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Assessment Of The Effect Of The Water Pump Connection Configuration On The Electric Power Demand For A Solar Powered Groundnut Farm Furrow Irrigation System

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Abstract— **In this paper, solar water pump sizing and assessment of the impact of water pump connection configuration on the required power for meeting the water demand of a furrow irrigation system for a one hectare groundnut farm is presented. The farm is located in Ebonyi state of Nigeria with 4.794 hours/day annual average peak sun hour on an optimally tilted plane. With seven days irrigation cycle, the daily water demand is $19.13\ \mathrm{m^3/day}$, the water flow rate is $3.99\ \mathrm{m^3/hr}$ and the total water head is 45 m. Gradfos online pump sizing tool was used to determine the operating pump power for three different pump configurations, namely; configuration 1, sizing with a single Grundfos SQFlex 16 SQF-10 solar submersible water pump; configuration 2, sizing with two Grundfos SQFlex 16 SQF-10 solar submersible water pumps connected in parallel and configuration 3, sizing with six single Grundfos SQFlex helical solar water pump model 11 SQF-2 where there are two sets of pumps in parallel and each set of pump consists of three pumps connected in series. The results showed that the configuration 1 and configuration 3 require 1.26 kWh to meet the daily water demand whereas configuration 2 required 1.2 kWh . This is about 95 % of the power required by configuration 1 and 3. As such, about 5 % of power can be saved by using configuration two (2). The idea presented in this paper will help solar power pumping system designers to reconsider their pump selection and connection configurations so as to achieve optimal power utilization.**

Keywords— Submersible Pump, Flow Rate , Irrigation, Irrigation Cycle, Furrow Irrigation, Water Demand, Solar Pump.

1. INTRODUCTION

Across Nigeria, Ebonyi state is known for their involvement in large-scale farming [1,2,3]. The availability of large expanse of land in the State further encourages the inhabitants to embark on large-scale farming. However, the weather condition in Ebonyi state is such that they witness longer dry season period as compared to the rainy season period [4,5,6,7]. Consequently, irrigation is required to meet the daily water demand of the crops in Ebonyi State.

In this paper, a typical furrow irrigation water supply for groundnut farm is considered. The analytical expressions for the determination of the daily water demand for the furrow irrigation process are presented. Also, mathematical expressions for computing the water flow rate and water head for the sizing of the water pump are presented. Although, the water flow rate and the water head are the major factors used in the selection of the solar water pump [8,9,10,11,12], there are several pumps that can still satisfy the required water flow rate and water head but with different electric power demand [9,13]. Particularly, the selected water pump performance characteristics and the pump connection configuration do affect the total power required to meet the water demand. As such, in this paper, three different water pump connection configurations are considered and their overall power demands are compared. Two different Gradfos water pump models are used in the assessment. An online water pump sizing tool from Gradfos [14] was also used to determine the actual operating power for the pumps at any given operating point determined by the water flow rate and the water head. The idea presented in this paper will help solar-powered water pump system designers to make choices when selecting the water pumps for their water pumping projects.

2. DETERMINATION OF WATER VOLUME REQUIRED FOR FURROW IRRIGATION PROCESS

Let the water volume per hectare in m^3/ha be denoted as $\mathrm{V_{ha}}$, the required water height in cm be denoted as $\mathrm{h_w}$, the furrow bed-to-bed distance in cm be denoted as d_{bb}, the width of the bed in cm be denoted as d_{wt} and the number of canals be denoted as n_{cn}, then [15];

$$n_{cn} = \left(\frac{\left(100 - \frac{d_{bb}}{100}\right)}{\left(\frac{d_{wt} + d_{bb}}{100}\right)} \right) + 1 \qquad (1)$$

$$\mathrm{V_{ha}} = \left(\frac{h_w((d_{bb})100)(n_{cn})}{100} \right) \frac{1}{100} \qquad (2)$$

According to [15], for furrow irrigation of groundnut farm, the width of bed (d_{wt}) is 40 cm, the bed-to-bed distance (d_{wt}) is 20 cm and the required water height (d_{wt}) is 4 cm, hence, the number of canals (n_{cn}) and the required volume of water per hectare $(\mathrm{V_{ha}})$ is given as;

$$n_{cn} = \left(\frac{\left(100 - \frac{20}{100}\right)}{\left(\frac{40+20}{100}\right)} \right) + 1 = \left(\frac{99.8}{0.6}\right) + 1 = 167.3$$

$$\mathrm{V_{ha}} = \left(\frac{4\big((20)100\big)(167.3)}{100}\right)\frac{1}{100} = 133.84$$

Let the discharge rate in $\mathrm{m^3}$/hr be denoted as Q, the irrigation cycle in days be denoted as n, the number of hectares to be irrigated in one irrigation cycle be denoted as K and the duration of irrigation per day in hours be denoted as T, then;

$$Q = \left(\frac{\mathrm{V_{ha}}}{\mathrm{T}}\right)\frac{K}{\mathrm{n}} \tag{3}$$

The total area covered by the groundnut farm is hectares (hence, k = 1.0 ha). The case study farm is located in Afikpo with annual average Peak Sun Hour (PSH) of 4.7 hours/day which at the optimal tilt angle with transposition factor of 1.02 becomes 4.794 hours/day. Also, a seven (7) days irrigation cycle is adopted to cover the entire 1.0 ha farm. Essentially, n = 7 days and T = 4.794 hours/day, hence, the water flow rate (Q) in $\mathrm{m^3}$/hr is given as;

$$Q = \left(\frac{133.84}{4.794}\right)\frac{1.0}{7} = 3.99\ \mathrm{m^3/hr} = \frac{3.99}{3600} = 0.00111\ \mathrm{m^3/s}$$

Let the area irrigated per day be denoted as $\mathrm{A_{fupd}}$ in $\mathrm{m^2}/day$ while the volume of water required per day be denoted as $\mathrm{V_{fupd}}$ in $\mathrm{m^3}/day$, then;

$$\mathrm{V_{fupd}} = (Q)T = \left(\frac{K}{\mathrm{n}}\right)\mathrm{V_{fupha}} \tag{4}$$

$$\mathrm{A_{fupd}} = \frac{(\mathrm{V_{fupha}})K}{\mathrm{V_{fupd}}} = \left(\frac{\mathrm{K}}{\mathrm{n}}\right) \tag{5}$$

With the given values,

$$\mathrm{V_{fupd}} = (Q)T = (3.99)4.794 = 19.13\ \mathrm{m^3}/day$$

$$\mathrm{A_{fupd}} = \left(\frac{\mathrm{K}}{\mathrm{n}}\right) = \left(\frac{1.0}{7}\right) = 0.143\ ha\,/day$$

3. DETERMINATION OF THE TOTAL DYNAMIC HEAD

The total dynamic head denoted as H_{TDH}, is given as [16];

$$H_{TDH} = \mathbf{H_{STSM}} + H_{DH} \tag{6}$$

Where static head for submersible pump is denoted as $\mathrm{H_{STSM}}$ and the dynamic head is denoted as $\mathrm{H_{DH}}$. The dynamic head , H_{DH} is due to frictional as the water flows through the pipe; a value of 6% is assumed. Hence,

$$H_{DH} = 0.06(H_{STSM}) \tag{7}$$

$$H_{TDH} = \mathbf{H_{STSM}} + 0.06(H_{STSM}) = \mathbf{1.06\ (H_{STSM})} \tag{8}$$

Meanwhile, the static head, $\mathbf{H_{STSM}}$ is given as [16];

$$H_{STSM} = \mathrm{H_{PL}} + H_{LFSL} \tag{9}$$

Where, the static water level is denoted as $\mathrm{H_{SWL}}$, the pumping level is denoted as $\mathrm{H_{PL}}$ and the lift from surface level is denoted as $\mathrm{H_{LFSL}}$. In the case study, $\mathrm{H_{PL}} = 22\ m$ and $H_{LFSL} = 20$ m then;

$$H_{STSM} = 22 + 20 = 42\ \mathrm{m}$$

$$H_{TDH} = 1.06\ (\mathrm{H_{STSM}}) = 1.06\ (42) = 44.5\ \mathrm{m} \approx 45\ m \approx 148 ft$$

4. SELECTION OF THE WATER PUMP

The pump is selected based on the water flow rate (Q) which is $3.99\ \mathrm{m^3/hr}$ and the Total Dynamic Head, $\mathrm{H_{TDH}}$ which is 45 m or 148 ft. In this paper, two different models of submersible pumps from Gradfos are selected and the total power ratings are compared. The pumps are Grundfos SQFlex 16 SQF-10 solar submersible water pump and Grundfos SQFlex helical solar water pump model 11 SQF-2 and their electrical data are presented in Table 1. The pumps actual operating power depends on the specific operating point which is determined by the water flow rate (Q) and the water head (TDH) . Again, a given Q and TDH can be achieved by a single pump and also by two or more pumps connected in series or in parallel. When water pumps are connected in parallel their water head (TDH) remains the same but the flow rate adds up. Conversely, when water pumps are connected in series their water head adds up but their water flow rate remains the same. In this paper single pump sizing, parallel pump and series cum parallel sizing options are examined and the resultant total required electrical power are compared. In the pump selection, the overall pump operating point to be achieved is flow rate, Q = $3.99\ \mathrm{m^3/hr}$ and total dynamic head TDH = 45 m or 148 ft

Table 1 The Electrical data On The selected Gradfos solar submersible water Pumps

Parameter	Grundfos SQFlex 16 SQF-10 solar submersible water pump	Grundfos SQFlex helical solar water pump model 11 SQF-2
Power input – (maximum)	1.4 kW	1.4 kW
Rated voltage ac	1 x 90-240 V	1 x 90-240 V
Rated voltage dc	30-300 V	30-300 V
Rated current	8.4 A	8.4 A

4.1 SIZING WITH A SINGLE PUMP

The overall pump operating point is Q = $3.99\ \mathrm{m^3/hr}$ and TDH = 45 m. The Grundfos online tool for pump selection based on the pump operating point is used to determine the pump actual operating power at the given operating point for a Grundfos SQFlex 16 SQF-10 submersible solar water pump. At the given operating point (Figure 1) of Q = $3.99\ \mathrm{m^3/hr}$ and TDH = 45 m (Figure 1), the solar pump require 1.26 kW power from the PV module.

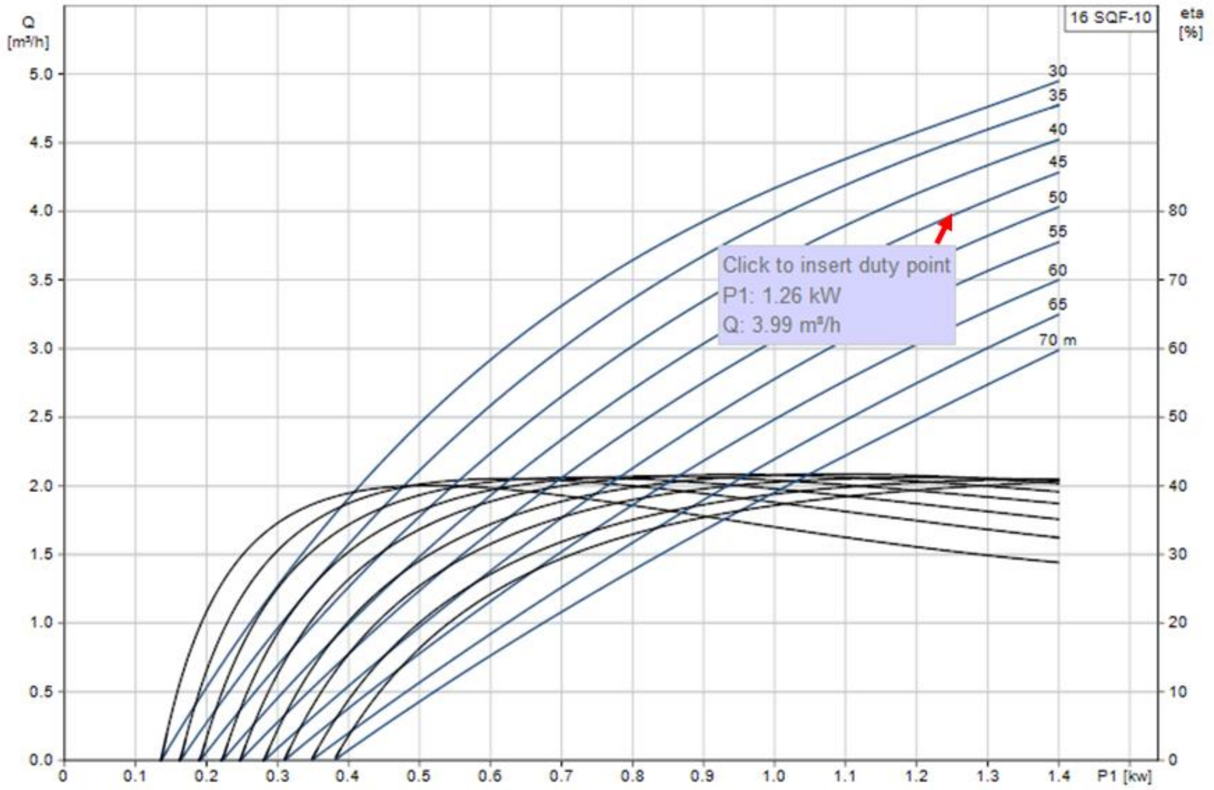

Figure 1 Grundfos SQFlex 16 SQF-10 solar submersible water pump operating power (1.26kW) and flow rate (3.99m3/h) at THD of 45 m [15]

4.2 Sizing with two pumps in parallel

Again, the overall pump operating point is Q = $3.99\ \mathrm{m^3/hr}$ and TDH = $45\ \mathrm{m}$. When pumps are connected in parallel their flow rates add up but their water heads remain the same. In this case, the Grundfos online tool is used to determine the pump actual operating power when two (2) Grundfos SQFlex 16 SQF-10 submersible solar water pumps are connected in parallel to meet the required overall pump operating point. In this case, the operating point of each of the pumps is Q1 = Q2 = $\frac{3.99\ \mathrm{m^3/hr}}{2} = 1.99\ \mathrm{m^3/hr}$ and TDH1 =TDH2 = $45\ \mathrm{m}$. The, Grundfos online tool result in Figure 2 shows that each of the pumps require 0.6 kW power from the PV module at the given operating point of Q1 = $1.99\ \mathrm{m^3/hr}$ and TDH1 = $45\ \mathrm{m}$. Hence, a total of 1.2 kW power is required to meet the water demand of the farm when two Grundfos SQFlex 16 SQF-10 solar submersible water pumps are connected in parallel. This is about 95 % of the power required when single Grundfos SQFlex 16 SQF-10 solar submersible water pump is used which is an improvement of about 5 %.

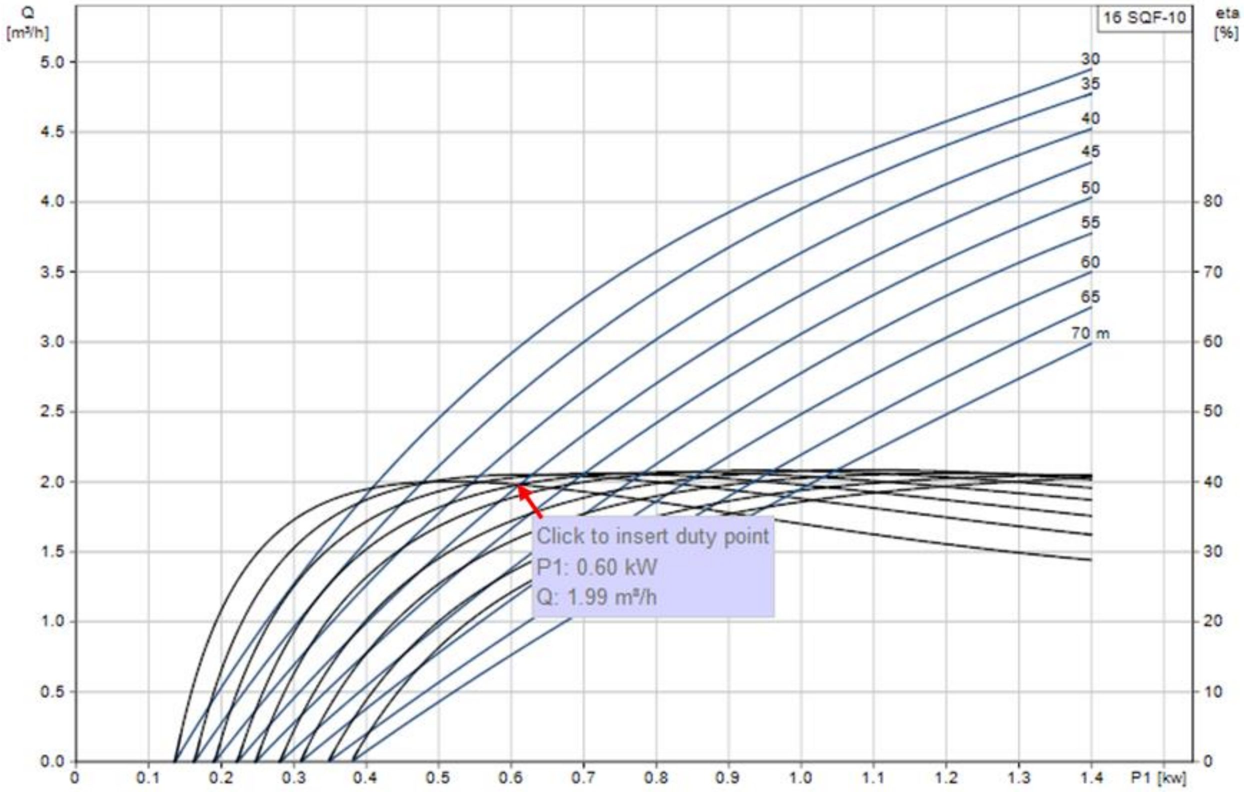

Figure 2 Grundfos SQFlex 16 SQF-10 solar submersible water pump operating power (0.6kW) and flow rate (1.99m3/h) at THD of 45 m [15]

4.3 SIZING WITH MANY PUMPS IN SERIES AND IN PARALLEL

Once more, the overall pump operating point is Q = $3.99\ \mathrm{m^3/hr}$ and TDH = $45\ \mathrm{m}$. When pumps are connected in series their flow rates remains the same but their water heads add up. In this case, the Grundfos online tool is used to determine the pump actual operating power when six pumps are used; with two parallel set of pumps where each set is made up of three pumps in series. In this case, the pump used is the Grundfos SQFlex helical solar water pump model 11 SQF-2 submersible solar water pump. Again, the operating point of each of the pumps is Q1 = Q2 = Q3 = $\frac{3.99\ \mathrm{m^3/hr}}{2} = 1.99\ \mathrm{m^3/hr}$ and TDH1 = TDH2 = TDH2 = $\frac{45\ \mathrm{m}}{3} = 15\ \mathrm{m}$. So, when three of the pumps are connected in series, the total water head bedcomes; TDHs1 = TDH1 +TDH2 + TDH3 = $15 + 15 + 15 = 45\ m$. So, the three pumps in series have an operating point of TDHs1 and Qs1 = Q2= $1.99\ \mathrm{m^3/hr}$.

Furthermore, when two sets of the three pumps in series are connected in parallel, their flow rate add up to give Q = Qs1 + Qs2 = $\frac{1.99\ \mathrm{m^3}}{\mathrm{hr}} + 1.99\ \mathrm{m^3/hr} = \frac{3.99\ \mathrm{m^3}}{\mathrm{hr}} = 3.96\ \mathrm{m^3}$.

The, Grundfos online tool result in Figure 3 shows that at the operating point of Q1 = $1.99\ \mathrm{m^3/hr}$ and TDH1 = $15\ \mathrm{m}$, each of the pump require 0.21 kW power from the PV module. Hence, a total of 1.26 kW power is required to meet the water demand of the farm when six (6) Grundfos SQFlex helical solar water pump model 11 SQF-2 solar submersible water pumps are connected with two sets of three series pump connected in parallel. This is the same power required when a single Grundfos SQFlex 16 SQF-10 solar submersible water pump is used.

In essence, the second option is the best, as it gives about 5 % reduction on the required power to deliver the daily water demand for the farm.

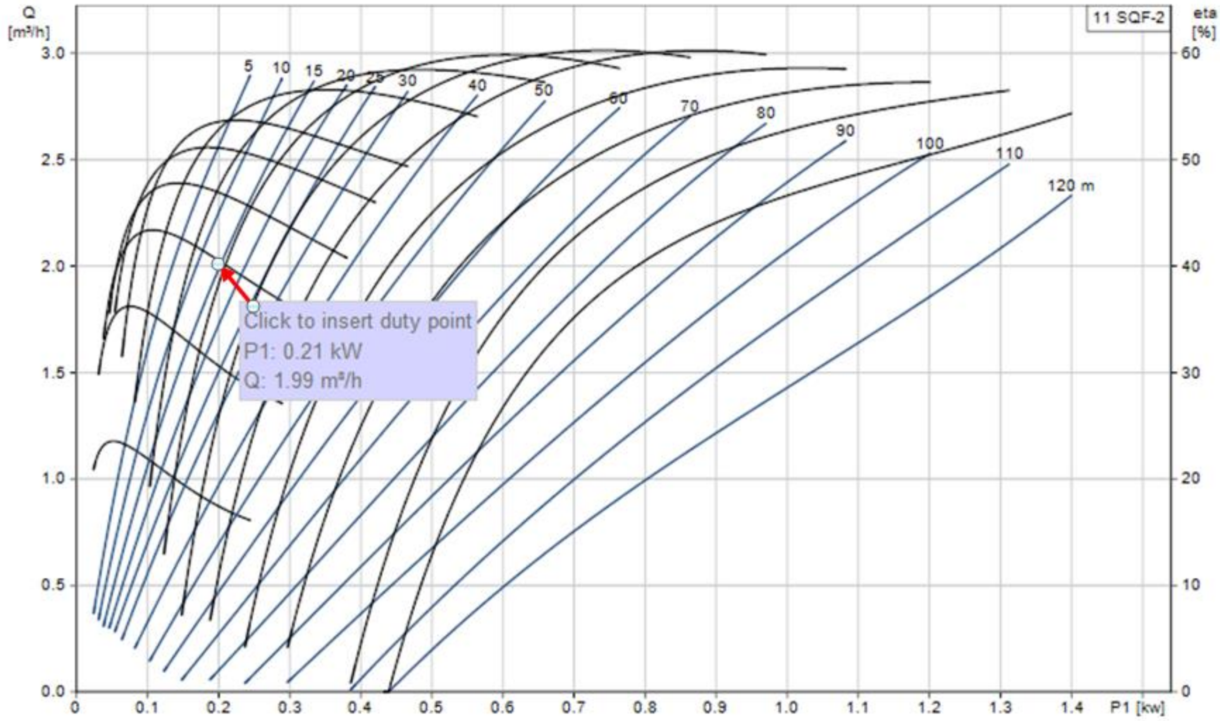

Figure3 Grundfos SQFlex helical solar water pump model 11 SQF-2 operating power (0.2kW) and flow rate (1.99m3/h) at THD of 15 m [15]

5 CONCLUSION

The daily water demand for furrow irrigation system used in a groundnut farm is presented. The expected flow rate and total dynamic head are determined using relevant mathematical expressions. The flow rate and total dynamic head are then taken as the overall pump operating which is used to select different water pump connection configurations that can meet the daily water demand . The results showed that two pumps connected in parallel were better in terms of required power than the single pump scenario. Also, six (6) pumps connected in two batches in parallel where each batch consist of three pumps in series required the same power as the single pump scenario. In all, the paper demonstrated that appropriate selection and connection of water pumps can provide some significant improvement in the power efficiency of the solar water pumping system.

REFERENCES

1. Nwalieji, H. U., & Chen, Z. (2016). Comparative Profit Analysis of Rice Production Enterprise among Farmers in Anambra and Ebonyi States, Nigeria. *Asian Journal of Agricultural Extension, Economics & Sociology*, *8*(3), 1-11.
2. Prisicilla, O. N., & Obioma, O. M. (2015). Rural Development and Food Security Programmes in Nigeria: Issues and Challenges. *Journal of Policy and Development Studies*, *289*(1850), 1-13.
3. Chukwu, V. A., & Oselebe, A. A. (2014). LEVEL OF PARTICIPATION AND BENEFITS OF THE NATIONAL PROGRAMME FOR FOOD SECURITY (NPFS) AMONG RURAL WOMEN IN EBONYI STATE, NIGERIA UMEH, GN. *Global Journal of Agricultural Research*, *2*(4), 19-26.
4. Nwofe, P. A., & Ekpe, J. E. (2014). Potentials of renewable energy in Ebonyi State, Nigeria. *British Journal of Environmental Sciences*, *2*(4), 1-10.
5. Mohammed, H. (2015). Microbial Status of Prison Inmates in Abakaliki Prison, Ebonyi State Southeastern Nigeria. *Global Journal of Medicine Researches and Studies*, *2*(1), 7-11.
6. Obasi, A. I., Ekpe, I. I., & Igwe, E. O. (2015). The physical properties of soils within major dumpsites in Abakaliki Urban, Southeastern Nigeria, and their implications to groundwater contamination. *International Journal of Agriculture and Forestry*, *5*(1), 17-22.
7. Akpa, E. C. (2014). *Gender and environmental degradation in agrarian communities of Ebonyi State, Nigeria* (Doctoral dissertation).
8. Joynal, J. B., Raka, N. T., & Mithu, H. M. (2017). *Design & economic analysis of a solar-powered water pumping system for crop irrigation* (Doctoral dissertation, BRAC University).
9. Van Pelt, R., Weiner, C., & Waskom, R. (2008). Solar-powered groundwater pumping systems. *Natural resources series. Water; no. 6.705*.
10. Gouws, R., & Lukhwareni, T. (2013). Factors influencing the performance and efficiency of solar water pumping systems: A review. *International Journal of Physical Sciences*, *7*(48), 6169-6180.
11. Benghanem, M., Daffallah, K. O., & Almohammedi, A. (2018). Estimation of daily flow rate of photovoltaic water pumping systems using solar radiation data. *Results in Physics*, *8*, 949-954.

12. Setiawan, A. A., Purwanto, D. H., Pamuji, D. S., & Huda, N. (2014). Development of a solar water pumping system in Karsts Rural Area Tepus, Gunungkidul through student community services. *Energy Procedia*, *47*, 7-14.
13. Otuagoma, S. O., Ogujor, E. A., & Kuale, P. A. (2016). DETERMINATION OF HEAD FOR SMALL HYDROPOWER DEVELOPMENT: A CASE STUDY OF RIVER ETHIOPE AT UMUTU. *Nigerian Journal of Technology*, *35*(1), 190-195.
14. Gradfos (2018) Gradfos online water pump sizing tool Available at : https://product-selection.grundfos.com/product-detail.product-detail.html?custid=GMA&productnumber=95027350&qcid=466345587. Accessed on 12 December 2018.
15. Khan, M. T. U. I., & Pathik, B. B. (2014). A comprehensive study on photovoltaic irrigation system for different crop cultivation: financial evaluation perspective. *Journal of Electrical Engineering*, *2*, 228-237.
16. NSW Farmers, GSES,(2015), Solar-powered pumping in agriculture: A guide to system selection and design. NSW Farmers, 2015