ATMOSPHERIC PRECIPITABLE WATER VAPOUR IN JOS, NIGERIA

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Abstract

Data from the Agro-meteorological station, Department of Geography and Planning, University of Jos (latitude: 09° 57′ N, longitude: 08° 53′ E and altitude: 1,159m above msl), for the periods 1992 to 2002, have been used for this investigation. The correlations between the natural logarithm of the precipitable water vapour PWV, and the dew-point temperature T_d and also relative humidity h, were investigated. Multiple regressions analysis was done on PWV and clearness index K_p sunshine index S and relative humidity h. Results show a new logarithmic relationship between PWV and h and that the maximum precipitable water vapour in the atmosphere of Jos in the month of August has a value of 4.44±0.47cm, while the minimum of 1.54±0.47cm was found in the month of February. The regression models have been presented and discussed.

Keywords: *Precipitable water vapour, dew-point temperature, relative humidity.*

Introduction

Water vapour is an important link connecting the various components of the hydrological cycle. In addition to the fact that water vapour is the source of all clouds and precipitations, it has the ability to absorb not only radiant energy emitted by the earth, but also some solar energy. Therefore, along with carbon dioxide, it has a controlling influence on energy transfer through the atmosphere as a result of the heat energy from solar radiation changing the state of water from liquid to vapour at free water surfaces and bare soils in order to satisfy atmospheric water deficit. The phenomenon is referred to as evaporation. Furthermore, growing plants take up water from the soil or water body to give up more of it at leaf surfaces to the atmosphere in a process called transpiration.

An important water vapour parameter is the precipitable water vapour (*PWV*). It is the total amount of water in the zenith direction, between the underlying surface and the top of the atmosphere. In practice, it is the thickness of the layer of liquid water that would be formed if all the vapour in the zenith direction were condensed at the surface of a unit area; $1mm$ of the layer corresponding to $1kgm^{-2}$ (Okulov et al, 2002). Precipitable water vapour plays a crucial role in atmospheric dynamics through the release of huge amounts of latent heat associated with condensation. Knowledge of the distribution of PWV is of paramount importance in weather research and forecasting (NASA, 2004). Tardy (2002), has shown that the proper way to diagnose the moisture content of the atmosphere is to use an absolute measurement of atmospheric moisture such as PWV.

Estimates of PWV in the atmosphere have been made with sun-photometer Voltz (1974). Although the technique is viable only during clear daytime condition (Sierk et al., 1997; Plana-Fatori et al., 1998). Bevis et al.(1992) have shown that the Global Positioning Satellite(*GPS*) Signal method could be adapted to estimate the *PWV* with results comparable to those obtained from Water Vapour Radiometer (*WVR*) reported by Emardson et al.(1998). Reitan (1963) and later Leckner (1978) proposed ground based meteorological data incorporating water vapour and temperature to estimate the *PWV*. Using the exponential decrease of water vapour with height in the atmosphere, Reitan (1963) proposed that

$$PWV = \frac{483e_o}{T} \quad (1)$$

and Leckner(1978)

$$PWV = \frac{493e_o}{T} \quad (2)$$

where e_0 is the vapour pressure (in milibar) and T is surface temperature (in Kelvin). The difference between (1) and (2) arise from the choice of the most representative value for the scale height. Reitan (1963) in studying monthly means of PWV and station dew point temperature, T_d, over continental United State of America, developed an excellent linear relationship between natural logarithm of the PWV(cm) and T_d(°C), viz,

$$\ln PWV(cm) = 0.1102 + 0.0613 T_d(°C) \quad (3)$$

Won in 1977 developed a similar expression for all Canadian seasons (Okulov et al., 2002). In Nigeria, Maduekwe and Ogunmola (1997) have used the Reitan type of expression to evaluate PWV in Sokoto. Although, Kondratyev and Moskalenko have developed a simple correlation between PWV and surface level temperature, its application has not received a wide level of acceptance because it underestimates the amount of precipitable water (Okulov et al., 2002).

In this paper we present the evaluation of precipitable water vapour PWV, its monthly variation and seasonal variations in Jos (latitude: 09° 57′ N, longitude: 08° 53′ E and altitude: 1,159m above msl) using meteorological data of eleven years, 1992 2002. The aim is to express precipitable water in terms of surface humidity parameters, clearness index and sunshine hours. The values obtained in this work, it is hoped, will be comparable to those generated from satellite techniques and ground-based microwave radiometry when available at the location.

Site and Database

The agro-meteorological station of the Department of Geography and Planning, University of Jos provided the data for this work. The station is on latitude 09° 57′N, longitude 08° 53′E and at an altitude of 1159m above mean sea level.

The station uses Sixe thermometer placed in a Stevenson screen to measure the ambient temperature, maximum and minimum temperature (°C). The Gun-Bellani radiation integrator measures the solar radiation in millimeter (mm) while the sunshine duration is measured with Campbell-Stokes sunshine recorder. The dew point temperature, vapour pressure and relative humidity are all estimated from standard hygrometric tables following the readings of wet and dry thermometers (psychrometer) kept in the Stevenson screen.

Data Analysis

The mean monthly values of the data collected, ambient temperature $T(K)$, vapour pressure $e_o(mbar)$, dew-point temperature T_d(°C), relative humidity $h(\%)$, clearness index K_t, Sunshine index S, and precipitable water vapour $PWV(cm)$ were obtained for each month of the years (1992 2002). The monthly mean of the PWV was calculated using the exponential decay model of Leckner (1978) given in equation (2). To obtain the constants of the Reitan type of equation (3) suitable for Jos the logarithm of PWV values thus obtained were plotted against the dew-point temperature T_d. Also the PWV values were plotted against relative humidity values, clearness index and sunshine index. The Microsoft Excel® spreadsheet computer package was used for the data analysis in fixing the line of best fit, calculating the intercepts and the standard error of estimation (SEE). Then the root-mean-square error (RMSE) and the mean bias error were estimated manually using the following expressions:

$$\text{RMSE} = \left[\frac{1}{n} \sum_{i=1}^{n} d_i^{\,2} \right]^{\frac{1}{2}} \quad (4)$$

and

$$\text{MBE} = \frac{1}{n}\sum_{i=1}^{n} d_i \qquad (5)$$

where $d_i = H_e - H_m$ (the difference between the i[th] estimated and the i[th] measured values) and n is the number of data points (in this investigation n = 129).

Results

PWV and dew-point temperature

The scattergram of ln(*PWV*) against the dew-point temperature T_d, Fig. 1, shows a clear linear relationship with a very good linear correlation of 0.96 and standard error of estimation (SEE) of 0.14. The root-mean-square error (RMSE) gave a value of 0.02. The line of best fit drawn through the scattergram has the expression

$$\ln(PWV) = 0.2979 + 0.0638 T_d \qquad (6)$$

The slope value of 0.0638 $°C^{-1}$ compares well with other published values for other locations around the world as shown in Table 1.

The intercept for each location varies considerably as can be seen from the table. A closer look at Fig. 1 seems to suggest two linear distributions lying side by side. An attempt was made to separate these linear distributioins, which are shown in Figures 2 and 3. The linear fit of Figure 2 is the upper portion of the distribution in Fig. 1 while Fig. 3 is the lower portion. For Fig. 2, the slope = 0.0608 $°C^{-1}$, intercept = 0.4233, correlation coefficient r = 0.995, SEE = 0.0415 while for Fig. 3,slope = 0.0641 $°C^{-1}$, intercept = 0.0867, r = 0.995 and SEE = 0.0463.

PWV and relative humidity, h

The correlation between *PWV* and relative humidity *h*, is given as follows:

$$PWV = 0.41525 + 0.05399h$$

In equation (7), r = 0.92, SEE = 0.52 and RMSE = 0.52. Figure 4 is a graph of equation 7. Another expression, which describes the correlation of *PWV* and humidity, is logarithmic in *h* and is given as

$$PWV = 2.4631 \ln(h) + 6.2374$$

Table 1: Slope and intercept values for different locations

Author(s)	Year	Location	Value of slope (/°C)	Intercept(cm)
Reitan	1963	U.S.A	0.06138	0.1102
Won	1977	Canada	0.05454	-0.4539
Maduekwe & Ogunmola	1997	Sokoto, Nigeria	0.06480	0.0546
This work	2004	Jos, Nigeria	0.06381	0.2979

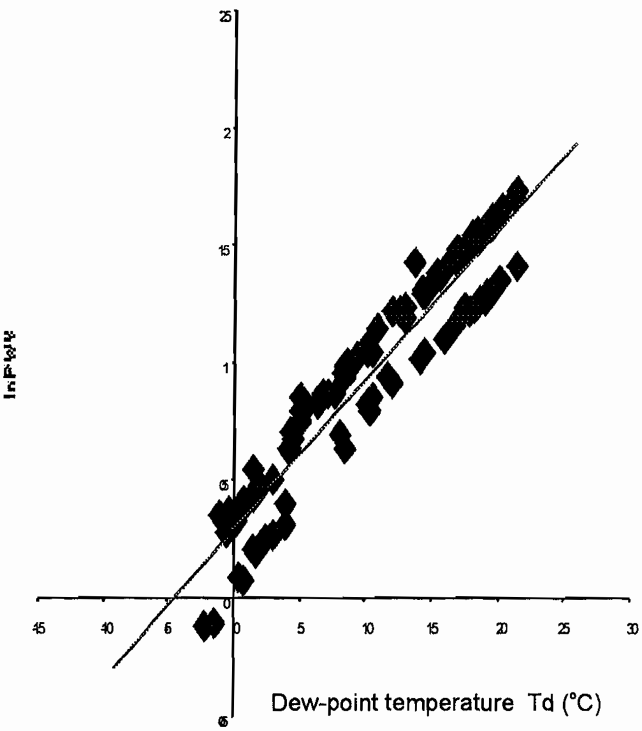


Fig. 1. Scattergram of *ln(PWV)* against dew-point temperature $T_d(^{\circ}C)$.

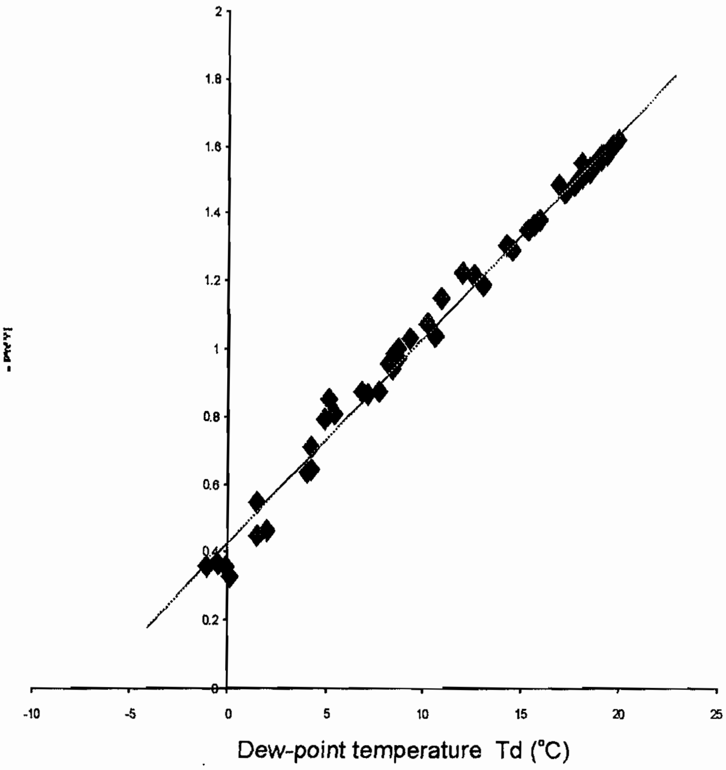


Fig. 2. Upper portion of the distribution in Fig. 1

with the following statistical behavior: r = 0.92, SEE = 0.23 and RMSE = 0.50. Fig 5 is a graphical representation of equation (8).

PWV, Clearness index K_t and sunshine index S

The relationship between *PWV* and clearness index K_t is given as

$$PWV = 5.694 + 4.521K_t$$

having a correlation coefficient r = -0.48.

\The scatter diagram of equation (9) is shown in Fig. 6. An expression for the relationship of *PWV* with sunshine index *S* is

$$PWV = 6.253 + 5.925S$$

with a correlation coefficient r = -0.64. The plot of *PWV* against *S* is given in Fig. (7). It is evident that there is little linear correlation between PWV and K_t or S indicated in the diagrams of Figs. 6 and 7, but on performing a simple multiple linear regression between *PWV*, clearness index, sunshine index and relative humidity, the multiple correlation coefficient was found to be 0.81, the standard error of estimation 0.54 and the root-mean-square error 0.63.

The multiple regression equation is

$$PWV = 0.508436K_t + 0.114106S + 0.0544071h + 0.01704$$

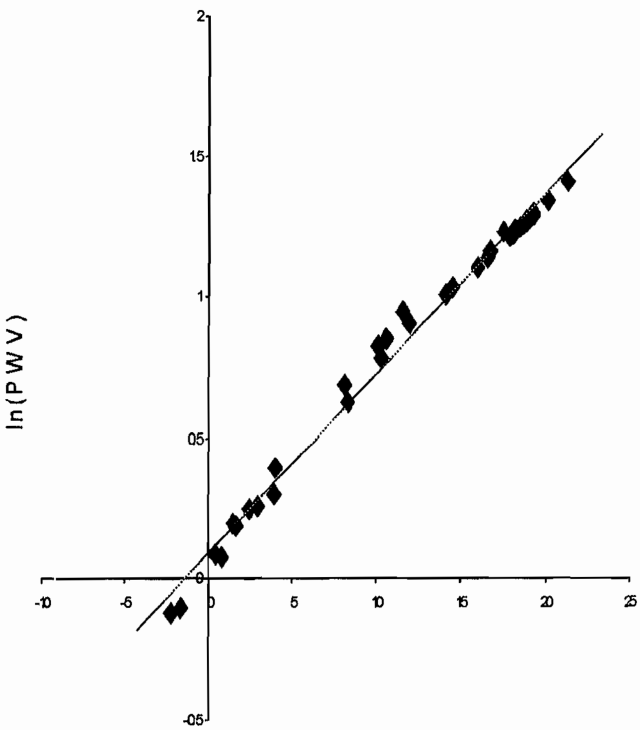


Fig. 3: Lower portion of the distribution in Fig. 1.

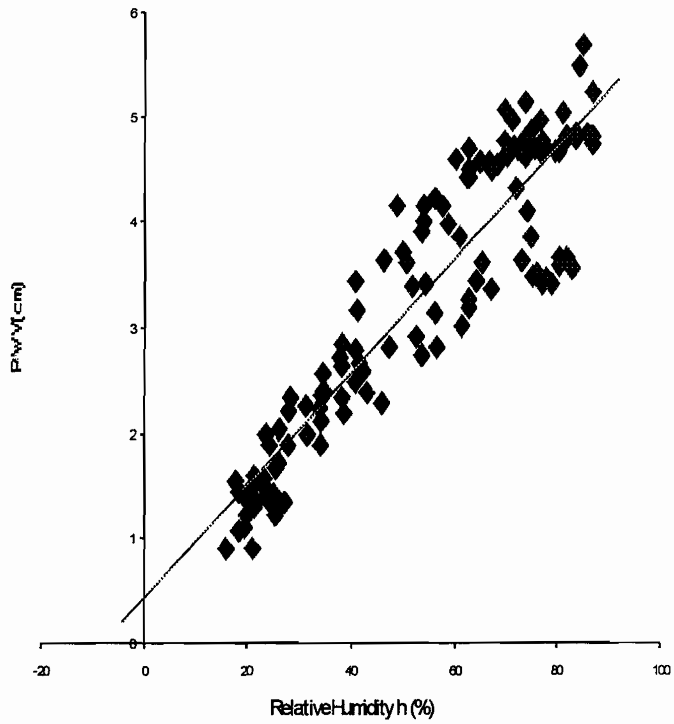


Fig. 4: Scattergram of Precipitable Water Vapour (*PWV*) against Relative Humidity *h(%)*.

Seasonal Correlations

The two seasons experienced in Nigeria have durations in Jos as follows: rainy season, from May to October and dry/harmattan season lasting from November of one year to April of the following year. The variations of *PWV* described by equations (6) and (7) now have the expressions:

Rainy season:

$$\ln(PWV) = 0.278716 + 0.06397T_d \quad (12)$$

$$r(\ln PWV, T_d) = 0.62$$

$$PWV = 1.9974 + 0.03219h \quad (13)$$

$$r(PWV, h) = 0.46$$

Dry /Harmattan season

$$\ln(PWV) = 0.2699 + 0.07052T_d \quad (14)$$

$$r(\ln PWV, T_d) = 0.94 PWV = 0.003588 + 0.06586h \quad (15)$$

$$r(PWV, h) = 0.92$$

It can be seen from equations (12) through (15) that a better correlation of *PWV* with T_d, and *h* is obtained for the dry/harmattan season values than the rainy season.

Decade monthly average of PWV

Figure 8 shows the decade monthly average of *PWV* in Jos. The month of August records the lowest value of 4.4±0.5*cm* while February records the lowest value of 1.5±0.5*cm*. In Fig. (9) is displayed the time series of monthly-mean variation of *PWV* for Jos (1992 2002). The minima are observed to occur during the months of January and February while the maxima corresponds to the peak of the rainy season in July, August and September. The eleven-year period average of *PWV* in Jos is 39.6±5.8*cm*.

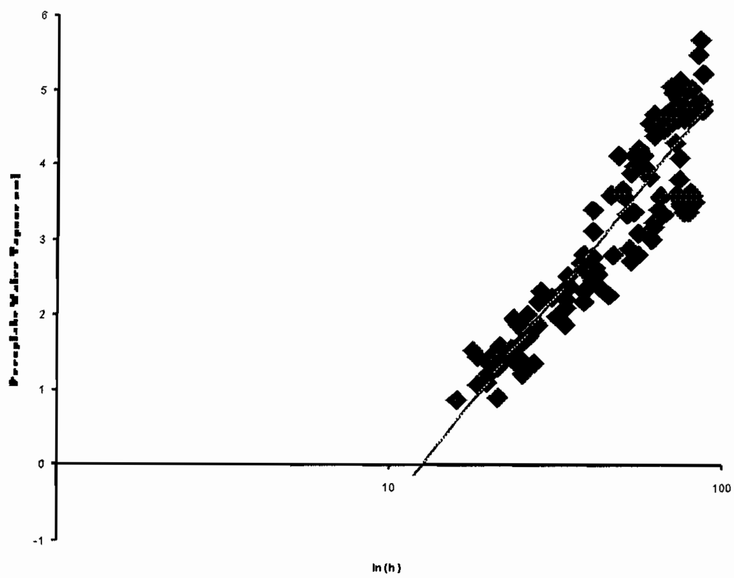


Fig. 5: Plot of Precipitable Water Vapour against ln(h) on a linear-log scale.

Discussion

Variation of *PWV* with T_d

Various correlations, equations (6) to (11), of precipitable water with easy-to-measure ground-based meteorological parameters have been provided in this work for Jos. Equation (6) which is the Reitan (1963) equation applied to Jos is found to be in good agreement with the results of other investigators elsewhere. Fig. 2, being the lower distribution shown on Fig. 1, was found to represent the *PWV* for the years 1996 1998 and 1999. Referring to fig. 9, it will be observed that the three years in question have values of lower *PWV* (or drier atmosphere) and a corresponding lower intercept of 0.1 than all the years under study. Hence it may be inferred that the intercept of equation (6) can be used to categorize the relative climatic atmospheric water burden of a place. Thus in Table 1, the intercept for Jos (0.2979*cm*) is seen to be higher than that of Sokoto (0.0546*cm*); the atmosphere of Sokoto being generally drier than that of Jos. In the same vein, Canada has the driest atmosphere of the cities listed in the table.

Variation of *PWV* with h, K_t and S

Equations (7) and (8) giving linear relations of *PWV* with h and ln$h$ respectively should be expected because the relative humidity h is also a measure of the atmospheric moisture content. Equation (8) having a lower standard error of estimates (SEE = 0.23) gives a better fit than equation (7) with SEE of 0.52. However, from the statistical analysis carried out, their performance (both having r = 0.92) is not as good as that of equation (6) (r = 0.995) in estimating the *PWV*. Nevertheless the equations are recommended to be verified for other regions to assess their applicability.

Neither the variation of *PWV* with K_t nor with S gives a good fit as can be seen on figures 6 and 7 and the correlation equations (9) and (10). In spite of these, a multiple regression of *PWV* with K_t, S and h gives 0.81 as the correlation of multiple regression. The good regression coefficient not withstanding, this technique is not as simple and convenient as the others.

Seasonal And Decade Variations of PWV

Using equations (12) and (14), their intercepts are of the same magnitude; hence this parameter cannot be used to describe seasonal variations at a location. In terms of correlation coefficients, a higher value of r is obtained for the dry season data. The maximum *PWV* value of 4.4±0.5*cm* in the month of August and minimum of 1.5±0.5*cm* in February are comparable to 3.8*cm* maximum and 1.0*cm* minimum obtained by

Utah (1993) at the same site using the Voltz (1974) multispectral sun-photometer measurements. Also the Jos maximum value of *PWV* is similar to the value of $4.43\pm0.05cm$ in the month of August obtained by Maduekwe and Ogunmola (1997) for Sokoto. In Jos, the wettest month of the year is August while the driest is February at the same location.

The eleven-year (1992 2002) monthly mean variation of the *PWV* in Jos given in Fig. 9 shows a pattern similar to that obtained in Estonia from radiosonde data (1990 2001) by Okulov et al (2002). Except for the three years 1996, 1998 and 1999, with lower *PWV* values, the yearly totals of *PWV* in Jos are within a close range of 39 47*cm*.

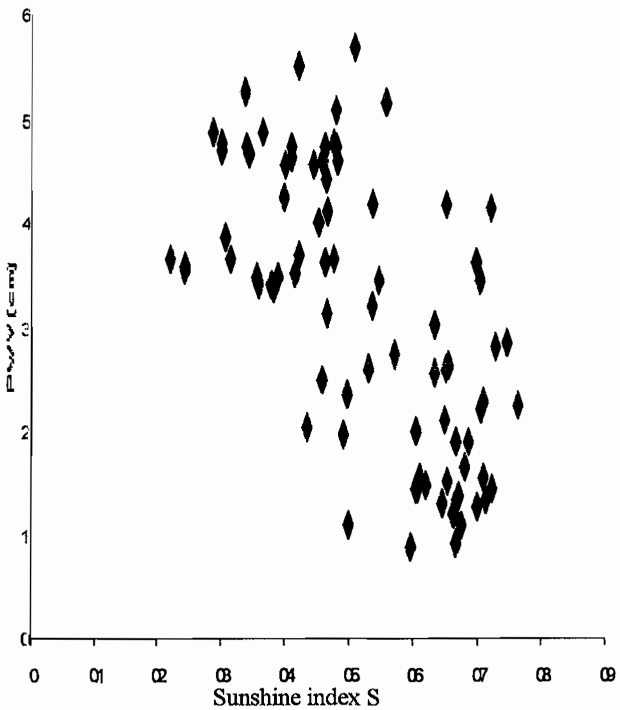
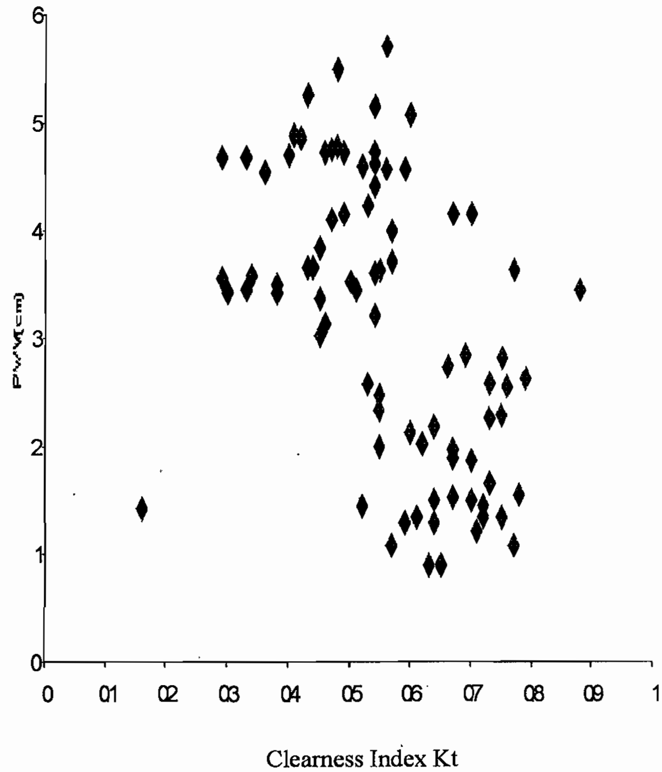


Fig. 6. Scattergram of precipitable water vapour against sunshine index.



vapour against clearness index.

Conclusion

The correlation of precipitable water vapour (*PWV*) with dew-point temperature T_d gives the best estimate of *PWV* in Jos. The correlation of *PWV* with meteorological parameter of relative humidity h is ranked second to the dew-point temperature correlation. The introduction of sunshine index, clearness index, along with relative humidity into a multiple regression analysis of *PWV* gives an acceptable coefficient of determination. The maximum precipitable water vapour in the atmosphere of Jos is found in the month of August while the minimum value occurs in February.

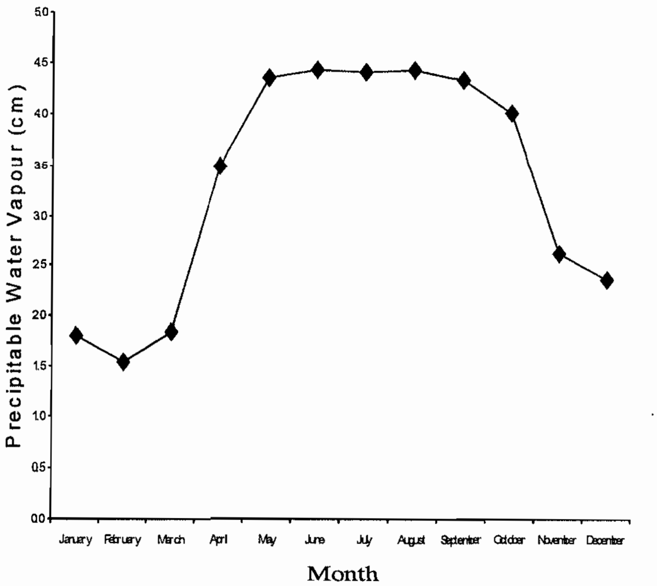


Fig. 8: Line graph of decade monthly average precipitable water vapour in Jos, Plateau State, Nigeria.

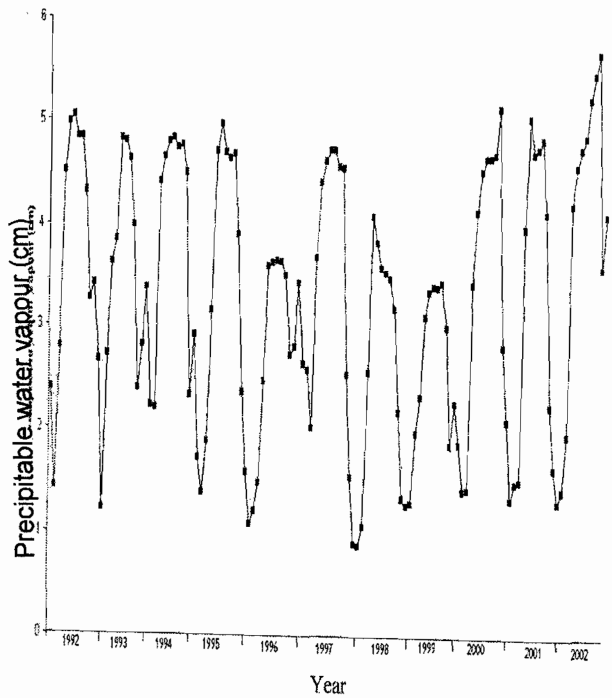


Fig.9: Time series of monthly-mean variation of PWV(cm) for Jos, Nigeria(1992-2002).

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