PV: 125% of Photovoltaic = 1.25 x 102.6 = 128.25amps

NEC 125%: = 1.25 x 128.25 = 160.3125 5amps

The current capacity of American Wire Gauge (AWG) 4 cable at 30^0C in free air is 250amps. The rated current capacity of AWG 4 at 61 – 70 ^{0}C is 0.58 x 250 = 145 amps. This is more than 128.25 amps required for the solar array system.

The sub array current = 9 x 3.8 = 34.2apms

PV 125%: = 1.25 x 34.2 = 42.75amps

NEC 125%: = 1.25 x 42.75 = 53.4375amps

The current capacity of AWG 6 at 30^0 C is 90amps

The current capacity at 61 – 70^0C is 90 x 0.58 = 52.2amps**.** This is more than 42.75amps required for sub-array system.

Similar calculation was carried out to select AWG 8 for the pump controller to pump motor connection. Based on the above calculations to select the right size of cables, a 50amps DC Circuit Breaker was therefore used to protect the AWG 6 sub-array conductors. The required rating is actually 1.25 x 42.75 = 53.5amps but the next largest size of 60amps is used. The system wired with this new cable sizes and a circuit breaker installed to protect the pump controller.

RESULTS AND DISCUSSION OF FINDINGS

Borehole depths in Rivers State vary from 30 meters to 250 meters (Figure 5), while borehole diameters vary from 100mm to 250mm (Figure 6). Static water levels in Rivers State increase from the coastal areas towards the hinterland (0.3m in Okirika area to 21m in Obio-Akpor/Ikwerre areas. The depth to be cased and screened is determined from the lithologic log samples obtained during drilling or by logging the well with logging equipment. Data obtained on water installations in Rives State (Horizon Concept, 2000) showed that most of the borehole installations in the State

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have diameters of 150mm and total depths of 45 meters. Choice of size of wells or boreholes is dependent on the size of pump and expected volume of water to be pumped.

Solar irradiance (insolation) in the State varies from 3.2 kwh/m^2/day to 4.3 kwh/m2/day with August being the minimum because of cloudy conditions in this month (Figure 7). Solar panels will still produce maximum output to pump water in this month of rains and cloudy conditions because of the Maximum Power Point Tracker (MPPT) that increases the output of the panel. This helps to guarantee constant source of power for water pumping. Monthly minimum and maximum temperatures in the State are within solar panel's tolerable levels (Figure 8). These range of temperatures showed that solar panels can be used to pump water in the State without experiencing over heating effect due to high temperature as the maximum temperature that a solar panel can tolerate is 70^{0}C (Kyocera, 2004). Volumes of water pumped for each month of the year are presented in Figure 9. Less volumes are expected in the months of June, July and August, these months experienced cloudy weather and thus necessitate the used of backup batteries in the solar water system. Volumes of water pumped varied directly proportional to solar radiations and indirectly proportional to depths of boreholes as shown in Figures 10 and 11 respectively. Finding showed that it will take a 3.7kWp solar power array to deliver 20m3/day of water at a total head of 63.24m, for a daily insolation of 4kWh/m2/d.

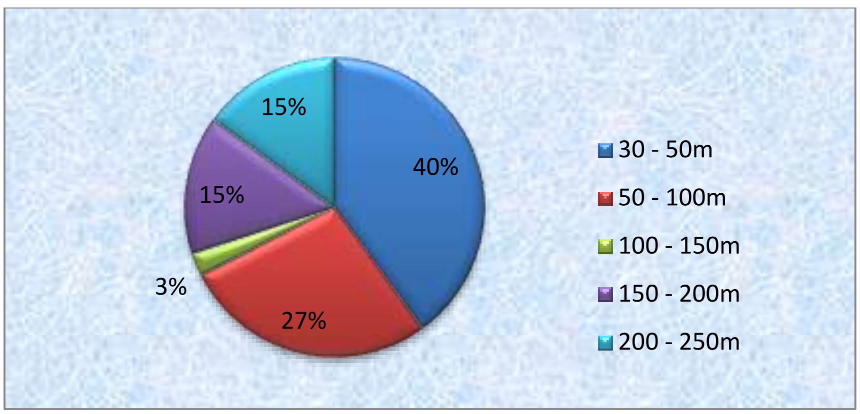

Figure 5: Borehole depths distribution in Rivers State.

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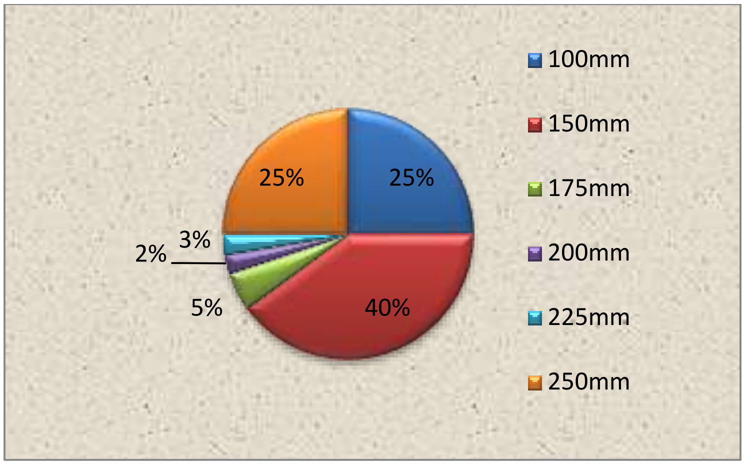

Figure 6: Borehole diameters distribution in Rivers State

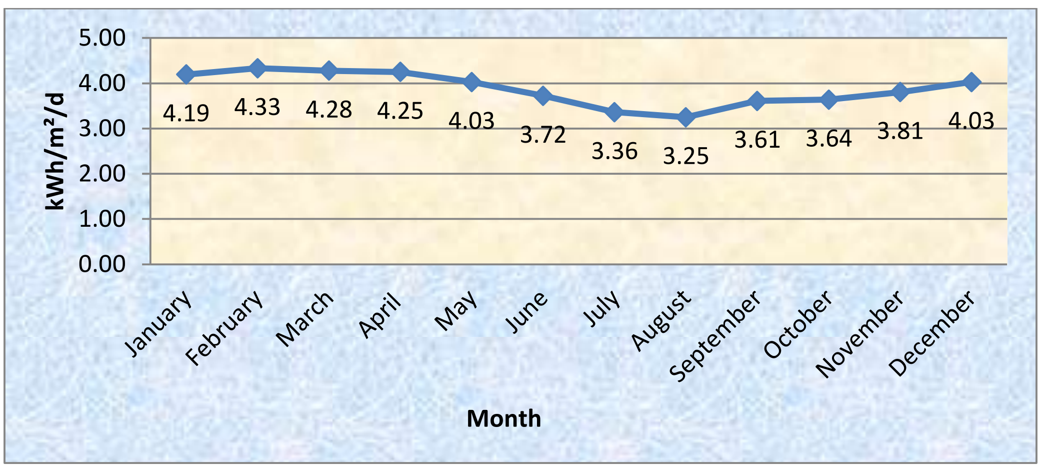

Figure 7: Monthly Solar radiation in Rivers State

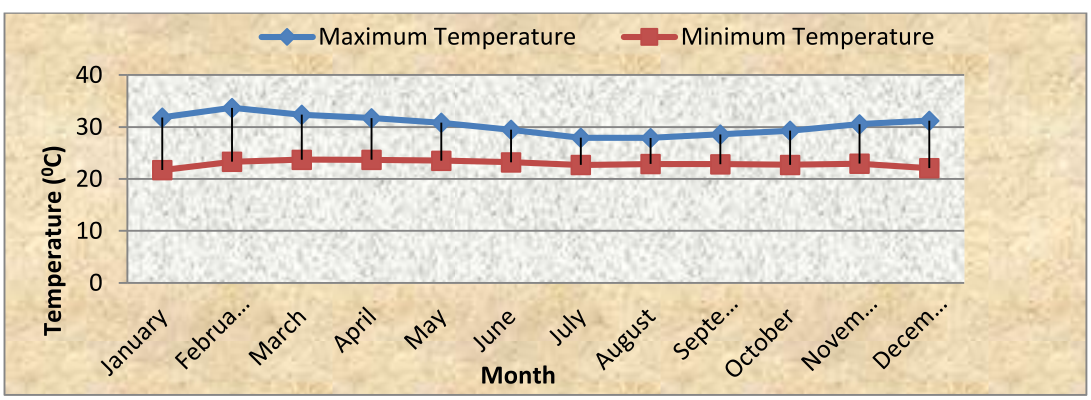

Figure 8: Monthly Maximum and Minimum Temperature in Rivers State

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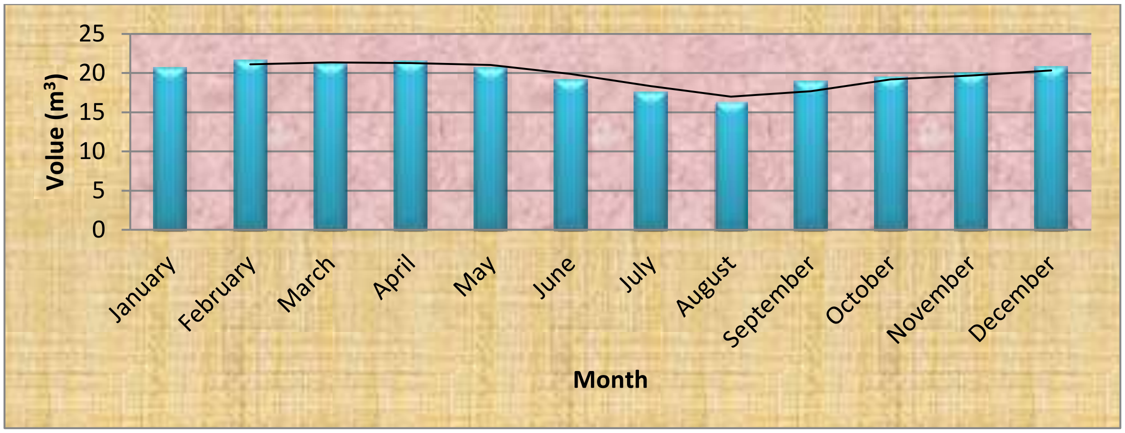

Figure 9: Monthly volume of water pumped

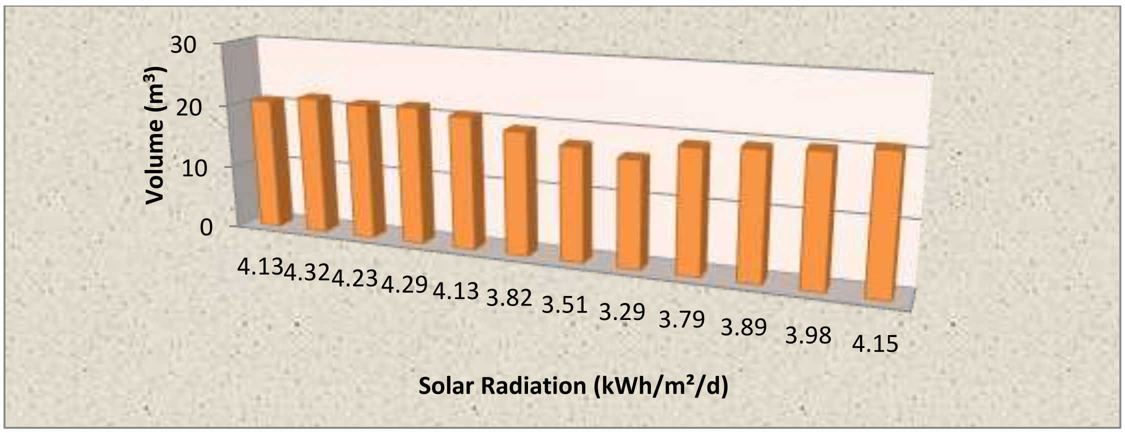

Figure 10: Variation of volume with solar radiation

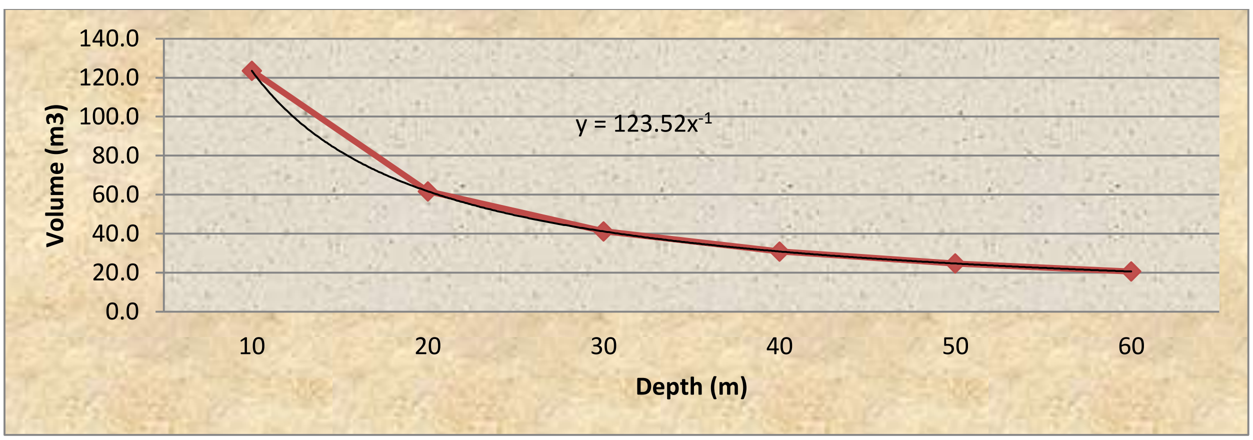

Figure 11: Variation of volume with depth

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Figure 12: Solar Water Pumping Station in a Rural Community in Edo State, Nigeria. Source: Solarmate, 2005

CONCLUSION

The study showed that Rivers State is blessed with abundance of sunshine throughout the year with annual daily, mean solar radiations up to 4.3 kWh/m2/day. With such high solar radiations (insolation), solar powered water pumps should be considered an appropriate option for long-term water delivery system for rural dwellers in the State. Study showed that solar water pumping systems are technically viable for use, beneficial for the environment and therefore forms attractive alternatives to diesel-driven pumping system in the rural areas of Rivers State.

RECOMMENDATION

To achieve sustainable water supply in rural areas of Rivers Sate, policy makers, decision makers, and water authorities in Rivers State as well as other non-governmental organizations should decide in favour of solar water pumping systems when providing water for the rural communities in the State.

Further research study is needed to comparatively evaluate the economic viability of solar water system and diesel-driven pumping system in rural communities in Rivers State.

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