Asian Journal of Research and Reviews in Physics

Volume 7, Issue 4, Page 43-56, 2023; Article no.AJR2P.104875
ISSN: 2582-5992

Estimation and Correlation of Surface Water Vapour Density in Benin, Nigeria

M. I. Iliyasu [a], D. O. Akpootu [b*], M. Momoh [b], Z. Abdullahi [c], A. Yusuf [d], N. Muhammad [e], S. A. Sidi [f], S. Aruna [b], M. Umar [b] and M. Y. Sani [g]

[a] Department of Science Laboratory Technology, Physics Unit, Ummaru Ali Shinkafi Polytechnic Sokoto, Nigeria.
[b] Department of Physics, Usmanu Danfodiyo University, Sokoto, Nigeria.
[c] Department of Physics, Adamu Augie College of Education, Kebbi State, Nigeria.
[d] Department of Science Education, Ibrahim Badamasi Babangida University, Lapai, Nigeria.
[e] Department of Physical and Health Education, Shehu Shagari College of Education Sokoto, Nigeria.
[f] Department of Mathematics and Statistics, Ummaru Ali Shinkafi Polytechnic Sokoto, Nigeria.
[g] Department of Science Laboratory Technology, Biology Unit, Ummaru Ali Shinkafi Polytechnic Sokoto, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. The data for the work was sourced and analyzed by author DOA. Author MM and DOA supervised the work. The work was drafted and edited by Author ZA. All the authors in this paper read and approved the final manuscript.

Article Information

DOI: 10.9734/AJR2P/2023/v7i4148

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/104875

Original Research Article

Received: 20/06/2023
Accepted: 26/08/2023
Published: 05/10/2023

ABSTRACT

The present study investigated the monthly average daily mean temperature, relative humidity, surface pressure, cloud cover, and sunshine hours associated with monthly variations in surface water vapour density (SWVD) for the period extending from 1979 to 2016 for Benin (Latitude 6.32^{0}N, Longitude 5.10^{0}E). The daily variation of SWVD for the dry season (November to March) and rainy season (April to October) for the year 2014 was examined. Statistical indices of

**Corresponding author: E-mail: davidson.odafe@udusok.edu.ng;*

coefficient of determination (R^2), mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE), Nash-Sutcliffe equation (NSE), and index of agreement (IA) were used to compare and evaluate the generated two variable SWVD-based models. The findings revealed that the level of SWVD varied throughout the investigation period on each day of the month. The SWVD is higher during the wet season than it is during the dry season, based to the monthly average daily values. The average SWVD was found to be at its highest point in the month of August during the rainy season and its lowest point in the month of December during the dry season (21.1448 gm^{-3}). The greatest amount of SWVD was observed on 23rd May, 2014 with 27.5731gm^{-3} and the lowest on 26th December, 2014 with 9.6567 gm^{-3}. Pressure and precipitable water vapour are related to each other using a multivariate correlation regression model that was constructed with R^2 = 100%, MBE = -0.0204 gm^{-3}, RMSE = 0.0206 gm^{-3}, MPE = 0.1105 %, NSE = 99.9897% and IA = 99.9974% was better appropriate for SWVD estimation with the best fitting and therefore can be used for estimating SWVD in Benin.

Keywords: Correlation models; dry season; ECMWF; rainy season; SWVD.

1. INTRODUCTION

Water vapour plays a very important function in studies on hydrological processes, climate change, weather systems and Earth’s energy balance [1–4]. “The most common greenhouse gas in the atmosphere is the water vapour which accounts for approximately 60 % of the phenomenon of natural greenhouse effect” [1,5]. At the surface, the water vapour which is also known as humidity is a key meteorological and climatological parameter that affects the comfort of human [6], also surface evapouration and plants’ transpiration. The surface specific (q) and relative humidity (RH) are customarily measured using wet and dry bulb thermometers or RH sensors exposed in thermometer screens at meteorological or weather stations [7].

“Water has been seen as the fundamental of hydrological cycle, which is inter or intra/ within or outside movement of water in the atmosphere, oceans, rivers, and seas, as well as on land. Transfer of heat and energy between the earth’s surface and the atmosphere and within the planet is possible due to hydrological cycle”. [8] “Water vapour is the most effective and primary greenhouse gas in the atmosphere, as it absorbs long wave radiation and radiates it back to the surface, which contributes to warming” [2,9–12,13]. “As the temperature of the Earth's surface and atmosphere increases, the atmosphere tends to hold more water vapour” [2]. “In the troposphere, water vapour molecules absorbed heat energy radiated from the Earth's surface” [14].

“The atmosphere tends to store more water vapour as the Earth's surface temperature rises. As a result of this atmospheric water vapor's role as a greenhouse gas, it absorbs energy that would otherwise reduce the amount of electromagnetic radiation that travels through the atmosphere, which could result in localised or global warming. Water vapour content in the air at ground level varies from less than 0.001% in the arctic to more than 6% in the tropics on average” [15–16]. “This amount decreases rapidly with height” [13].

“One of the most complex and difficult scientific issues facing the climate science community today is understanding the mechanisms that control the natural stability and changes in the climate system. Because of this, human actions that cause external forcing, such as the emission of greenhouse gases and changes in land use, are only partially predicted” [17-18]. This is so because scientists lack the ability to actually do so since they cannot foretell population change, economic change, technological development and other relevant characteristic of future human activities [18].

The present study investigates the SWVD variation on a daily and monthly scale, as well as an analysis of the monthly variation using meteorological indicators for Benin, an area in South Western Nigeria. Two variable correlation models for estimating SWVD for the site were also constructed as part of the study.

2. METHODOLOGY

The European Centre for Medium-Range Weather Forecasts (ECMWF) at 2 m height provided the daily and monthly meteorological data for Benin, Nigeria, which are the average minimum temperature, maximum temperature, relative humidity, surface pressure, cloud cover, and sunshine hours that were used in this study. The study period is for 38 years extending from 1979 to 2016.

The following expression relates the surface water vapour density (SWVD), vapour pressure (e), and mean temperature (T) [1,16,18] as:

$$SWVD = 216.7\left(\frac{e}{T}\right) \tag{1}$$

They also obtained vapour pressure (*e)* using the expression as

$$e = RH\left(\frac{e_s}{100}\right) \tag{2}$$

where RH and e_s stand for saturated vapour pressure and relative humidity, respectively. The Claussius Clapeyron equation was used to calculate the saturation vapour pressure [1,16,18] defined as:

$$log_{10}e_s = 9.4051 - \left(\frac{2353}{T}\right) \tag{3}$$

The mean temperature T, was also obtained using [19]

$$T = \frac{T_{max} - T_{min}}{2} \tag{4}$$

T_{max} and T_{min} are the maximum and minimum temperatures respectively. The SWVD is in gm^{-3} and e and e_s are in millibars (mb), T and RH are in Kelvin (K) in percentage (%) respectively.

The ambient Temperature T and Partial Pressure P_s are related by a correlation model as reported by [1] which is expressed by the semi empirical equation

$$P_s = \exp\,(26.23 - \frac{5416}{T}) \tag{5}$$

The precipitable water in terms of relative humidity is presented with the following formula [20].

$$W = \frac{(0.493\varphi_r Ps)}{T} \tag{6}$$

where φ_r is relative humidity in fractions of one, T and p_s are the ambient temperature and partial pressure of water vapour in saturated air respectively.

Then dew point temperature T_{dew} was estimated using [21].

$$T_{dew} = T - \frac{100 - RH}{5} \tag{7}$$

where T and RH are the mean temperature (Kelvin) and relative humidity (%).

The virtual temperature ($T_{virtual}$) was calculated using [22].

$$T_{virtual} = \frac{T}{1 - \frac{e}{p}(1 - \epsilon)} \tag{8}$$

where e is the vapour pressure and ϵ is a constant given as 0.622

The potential temperature $T_{potential}$ was estimated using [22]

$$T_{potential} = T_{mean}(\frac{p_o}{p})^{\frac{R}{Cp}} \tag{9}$$

The expression (equation 9) is known as the Poisson's equation where p_o is the standard pressure usually taken as 1000hPa and $\frac{R}{C_p} = 0.286$

2.1 The Developed Two Variable Correlation Models

The proposed two variable correlation models are of the form:

$$SWVD = a + bP + cCC \tag{10}$$

$$SWVD = a + bP + cSSH \tag{11}$$

$$SWVD = a + bP + cPWV \tag{12}$$

where P, CC, SSH, and PWV stand for Surface Pressure, Cloud Cover, Sunshine Hours, and Precipitable Water Vapour, respectively, and a, b, and c are empirical constants.

2.2 Validation of the Models

The models are validated by testing statistically the Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), Nash-Sutchliffe equation (NSE), Index of Agreement (IA) and coefficient of determination (R^2) for each of the models. According to [23–30], the expressions for the MBE, RMSE and MPE are given as follows.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(SWVD_{i,cal} - SWVD_{i,mea}) \tag{13}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(SWVD_{i,cal} - SWVD_{i,mea}\right)^2\right] \tag{14}$$

$$MPE = \left(\frac{\frac{1}{n}\sum_{i=1}^{n} SWVD_{i,mea} - SWVD_{i,cal}}{SWVD_{i,mea}} \right) . 100\% \quad (15)$$

$$NSE = 1 - \frac{\sum_{1}^{n} (SWVD_{i,mea} - SWVD_{i,cal})^2}{\sum_{1}^{n} \left(SWVD_{i,mea} - \overrightarrow{SWVD_{i,meas}} \right)^2} \quad (16)$$

$$IA = 1 - \frac{\sum_{i=1}^{n} (SWVD_{i,cal} - SWVD_{i,mea})^2}{\sum_{i=1}^{n} \left(|SWVD_{i,cal} - SWVD_{i,mea}| + \left| SWVD_{i,mea} - \overrightarrow{SWVD_{i,mea}} \right| \right)^2} \quad (17)$$

From equation (13) to (17) $SWVD_{i,cal}$, $SWVD_{i,mea}$ and n are the i^{th} calculated, i^{th} measured values of daily Surface Water Vapour Density and total number of observations respectively, also $\overrightarrow{SWVD_{i,meas}}$ is the mean Surface Water Vapour Density.

According to Chen et al. [31], an MBE value of zero is desirable. Furthermore, the performance of the model is improved by lower values for the MBE, RMSE, and MPE. MPE and MBE positive values denote overestimation, while MPE and MBE negative values denote underestimate. [32–37] The ideal percentage error range is between 10% and +10%. High R^2, NSE, and IA values are preferred. While R^2, MPE, NSE, and IA are expressed in percentage (%), the MBE and RMSE are expressed in gm^{-3} [38–41].

3. RESULTS AND DISCUSSION

3.1 Surface Water Vapour Density and its Variation Meteorological Parameters for Benin

Fig. 1 shows the monthly variation of SWVD for Benin. The result indicated that the SWVD are higher in the rainy season is greater than in the dry season. It was observed that the maximum and minimum values of SWVD of 21.4753 gm^{-3} and 15.1798 gm^{-3} occurred in the months of June and January respectively. Furthermore, following its peak in June, SWVD drops in the months of July and August before increasing in the month of September. This discovery is consistent with the findings reported by Akpootu et al. [16] for Owerri, Nigeria.

Fig. 2 depicts the diurnal variation of SWVD specifically for the dry season in Benin. The outcome demonstrated variations in the SWVD quantity with the maximum and minimum values 27.5624 gm^{-3} and 9.6567 gm^{-3} on the 23rd March, 2014 and 26th December, 2014 respectively.

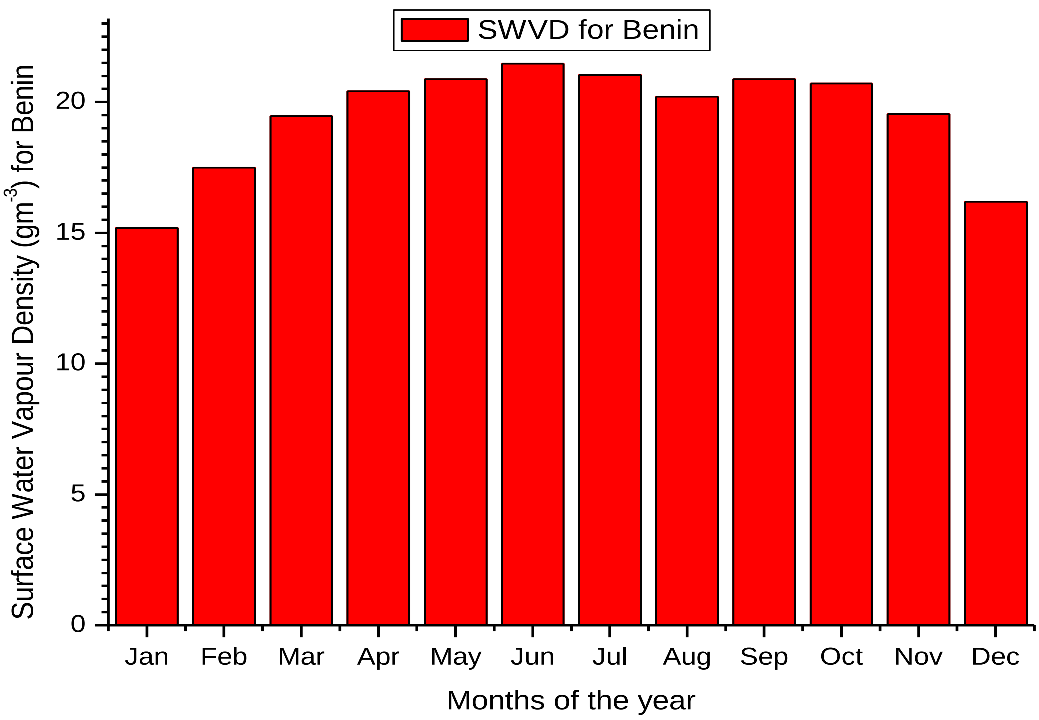

Fig. 1. Monthly variations of SWVD for Benin, Nigeria

Fig. 3 depicts the diurnal SWVD variation specifically for the rainy season in Benin. The result shows that the maximum the minimum values of SWVD occurred with 27.5731 gm^{-3} and 16.0151 gm^{-3} on the 23rd May, 2014 and 10th August, 2014 respectively.

SWVD was determined to have an average value of 21.1448 gm^{-3}. The SWVD's values fluctuate throughout the dry and wet seasons, according to the outcomes of its diurnal variations. Generally speaking, the 23rd of May 2014 marked the maximum value of surface water vapour density with 27.5731 gm^{-3} and the lowest on 26th December, 2014 with 9.6567 gm^{-3}.

Benin's monthly seasonal variation in SWVD was shown in Fig. 4. together with the average temperature. The SWVD steadily grew from its lowest point of 15.1798 gm^{-3} in January to its highest point of 21.4753 gm^{-3} in June, then reduced in August with a dip downward that increased subsequently to September and finally dropped to December. The mean temperature rose along with the SWVD starting in January and peaked in March at 300.9395 K. It then fell until it reached its lowest point in August at 297.6724 K, before rising again to reach December. The short spell of dryness known as August Break, which coincided with the region's lowest temperature, may have contributed to the decline in SWVD that was reported in August. SWVD values were found to be high and low, respectively, during the dry and rainy seasons; while mean temperature indicated the opposite.

The monthly variation of SWVD with RH in Benin is depicted in Fig. 5. The outcome revealed that the relative humidity has increased by 57.8482% from its lowest point in January to its maximum value of 90.7671 % in July then drops down to August increases to September then dropped down to December with 61.6150 % the variation with SWVD is in phase therefore there was a close similarities between their characteristics.

The fluctuation of SWVD with surface pressure is shown in Fig. 6; the result shows that the magnitude of surface pressure decreases from January to March then increases from April to its maximum value of 1000.9250 mbars in July then continue dropping to December. The minimum value of 996.9097 mbars was observed in March.

The seasonal variation of SWVD for Benin is depicted in Fig. 7. together with cloud cover. Both the cloud cover and SWVD increased from January to April with a little drop down in May then increase to July then continue, reaching to its highest level of 0.8886 in the month of September, and then decreased from October to its minimum value of 0.5070 in the month of December.

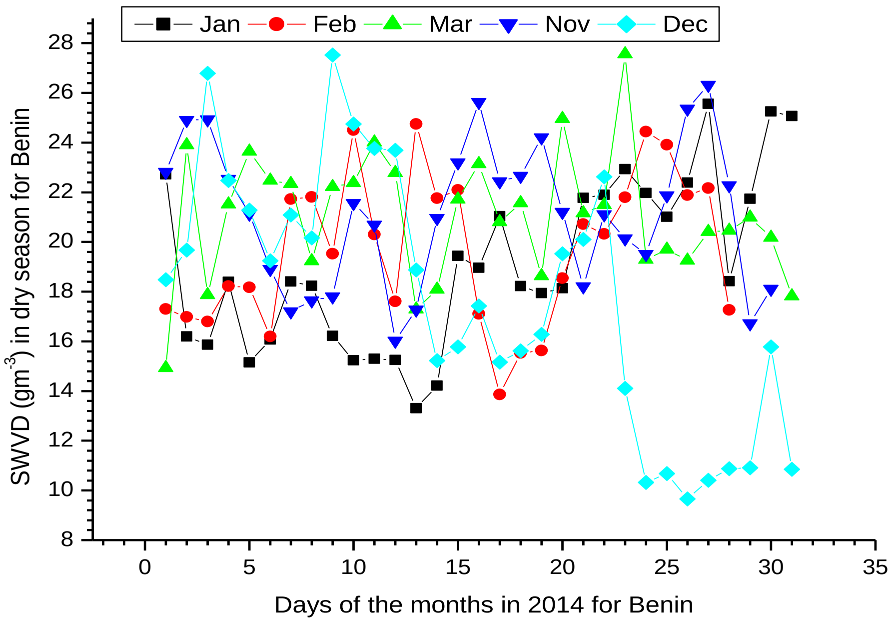

Fig. 2. Diurnal variation of SWVD in the dry season for Benin Nigeria

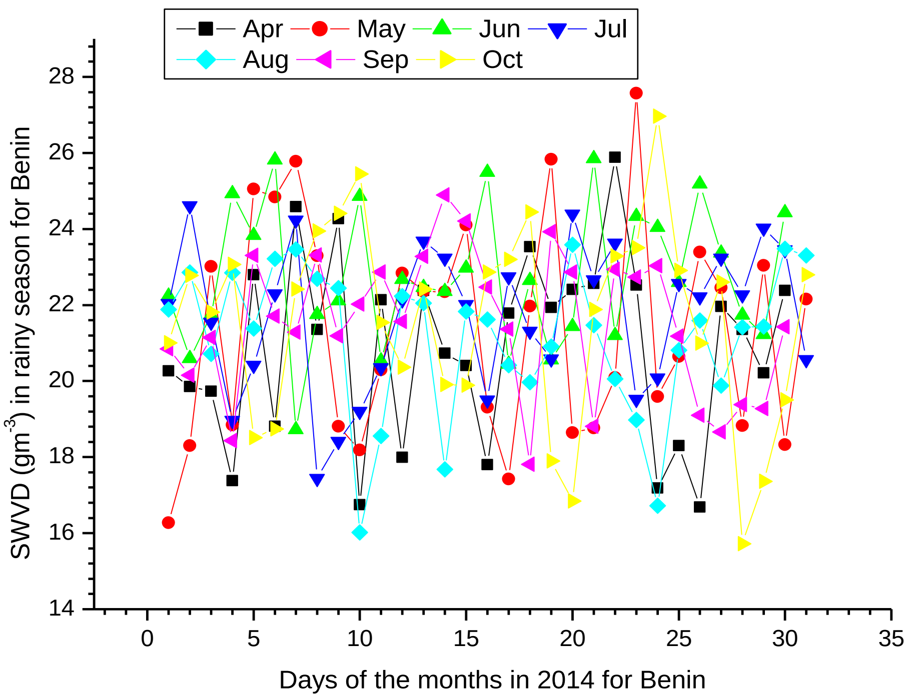

Fig. 3. Diurnal variation of SWVD in the rainy season for Benin Nigeria

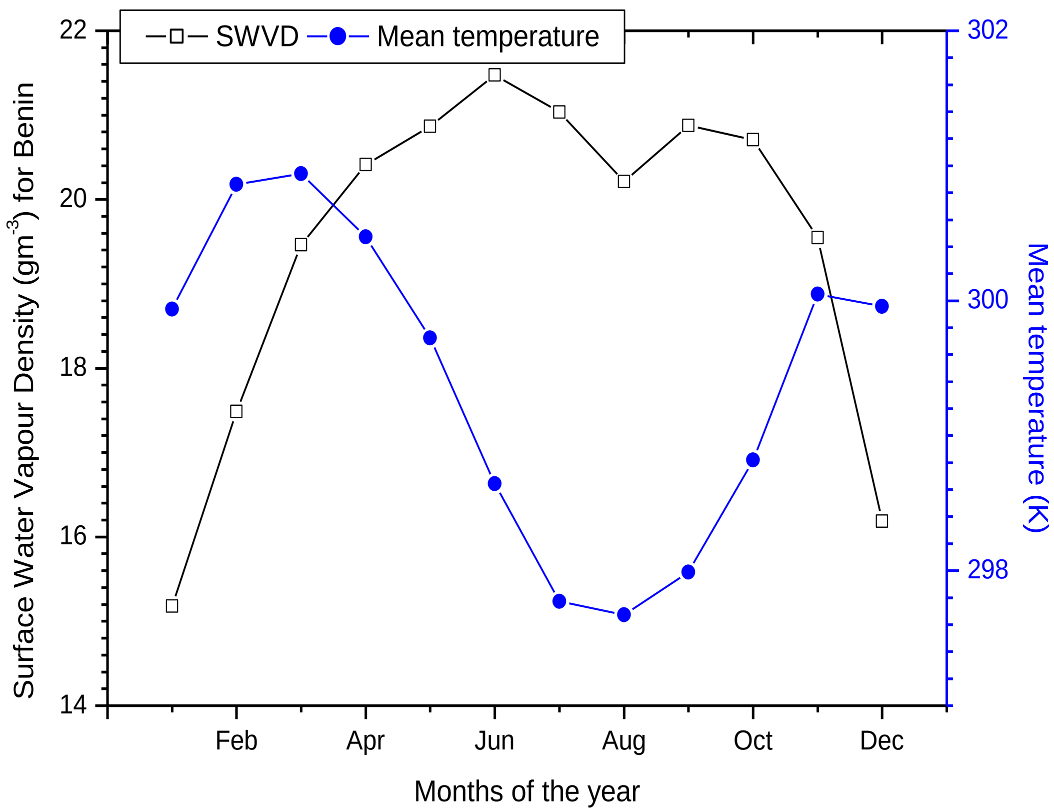

Fig. 4. Variation of SWVD with mean temperature for Benin

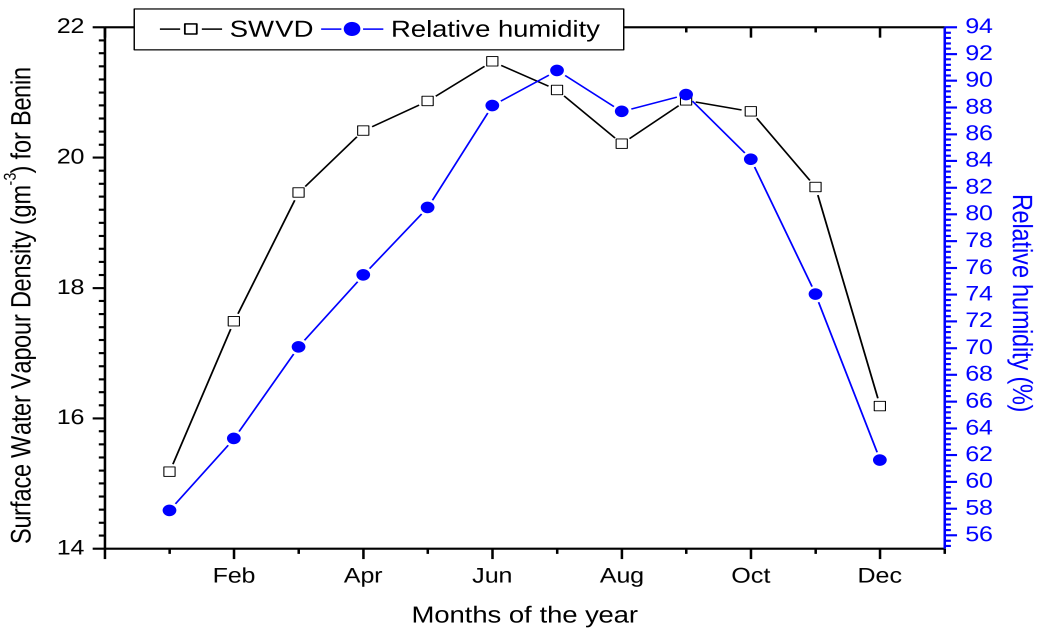

Fig. 5. Variation surface water vapour density with relative humidity for Benin

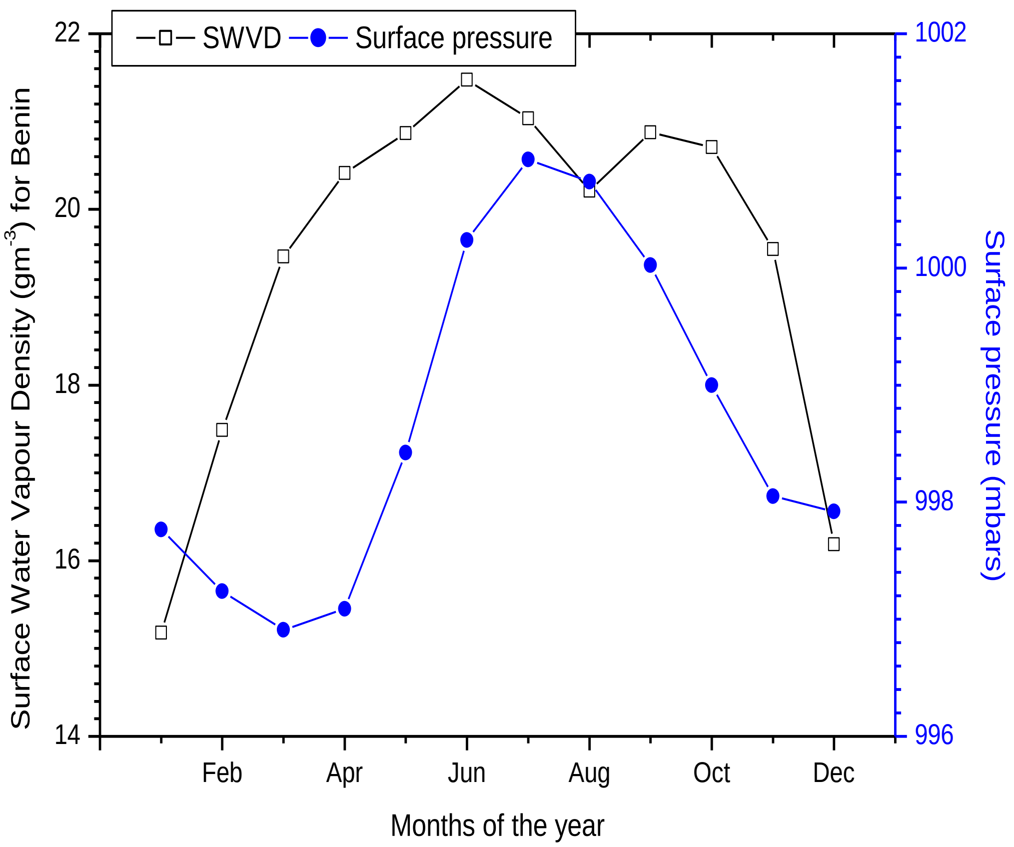

Fig. 6. Variation of SWVD with surface pressure for Benin

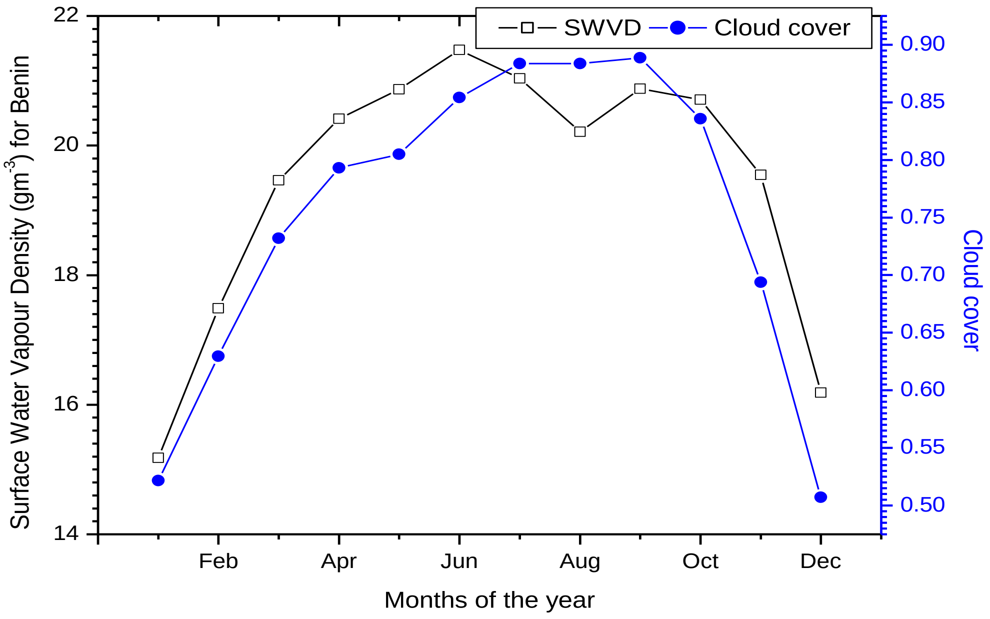

Fig. 7. Variation of SWVD with cloud cover for Benin

The seasonal variation of SWVD for Benin is depicted in Fig. 8. together with sunshine hours. From January through May, the sunshine hours decline and increase at nearly equal intervals before decreasing to its minimum value in August (6.4278 hours), which coincided with the SWVD's August break. Sunshine hours rise from their lowest point in August to their highest point of 7.8356 hours in December. The outcome showed that, for SWVD, high and low values of sunshine hours were seen during the dry and wet seasons, respectively.

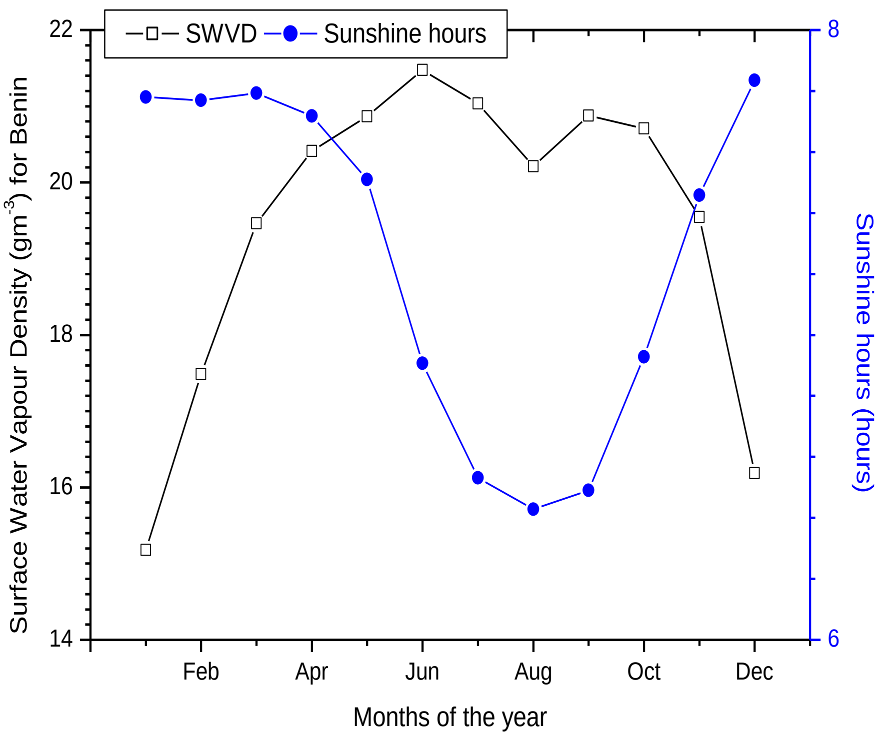

Fig. 8. Variation of SWVD with sunshine hours for Benin

The seasonal variation of SWVD with Precipitable Water Vapour (PWV) is depicted in Fig. 9. The result shows that the SWVD increase in the same pattern PWV they increase significantly from January until they reach their minimum value of 21.0359 gm^{-3} and 4.6697 cm in the month of July, the sudden drop in value of both the SWVD and the PWV in the month of August which is signified by the popular August break in the region.

3.2 Variation of Mean Temperature, Virtual Temperature, Potential Temperature and Dew Point Temperature for Benin

The seasonal change of the mean temperature, dew point temperature, virtual temperature, and potential temperature (T_d, T_v, T_p, and T_m) for Benin is depicted in Fig. 10. The result indicated that the mean temperature, the virtual temperature and potential temperature were almost the same and at the same rate of variation with SWVD, they all increase from January to their maximum values of 300.9395 K for mean temperature, 300.9292 K for virtual temperature and 301.2060 K for potential temperature. The temperatures continued to drop down from their maximum values to August where they also reached their minimum values of 297.6724 K for mean temperature, 297.6619 K for virtual temperature and 297.6096 for potential temperature. After the minimum level the temperatures rose to November then drop to December.

3.3 Two Variable Correlation Model for Benin

Based on equations 10 to 12, the two-variable correlation model generated for Benin is expressed as:

$$SWVD = 295 - 0.288P + 16.3CC \qquad 18a$$
$$SWVD = 1053 - 1.00P - 4.80SSH \qquad 18b$$
$$SWVD = 0.363 - 0.000364P + 4.51PWV \qquad 18c$$

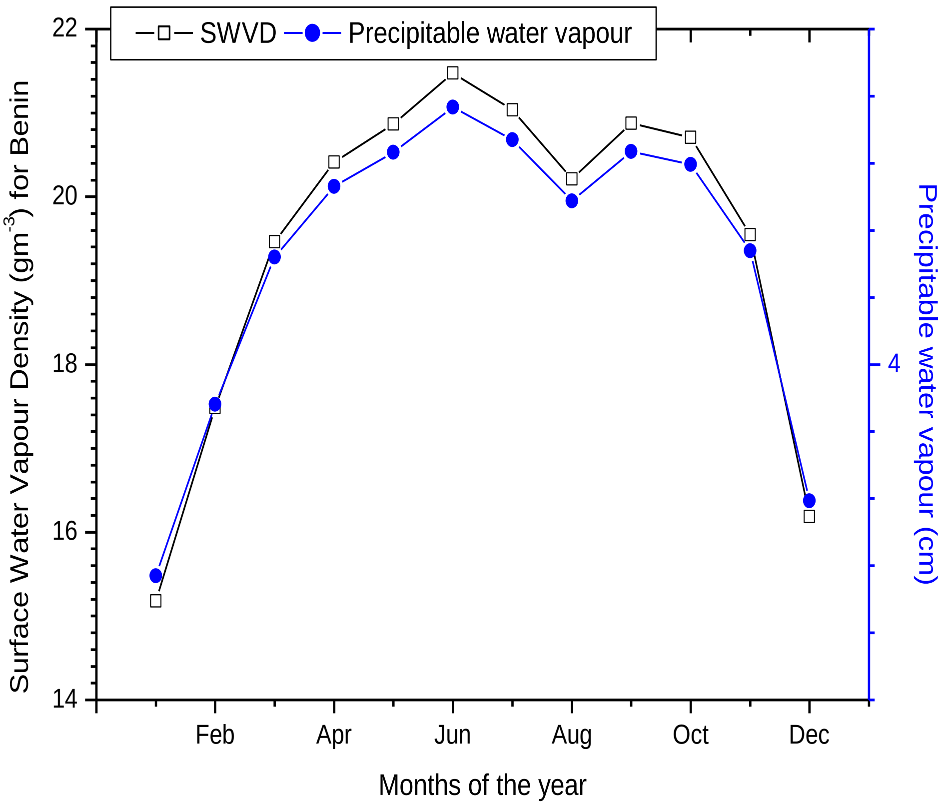

Fig. 9. Variation of SWVD with precipitable water vapour for Benin

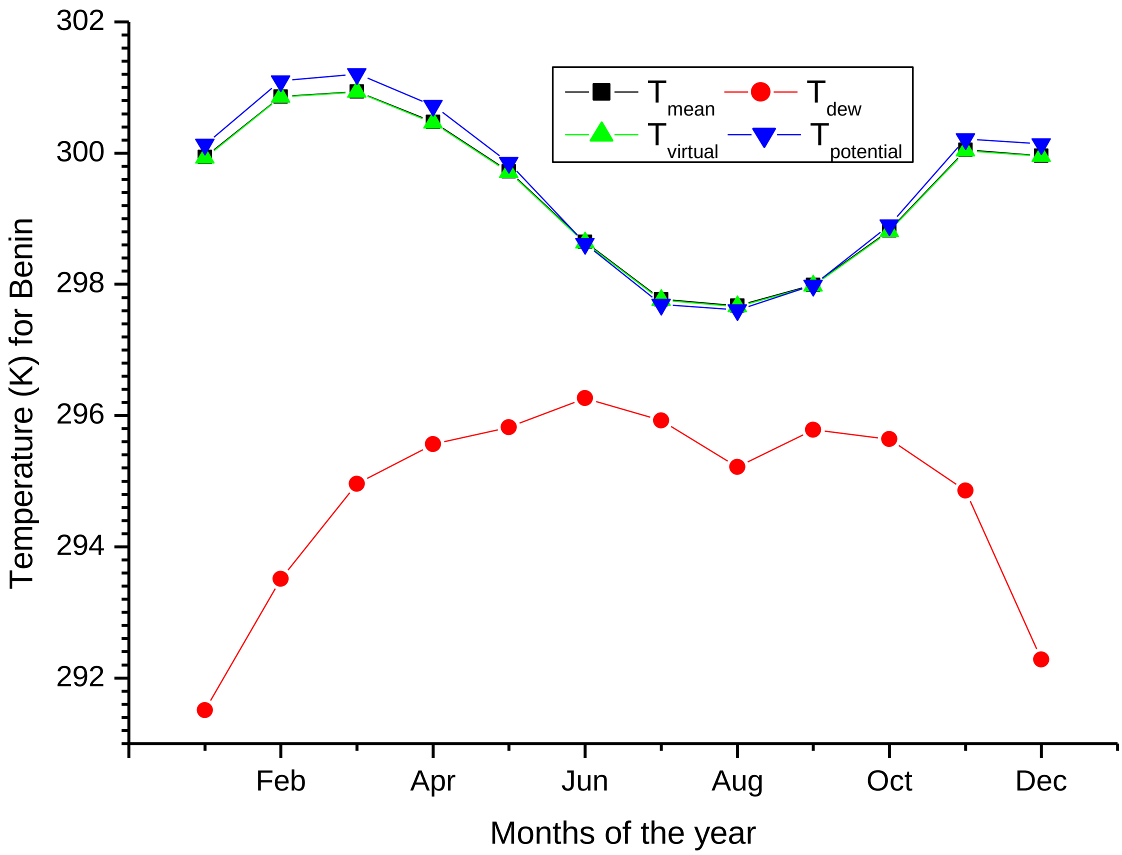

Fig. 10. Variation of SWVD with temperature (T_m, T_p, $T_v$and T_d) for Benin

From Table 1a above equation 18c has the highest R^2, NSE and IA it also has lowest RMSE which shows that it is the best equation for estimating SWVD in the location, but equation 18b is the best in terms of MBE and MPE.

The ranking from Table 1b shows that both equation 18a and 18c are suitable for estimation of SWVD for Benin and stations with similar weather conditions, as they has equal and lowest ranking.

Fig. 11. shows the seasonal variation of SWVD with and the developed equations, the result shows that equation 18b overestimates SWVD in January and February, then August September and December. In addition, it undervalues it from March to July.

Table 1a. Statistical validation tests for Benin

Models	R^2	MBE	RMSE	MPE	NSE	IA
18a	92.5	0.1851	0.5714	-1.0531	96.5993	99.1695
18b	47.4	-0.0064	1.4271	-0.5888	78.7859	93.8017
18c	100	0.2882	0.2882	-1.4977	99.1346	99.7986

Table 1b. Ranking for the models

Models	R^2	MBE	RMSE	MPE	NSE	IA	Ranking
18a	2	2	2	2	2	2	12
18b	3	1	3	1	3	3	14
18c	1	3	1	3	1	1	10

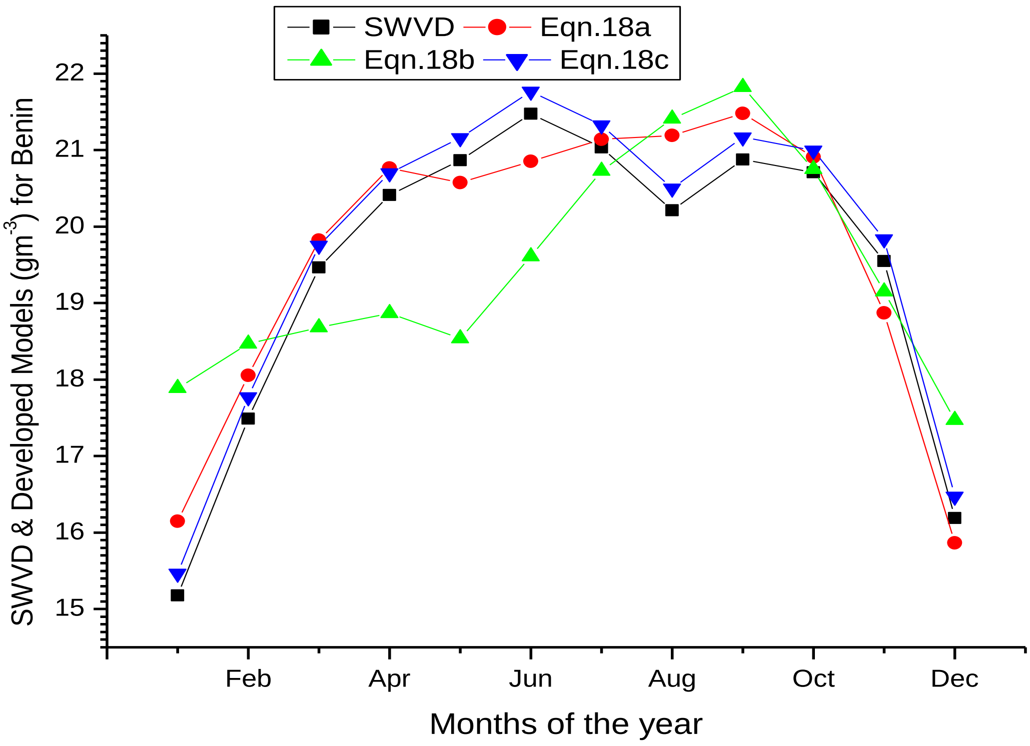

Fig. 11. Monthly variation of SWVD and developed models for Benin

4. CONCLUSION

In the present study, data from the European Centre for Medium-Range Weather Forecasts (ECMWF) for Benin, which is located in the Coastal region of Nigeria, were used to examine the monthly SWVD and its change with other meteorological parameters throughout the period spanning from 1979 to 2016. For the year 2014, the daily variance during the dry and wet seasons was also examined. The R^2, MBE, RMSE, MPE, NSE, and IA statistical indices were used to assess three straightforward two-variable correlation models. It was found that for the area, high SWVD values are recorded during the wet season and low SWVD values during the dry season. Surface water vapour density peaked on May 23, 2014, with 27.5731 gm^{-3}, and it's lowest on December 26, 2014, with 9.6567 gm^{-3}. With the lowest RMSE and maximum R^2, NSE, and IA, the model that relates Pressure (P) with Precipitable Water Vapour (PWV) was found to be the best for SWVD estimation in Benin.

ACKNOWLEDGEMENTS

The authors wish to thank the European Centre for Medium-Range Weather Forecasts (ECMWF) for providing all the necessary meteorological data used in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Akpootu DO, Iliyasu MI, Mustapha W, Salifu SI, Sulu HT, Arewa SP, Abubakar MB. Models for Estimating Precipitable Water Vapour and Variation of Dew Point Temperature with Other Parameters. Journal of Water Resources and Ocean Science. 2019a;8(3):28-36
DOI: 10.11648/j.wros.20190803.11
2. Held IM, Soden BJ. Water vapour feedback and global warming, Annual Review of Environment and Resources. 2000;25:441- 475.
3. Trenberth KE, Fasullo J, Smith L. Trends and variability in column-integrated atmospheric water vapour. Climate Dynamics. 2005;(24)7-8:741-758.
4. Wang J, Carlson DJ, Parsons DB. Performance of operational radiosonde

humidity sensors in direct comparison with a chilled mirror dew-point hygrometer and its climate implication. Geophysical Research Letters. 2003;30:16.

5. Wagner T, Beirle S, Grzegorski M. Global trends (1996-2003) of total column precipitable water observed by Global Ozone Monitoring Experiment (GOME) on ERS 2 and their relation to near-surface temperature. Journal of Geophysical Research: Atmospheres. 2006; 111:12, Article IDD12102.
6. Changnon DM, Sandstrom, C, Schaffer C, Relating changes in agricultural practices to increasing dew points in extreme Chicago heat waves. Climate Resources. 2003;24:243–254.
7. Dai A. Recent climatology, variability, and trends in global surface humidity. Journal of Climate Change. 2006; (19)15:3589-3606.
8. Akpootu DO, Momoh M, Abdullahi Z, Umar M. Estimation of Surface Water Vapour Density and its Variation with other Meteorological Parameters over Akure, Nigeria. Saudi J Eng Technol. 2023;8(8):189-99.
9. Zhao Y, Gong L, Zhou B, Huang Y, Liu C. Detecting tomatoes in greenhouse scenes by combining AdaBoost classifier and colour analysis. Biosyst. Eng. 2016; 148:127–137.
10. Dai A, Wang J, Thorne P. A new approach to homogenize daily radiosonde humidity data. Journal of Climate Change. 2011;(24)4:965-991.
11. Khalameyda DD. Influence of fluctuations in the troposphere refractive index on the interferometer measurement accuracy of radio wave angles of arrival. Telecommun. Radio Eng. 2011;70.
12. Khaniani AS, Nikraftar Z, Zakeri S. Evaluation of MODIS Near-IR water vapour product over Iran using groundbased GPS measurements. Atmospheric Resources. 2020;231:104657.
13. Solomon S, Rosenlof KH, Portmann RW, Daniel JS, Davis SM, Sanford TJ, Plattner GK. Contributions of stratospheric water vapor to decadal changes in the rate of global warming. Science. 2010 Mar 5;327(5970):1219-23.
14. Israel E, David AK, Samuel OO, Gabriel AA, Omolara EG. Global Distribution of Surface Water Vapour Density Using in Situ and Reanalysis Data. Journal of Water Resources and Ocean Science. 2020; 9(3):64-70.
DOI: 10.11648/j.wros.20200903.12
15. Ajayi GO. Physics of the tropospheric radio propagation. Proceedings of the ICTP College on Theoreticaland Experimental Radio Propagation Physics. 1989;6–24.Trieste, Italy.
16. Akpootu DO, Mustapha W, Rabiu AM, Iliyasu MI, Abubakar MB, Yusuf SO, Salifu SI. Estimation of surface water Vapour Density and its Variation with other Meteorological Parameters over Coastal region of Nigeria. Hydrology. 2019;7(3): 46-55.
DOI: 10.11648/j.hyd.20190703.12
17. IPCC. Intergovernmental Panel on Climate change. Third Assessment Report: Climate change WG1: The scientific basis, summary for policymakers, Geneva, Switzerland; 2001.
18. Adeyemi B, Ogolo EO. Diurnal and Seasonal Variation of Surface Water Vapour Density over some Meteorological Station in Nigeria. Ife Journal of Science. 2014;16(2):181-189.
19. Akpootu DO, Iliyasu MI, Nouhou I, Aina AO, Idris M, Mustapha W, Ohaji DE, Muhammad AD. Estimation and Variation of Saturation Mixing Ratio and Mixing Ratio over Potiskum, Nigeria. Nigerian Journal of Basic and Applied Science. 2022a;30(1):49-54.
DOI:http://dx.doi.org/10.4314/njbas.v30i1.7
20. Leckner B. The spectral distribution of solar radiation at the earth's surface—elements of a model. Sol Energy. 1978;20 (2):143-150.
21. Lawrence MG. The relationship between relative humidity and the dewpoint temperature in moist air: A simple conversion and applications. Bull. Amer. Meteor. Soc. 2005;86:225-233.
DOI: http;//dx.doi.org/10.1175/BAMS-86-2-225.
22. Wallace JM, Hobbs PV. Atmospheric Science, An Introductory Survey, 2nd Edition, Elsevier. 2006;66-82.
23. El-Sebaii A, Trabea A. Estimation of Global Solar Radiation on Horizontal Surfaces over Egypt, Egypt. J. Solids. 2005;28(1):163-175.
24. Gana NN, Akpootu DO. Angstrom Type Empirical Correlation for Estimating Global Solar Radiation in North- Eastern Nigeria. The International Journal of Engineering And Science. 2013a;2(11):58-78.

25. Gana NN, Akpootu DO. Estimation of global solar radiation using four sunshine based models in Kebbi, North-Western, Nigeria. Pelagia Research Library. 2013b; 4(5):409-421.
26. Akpootu DO, Gana NN. Comparative Study of Global Solar Radiation between Nguru and Abuja. A paper presented at the 24th Annual Congress and Colloquium of the Nigerian Association of Mathematical Physics held at University of Benin, Benin City, Nigeria on the 25th-28th February. 2014.
27. Akpootu DO, Sanusi YA. A New Temperature-Based Model for Estimating Global Solar Radiation in Port-Harcourt, South-South Nigeria. The International Journal of Engineering And Science. 2015; 4(1): 63-73.
28. Olomiyesan BM, Akpootu DO, Oyedum DO, Olubusade JE, Adebunmi SO. Evaluation of Global Solar Radiation Models Performance using Global Performance Indicator (GPI): A Case Study of Ado Ekiti, South West, Nigeria. A paper presented at the 43rd Annual Nigerian Institute of Physics, National Conference, held at the Nnamdi Azikiwe University, Awka, Anambra State. 2021;26-29.
29. Akpootu DO, Iliyasu MI. The Impact of some Meteorological Variables on the Estimation of Global Solar Radiation in Kano, North Western, Nigeria. Journal ofNatural Sciences Research. 2015a; (5)22:1 – 13.
30. Akpootu DO, Iliyasu MI. A Comparative Study of some Meteorological Parameters for Predicting Global Solar Radiation in Kano, Nigeria Based on Three Variable Correlations. Advances in Physics Theories and Applications. 2015b;49: 1–9.
31. Chen R, Ersi K, Yang J. Validation of five global radiation Models with measured daily data in China. Energy Conversion and Management. 2004;45,1759-1769.
32. Merges HO, Ertekin C, Sonmete MH. Evaluation of global solar radiation Models for Konya, Turkey. Energy Conversion and Management. 2006;47:3149-3173.
33. Akpootu DO, Momoh M. Empirical Model for Estimating Global Solar Radiation in Makurdi, Benue State, North Central Nigeria. A paper presented at the 36th Annual Nigerian Institute of Physics, National Conference, held at the Department of Physics, University of Uyo, Nigeria on. 2014;26-29,
34. Akpootu DO, Sulu HT. A Comparative Study of Various Sunshine Based Models for Estimating Global Solar Radiation in Zaria, North-Western, Nigeria. International Journal of Technology Enhancements and Emerging Engineering Research. 2015; 3(12):1 – 5.
35. Akpootu DO, Tijjani BI, Gana UM. Empirical models for predicting global solar radiation using meteorological parameters for Sokoto, Nigeria. International Journal of Physical Research. 2019c;7(2):48 – 60. DOI: 10.14419/ijpr.v7i2.29160
36. Akpootu DO, Tijjani BI, Gana UM. Sunshine and Temperature Dependent Models for Estimating Global Solar Radiation Across the Guinea Savannah Climatic Zone of Nigeria. American Journal of Physics and Applications. 2019d;7(5): 125-135. DOI: 10.11648/j.ajpa.20190705.15.
37. Akpootu DO, Tijjani BI, Gana UM. New temperature dependent models for estimating global solar radiation across the midland climatic zone of Nigeria. International Journal of Physical Research. 2019e;7(2):70 – 80. DOI: 10.14419/ijpr.v7i2.29214
38. Akpootu DO, Tijjani BI, Gana UM. New temperature dependent models for estimating global solar radiation across the coastal climatic zone of Nigeria. International Journal of Advances in Scientific Research and Engineering (ijasre). 2019f;5(9):126 – 141. DOI: 10.31695/IJASRE.2019.33523
39. Akpootu DO, Abdullahi Z. Development of sunshine based models for estimating global solar radiation over kano and Ikeja, Nigeria. FUDMA Journal of Sciences (FJS). 2022;(6)3: 290 – 300. DOI: https://doi.org/10.33003/fjs-2022-0603-1001
40. Akpootu DO, Iliyasu MI, Olomiyesan BM, Fagbemi SA, Sharafa SB, Idris M, Abdullahi Z, Meseke NO. Multivariate Models For Estimating Global Solar Radiation In JOS, Nigeria. Matrix Science Mathematic (MSMK). 2022b; 6(1): 05-12. DOI:http://doi.org/10.26480/mkmk.01.2022.05.12
41. Akpootu DO, Alaiyemola SR, Abdulsalam MK, Bello G, Umar M, Aruna S, Isah AK, Aminu Z, Abdullahi Z, Badmus TO.

Sunshine and Temperature Based Models for Estimating Global Solar Radiation in Maiduguri, Nigeria. Saudi Journal of Engineering and Technology. 2023; 8(5):82-90.
DOI: 10.36348/sjet.2023.v08i05.001.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/104875