



Research Article

Investigation and Multivariate Models for Estimation of Surface Water Vapour Density in Ikeja, Nigeria

^{1*}Zakariya Abdullahi, ²Davidson Odafe Akpootu, ²Musa Momoh, ³Lawal Sa'ad, ¹Yusuf Ibrahim Bawa, ⁴Abubakar Muhammad Yabo, ⁵Ibrahim Nouhou, ²Emmanuel Oluwamayowa Agidi, ⁶Abdullahi Yusuf and ²Sunday Bongde Yohanna

¹Department of Physics, Adamu Augie College of Education Argungu Kebbi State

²Department of Physics, Usmanu Danfodiyo University Sokoto, Nigeria

³Department of Physics, Federal University Gusau

⁴College of Nursing Sciences Tambuwal

⁵Département de Physique, Faculté des Sciences et Techniques (FST), Université Dan Dicko Dankoulodo, Maradi République du Niger

⁶Department of Science Education, Ibrahim Badamasi Babangida University, Lapai, Nigeria

*Corresponding author's Email: kyangazak@gmail.com, doi.org/10.55639/607.302928

ARTICLE INFO:

ABSTRACT

Keywords:

Meteorological Parameters, Ikeja, Statistical Indices, SWVD

Over a thirty-eight-year period (1979-2016), the study looked at the relationships between monthly fluctuations in Surface Water Vapour Density (SWVD) and meteorological factors such temperature, relative humidity, surface pressure, cloud cover, and hours of sunshine in Ikeja on a monthly average. With two average months included in each season, the study examined the daily differences in the two different seasons' surface water vapour densities in 2014. The results showed that during the course of the investigation, there were daily fluctuations in the density of surface water vapor. The highest and lowest SWVD values were found to be 20.9244 gm^{-3} and 16.0135 gm^{-3} , respectively, in the months of June and January. The statistical indices of mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE), Nash-Sutcliffe equation (NSE), coefficient of determination (R^2), and index of agreement (IA) were used to compare the created SWVD-based models. To ascertain which of the three straightforward models of correlation using two variables was more appropriate for estimating surface water vapour density (SWVD) for the location being studied, the model that relates pressure and precipitable water vapour was adjudicated to be the most appropriate. The results obtained in this study will help hydrometeorologists to know the amount of SWVP in the studied location.

Corresponding author: Zakariya Abdullahi, Email: kyangazak@gmail.com
Department of Physics, Adamu Augie College of Education Argungu Kebbi State

INTRODUCTION

Water vapor exhibits numerous intriguing properties that captivate scientists worldwide. According to Maghrabi and Dajani (2013), it is the most prevalent and variable of the main atmospheric gases. Various methods are employed to measure atmospheric water vapor, ranging from remote sensing techniques, such as space-based water vapor radiometers, to in situ measurements using radiosondes. Several studies have focused on comparing radiosonde and satellite observations (Randel et al., 1996; Lim et al., 2002; Rind, 1998; Spencer and Braswell, 1997; Roca et al., 2002; Adeyemi, 2009). Water vapor plays a crucial role in the hydrological cycle, mediating interactions between the atmosphere and the Earth's surface (Akpootu, 2019a). According to Akpootu et al. (2019b) and Kiehl and Trenberth (1997), water vapor is the most significant greenhouse gas in the atmosphere, as it absorbs the majority of solar radiation. The earth's atmospheric water vapor varies significantly over time and space, depending largely on air temperature. Understanding its distribution is crucial for comprehending weather patterns and the earth's climate. Water vapor is the most significant greenhouse gas, contributing to approximately two-thirds of the natural greenhouse effect. According to climate models, a 12%–25% increase in atmospheric water vapor has a global mean radiative effect equivalent to doubling the concentration of carbon dioxide (Adeyemi, 2009; Harries, 1997). Water vapor helps maintain the earth's surface temperature above freezing, and without this natural greenhouse effect, the surface temperature would be 32 K lower than its current state (Adeyemi, 2009; Roca et al., 2002).

Water vapor is one of the most dynamic elements in the atmosphere (Israel et al., 2015). Although upper tropospheric water vapor constitutes a small fraction of the total vapor mass, it has a disproportionately large effect on outgoing long wave radiation (Hartmann and Udelhofen, 1995).

Water vapor density is most pronounced and variable within the lowest 2 km of the troposphere, especially in high-altitude tropical regions (Willoughby et al., 2008; Israel et al., 2015).

Understanding the mechanisms that govern the climate system's stability and unpredictability is a complex scientific challenge, compounded by the unpredictable nature of human activities that cause external forcing, such as greenhouse gas emissions and land use changes (IPCC, 2001). Therefore, it is crucial to improve our understanding of water vapor's distribution, interactions with clouds, radiative properties, atmospheric composition, solar radiation processes, and the impact of volcanic eruptions (Ogolo & Adeyemi, 2014).

Traditionally, precipitable water vapor has been measured using radiosondes to create vertical profiles. However, this method is expensive, limiting its routine use. More advanced and costly techniques include sunphotometers, water vapor radiometers (WVRs), satellite retrieval methods, and GPS receiver methods. These methods have been favorably compared with radiosonde observations (England *et al.*, 1992; Coster et al., 1996; Linfield et al., 1997; Boccolari et al., 2002; Bai and Feng, 2003; Jade et al., 2005; Park et al., 2012).

Ikeja was chosen in this study because it is found in the coastal region of Nigeria where rainfall is dominant almost throughout the year; hence, the need to ascertain the amount and the peak value of SWVD during the rainy season. More so, to develop models capable of estimating this important meteorological parameter using readily available climatic data. Investigation of this kind has not been carried out as at the time of this study.

The daily and monthly variations in surface water vapour density were examined in this study for Ikeja, which is located in South Western, Nigeria, in addition to the monthly variance using surface pressure, mean temperature, relative humidity, cloud cover, and sunshine hours as meteorological factors. The study also constructed a novel model to estimate the vapour

density of surface water, and descriptive statistical analysis was done to determine the models' validity.

MATERIALS AND METHODS

Study Area

Situated 10.5 miles (17 km) northwest of Lagos metropolis is Ikeja, the capital town of Lagos state. Originally inhabited by the Yoruba people, the region was plundered until the middle of the 19th century in search of slaves. It developed into an agricultural hinterland for Lagos around the beginning of the 20th century, which is when Nigerian kola nuts were first planted. Ikeja developed into a residential and commercial suburb of Lagos following the construction of the Lagos-Ibadan railway in 1901 and the expansion of Lagos as a port. Ikeja was officially named in 1976, but it was first developed as an industrial

park in the middle of the 1960s, divisions of Ikeja.

Ikeja, the capital city of Lagos State, is located in the southwest of Nigeria on the narrow plain of the Gulf of Benin. Stretching over 180 kilometres along the Guinea Coast of the Bight of Benin on the Atlantic Ocean, Lagos State is roughly located between latitudes 60° 22'N and 60° 42'E and 32° 2'E, respectively. Ogun State, Nigeria, borders it to the east and north, while the Republic of Benin borders it to the west. Its territorial and political jurisdiction encompasses not just the four administrative districts of Ikorodu, Epe, and Badagry, commonly referred to as IBILE, but also the metropolis of Lagos. When combined, these divisions encompass 3,577 square kilometres, or 358,862 hectares, or 0.4% of the 923,773 sq. km. total land area of Nigeria.



Figure 1: Google map of Ikeja

METHODOLOGY

Radiosondes, ground-based microwave radiometers, Laser Imaging Detection and Ranging (LIDAR) systems, Light Amplification by Stimulated Emission of Radiation (LASER) systems, and Global Positioning System (GPS) satellites are often the main methods for measuring SWVD. However, because of the expense and complexity of operation, each

approach has its own disadvantages. This study develops three basic linear regression models for calculating SWVD and uses easily accessible meteorological parameters—temperature and relative humidity—for Ikeja, which is located across Nigeria's coastal climatic zone.

The monthly and daily meteorological data at a height of two metres were provided by the European Centre for Medium-Range Weather

Forecasts (ECMWF) for Ikeja, Nigeria. The average maximum and minimum temperatures, relative humidity, surface pressure, cloud cover, and sunshine hours were all included in the data.

According to Ojo and Adeyemi (2014), Akpootu and Gana, (2014), Akpootu and Iliyasu, (2015a) Akpootu and Abdullahi (2022), the World Meteorological Organization (1967) said that thirty years or more of data series are required for

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

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

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

where RH and e_s stand for saturated vapour pressure and relative humidity, respectively. The Clausius Clapeyron equation was used to calculate the saturation vapour pressure Akpootu

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

The mean temperature T, was also obtained using Akpootu et al (2019e)

$$T = \frac{T_{max} - T_{min}}{2} \quad (4)$$

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

$$P_s = \exp \left(26.23 - \frac{5416}{T} \right) \quad (5)$$

The precipitable water in terms of relative humidity is presented with the following formula, according to Leckner, (1978)

$$W = \frac{(0.493 \phi r P_s)}{T} \quad (6)$$

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

$$T_{dew} = T - \frac{100 - RH}{5} \quad (7)$$

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

Wallace and Hobbs, (2006), used

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

To obtain the virtual temperature ($T_{virtual}$), where e is the vapour pressure and ϵ is a constant given as 0.622

The potential temperature $T_{potential}$ was estimated using Wallace and Hobbs (2006).

$$T_{potential} = T_{mean} \left(\frac{P_0}{p} \right)^{\frac{R}{c_p}} \quad (9)$$

optimal climate modeling. The study period in this regard spans 38 years, from 1979 to 2016.

The relationship between mean temperature (T), vapour pressure (e), and surface water vapour density (SWVD) is given by the following formula according to Akpootu *et al* (2019c), Akpootu et al (2019d), Adeyemi and Ogolo (2014), and Akpootu et al (2023a) Akpootu and Sanusi, (2015b), Akpootu et al. (2019e):

et al (2019c), Akpootu et al (2019d), Adeyemi and Ogolo (2014) Akpootu et al (2023b), Akpootu et al., (2022), Akpootu et al. (2019f) defined as:

Akpootu *et al.*, (2019f) reported that the ambient Temperature T and Partial Pressure P_s are related by a correlation model which is expressed by the semi empirical equation;

expressed in fractions of one. Next, Lawrence (2005) was used to determine the dew point temperature T_{dew} .

expression (9) is the Poisson’s equation. p_o represents the standard pressure usually taken as 1000hPa and $\frac{R}{c_p} = 0.286$

The Development of Two Variable Correlation Models

The following is the format of the predicted two-variable correlation models:

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

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

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

The variables P, CC, SSH, and PWV represent surface pressure, cloud cover, sunshine hours, and precipitable water vapour, respectively. The empirical constants a, b, and c are also included. These meteorological parameters are selected on the basis that they have influence on the SWVD

Validation of the Models

To validate the models, statistical tests are performed on each of the following: The

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

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

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

$$NSE = 1 - \frac{\sum_1^n (SWVD_{i,meas} - SWVD_{i,cal})^2}{\sum_1^n SWVD_{i,mea} - SWVD_{i,mea}} \tag{16}$$

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

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

According to Chen et al. (2004), a low RMSE is preferred and a zero value for MBE is optimal. The model performs better when the MBE and RMSE values are less. Positive MBE and MPE values indicate an average level of overestimation in the computed values, whereas negative values

coefficient of determination (R^2), Nash-Sutchliffe equation (NSE), Mean Bias Error (MBE), Index of Agreement (IA), Root Mean Square Error (RMSE), and Mean Percentage Error (MPE). According to Adeyemi and Ogolo (2014) and Akpootu et al., (2023b), the MBE, RMSE, NSE, IA, and MPE have the following expressions.

indicate underestimating. It is preferable for MPE to be low. According to Merges et al. (2006), a percentage error of between -10% and +10% is deemed acceptable. It is preferred to have high R^2 , NSE, and IA values. R^2 and MPE are expressed in percentage (%), whereas MBE and RMSE are expressed in gm^{-3} .

RESULTS AND DISCUSSION
Variation of Meteorological Parameters with SWVD for Ikeja

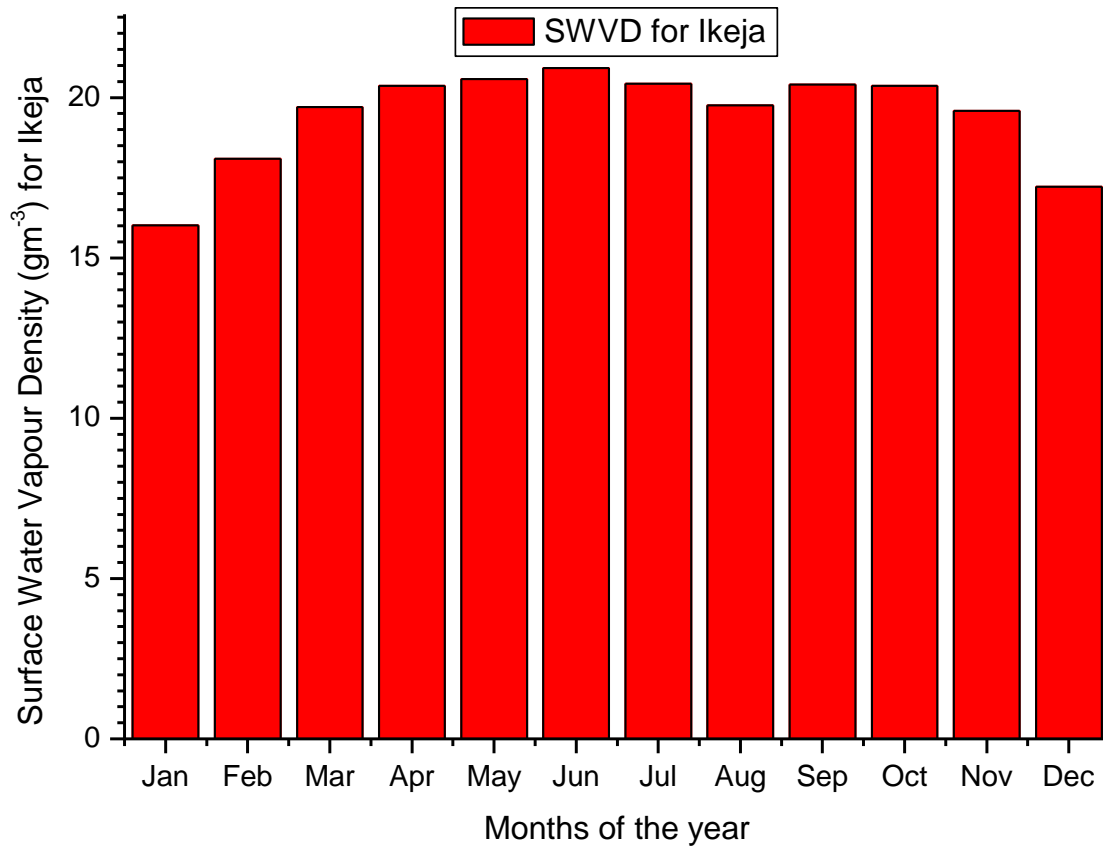


Figure 2: SWVD Variation for Ikeja Using Meteorological Parameters

The monthly fluctuation of SWVD for Ikeja is displayed in Figure 2. The results show that the wet season has greater SWVD than the dry season. The SWVD values for the months of January and June were determined to be 16.0135 gm⁻³ and 20.9244 gm⁻³, respectively. In addition, SWVD decreases in July and August before rising in September after reaching a peak in June.

The findings of Akpootu *et al.*, (2019c) for Owerri, Nigeria, are consistent with this conclusion where they observed that the maximum average value of SWVD of 21.002gm⁻³ occurred in the month of June during the rainy season and minimum value of 14.653gm⁻³ in the month of January during the dry season.

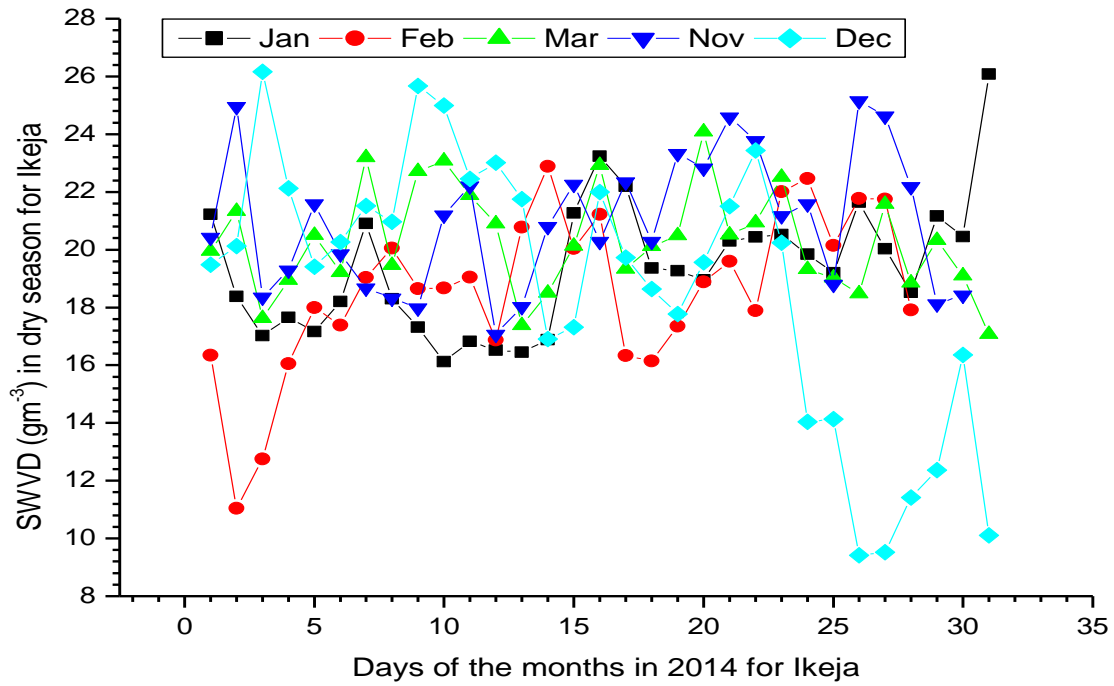


Figure 3. diurnal variation of SWVD during the dry season for Ikeja

Figure 3 specifically shows the diurnal fluctuation in SWVD for the Ikeja dry season. The findings revealed variations in the SWVD quantity, with December 26, 2014 and December 3, 2014 having the greatest and lowest values, respectively, at 26.16574 gm^{-3} and 9.417691 gm^{-3} .

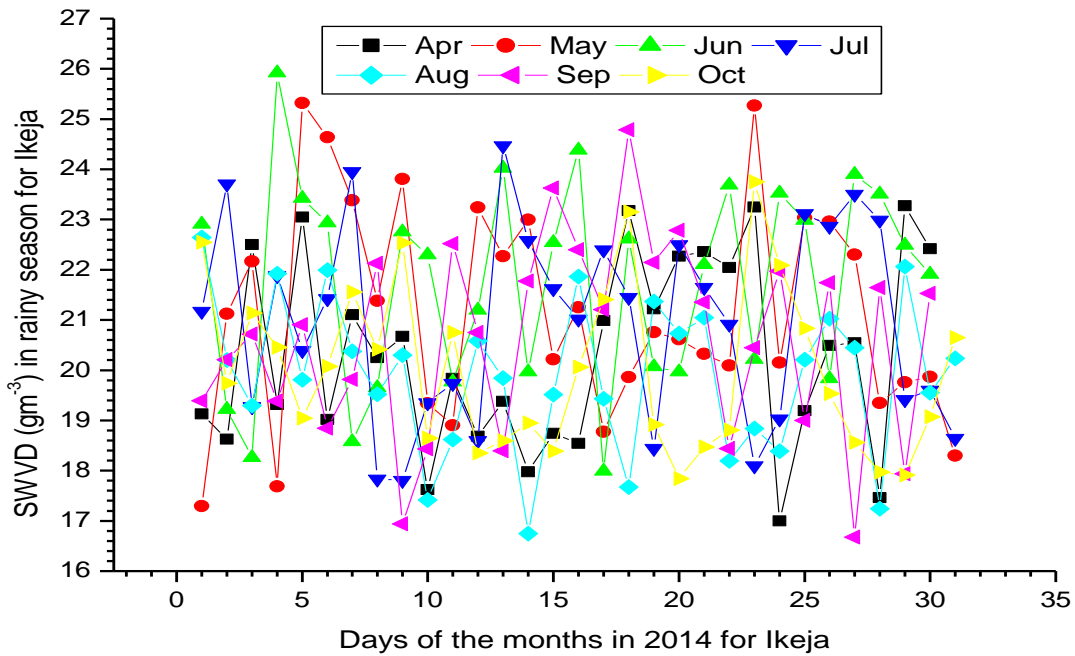


Figure 4: Diurnal Variation of SWVD in the Rainy Season for Ikeja Nigeria

Figure 4 portrays the diurnal SWVD variations specifically for the rainy season in Ikeja. The result shows that the maximum the minimum

values of SWVD occurred on the 4th June, 2014 and 28th September, 2014 with 25.9170 gm⁻³ and 16.6775 gm⁻³ respectively.

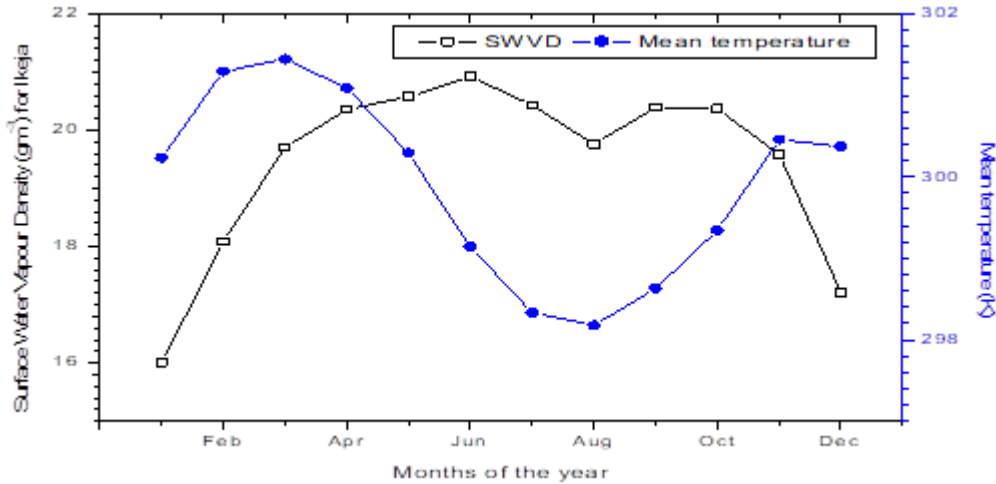


Figure 5: Variation of SWVD with Mean Temperature for Ikeja

Figure 5 showed the average temperature as well as the monthly seasonal variation in SWVD for Ikeja. The SWVD increased progressively from its lowest point of 15.1798 gm⁻³ in January to its greatest value of 21.4753 gm⁻³ in June. After that, it fell in August, dropped once more, increased in September, and then dropped until December. The mean temperature rose in tandem with the SWVD starting in January. At 300.9395 K, it

peaked in March and then gradually decreased until August, when it started to increase once more until December. The short dry spell known as August Break, which coincided with the lowest temperature in the region, may have contributed to the fall in SWVD that was reported in August. SWVD values were found to be high and low, respectively, during the rainy and dry seasons while mean temperature indicated the opposite.

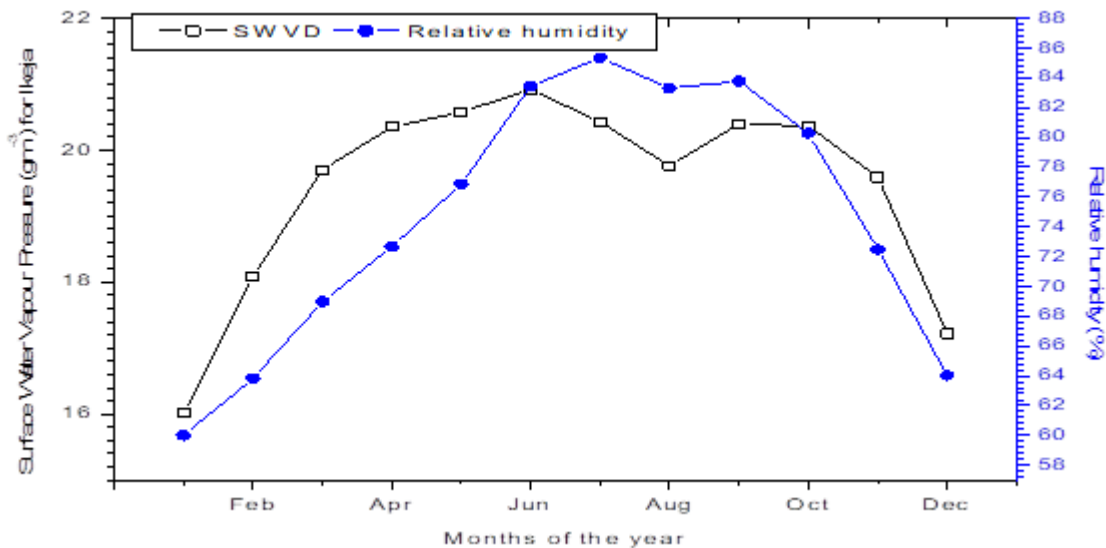


Figure 6: Variation of Surface Water Vapour Density with Relative Humidity for Ikeja

Figure 6 shows the monthly variation of SWVD with RH in Ikeja. The result showed that the relative humidity had increased from 60.0071 %, which was its lowest point in January, to its maximum value of 85.3579 %. It then dropped to

August, increased to September, and then dropped to December. Since the variation with SWVD is in phase, there were strong similarities between their characteristics.

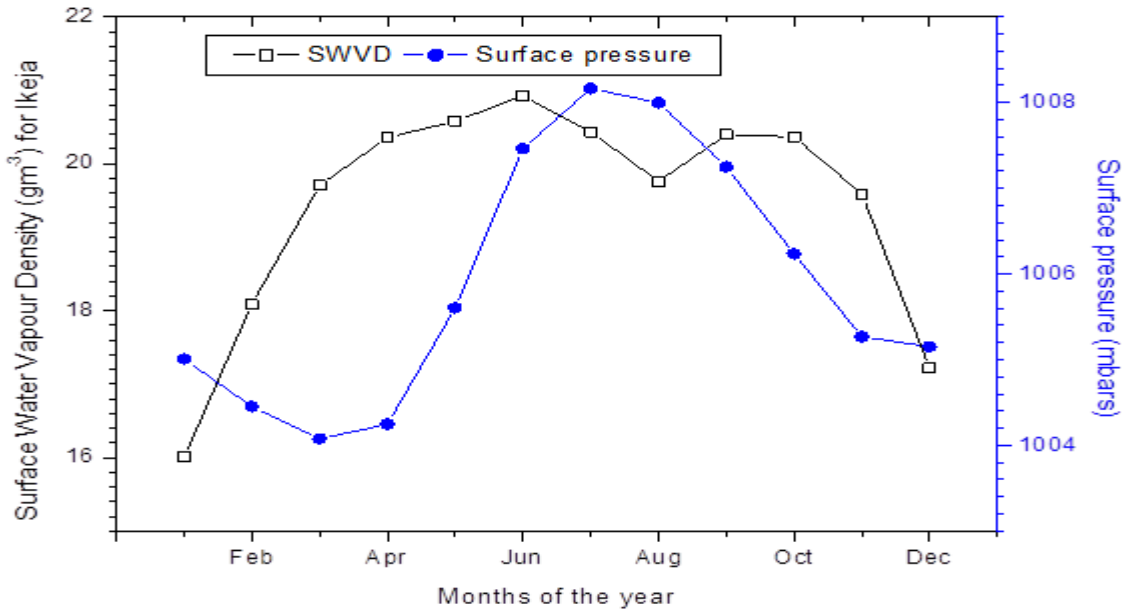


Figure 7: Variation of SWVD with Surface Pressure for Ikeja

Figure 7 illustrates the relationship between SWVD and surface pressure fluctuation. The data indicates that the surface pressure magnitude drops in January, climbs in April, reaches its

highest value of 1008.168 mbars in July, and then continues to decline until December. In March, the lowest reading of 1004.0784 mbars was recorded.

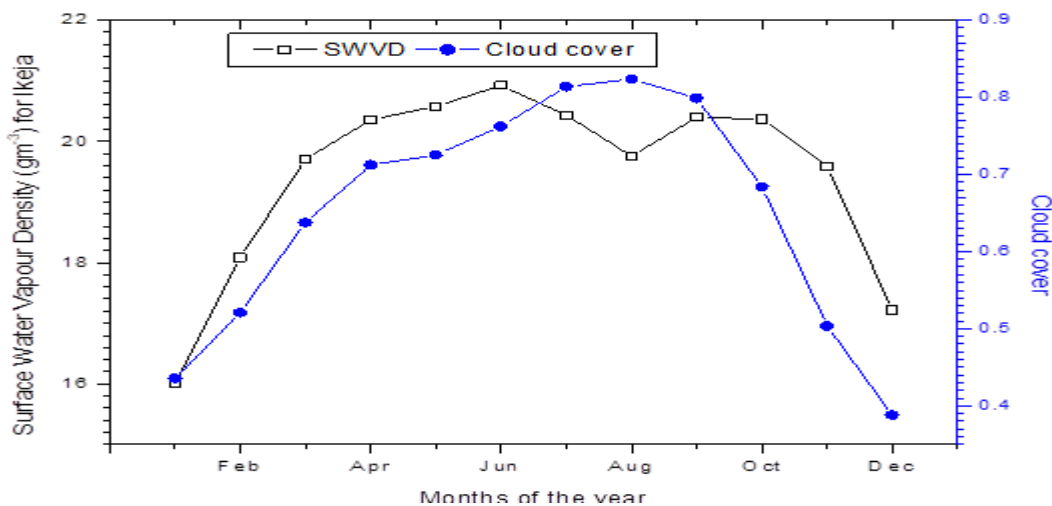


Figure 8: Variation of SWVD with Cloud Cover for Ikeja

The seasonal variation of SWVD for Ikeja with cloud cover is displayed in Figure 8. Which shows that between January and April, there was a rise in cloud cover and SWVD; in May, there

was a minor decline; in July there was an increase; up to September, the cloud cover reached its highest level of 0.8838. It also

declined to 0.3879, in October and December respectively.

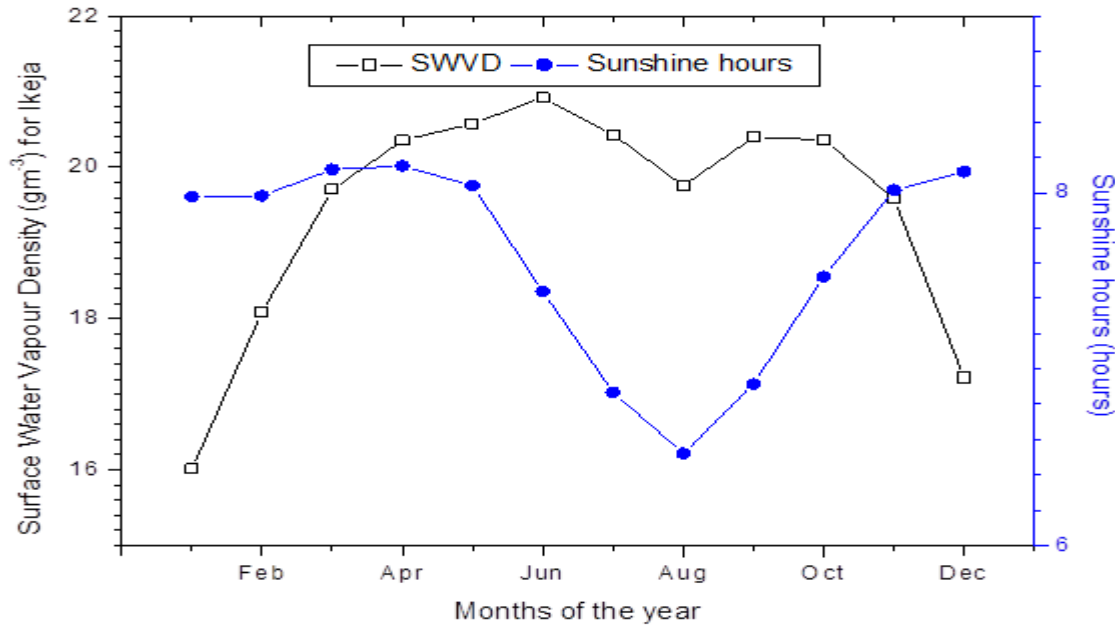


Figure 9: Monthly variation of SWVD WITH Sunshine Hours for Ikeja

Figure 9 shows the seasonal fluctuation of SWVD with sunlight hours for Ikeja. The sunlight hours decrease and increase at about similar intervals from January through May, reaching a minimum of 6.5206 hours in August that corresponded with the SWVD's August

hiatus. Sunshine hours increase, peaking at 8.1512 hours in December after falling to their lowest point in August. The results demonstrated that during the dry and rainy seasons, respectively, high and low values of sunlight hours were observed for SWVD.

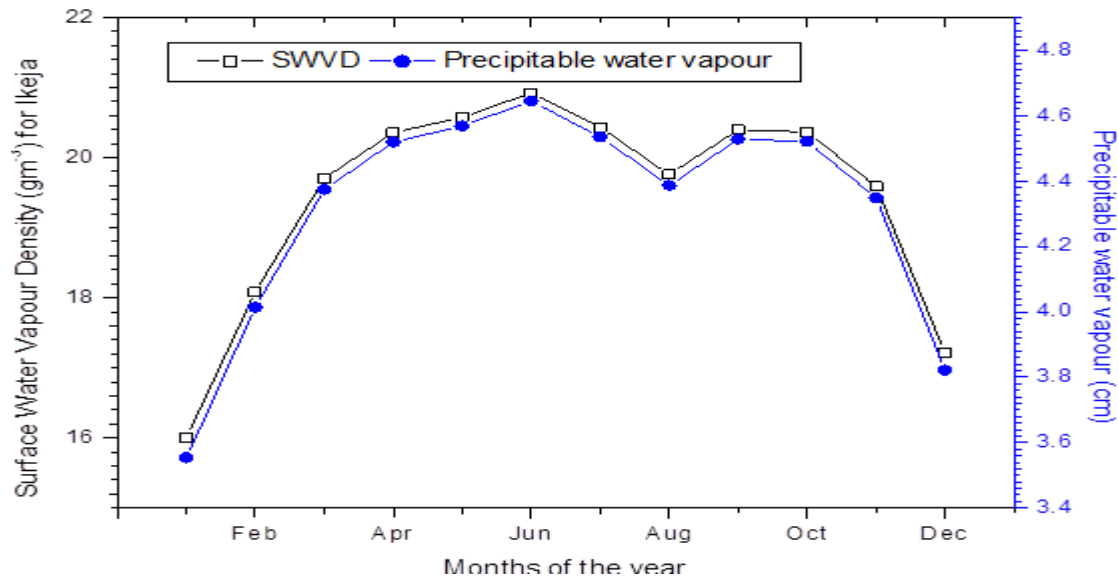


Figure 10: Variation of SWVD with Precipitable Water Vapour (PWV) for Ikeja.

Figure 10 shows the seasonal change of SWVD with Precipitable Water Vapour (PWV). The data indicates that the SWVD and PWV increased in a similar manner starting in January and continuing

until they reached their lowest values of 20.9244 gm^3 and 4.6448 cm in July. In August, both the SWVD and PWV suddenly decreased in value, which is indicative of the well-known August

break in the area. Fig. 9 shows the seasonal change of SWVD with Precipitable Water Vapour (PWV). The findings indicate that the SWVD increased according to the same trend as the PWV, increasing dramatically from January to their highest value of 3.5546 cm and 16.0135

gm^{-3} and their peak values of 21.0359 gm^{-3} and 4.6697 cm in July, respectively. The region's well-known August break serves as a marker of the abrupt decline in the values of the SWVD and PWV in August.

Variation of Mean Temperature, Virtual Temperature, Potential Temperature and Dew Point Temperature for Ikeja

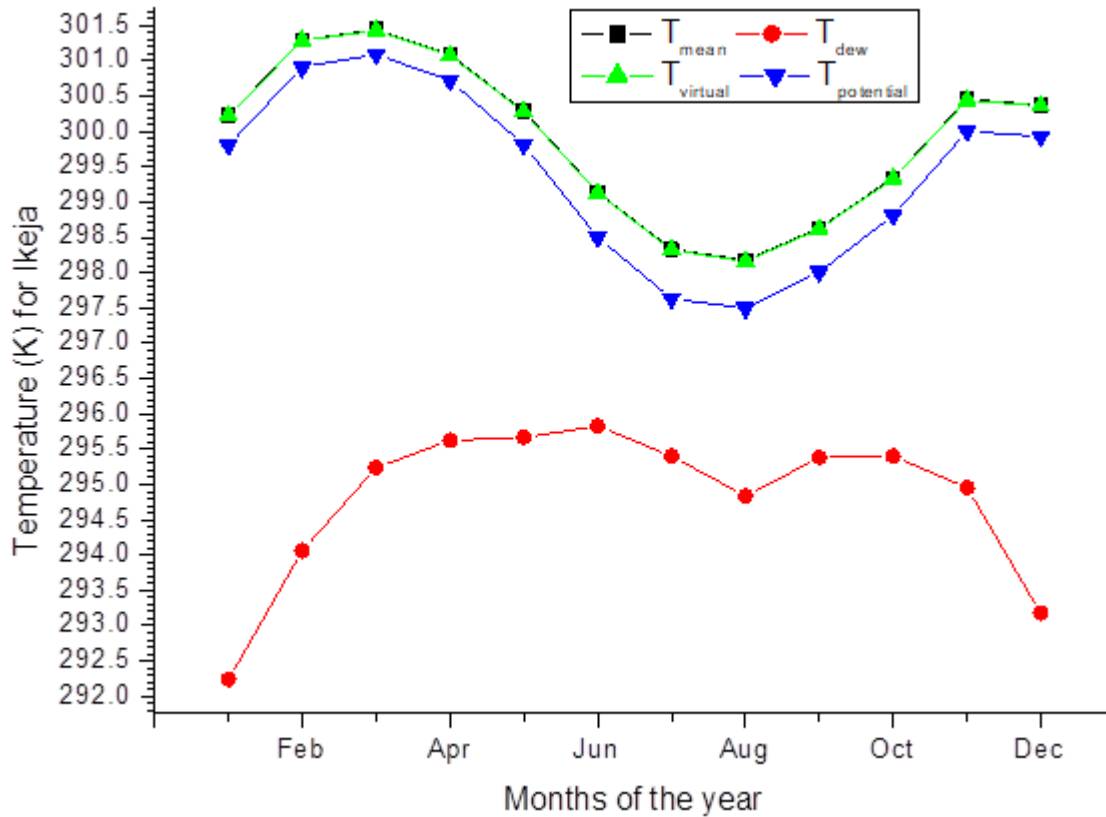


Figure 11: Variation of SWVD with Temperatures (T_m , T_d , T_v and T_p) for Ikeja

The monthly variation of the potential temperature ($T_{potential}$), virtual temperature ($T_{virtual}$), dew point temperature (T_{dew}), and mean temperature (T_{mean}) for Ikeja is displayed in Figure 11. The findings showed that the mean temperature and virtual temperature had the greatest profiles on the graph; their maximum and lowest values, 301.443 K and 301.433 K and 298.175 K and 298.165 K, respectively, were recorded in the months of March and August. At 292.236 K, the dew point temperature had the lowest recorded figure in January. The temperature of the dew point rises from its lowest point in January to July, then falls in August,

reaches its highest value of 294.836 K in September, and then falls in December. According to the study's findings, the mean, virtual, and potential temperatures all show high values during the rainy season and low values during the dry season, while the dew point temperature records high values during the rainy season and low values during the dry season. This implies that the mean, virtual, and potential temperatures reflect different values than the dew point temperature. This result is in line with the work reported by Akpootu *et al.*(2023b) and Iliyasu *et al.* (2023)

Two Variable Correlation Models for Ikeja

The two variable correlation models established for Ikeja are based on equations 10, 11 and 12 as follows:

$$SWVD = 268 - 0.254P + 4.50PWV \quad (18a)$$

$$SWVD = -606 + 0.619P + 0.43SSH \quad (18b)$$

$$SWVD = 0.351 - 0.000350P + 4.51PWV \quad (18c)$$

Table 1: Statistical validation test for Ikeja

Models	R ²	MBE	RMSE	MPE	NSE	IA
18a	74.5	-0.31876	0.805668	1.484802	69.80363	90.95377
18b	20.3	0.490539	1.39792	-3.04838	9.091029	52.18109
18c	100	0.02046	0.02052	-0.10517	99.98041	99.99511

Table 1 is a validation test for the developed models which shows that equation 18c is regarded the best equation as it has highest R²,NSE and IA, it also has the lowest MBE, RMSE and MPE.

Table 2: Ranking of the Validated Equation

Models	R ²	MBE	RMSE	MPE	NSE	IA	Ranking
18a	2	2	2	2	2	2	12
18b	3	3	3	3	3	3	18
18c	1	1	1	1	1	1	6

From the table 2 above we can see that equation 18c has the lower ranking and therefore is the best equation that estimate Surface SWVD in Ikeja and other stations with similar meteorological conditions.

CONCLUSION

This study examined the monthly SWVD and its changes with other meteorological parameters during a 38-year period, from 1979 to 2016, using data from the European Centre for Medium-Range Weather Forecasts (ECMWF) for Ikeja, which is located in western Nigeria. The daily variation throughout the dry and wet seasons was also looked at during 2014. The three simple two-variable correlation models were evaluated for validity using the R², MBE, RMSE, MPE, NSE, and IA statistical indices because the use of LIDAR, LASER, GPS, etc is expensive and its complexity in operation. It was discovered that

the area has low SWVD values during the dry season and high values during the rainy season. Surface water vapour density reached its highest point of 25.9170 gm⁻³ on June 4, 2014, and its lowest point on December 3, 2014, with 9.417691 gm⁻³. With the lowest RMSE and highest R², NSE, and IA, the model relates Pressure (P) with Precipitable Water Vapour (PWV) was found to be the best for SWVD estimate in Ikeja.

ACKNOWLEDGEMENTS

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

- Adeyemi, B & Ogolo, E. O (2014). "Diurnal and seasonal variations of surface water vapour density over some meteorological stations in Nigeria." *Ife Journal of Science* vol.16: no. 2.
- Adeyemi, B. (2009), Empirical Modeling of Layered Integrated Water Vapor Using Surface Mixing Ratio in Nigeria, *American Meteorological Society* DOI: 10.1175/2008JAMC1929.1 2009.
- Akpootu, D. O & Gana N. N. (2014). 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.
- Akpootu, D. O & Iliyasu, M. I. (2015a). The Impact of some Meteorological Variables on the Estimation of Global Solar Radiation in Kano, North Western, Nigeria. *Journal of Natural Sciences Research*. (5)22:1 – 13.
- Akpootu, D. O & Iliyasu M. I. (2015b). 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*. 49:1–9
- Akpootu, D. O & Sanusi, Y. A. (2015) A New Temperature-Based Model for Estimating Global Solar Radiation in Port-Harcourt, South-South Nigeria. *The International Journal of Engineering and Science*.4(1): 63-73.
- Akpootu, D. O., Tijjani, B. I & Gana U. M. (2019e). New temperature dependent models for estimating global solar radiation across the midland climatic zone of Nigeria. *International Journal of Physical Research*.7(2):70 – 80.DOI: 10.14419/ijpr.v7i2.29214
- Akpootu, D. O., Tijjani, B. I & Gana, U. M. (2019d), Sunshine and Temperature Dependent Models for Estimating Global Solar Radiation Across the Guinea Savannah Climatic Zone of Nigeria. *American Journal of Physics and Applications*. 7(5): 125-135.DOI: 10.11648/j.ajpa.20190705.15.
- Akpootu, D. O., Tijjani, B. I & Gana, U. M. (2019f). 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)*. 5(9):126 – 141.DOI: 10.31695/IJASRE.2019.33523
- Akpootu, D. O., Momoh M., Abdullahi Z & Umar, M. (2023b). Estimation of Surface Water Vapour Density and its Variation with other Meteorological Parameters over Akure, Nigeria. *Saudi Journal of Engineering and Technology*., 8(8): 189-199. DOI: 10.36348/sjet.2023.v08i08.001
- Akpootu, D. O., & Abdullahi, Z. (2022). Development of Sunshine Based Models for Estimating Global Solar Radiation over Kano and Ikeja, Nigeria. *FUDMA Journal of Sciences (FJS)*, 6(3), 290 – 300. DOI: <https://doi.org/10.33003/fjs-2022-0603-1001>
- Akpootu, D. O., Alaiyemola, S. R., Abdulsalam, M. K., Bello, G., Umar, M., Aruna, S., Isah, A. K., Aminu, Z., Abdullahi, Z., & Badmus, T. O. (2023a). Sunshine and Temperature Based Models for Estimating Global Solar Radiation in Maiduguri, Nigeria. *Saudi Journal of Engineering and Technology*, 8(5), 82-90. DOI: 10.36348/sjet.2023.v08i05.001.
- Akpootu, D. O., Iliyasu, M. I., Mustapha, W., Salifu, S. I., Sulu, H. T., Arewa, S. P., & Abubakar, M. B. (2019a). Models for Estimating Precipitable Water Vapour and Variation of Dew Point Temperature with Other Parameters. *Journal of Water Resources and Ocean Science*, 8(3), 28-36 doi: 10.11648/j.wros.20190803.11
- Akpootu, D. O., Iliyasu, M. I., Olomiyesan, B. M., Fagbemi, S. A., Sharafa, S. B.,

- Idris, M., Abdullahi, Z., & Meseke, N. O. (2022b). Multivariate Models for Estimating Global Solar Radiation in Jos, Nigeria. *Matrix Science Mathematic (MSMK)*, 6(1), 05-12. DOI: <http://doi.org/10.26480/mkmk.01.2022.05.12>
- Akpootu, D. O., Mustapha, W., Rabi, A. M., Iliyasu, M. I., Abubakar, M. B., Yusuf, S. O., and Salifu. S. I., (2019b) "Estimation of Surface Water Vapour Density and Its Variation with Other Meteorological Parameters over Owerri, South Eastern, Nigeria." *Hydrology*. Vol. 7, No. 3, 2019, pp. 46-55. doi: 10.11648/j.hyd.20190703.12
- Akpootu, D. O., Tijjani, B. I., & Gana, U. M. (2019c). Empirical models for predicting global solar radiation using meteorological parameters for Sokoto, Nigeria. *International Journal of Physical Research*, 7(2), 48–60. DOI: 10.14419/ijpr.v7i2.29160
- Akpootu, D.O., Iliyasu, M. I., Abubakar, M. B., Rabi, A. M., Mustapha, W., Okany, C. L., & Salifu, S. I. (2019d). Developing Empirical Model for Estimating Photosynthetically Active Radiation over Akure, South western, Nigeria. *International Journal of Advances in scientific Research and Engineering (IJASRE)*, 5(10), 59-73. DOI: 10.31695/AJASRE.2019.33546
- Akpootu, D.O., Iliyasu, M. I., Mustapha, W., Salifu, S.I., Sulu, H. T., Samson Philip Arewa, S. P. and Abubakar. M. B (2019e). "Models for Estimating Precipitable Water Vapour and Variation of Dew Point Temperature with Other Parameters at Owerri, South Eastern, Nigeria." *Journal of Water Resources and Ocean Science*. Vol. 8, No. 3, 2019, pp. 28-36. doi: 10.11648/j.wros.20190803.11
- Bai, Z & Feng, Y. (2003). GPS "Water Vapor Estimation using Interpolated Surface Meteorological Data from Australia Automated Weather Stations." *Journal of Global Positioning Systems*, 2(2), 83 – 89.
- Boccolari, M., Fazlagic, S., Frontero, P., Lombroso, L., Pugnaghi, S., Santangelo, R. Corradini, S., & Teggi, S. (2002). "GPS Zenith Total Delays and Precipitable Water in Comparison with Special Meteorological Observations in Verona (Italy) during MAP-SOP." *Annals of Geophy.*, 45(5), 599 – 608.
- Coster, A. J., Niel, A. E., Solheim, F. S., Mends, V.B., Toor, P. C., Buchmann, K. P., & Upham, C. A. (1996). Measurements of Precipitable Water Vapor by GPS
- England, M. N., Ferrare, R. A., Melfi, S. H., Whiteman, D. N., & Clark, T. A. (1992). "Atmospheric water vapor measurements: Comparison of microwave radiometry and lidar," *Journal of Geophysical Resources.*, 97, 899.
- Harries, J. E (1997). Atmospheric radiation and atmospheric humidity. *Quarterly Journal of Meteorol. Society*. 123: 2173-2186.
- Iliyasu, M. I., Akpootu, D. O., Momoh, M., Abdullahi, Z., Yusuf, A., Muhammad, N., Sidi, S. A., Aruna, S., Umar, M & Sani, M. Y (2023). Estimation and Correlation of Surface Water Vapour Density in Benin, Nigeria. *Asian Journal of Research and Reviews in Physics.*, 7(4), 43-56. DOI: 10.9734/AJR2P/2023/v7i4148
- IPCC, (2001). Intergovernmental Panel on Climate change. Third Assessment Report: Climate change 2001. WG1: The scientific basis, summary for policymakers, Geneva, Switzerland.
- Israel, E., Kayode, A. & Olusola, O. (2015). "Spatio-Temporal Variability of Water Vapour Density over Nigeria using CM SAF Data" *Advances in Physics Theories and Applications* vol. 45.
- Jade, S., Vijayan, M. S. M., Gaur, V. K., Prabhu, T.P., & Sahu, S. C. (2005). Estimates of precipitable water vapor from GPS data over the Indian subcontinent, *J. Atm. Solar-Terr. Phys.*, 67, 623–635.

- Kiehl, J. T & Trenberth, K. E (1997). Earth's Annual Global Mean Energy Budget. *Bull Am Meteorol Soc.* 78: 197-208.
- Lawrence, M. G (2005). The relationship between relative humidity and the dewpoint temperature in moist air: A simple conversion and applications. *Bull. Amer. Meteor. Soc.* 86:225-233. DOI: <http://dx.doi.org/10.1175/BAMS-86-2-225>.
- Leckner, B (1978). The spectral distribution of solar radiation at the earth's surface elements of a model. *Sol Energy* 20 (2),143-150.
- Lim, A., C. W. Chang, S. C. Liew, & L. K. Kwoh, (2002): Computation of atmospheric water vapour map from MODIS data for cloud-free pixels. *Proc. 23rd Asian Conf. on Remote Sensing*, Kathmandu, Nepal, Asian Assoc. Remote Sensing, 6 pp. [Available online at <http://www.gisdevelopment.net/aars/acrs/2002/had/had001pf.htm>.] Rind, D., 1998: Just add water vapor. *Science*, 281, 1152–1153.
- Linfield, R., Bar-Sever, Y., Kroger, P. & Keihm, S. (1997). Comparison of Global Positioning System and Water Vapor Radiometer Wet Tropospheric Delay Estimates, *TDA Progress Report*, 42-130.
- Maghrabi, A & Al Dajani, H. M., (2013). "Estimation of precipitable water vapour using vapour pressure and air temperature in an arid region in central Saudi Arabia" *Journal of the Association of Arab Universities for Basic and Applied Sciences* 14, 1-8.
- Park C., Roh, K., & Cho, J. (2012). "Radiosonde Sensors Bias in Precipitable Water Vapor From Comparisons with Global Positioning System Measurements," *J.Astron. Space Sci.* 29(3), pp.295-303, <http://dx.doi.org/10.5140/JASS.2012.29.3.295>.
- Randel, D. L., Vonder, T. H., Ringerud, M. A., Stephens, G. L., Greenwald, T. J. & Combs, C. L. (1996): A new global water vapor data set. *Bull. Amer. Meteor. Soc.*, 77, 1233–1246.
- Roca, R., M. Viollier, L. Picon, M & M. Desbois, (2002). A multi satellite analysis of deep convection and its moist environment over the Indian Ocean during the winter monsoon. *J. Geophysics Resources.*, 107, 8012, doi:10.1029/2000JD000040.
- Udelhofen, P. M. & Hartmann, D. L. (1995). "Influence of tropical cloud systems on the relative humidity in the upper troposphere." *Journal of Geophysics Resources.* 100: 7423 – 7440.
- Wallace, J. M & Hobbs, P. V (2006). *Atmospheric Science, An Introductory Survey*, 2nd Edition, Elsevier, pp 66-82
- Willoughby, A.A., Adimula. I. A., Aro, T. O. & Owolab, I. E. (2008). "Analysis of Radiosonde Data on Tropospheric Water Vapour in Nigeria, Nigeria." *Journal of Physics.* 20(2): 299-308
- WMO (1967). A Note on Climatological Normal. Technical Note. World Meteorological Organization, Geneva, Switzerland.