News models for Electrical energy evaluation and water flow rate prediction of the photovoltaic water pumping systems in Cameroon

Kodji Deli, Etienne Tchoffo Houdji, Albert Ayang, Dieudonne Kidmo Kaoga, Noel Djongyang

Abstract— **Energy yield of tree photovoltaic water pumping (PVWP) systems have been studied in order to predict real time water flow rate of a PV water pumping systems in the Sahelian regions of Cameroon. Four semi-experimental models have been developed for the purpose. Models are validated by measured data of water flow rate based on selected statistical parameters such as mean bias error (MBE), mean absolute bias error (MABE), root mean square error (RMSE) and determination coefficient (R^2). To know if the performance parameters perform data adequately, comparison are made among different models or model can be compared itself through ideal and recommended values of these parameters. It appears that for stations 1 and 2, the model 4 performed data better than other models since performance parameters are within the recommended values. Indeed, the MBE (%), MABE (%), RMSE (%) and (R^2), are respectively (-6.4), (8.83), (13.82) and (0.95), for station 1 and (-7.04), (9.83), (17.42), (0.97) for station 2. These performance parameters are within the rigorous criterion of the evaluation of models for these two stations. However, for the station 3, model 4 is recommended for the evaluation of water flow rate during the cloudiest day since Model 2 is recommended for the sunniest day. Indeed, for the cloudy day, the MBE (%), MABE (%), RMSE (%) and (R^2) are respectively (-6.49), (6.63), (8.72), (0.97) for cloudy day and (8.36), (14.52), (36.78), (0.705) for sunny day. Regarding these data the model 4 can be used to evaluate the water flow rate for any locations and for cloudy and sunny days.**

Index Terms—**energy evaluation, water flow rate prediction, models, PVWPS.**

I. INTRODUCTION

Photovoltaic (PV) power generation system is one of the most popular uses of the direct solar energy and its installation is rapidly growing because it is considered as a clean and environmentally friendly source of energy [1], [2] One of the most popular and promising applications of standalone photovoltaic (PV) systems nowadays is PV water pumping system (PVWPS) [3]. The use of photovoltaic system is very attractive for pumping water in rural area of developing countries because of their low maintenance, no pollution, easy installation, reliability and possibility of unattended operation and capacity to be matched to demand. It contributes to socio-economical development of the developing countries and is a real mean for the reduction of the greenhouse gases [4]-[6]. PVWPS consist in PV array, array mounting bracket and rack, pump controller, electrical ground for controller, DC or AC pump with safety ropes, mount, and well seal, wiring, water well, discharge tubing or piping, storage tank, tank flotation switch, water taps or access points [7]. Many other additional components can be added for more usability and flexibility of the photovoltaic water pumping system (Trailer Mounting, Batteries, Solar Tracking System, Low Well Switch and Sand Shroud). Depending on the components in the system, PVWPS can broadly be classified as presented in the Fig. 1 [8].

One of the keys to success of the PVWPS is the design and sizing. To achieve improvements in PV pumping design, it is necessary to study and model photovoltaic water pumping systems. Some authors developed algorithms to determine the optimum sizing for the PV water pumping installation depending on the load demand and the site characteristics [9]-[11], demonstrating that an optimum sizing allows to decrease considerably the water pumping installation cost [12]. Other researchers concentrated on the optimum use of the photovoltaic energy generated by establishing management algorithms using intelligent tools, namely Fuzzy logic [13], [14]. A good sizing and energy use require an efficient extraction of the photovoltaic power. This requires the use of a technique that allows extracting the maximum PV power generated, known as Maximum Power Point Tracking or MPPT [15], despite the fact that good designing and sizing brings technical and financial feasibility to the PVWPS, there are still obstacles inhibiting a larger implementation of PV pumping systems [16]. Among these, the lack of accurate tools for the prediction of the system performances and consequently the water flow rate from PVWPS [17].

Many research has focused on the development of empirical models that are able to predict photovoltaic water pumping system performance for some climatic area around the world. These empirical models use parameters as: global solar radiation, PV array area, ambient temperature, temperature of a PV module, latitude, orientation and inclination of PV array, longitude, albedo, nominal PV module efficiency, Nominal operating cell temperature (NOCT), PV temperature coefficient, miscellaneous power conditioning losses, miscellaneous PV array losses, temperature of reference, and moto-pump and inverter efficiency [14], [18], [19]. But none of them appear to be perfect and satisfactory, therefore to improve the accuracy of these empirical models, semi-empirical models have to be studied by measuring in one hand certain parameters in order to reduce the losses leading to the imperfection of the

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empirical model. In other hand the solar radiation utilizability ϕ defined as the fraction of total radiation incident on a surface that exceeds a specified intensity level called the critical level [20], [21]. This critical level would be the insolation threshold of the PV pumping system (the solar intensity at which the PV pumping system starts its operation) [22].

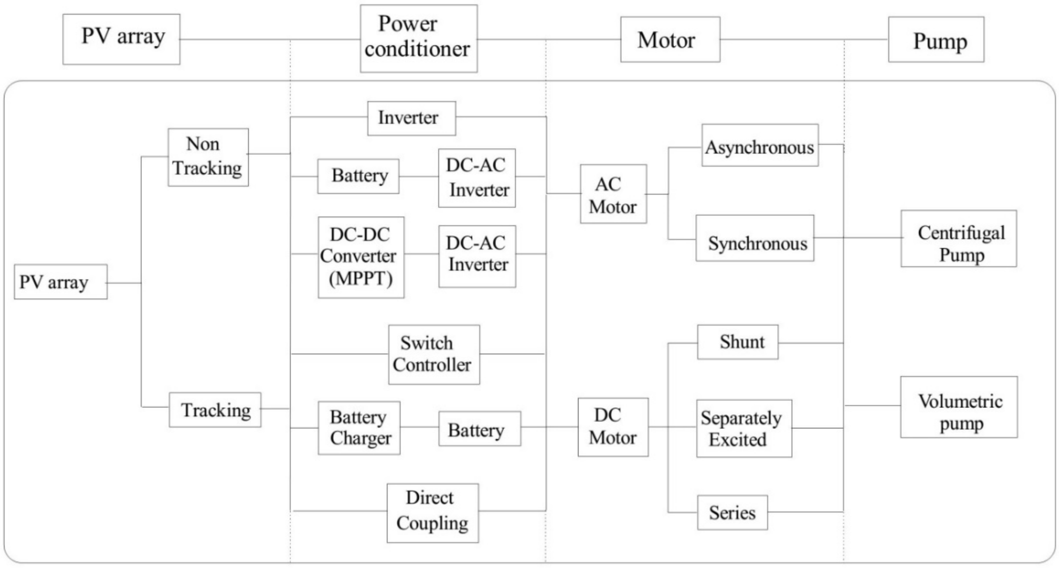

Fig. 1: The most common components of PV water pumping systems

Table 1: Characteristics of the PV Pumping Stations

Stations	**STATION I**	**STATION II**	**STATION III**
Geographical coordinates	10°19'N, 15°16'E	9°59'N, 15°25'E	10° 58′N, 14° 30′E
Altitude	319m	325 m	337m
Power installed (Wp)	600	600	1500
Characteristics of PV module	75Wc/12V I=4,36A; Icc=4.60A	75Wc/12V I=4,36A; Icc=4.60A	75Wc/12V I=4,36A; Icc=4.60A
Total head (m)	60	80	86,6
Storage capacity (m^3)	6	4	20
Inclination angle of the module (°)	15	15	15
Number of modules	8	8	20
Nominal PV module efficiency	11.7%	11.7%	11.7%
PV temperature coefficient(%/°C)	0.4	0.4	0.4
PV array area (m^2)	5.109312	5.109312	12.77328
Reference temperature(°C)	25	25	25
Pump type	SQFlex 2.5-2	SQFlex 2.5-2	SQFlex 2.5-2
Pump range voltage	30-300 VDC or 90-240 VAC	30-300 VDC or 90-240 VAC	30-300 VDC or 90-240 VAC
Pump manufacturer	Grunfos	Grunfos	Grunfos
Pump system efficiency (%)	45	45	45

II. STUDIED WATER PUMPING SYSTEMS (PVWPS)

Three solar water pumping systems are selected as the case study for the determination of the PVWPS performances. These stations are located in the Sahelian regions of Cameroon. Their surface azimuth angles are zero and the inclinations are 15°, PVWP system consists of a PV array, inverter, submersible pump, storage tank, and auxiliary system of measuring devices as weather monitoring sensors, current, voltage, temperature, water flow rate. The stations work without electrical storage batteries. Their characteristics and geographical coordinates are shown in Table 1.

Water pump can be powered by 30-300 V_{DC} or 90-240 V_{AC} –10%/+6%, 50/60 Hz, the run- up time depends on energy source and there is no limitation of the number of starts/stop per hour. The pump must be completely submerged in the pumped liquid and must be placed at maximum 150 m below the static water level (15 bars). It is equipped with two elements: a CU 200 SQFlex control unit with 5W power consumption, 10A maximum back-up fuse and the IO 100 SQFlex switch box with 300V_{DC}, 265V_{AC} maximum voltage and 8,5A current. Their operating temperature is in the range of -30/50°C.

III. MATERIALS AND METHODS

A. *Photovoltaic pumping system sizing*

The good sizing of PVWPS is essential to complete the economical viability of systems since it determine the size of different elements of the water pumping system. Thus, the hydraulic energy required per day (kWh) is calculated based on (1) [23], [24].

$$E_{hydr} = \rho g(h + \Delta H)V = \eta_s E_{pv} \quad (1)$$

Where V is the volume of water required in m³/day, η_s is the subsystem (motor, pump and inverter) efficiency and E_{pv} is the PV delivered energy. The electric power of PV generator P_c (peak power) is given by (2) [16], [25].

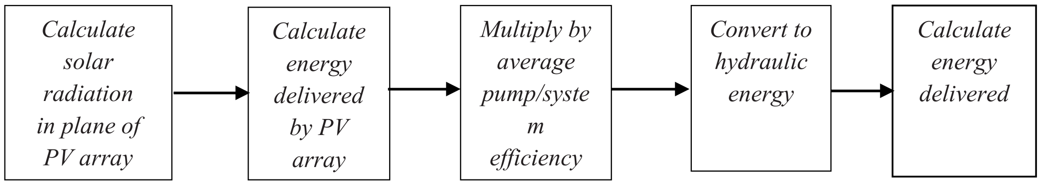

Fig. 2: Water pumping system model flowchart.

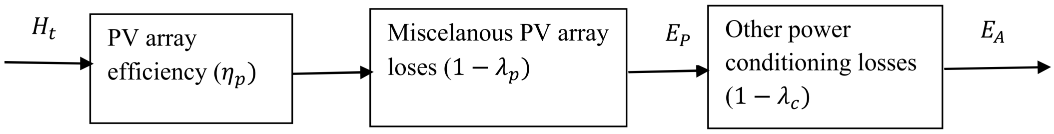

Fig. 3: PV array model flowchart

$$P_c = 2{,}725 * 10^{-3} \frac{Q_d(h+\Delta H)}{K_P \eta_{ond} \eta_{mp} E_i} \quad (2)$$

Where Q_d is daily flow rate (m³/day); h is the pumping head in m; ΔH is the hydraulic losses in (m;) K_p is the array mismatch factor, that is, the ratio of the power output of the photovoltaic array under operating conditions to its power output at the maximum power point. The generally accepted value for designing of a photovoltaic system is (0.85–0.90) on average. η_{ond} = inverter effectiveness ($\eta_{inv} = 0{,}96$) if no inverter is used, ($\eta_{inv} = 1$) in this case a DC motor is used. η_{mp}= daily mean effectiveness of the motor pump, E_i = daily average irradiation kWh/m²/. day, corresponding to the worst month of the year.

B. *Water pumping system models and design*

The Photovoltaic Model can be used to evaluate the energy production and financial performance of photovoltaic projects, from small-scale water pumping systems to intermediate residential off-grid systems to large grid-connected systems, anywhere in the world. There are two basic flowcharts used to evaluate PVWPS models the water pumping system model flowchart and the PV Array model flowchart as presented in the Fig. 2 and Fig. 3 [22], [26].

The efficiency of the PV module on site is given by (3):

$$\eta_p = \eta_{ref}[1 - \beta_{ref}(T_c - T_{ref}) + \gamma log_{10} I(t)] \quad (3)$$

in which η_{ref} is the module's electrical efficiency at the reference temperature, T_{ref} and at solar radiation of $1000\ W/m^2$. The temperature coefficient, β_{ref}, and the solar radiation coefficient, γ, are mainly material properties, having values of about 0.004 K^{-1} and 0.12, respectively, for crystalline silicon modules [27]. γ, however, is usually taken as zero [26] and (4) is reduced to (4):

$$\eta_p = \eta_{ref}[1 - \beta_{ref}(T_c - T_{ref})] \quad (4)$$

This represents the traditional linear expression for the PV electrical efficiency [28]. The quantities η_{ref} and β_{ref} are normally given by the PV manufacturer. However, they can be obtained from flash tests in which the module's electrical output is measured at two different temperatures for a given solar radiation flux [29]. The actual value of the temperature coefficient, in particular, depends not only on the PV material but on T_{ref} as well. It is given by (5):

$$\beta_{ref} = \frac{1}{T_0 - T_{ref}} \quad (5)$$

in which T_0 is the (high) temperature at which the PV module's electrical efficiency drops to zero [30]. For crystalline silicon solar cells, this temperature is 270°C [28]. T_c is related to the mean monthly ambient temperature Ta through Evans' formula (6) and (7) [26], [31].

$$T_c - T_a = (219 + 832\overline{K}_t)\frac{NOCT-20}{800} \quad (6)$$

$$T_c = T_a + G\frac{NOCT-20}{800} \quad (7)$$

Where *NOCT* is the Nominal Operating Cell Temperature and $\overline{K}_t$ the monthly clearness index. η_{ref} *NOCT* depend on the type of PV module considered.

For the PV module used in this study the η_{ref} is equal to 11.7%. and NOCT is equal to 45°C However, (7) is valid when the array's tilt is optimal (equal to the latitude minus the declination). If the angle differs from the optimum, the right side of (6) and (7) has to be multiplied by a correction factor C_f defined by Compare in 2009, (8) [32].

$$C_f = 1 - 1.17\ 10^{-4}(\beta_{opt} - \beta)^2 \qquad (8)$$

Where β_{opt} is the optimum tilt angle and β is the actual tilt angle, both expressed in degrees.
The energy delivered by the PV array, E_P, is simply in (9):

$$E_P = A\eta_P\bar{H}_t \qquad (9)$$

Where A is the area of the array. It has to be reduced by miscellaneous PV array losses λ_p and other power conditioning losses λ_c.

The array energy available to the load and the battery is given by (10):

$$E_e = A\eta_p H_t(1-\lambda_p)(1-\lambda_c) \qquad (10)$$

The overall array efficiency, η_A, is defined by (11):

$$\eta_A = \frac{E_e}{A\bar{H}_t} \qquad (11)$$

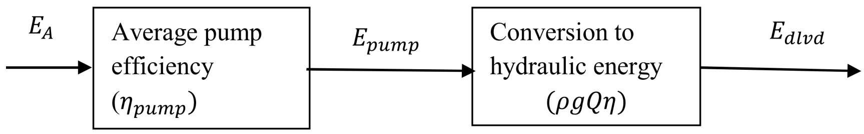

Fig. 4: Water pumping system model

C. Photovoltaic Water Pumping Model

The water pumping model is based on the simple equations [33] and is shown schematically in the Fig. 4 [22]. The daily hydraulic energy demand E_{hydr} , in Wh, corresponding to lifting water to a height h (in m) with a daily volume Q (in m^3/d) is derived by (12):

$$E_{hydr} = \rho g Q h(1+\eta_f) = \rho g Q H \qquad (12)$$

Where g is the acceleration of gravity (9.81 m/s^2), ρ is the density of water (1000 kg/m^3) and η_f is a factor accounting for friction losses in the piping in percentage of geometric head h. This hydraulic energy translates into an electrical energy requirement E_e given by (13):

$$E_e = (\frac{E_{hydr}}{\eta_{mp}}) \qquad (13)$$

Where η_{mp} is the pump system efficiency.
If the pump is AC, (13) has to be modified to take into account the inverter efficiency η_{inv} as in (14):

$$E_e = \left(\frac{\rho g Q h(1+\eta_f)}{\eta_{mp}\eta_{inv}}\right) \qquad (14)$$

The hourly volume pumping (flow rate) Q (m^3/h), which can be expressed by combining (10) and (14) to get (15):

$$Q = (\frac{A\eta_p H_t(1-\lambda_p)(1-\lambda_c)\eta_{mp}\eta_{inv}}{\rho g h(1+\eta_f)}) \qquad (15)$$

D. Prospected Models

In this paper four models have been developed in order to predict in one hand energy delivred by the PV generator of the PVWPS and in other hand the flow rate delivered by the PVWPS amongst these models, model II and model IV are modified models that uses Solar radiation utilizability ϕ, defined as the fraction of total radiation incident on a surface that exceeds a specified intensity level called the critical level [20], [34]. This critical level is the insolation threshold of the PV pumping system (the solar intensity at which the PV pumping system starts its operation) [22]. The critical level of a PV pumping system depends on the characteristics of the system components (type of motor, pump, Panel size, head) [17] The critical solar intensity level I_c is the minimum intensity necessary to produce a net energy output. When solar intensity is less than the critical level, the flow rate Q is zero.

The operating time is the period of the day where solar intensity exceeds the minimum solar intensity necessary to produce a net energy output. In these conditions, to determine water requirement, measurements have been done in each station in order to know the critical solar intensity level (I_C) necessary to produce a net water flowrate. Four models have been used here for the purpose.

Model 1

It consists in the evaluation of the water flow rate using measured electrical power output (E_e)of each station. This method can help neglecting miscellaneous losses. Since motor pump is DC powered the $\eta_{inv} = 1$. The flow rate is then obtained by (16) using (14):

$$Q = \left(\frac{E_e * \eta_{mp}}{\rho * g * h(1+\eta_f)}\right) \qquad (16)$$

Model 2

This model considers the ***model 1*** by using solar radiation utilizability as in (17). To use this concept, measurements have been done in the three different stations, the measured value correspond to the on-field threshold value (I_c) of the solar radiation to start the operation of the motor pump. These values are 220 (W/m^2), 310 (W/m^2), 160 (W/m^2), respectively for the station I, II and III.

$$Q = \begin{cases} \left(\frac{E_e*\eta_{mp}}{\rho*g*H}\right), & I \geq I_c \\ 0, & I < I_c \end{cases} \tag{17}$$

Model 3

This method measures directly water flow from Irradiance using (10).

$$Q = \left(\frac{A*\eta_p*H_t*(1-\lambda_p)(1-\lambda_c)*\eta_{mp}}{\rho*g*h(1+\eta_f)}\right) \tag{18}$$

the main limitation of this method is that, we must take in the literature the value of the Miscellaneous PV array losses supposed to be 5% and miscellaneous power conditioning losses are 2%.

Method 4

This model considers the ***model 3*** using solar radiation utilizability. To use this concept, measurement of the threshold value of the solar radiation to starts operating the PVWPS motor pump have been done for each station as mentioned above.

$$Q = \begin{cases} \left(\frac{A*\eta_p*I*t(1-\lambda_p)(1-\lambda_c)*\eta_{mp}*\eta_{inv}}{\rho*g*h(1+\eta_f)}\right), & I \geq I_c \\ 0, & I < I_c \end{cases} \tag{19}$$

Table 2: Performance metrics for model evaluations

Metrics	**Mathematical equations**
Root mean squared error (RMSE)	$\left(\frac{1}{n}\sum_{i=1}^{n}(Y_{i,m}-Y_{i,c})^2\right)^{1/2}$
Normalised Root mean squared error RMSE(%)	$\left(\frac{RMSE}{\bar{Y}_m}\right)*100$
Mean bias error (MBE)	$\frac{1}{n}\sum_{i=1}^{n}(Y_{i,c}-Y_{i,m})$
Normalised Mean absolute bias error MBE (%)	$\left(\frac{MBE}{\bar{Y}_m}\right)*100$
Mean absolute bias error (MABE)	$\frac{1}{n}\sum_{i=1}^{n}(Y_{i,c}-Y_{i,m})$
Normalised Mean absolute bias error MABE (%)	$\left(\frac{MABE}{\bar{Y}_m}\right)*100$
Mean percentage error MPE (%)	$\frac{1}{n}\sum_{i=1}^{n}\left(\frac{Y_{i,m}-Y_{i,c}}{Y_{i,m}}\right)*100$
Determination coefficient (R^2)	$1-\frac{\sum_{i=1}^{n}(Y_{i,m}-Y_{i,c})^2}{\sum_{i=1}^{n}(Y_{i,m}-\bar{Y}_m)^2}$

Table 3: Ideal and recommended values of performance parameters

	MBE (%)	**MPE (%)**	**MABE (%)**	**RMSE (%)**	**R^2**
Ideal value	Closer to zero	Closer to zero	Closer to zero	Closer to zero	Closer to 1
Recommended value	±10%	±10%	±10%	≤20%	1
Rigorous criterion	± 5%	± 5%	5%	≤15%	1

E. Statistical parameters used for models and validation criteria

All the different models presented above to assess the amount of water flow rate from PVWPS have to be validated. There are many statistical methods available in solar energy literature, these models deal with the assessment and comparison of estimated (predicted) values with measured one. In the present study statistical indicators, namely mean bias error (MBE), root mean square error (RMSE), mean absolute bias error (MABE), mean percentage error MPE) and determination coefficient (R^2) have been used [35]-[37].

The RMSE provides information on the short-term performance of the correlations by allowing a term-by-term comparison of the deviation between the calculated and measured values, the RMSE is always positive, a zero value is ideal. However, a few large errors in the sum can produce a significant increase in RMSE [38], [39]. The MBE therefore evaluate underestimation and over estimation, underestimation results in a negative value of MBE while a positive value represents an overestimation. MBE has a low desirable value and ideally its value should be zero. The mean of the absolute error (MABE) of the model gives the general overview or total error occurrence regardless of underestimation or overestimation by the model. It eliminates the unfair error cancellation which is found in MBE. The MABE with a value of zero implies that the model is perfectly predicting the data without any error [40]. Mean percentage error (MPE), is described as the measure of the extent of the error of values in terms of percentage of the observed or measured value [41]. Coefficient of determination or regression coefficient (R^2), is used as a statistical indicator that gives information about the best fit model. It determines how well the regression line approximates the real data points. A model is more efficient when R^2 is closer to 1 [42]. The normalized version of these metrics in percentages is obtained by dividing the mean measured values as presented in table 2. These metrics are preferred to comparing the predictive performance of the models over different datasets, where $Y_{i,m}$ is the i^{th} measured data, $Y_{i,c}$ is the i^{th} calculated data, $\bar{Y}_m$ is is the mean of the measured values and n is the total number of the observations.

The models used to compute water flow rate from PVWPS provide good performance if the MBE, MABE, MPE and RMSE have as low values as possible. The following quantitative recommendations are sometimes used [43], [44]. For water flow rate as specified in the table 3.

IV. RESULTS AND DISCUSSION

A. Electrical water pumping system performance

Miscellaneous PV array losses (%) and miscellaneous power conditioning losses (%) have to be neglected since measures have been done on-field and pumping stations are connected to the DC water pump. Electrical performance parameters are hence presented in the Fig. 5 for the stations 1 and 2, the daily mean value of the power output during the month varies from 195.46W to 350.70W, daily maximum power varies from 428.54W to 710.12W and daily energy produced varies from 2004.27Wh to 3360.88Wh. While for the station 3, the mean power output varies from 488.64W to 876.75W, the maximum output power varies from 1108.71W to 1775.31W and the daily energy produced varies from 5010.67 Wh to 8402.21 Wh, as indicated in Fig. 6.

B. *Observed water output*

The evaluation and prediction of the water output refers to the flow calculated using power input from the PV electrical output prediction models. In this study, the prediction of the water flow rate of different stations takes into account measured input electrical power of the pump (E_e) as given by (10). The main advantage of measuring power input of the motor pump is that miscellaneous losses are not to be taken arbitrary, since they are integrated in the measured data. Water flow rate is also predicted using measured solar radiation. For this purpose, solar radiation is measured each 5min in order to eliminate the over-estimation due to the irregular behavior of irradiance and consequently dynamic behavior of the pump. Indeed, miscellaneous losses and wire losses are considered here respectively as 5% and 2%.

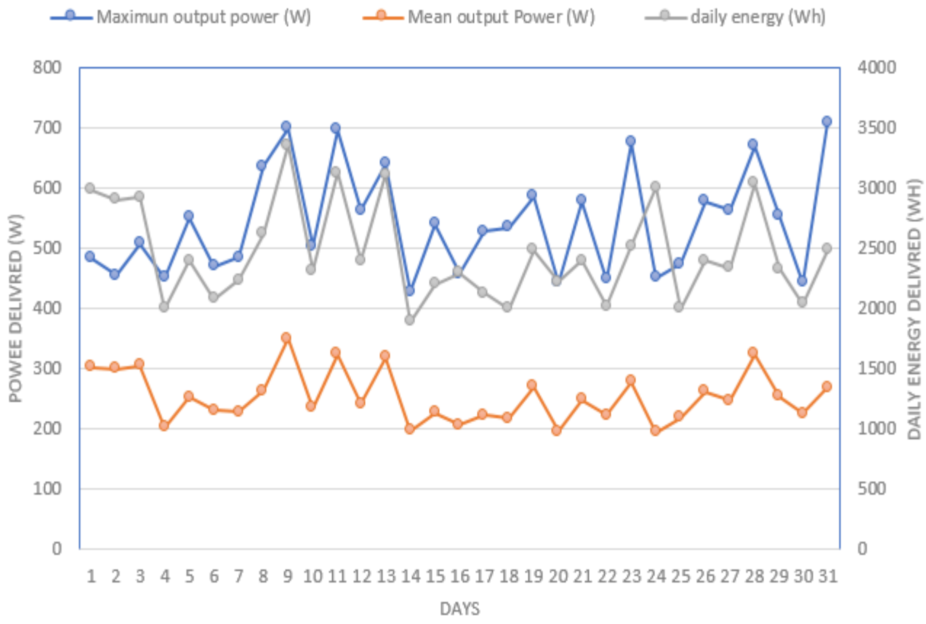

Fig. 5: Electrical performance of the PVWPS for the stations 1 and 2

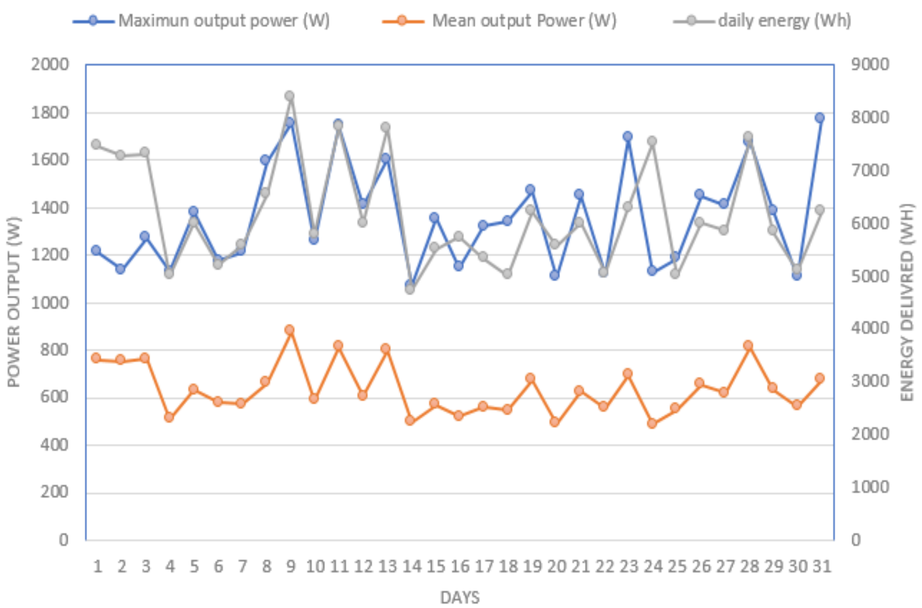

Fig. 6: Electrical performance of the PVWPS for the station 3

B1. Hourly water output

Using (14) and (15) associated to solar radiation utilizability, Fig. 7 and Fig. 8 have been plotted for different stations and for two special days of the month (the worst day and the sunniest day of the month of august) corresponding to the 4th of August and 09th of August. Since measurements have been done each 5min, flow rate is supposed to be the water delivered by pump each 5min.

From Fig. 7 and Fig. 8, we can observe that water is delivered for a positive value of irradiance when using the model 1 and 3. This is not the case when using the model 2 and 4. Indeed, as mentioned previously the threshold Irradiance to start the motor pump of the station 1 is 220W/m2. The curve of the model 1 and 2 are similar except for the Irradiance lower than 220W/m2 leading flow rate to zero. The maximum water flow rates are 103.6Liters/5min (13h 39min) and 160.8Liters/5min (13h 16min) respectively for worst and sunny day they have been obtained with the model 1 and 2.

Fig. 9 and Fig. 10 show the profile of the water flow rate during two days (cloudiest and sunniest) for the station 2. We can observe that for the model 1 and 3, water flowrate is supposed to be delivered. This is not true in reality since for the station 2 real functioning time is given by the curve of the model 2 and 4. Indeed, for Irradiance lower than 310 W/m2, the motor pump of the station 2 is not functioning and consequently cannot deliver water. That's why zero values of water flowrate are obtained for solar radiation lower than 310W/m2 for the model 2 and 4. For these curves the maximum values of water flow rate are 77.7 Liters (4th of August) and 120.6 L (9th of August).

The flow rate in the station 3 is given by Fig. 11 and Fig. 12 respectively for sunny and cloudy day. In this station, water output is observed during the day (sunny and cloudy) for the ***model 1 and 3***. However for the ***model 2 and 4,*** flow rate is sometimes equal to zero for solar radiation below 160W/m^2. Indeed, the maximum flow rate is 162liters/5min (4th August) and 279liters/5min (9th August). Maximum values are obtained from ***model 1 and 2***.

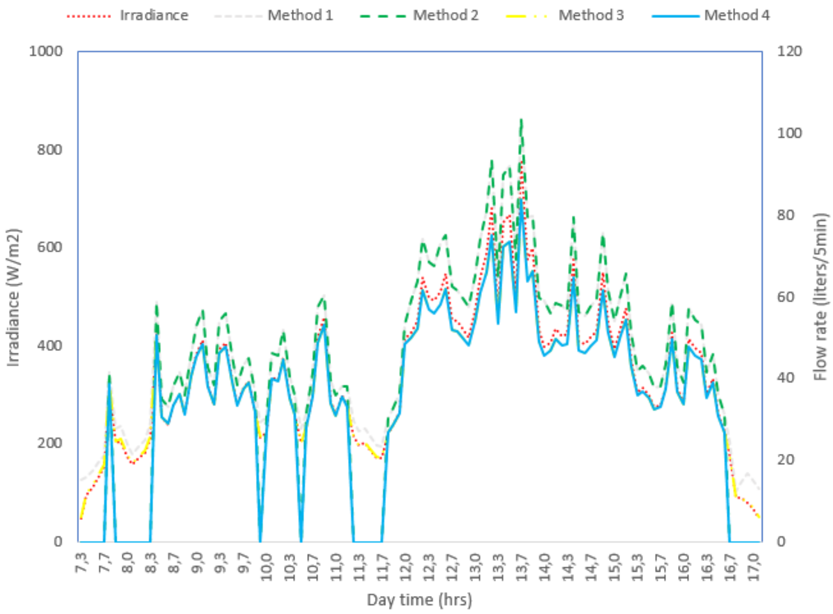

Fig. 7: Water flow rate from station 1 (4th of August 2016)

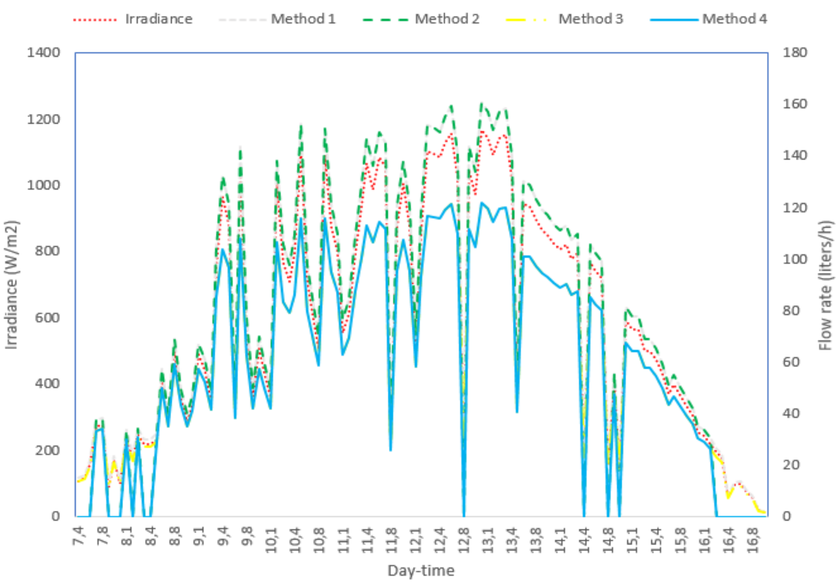

Fig. 8: Water flow rate from station 1 (9th of August 2016)

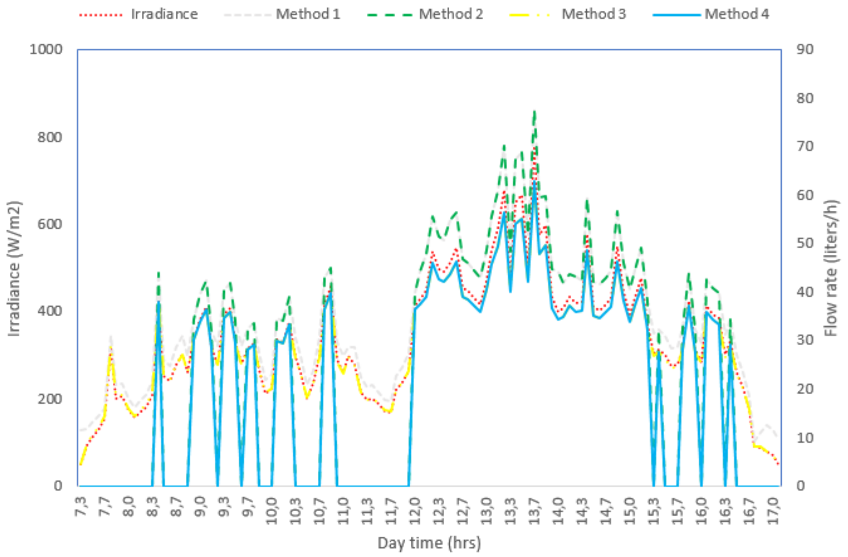

Fig. 9: Water flow rate from station 2 (4th of August 2016)

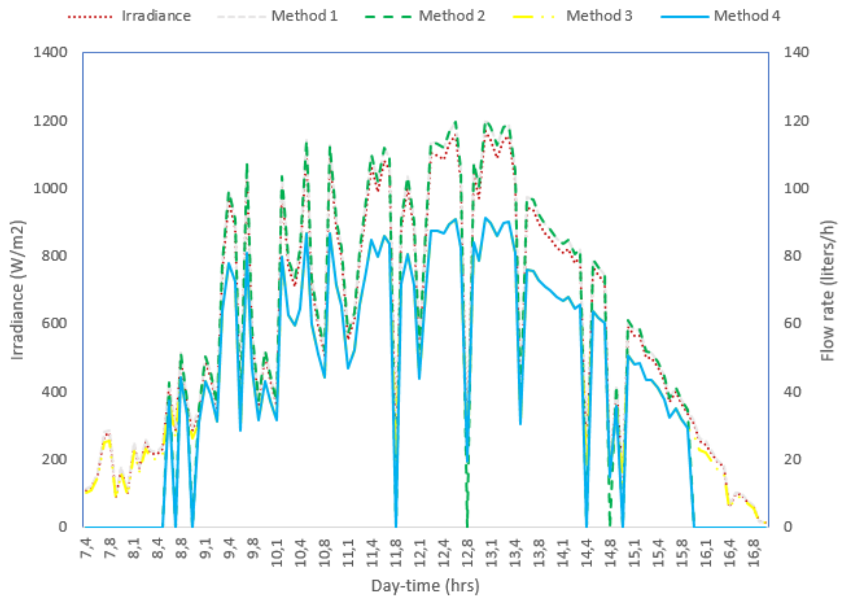

Fig. 10: Water flow rate from station 2 (9th of August 2016)

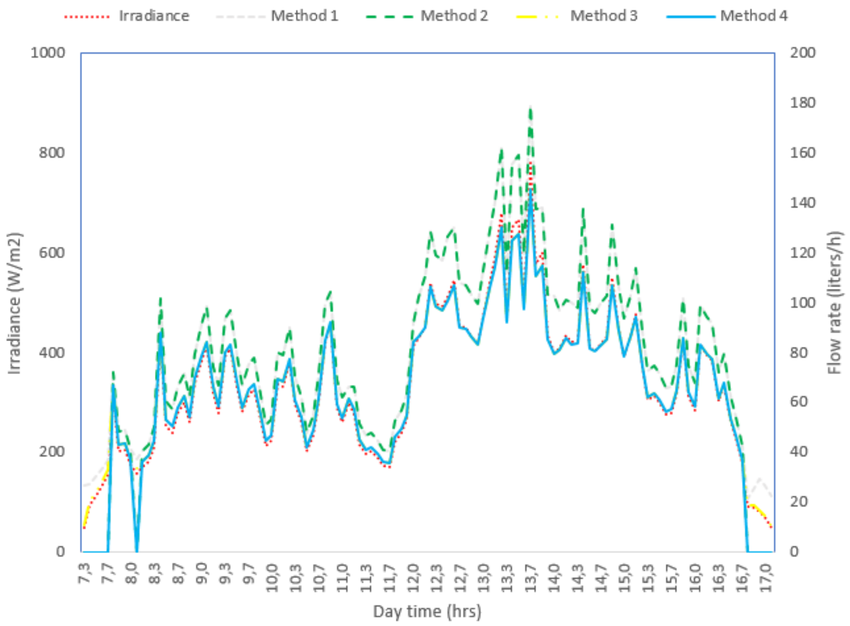

Fig. 11: Water flow rate from station 3 (4th of August 2016)

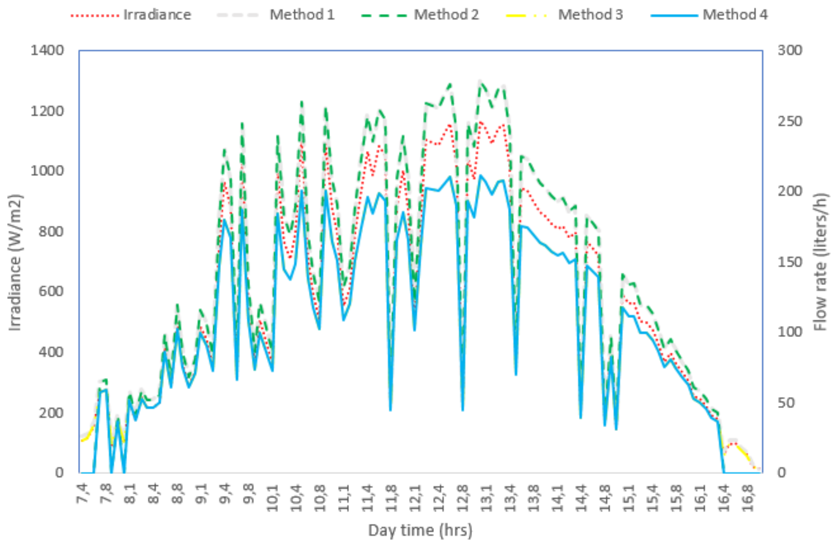

Fig. 12: Water flow rate from station 3 (9th of August 2016)

B2. Daily water output

To determine the predicted daily average water output. Fig 13, 14 and 15 summarise the predicted daily output flow and measured data for different stations. It is important to remember that the predictions of daily PV electrical output and daily water flow output were calculated for hours between 07am and 06pm corresponding to positive irradiance. For different stations we observe that daily water depends not only on the characteristics of the stations (total head, power installed) but depends on the solar radiation (climatic conditions). Indeed, the minimum water flow rate in all stations corresponds to the 4th of August and the maximum water flow rate is in the 9th of August. Measured daily flow rate vary from 4.449m^3 to 7.405 m^3 for the station 1, from 2.6m3 to 5.456m3 for the station 2, and from 8.362m^3 to 14.566m^3 for the station 3.

B3. Monthly output

To know the long-term performance of any PV station it is essential to evaluate monthly water requirement by the station despite its dependence on others factors. This evaluation permits to know water requirement in order to plan how to use water by the population. Indeed, for the three stations studied, the station 2 produced the lowest quantity of water whatever the model used, this is due to the fact that the total discharge head is higher in station 2 than station 1, for the same installed power. Although station 3 has the highest discharge head, it produces higher quantity of water due to the fact that installed power is more important than the two stations. The monthly measured values are respectively 178, 471 m^3, 120.646 m^3 and 323,808 m^3 for the stations 1, 2 and 3 as highlighted in the table 4.

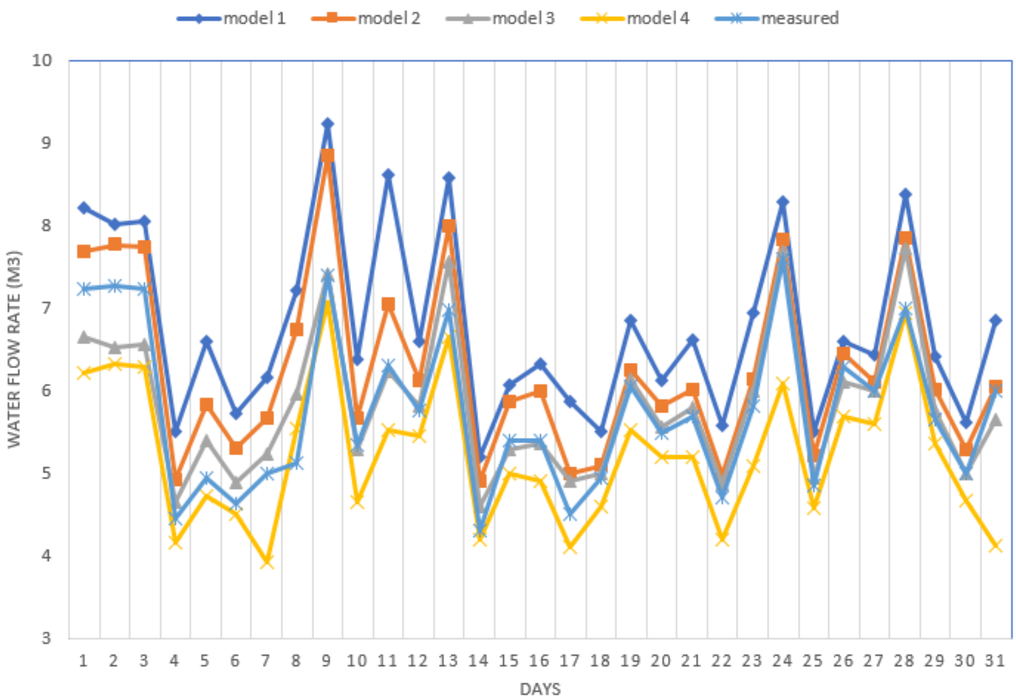

Fig. 13: Daily water flow rate for the station 1 (m^3)

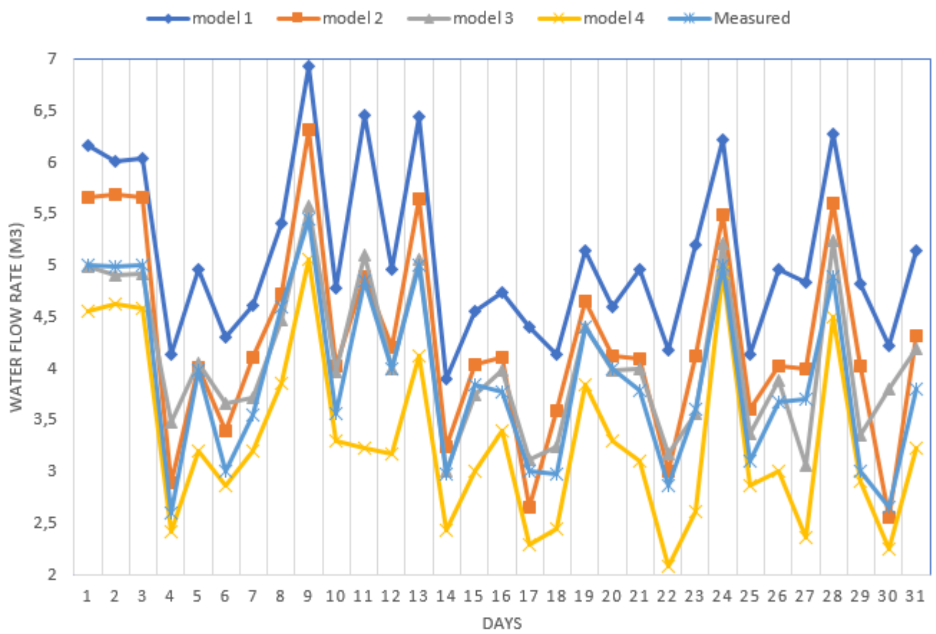

Fig. 14: Daily water flow rate for the station 2 in (m^3)

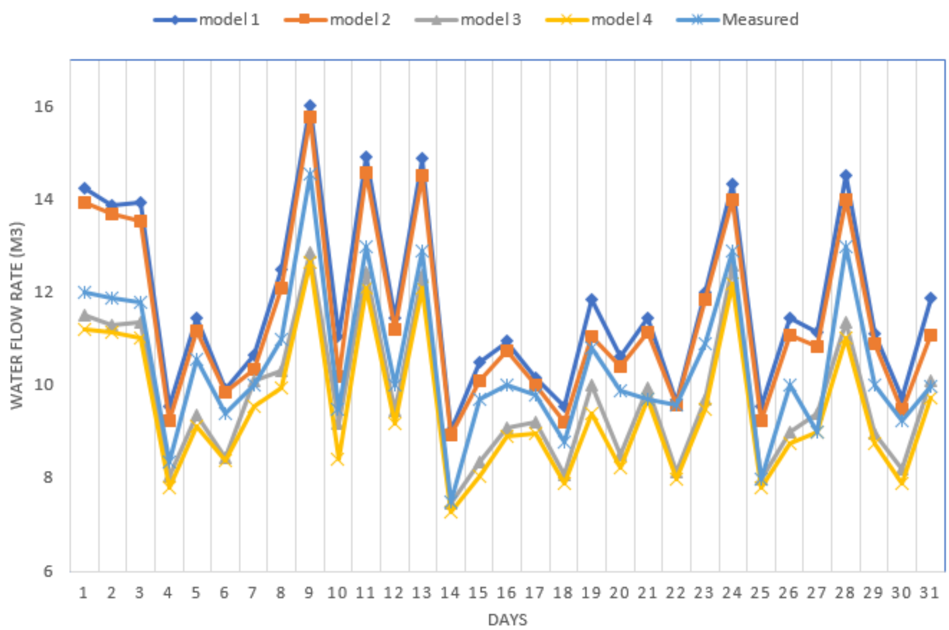

Fig. 15: Daily water flow rate for the station 3 (m^3)

Table 4: Monthly water flow rate from different stations on August

	Model 1	Model 2	Model 3	Model 4	Measured
Station 1	210.233	194.346	180.685	162.178	178.471
Station 2	157.676	132.511	126.281	102.785	120.646
Station 3	364.147	354.022	302.999	293.790	323.808

C. Performance evaluation of the models used

In developing countries, it is on interest to know water volume or flow rate of PV stations using electrical characteristics of PV systems in one hand and measured solar radiation in other hand. In order to know the accuracy of models, predicted values are validated by measured ones for two specific days where 5 min interval measurements of flow rate have been done. Performance parameters MBE, MABE, RMSE and R^2 are used for this purpose. The values of the performance parameters are summarised in the tables 5 to 7 for the cloudiest day and in the tables 8 and 9 for the sunniest day. To know if the performance parameters perform data adequately, comparison can be made among different models or model can be compared itself through ideal and recommended values of these parameters which are given in the table 5 below.

C1. Performance parameters for the day of August 4

From Tables 5 to 7 the values of MBE **(%)**, MABE **(%)**, RMSE **(%)** and R^2 are the most commonly used performance parameters in order to compare if models used can be validated by measured data. For the day of August 4 in the station 1, it is clearly seen that the model 4 perform data more adequately than other models. Indeed, the MBE(%)=**-6.401**, MABE(%)=**8.832**, RMSE(%)=**13.818** and R^2= 0.9656759 show that predicted values in the station 1 with the model 4 are correlated adequately with the measured ones. In station 2 therefore, the model 4 appears to be best model regarding the values of MBE (%) = **-7.044**, MABE (%) =**9.826**, RMSE (%) =**17.421** and R^2= 0.9693441. In the station 3, the model 4 always appear as the best model regarding the values of MBE (%) =**-6.486**, MABE (%) =**6.633**, RMSE (%) =**8.715** and R^2= 0.9656759. all these values are in accordance with validation criteria.

Table 5: Performance parameters August 4 station 1

Station 1	MBE (%)	MABE (%)	RMSE (%)	R²	Rank
Model 1	24.004	24.578	33.347	0.724	4
Model 2	10.940	11.514	17.061	0.928	2
Model 3	4.476	19.710	28.145	0.804	3
Model 4	**-6.401**	**8.832**	**13.818**	**0.953**	1

Table 6: Performance parameters August 4 station 2

Station 2	MBE (%)	MABE (%)	RMSE (%)	R²	Rank
Model 1	59.125	59.387	75.761	0.420	4
Model 2	11.225	11.487	20.236	0.959	2
Model 3	34.066	50.937	65.722	0.564	3
Model 4	**-7.044**	**9.826**	**17.421**	**0.969**	1

Table 7: Performance parameters August 4 station 3

Station 3	MBE (%)	MABE (%)	RMSE (%)	R²	Rank
Model 1	14.265	14.296	18.541	0.845	4
Model 2	10.463	10.494	13.566	0.917	3
Model 3	-3.729	9.389	12.974	0.924	2
Model 4	**-6.486**	**6.633**	**8.715**	**0.966**	1

C2. Performance parameters for the day of August 9

The performance parameters for the day of August 9 are summarised in the tables 8 to 10, respectively for station 1, 2 and 3. For the station 1, the appropriate parameters are given by the model 4. Indeed, MBE (%) = **-4.403**, MABE (%) = **12.526**, RMSE (%) = **27.154** and R^2= 0.854527. In the station 2, the best model is model 4 regarding the parameters MBE (%) =**-7.857**, MABE (%) =**8.451**, RMSE (%) =**11.971**and R^2= 0.9753814. However, in station 3 the best model is the model 2 as its parameters are MBE= **8.359**, MABE=**14.521**, RMSE= **36.789** and R^2= 0.7049837.

Table 8: Performance parameters August 9 station 1

Station 1	MBE (%)	MABE (%)	RMSE (%)	R²	Rank
Model 1	24.926	24.927	39.287	0.695	4
Model 2	19.590	19.591	36.906	0.731	3
Model 3	0.346	17.275	29.677	0.826	2
Model 4	**-4.403**	**12.526**	**27.154**	**0.855**	1

Table 9: Performance parameters August 9 station 2

Station 2	MBE (%)	MABE (%)	RMSE (%)	R²	Rank
Model 1	27.155	27.155	31.590	0.829	4
Model 2	15.868	15.868	21.856	0.918	3
Model 3	2.137	18.444	23.449	0.906	2
Model 4	**-7.857**	**8.451**	**11.971**	**0.975**	1

Table 10: Performance parameters August 9 station 3

Station 3	MBE (%)	MABE (%)	RMSE (%)	R²	Rank
Model 1	9.996	16.158	37.210	0.698	2
Model 2	**8.359**	**14.521**	**36.789**	**0.705**	1
Model 3	-11.647	16.174	37.956	0.686	4
Model 4	-13.119	14.701	37.620	0.691	3

V. Conclusion

This study deal with four semi-empirical models used for water flow rate of the PVWPS, to determine the most suitable model for the study area, models were compared using statistical parameters named MBE, MABE, RMSE, and R^2, The results indicate that the performance values of the selected models are relatively high since they are within the rigorous criterion of the evaluation of models. Thus, water flow rate from PVWP system can be predicted by models which use measured power of the station or solar radiation of the location. Indeed, some models developed here are in accordance with the measured data since parameters for the evaluation of models range between appropriate values. Regarding these data the model 4 can be used to evaluate the water flow rate for any locations and for cloudy and sunny days.

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AUTHORS' CONTRIBUTIONS

The major part of the works was done by corresponding author KD. however, co-authors also contributed significantly. The first co-author ETH and the second co-author AA, contributed to outlining the paper, methodology and associated theories and related description. The third co-authors DKK and ND contributed to format of the paper and its alignment with themes of the journal. Corresponding author is grateful to co-authors for their fruitful contribution in this work. All authors read and approved the final manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

REFERENCES

[1] D. Kodji, N. Djongyang, D. Njomo, D. Kidmo. "A Rainy Month Performance Evaluation of Photovoltaic Module and Performance Prediction of the PV Water Pumping Systems Under Soudano Sahelian Climate Conditions". *International Journal of Electrical Components and Energy Conversion.* 4(1), 2018, pp. 61-71. Doi: 10.11648/j.ijecec.20180401.17

[2] S. Verma,, S. Mishra,, S. Chowdhury, A. Gaur., S. Mohapatra, A. Soni, & P. Verma. "Solar PV powered water pumping system – A review". *Materials Today: Proceedings*, 46, 2021, pp. 5601–5606. Doi:10.1016/j.matpr.2020.09.434

[3] S. S. Chandel, M. N. Nagaraju, & R. Chandel. "Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies". *Renewable and Sustainable Energy Reviews*, 49, 2015, pp. 1084–1099. Doi:10.1016/j.rser.2015.04.083

[4] T. Khalib. "Design of photovoltaic water pumping systems at minimum cost for Palestine: A review". *Journal of applied Sciences,* 22, 2010, pp. 2773-2784.

[5] V. C. Sontake & V. R. Kalamkar. Solar photovoltaic water pumping system - A comprehensive review. *Renewable and Sustainable Energy Reviews*, 59, 2016, pp. 1038–1067. Doi:10.1016/j.rser.2016.01.021

[6] D. B. Singh, A. Mahajan, D. Devli , K. Bharti, S. Kandari, & G. Mittal. "A mini review on solar energy based pumping system for irrigation". *Materials Today: Proceedings*, 43, 2021, pp. 417–425. Doi:10.1016/j.matpr.2020.11.716

[7] K. Meah, S. Fletcher, & S. Ula. "Solar photovoltaic water pumping for remote locations". *Renewable and Sustainable Energy Reviews*, 12(2), 2008, pp. 472–487. Doi:10.1016/j.rser.2006.10.008

[8] N. Argaw, R. Foster, A. Ellis. "Renewable energy for water pumping applications in rural villages." NREL, 2001.

[9] J. Kaldellis, K. Kavadias, & D. Zafirakis. "Experimental validation of the optimum photovoltaic panels' tilt angle for remote consumers". *Renewable Energy*, 46, 2012, pp. 179–191. Doi:10.1016/j.renene.2012.03.020

[10] I. Yahyaoui., G. Tina, M. Chaabene & F. Tadeo. "Design and Evaluation of a Renewable Water Pumping System*". IFAC-PapersOnLine*, 48(30), 2015, pp. 462–467. Doi:10.1016/j.ifacol.2015.12.422

[11] A. Allouhi, Buker, M.S. El-houari, H. Boharb, A. Benzakour Amine, M. Kousksou, T. Jamil. "PV water pumping systems for domestic uses in remote areas: Sizing process, simulation and economic evaluation". Renewable Energy, 2018, Doi: 10.1016/j.renene.2018.08.019

[12] R. López-Luque, J. Reca, & J. Martínez. "Optimal design of a standalone direct pumping photovoltaic system for deficit irrigation of olive orchards". *Applied Energy*, 149, 2015, pp.13–23. Doi:10.1016/j.apenergy.2015.03.107

[13] I. Yahyaoui, S. Sallem, M. B. A. Kamoun & F. Tadeo. "A proposal for off-grid photovoltaic systems with non-controllable loads using fuzzy logic". *Energy Conversion and Management, 78,* 2014, *pp. 835–842.* Doi:10.1016/j.enconman.2013.07.091

[14] R. B. Ammar, M. B. Ammar & A. Oualha. "Photovoltaic power forecast using empirical models and artificial intelligence approaches for water pumping systems". *Renewable Energy,* 2020. Doi:10.1016/j.renene.2020.02.065

[15] I. Saady, M. Karim, B. Badre, N. El Ouanjli, M. Saad, M. Btissam. "Optimization and control of photovoltaic water pumping system using kalman filter based MPPT and multilevel inverter fed DTC-IM". *Results in Engineering,* 17, 2023, 100829, ISSN 2590-12300 Doi: 10.1016/j.rineng.2022.100829.

[16] I. Odeh, Y. G. Yohanis, & B. Norton. "Influence of pumping head, insolation and PV array size on PV water pumping system performance". *Solar Energy*, 80(1), 2006, pp. 51–64. Doi:10.1016/j.solener.2005.07.009

[17] I. Odeh. "Introducing new design and performance points for photovoltaic water pumping systems based on long-term field data analysis". *Journal of Renewable and Sustainable Energy*, 5(2), 2013, 023135. Doi:10.1063/1.4801753

[18] A. Mahjoubi, R. F. Mechlouch, B. Mahdhaoui, & A. B. Brahim. "Real-time analytical model for predicting the cell temperature modules of photovoltaic water pumping systems". *Sustainable Energy Technologies and Assessments, 6,* 2014, pp. *93–104.* Doi:10.1016/j.seta.2014.01.009

[19] A. Mahjoubi, R. F. Mechlouch, B. Mahdhaoui, & A. B. Brahim. "Real-time performance models for photovoltaic water pumping systems". *International Journal of Ambient Energy*, *36*(5), 2015, 210–224. Doi: 10.1080/01430750.2013.853203

[20] M. Kolhe, K. Agbossou, J. Hamelin & T. K. Bose. « Analytical model for predicting the performance of photovoltaic array coupled with a wind turbine in a stand-alone renewable energy system based on hydrogen". *Renewable Energy*, 28(5), 2003, pp 727–742. Doi: 10.1016/s0960-1481(02)00107-6

[21] M. Kolhe. *"Techno-Economic Optimum Sizing of a Stand-Alone Solar Photovoltaic System". IEEE Transactions on Energy Conversion, 24(2),* 2009, pp. *511–519.* Doi:10.1109/tec.2008.2001455

[22] Sharma, R. K., & Sharma, S. (2014). Design of HPCF with nearly zero flattened Chromatic Dispersion. International Journal of Engineering and Applied Sciences, 1(2).

[23] A. Al-Badi, H. Yousef, T. Al Mahmoudi, M. Al-Shammaki, A. Al-Abri, & A. Al-Hinai, A. "Sizing and modelling of photovoltaic water pumping system". *International Journal of Sustainable Energy*, 37(5), 2017, pp. 415–427. Doi:10.1080/14786451.2016.1276906

[24] R. Sharma, S. Sharma, & S. Tiwari. "Design optimization of solar PV water pumping system". *Materials Today: Proceedings,* 2019. Doi:10.1016/j.matpr.2019.11.322

[25] Z. Glasnovic & J. Margeta. "A model for optimal sizing of photovoltaic irrigation water pumping systems". *Solar Energy, 81(7),* 2007, pp. *904–916.* Doi:10.1016/j.solener.2006.11.003

[26] D.L. Evans. "Simplified method for predicting photovoltaic array output." *Solar Energy,* 27(6), 1981, pp. 555–560.

[27] G. Notton, C. Cristofari, M. Mattei & P. Poggi. "Modelling of a double-glass photovoltaic module using finite differences". *Applied Thermal Engineering, 25(17-18),* 2005, pp. *2854–2877.* Doi: 10.1016/j.applthermaleng.2005.02.008

[28] D. L. Evans and L. W. Florschuetz. "Cost studies on terrestrial photovoltaic power systems with sunlight concentration" *Solar Energy*, 19, 1977, pp. 255–262

[29] G. W. Hart, P. Raghuraman, *MIT Report*, 1982. DOE/ET/20279-202.

[30] H. P. Garg, R. K. Agarwa. "Some aspects of a PV/T collector/forced circulation flat plate solar water heater with solar cells" *Energy. Conversion. Management,* 36, 1996, pp. 87–99.

[31] M. V. Hadole, K. N. Tiwari & P. Bajpai. "Energy generation and flow rate prediction of photovoltaic water pumping system for irrigation". *Environment, Development and Sustainability,* 2020. Doi:10.1007/s10668-020-00886-9

[32] I. Compaore, J. Raharijaona, Y. Coulibaly & B. Daky. "Effectiveness evaluation of photovoltaic powered water pumping units in sahelian area". *IEEE Electrical Power & Energy Conference (EPEC)*, 2009. Doi:10.1109/epec.2009.5420985

[33] Sharma, Ravindra Kumar, et al. "A design of hybrid elliptical air hole ring chalcogenide As2Se3 glass PCF: application to lower zero dispersion." International Journal of Engineering Research and Technology, vol. 1, no. 3, May 2012.

[34] M. Kolhe, S. Kolhe & J. C. Joshi. "Determination of daily volume of pumped water as a function of mechanical energy from a photovoltaic water-pumping system". *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of* Power and Energy, 215(3), 2001, pp. 399–402. Doi:10.1243/0957650011538514

[35] F. Besharat, A. A. Dehghan & A. R. Faghih. "Empirical models for estimating global solar radiation: A review and case study". *Renewable and Sustainable Energy Reviews,* 21, 2013, pp. 798–821. Doi:10.1016/j.rser.2012.12.043

[36] E. Quansah,. L. K. Amekudzi, P. Kwasi, J. Aryee, O.R. Boakye, B . Dziewornu, R.S. Mubarick. "Empirical Models for Estimating Global Solar Radiation over the Ashanti Region of Ghana. Journal of Solar Energy 2014;. ID 897970, 6 pages Doi: 0.1155/2014/897970

[37] A. Takilalte, S. Harrouni, M. R. Yaiche & L. Mora-López. New approach to estimate 5-min global solar irradiation data on tilted planes from horizontal measurement. *Renewable Energy*, 2019. Doi:10.1016/j.renene.2019.07.165

[38] M. J. Ahmad & G. N. Tiwar. "Evaluation and comparison of hourly solar radiation models". *International Journal of Energy Research*, 33(5), 2009, pp. 538–552. Doi: 10.1002/er.1474

[39] M. J. Ahmad & G. N. Tiwari. "Solar radiation models-A review". *International Journal of Energy Research,* 35(4), 2011, pp. 271–290. doi:10.1002/er.1690

[40] A. A. Adeala, H. Zhongjie and C. C. Enweremadu. "Evaluation of global solar radiation using multiple weather parameters as predictors for South Africa provinces." *Thermal Science*, 19, 2014, pp. 495-509.

[41] B. Jamil & N. Akhtar. "Comparison of empirical models to estimate monthly mean diffuse solar radiation from measured data: Case study for humid-subtropical climatic region of India*". Renewable and Sustainable Energy Reviews, 77,* 2017, pp. *1326–1342.* Doi:10.1016/j.rser.2017.02.057

[42] B.G Akinoglu. *Recent Advances in the Relations between Bright Sunshine Hours and Solar*. In: Badescu V, editor. Modeling solar radiation at the earth surface. Berlin: Springer; 2008, chapter 5:115–143

[43] C.A. Gueymard, D.R. Myers. *Validation and ranking methodologies for solar radiation models.* In: Badescu V, editor. Modeling solar radiation at the earth surface. Berlin: Springer 2008; chapter 20: 479–509

[44] V. Badescu. *Modeling Solar Radiation at the Earth's Surface*. Springer-Verlag Berlin Heidelberg, 2008, ISBN: 978-3-540-77454-9.