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Full Length Research Article

Estimation and Variation of Saturation Mixing Ratio and Mixing Ratio over Potiskum, Nigeria

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ABSTRACT
In this study, the monthly average mean temperature, relative humidity and surface pressure data obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) for a period of thirty-eight (1979 – 2016) years was employed to estimate the saturation mixing ratio and mixing ratio for Potiskum located in the Sahelian climatic zone of Nigeria. The monthly variation of saturation mixing ratio and mixing ratio with the meteorological parameters during the period under focused was investigated. The results revealed that the maximum and minimum values of saturation mixing ratio were found in the months of May and December with 31.7067 g kg^{-1} and 17.5980 g kg^{-1}, respectively. The maximum and minimum values of saturation mixing ratio were found in the months of September and February with 20.6797 g kg^{-1} and 4.1153 g kg^{-1}, respectively. The results showed that high values of mixing ratio were observed during the rainy season and low values during the dry season. The monthly variation of saturation mixing ratio with mean temperature and the monthly variation of mixing ratio with relative humidity depicts direct relationship. The monthly variation of saturation mixing ratio with atmospheric pressure and relative humidity and the monthly variation of mixing ratio with mean temperature and atmospheric pressure varies differently.
Keywords: Saturation Mixing Ratio, Mixing Ratio, Meteorological Parameters, Potiskum, ECMWF.

INTRODUCTION
Water can exist as a solid, liquid, or gas at typical conditions found on Earth. The process of liquid water becoming water vapour is called evaporation and this process requires energy. The opposite process is called condensation, where water vapour becomes liquid water, releasing energy. Condensation is especially important in atmospheric science because this is the process that allows clouds to form. Predicting the rate of condensation (evaporation) of water vapour onto (from) cloud droplets under a given value of saturation ratio (S) is an important subject in the physics and chemistry of aerosols and clouds, but the quantitative aspect remains controversial (Mozurkewich, 1986; Kolb *et al*., 2010). The expansion chamber is one of the experimental techniques for measuring the rate of droplet growth under a given saturation ratio (Wagner, 1975; Winkler *et al*., 2006). It is believed that the temperature after expansion can be predicted by the Poisson equation without consideration of any latent heat released by expansion that occurs so quickly (Moteki and Kondo, 2013).

The saturation mixing ratio (w_s) with respect to water is defined as the ratio of the mass (m_{vs}) of water vapour in a given volume of air that is saturated with respect to a plane surface of pure water to the mass (m_d) of the dry air (Wallace and Hobbs, 2006). The amount of water vapour in a certain volume of air may be defined as the ratio of the mass (m_v) of water vapour to the mass of dry air; this is called the mixing ratio, w. It is typically expressed as grams of water vapour per kilogram of air (g kg^{-1}) (Wallace and Hobbs, 2006). The main factors to control the quantity of moist air are the temperature and pressure. As the air temperature increases, the amount of water vapour is also increasing (Przybylak, 2016; Vicente-Serrano *et al*., 2016).

The amount of moisture air can hold depends on its temperature and pressure (Bahadori *et al*., 2013). Although water vapour constitutes only a small proportion of the atmosphere, the role it plays in atmospheric phenomena is extremely important. Water vapour is a significant absorber and emitter of radiation. Since the processes of evaporation and condensation are accompanied by the absorption and release of heat, changes in the amount and distribution of atmospheric water vapour are of fundamental importance in thermal processes of the atmosphere (Singh *et al*., 2002; Shallcross, 2005; Hasan, 2012). The role water vapour plays in atmospheric phenomena is extremely important. Saturation of moist air at a given temperature and pressure occurs if its mixing ratio is such that the moist air can coexist in a stable condition with an associated condensed phase at the same temperature and pressure (Bahadori *et al*., 2012).

The saturation mixing ratio is useful to calculate the relative humidity which is a ratio, expressed in percent, of the amount of water vapour in the air (actual mixing ratio) compared to the amount of water vapour the air can hold (saturation mixing ratio) (Bahadori *et al*., 2012). The vapour pressure (*e*) of water in the atmosphere is independent of the presence of other gases, i.e., it is the partial pressure due to water vapour. If an enclosure is maintained at a given temperature so as to confine a fixed volume over a water surface, the vapour pressure within the enclosure will come to a value that depends only on temperature and is known as the saturation vapour pressure. Below 0 °C, the saturation vapour pressure over supercooled water (e_w) is different from that over ice (e_i) (Burger, 1975; Singh *et al*., 2002; Hasan, 2010; Bahadori, 2011 and Hasan, 2012).

Bahadori *et al*. (2012) attempted to develop a simple-to-use Arrhenius-type function to estimate the mixing ratio for saturated air over water as a function of pressure and temperature. They reported that the estimations were found to be in excellent agreement with the data reported in the literature, with the average absolute deviation being around 0.4 %. There is no meteorological station in Nigeria that measures saturation mixing ratio and mixing ratio. Generally, there are scanty studies on estimation of saturation mixing ratio and mixing ratio in the literature. This study also investigates how these important parameters vary with other atmospheric meteorological parameters as there is no account of such study in Potiskum which is the location under investigation.

The purpose of this study was to estimate the saturation mixing ratio and mixing ratio over Potiskum, Nigeria and to investigate their variation with meteorological parameters for the period under investigation.

MATERIALS AND METHODS

Study Area

Nigeria being a tropical region has two seasons, the wet and the dry. The wet season is characterized by heavy rainfall. The season falls between the months of April and October. The dry season, on the other hand, is characterized by scanty or no rainfall and dry dust laden atmosphere. The season falls between the months of November and March (Agunlejika and Raji 2010).

In Potiskum, the wet season is hot and mostly cloudy while the dry season is sweltering and partly cloudy. Over the course of the year, the temperature typically varies from 57 °F to 104 °F and is rarely below 51 °F or above 108 °F. The study area under investigation is Potiskum (Latitude 11.70 °N, Longitude 11.03 °E and altitude 414.8 m above sea level) Yobe State, Nigeria as shown in Figure 1.

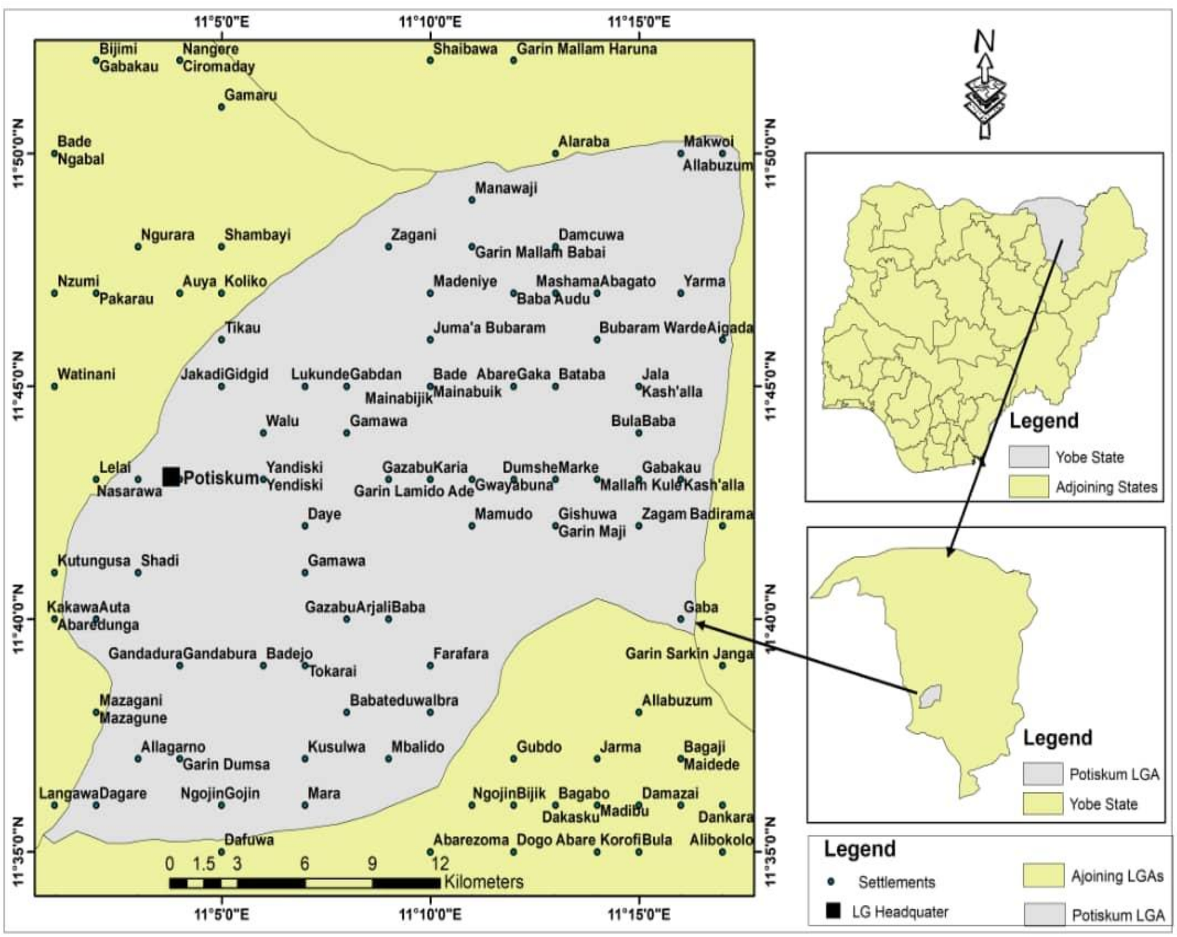

Figure 1: Map of Nigeria showing the study area

Data Collection

The monthly average minimum temperature, maximum temperature, relative humidity and atmospheric pressure meteorological data used in this study were obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) (https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5) at 2 m height for Potiskum, Yobe State, Nigeria during the period of thirty eight years (1979 – 2016).

METHODS

The thirty- eight years meteorological parameters obtained from the archive of ECMWF were averaged into monthly data. The mean temperature was obtained by taken the average of minimum and maximum temperatures.

The mean temperature T was obtained using equation (1) (Akpootu *et al*., 2019)

$$T = \frac{T_{max} + T_{min}}{2} \quad (1)$$

where T_{max} and T_{min} are the maximum and minimum temperatures respectively. The temperature, T is in Kelvin (K).

The saturation mixing ratio, w_s is given as (Wallace and Hobbs, 2006)

$$w_s = \frac{m_{vs}}{m_d} \quad (2)$$

m_{vs} is the mass of saturation vapour in g, m_d is the mass of dry air in kg and the saturation mixing ration, w_s is in g kg^{-1}

The saturation vapour pressure, e_s is expressed as (Wallace and Hobbs, 2006)

$$e_s = \rho_{vs} R_v T \quad (3)$$

ρ_{vs} is the saturation vapour density, R_v is the gas constant for 1 kg of vapour and T is the temperature.

The dry air pressure based on Dalton's law of partial pressure is expressed as (Wallace and Hobbs, 2006)

$$(p - e_s) = \rho_d R_d T \quad (4)$$

p is the total pressure, ρ_d is the dry air density and R_d is the gas constant for 1 kg of dry air.

In terms of densities and ideal gas equation, the w_s is expressed as (Wallace and Hobbs, 2006)

$$w_s = \frac{\rho_{vs}}{\rho_d} = \frac{e_s / R_v T}{(p - e_s) / R_d T} \quad (5)$$

$$w_s = \frac{0.622 e_s}{(p - e_s)} \quad (6)$$

With $\frac{R_d}{R_v} = 0.622$

For the range of temperatures observed in the atmosphere $p \gg e_s$ therefore

$$w_s \approx 0.622 \frac{e_s}{p} \quad (7)$$

The saturated vapour pressure was evaluated using the Claussius Clapeyron equation (Akpootu *et al*., 2019) defined as:

$$Log_{10}\, e_s = 9.4051 - \left(\frac{2353}{T}\right) \quad (8)$$

e_s from equation (8) becomes

$$e_s = 10^{\left[9.4051 - \left(\frac{2353}{T}\right)\right]} \quad (9)$$

The mixing ratio, w was obtained using (David *et al*., 2016; Wallace and Hobbs, 2006)

$$w = RH \left(\frac{w_s}{100}\right) \quad (10)$$

where RH is the relative humidity in percentage (%).

Equations (1) to (10) was used in the computations using Microsoft office Excel. The saturation mixing ratio and mixing ratio were estimated using equations (7) and (10), respectively. Origin 60 software was used to plot the graphs showing the monthly variation of saturation mixing ratio and mixing ratio with meteorological parameters of mean temperature, relative humidity and atmospheric pressure. The mapping showing the location was done using ArcGIS software.

RESULTS AND DISCUSSION

Figure 2 shows the monthly variation of saturation mixing ratio for Potiskum during the study period. The variation for the various months was obtained using equation (7). The Figure revealed that the saturation mixing ratio increases from the month of January until it reaches its peak value of 31.7067 g kg^{-1} in the month of May and then decreases to August; the saturation mixing ratio suddenly increases from August to October and then fall sharply to its minimum value of 17.5980 g kg^{-1} in December. The average value of saturation mixing ratio during the rainy season is 26.6357 g kg^{-1} and in the dry season is 22.8614 g kg^{-1}. This indicates that the saturation mixing ratio is higher during the rainy season than in the dry season for this location, as a result of the harmattan wind blowing Sahara dust over the region making the dust in the atmosphere to dim the sunlight thereby reducing the temperature during the dry season.

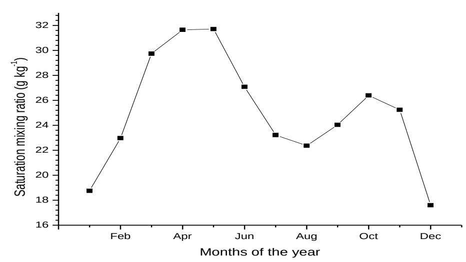

Figure 2: Monthly variation of saturation mixing ratio during the period of thirty-eight years (1979 -2016) for Potiskum.

Figure 3 shows the monthly variation of mixing ratio for Potiskum during the study period. The variation for the various months was obtained using equation (10). It was observed that the mixing ratio decreases slightly in its value from January to its minimum value of 4.1153 g kg^{-1} in February and then increases to the month of May which then decreases slightly to August and increases to its maximum value of 20.6797 g kg^{-1} in the month of September which then falls sharply to December. The Figure further revealed that high values of mixing ratio were observed during the rainy season and low values during the dry season as a result of the suspended dust particles in the atmosphere which tend to lower the temperature during the dry season for the location under investigation.

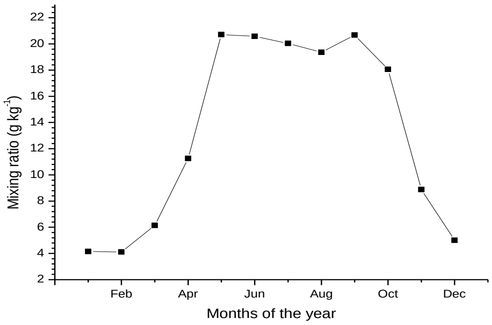

Figure 3: Monthly variation of mixing ratio during the period of thirty-eight years (1979 – 2016) for Potiskum.

Figure 4 shows the monthly variation of saturation mixing ratio with mean temperature for Potiskum during the investigation period. The saturation mixing ratio varies similarly with the mean temperature; that is, they are in tandem with each other indicating that the saturation mixing ratio has a direct relationship with the mean temperature. The result in this study is in agreement with that reported by Bahadori *et al*. (2012) as depicted in Fgure 1 and 2 of their study where it was also shown that as the saturation mixing ratio increases the temperature increases as well and vice versa. Also, as reported by Przybylak, (2016) and Vicente-Serrano *et al*. (2016) where similar observation was testified.

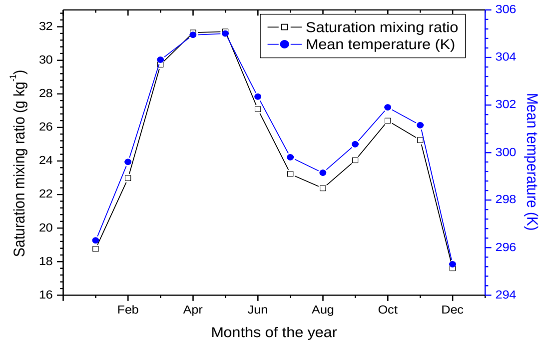

Figure 4: Monthly variation of saturation mixing ratio with mean temperature during the period of thirty-eight years (1979-2016) for Potiskum.

Figure 5 shows that as the saturation mixing ratio increases from January to its maximum value in May. The atmospheric pressure decreases from January to its minimum value of 960.4400 hPa in April, the atmospheric pressure further increases from April to July and decreases to August; the saturation mixing ratio decreases from its maximum value to August.

The atmospheric pressure increases from August to September and decreases to October maintaining almost similar value in November and rises sharply to December; the saturation mixing ratio increases from August to October and decreases slightly to November and fall sharply to December. The result in this study revealed that as the saturation mixing ratio increases from January to April, the atmospheric pressure decreases in the same months. Also, as the saturation mixing ratio decreases from May to July the atmospheric pressure increases in the same month suggesting an inverse relationship between the saturation mixing ratio and the atmospheric pressure.

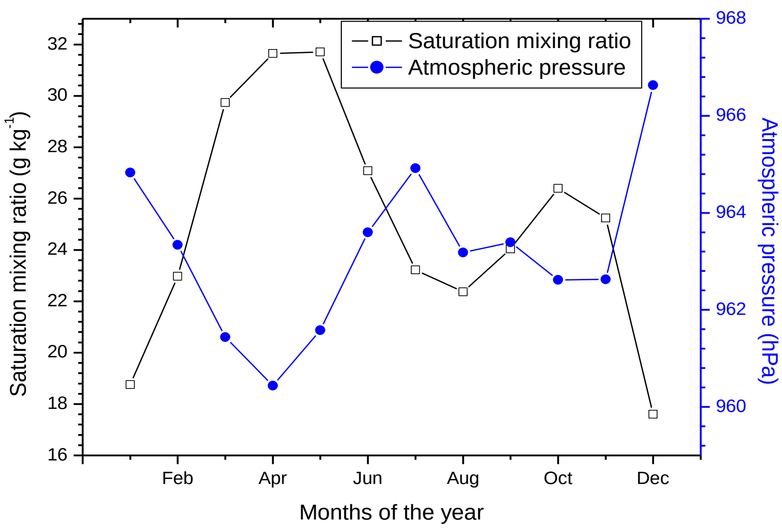

Figure 5: Monthly variation of saturation mixing ratio with atmospheric pressure during the period of thirty-eight years (1979 – 2016) for Potiskum

Figure 6 shows that as the saturation mixing ratio increases from January to its maximum value in May; the relative humidity decreases slightly from January to its minimum value in February and then increases to July which maintains almost similar values between the months from July to September and then decreases to December. Similarly, the saturation mixing ratio decreases from October to December. The result indicated that the monthly variation of saturation mixing ratio varies significantly with the relative humidity

Figure 7 shows that as the mixing ratio slightly decrease from January to its minimum value in February and then increases to May, the mean temperature increases from January to its maximum value of 303.9000 K in May; the mixing ratio and the mean temperature decreases from May to August; as the mixing ratio increases from August to its maximum value in September and then decreases to December.

The mean temperature increases from August to October and then decreases to December. This shows that the monthly variation of mixing ratio varies significantly with temperature.

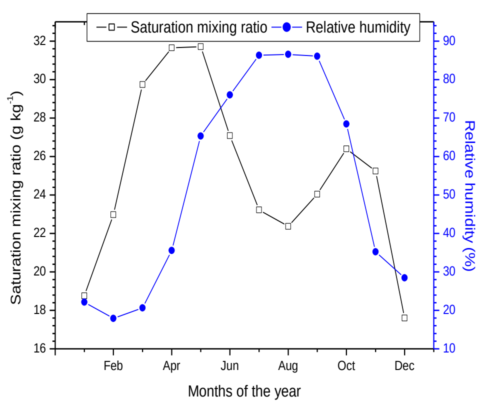

Figure 6: Monthly variation of saturation mixing ratio with relative humidity during the period of thirty-eight years (1979 – 2016) for Potiskum

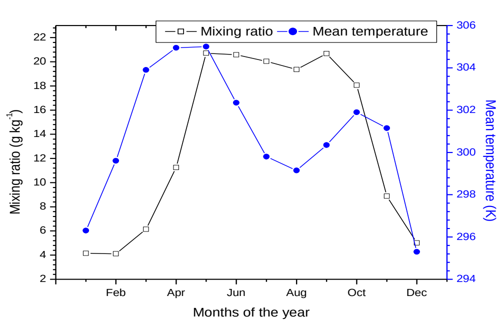

Figure 7: Monthly variation of mixing ratio with mean temperature during the period of thirty eight years (1979 – 2016) for Potiskum

Figure 8 shows that as the mixing ratio decreases to February and increases subsequently to May, the atmospheric pressure decreases from January to its minimum value of 960.4400 hPa in April and then increases to July and decreases to August while the mixing ratio decreases from May to August. The mixing ratio further increases to September and then dropped to December; the atmospheric pressure slightly increases from August to September; decreases to October with almost constant value in November and then rises sharply to December. The result indicated that the monthly variation of mixing ratio varies significantly with the atmospheric pressure.

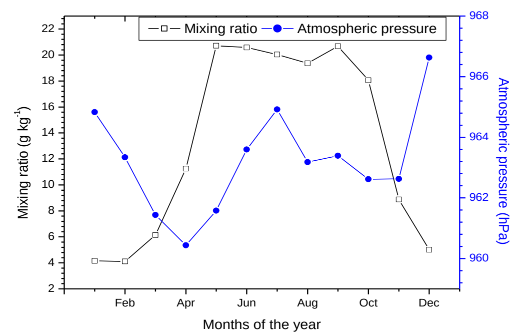

Figure 8: Monthly variation of mixing ratio with atmospheric pressure during the period of thirty- eight years (1979 – 2016) for Potiskum

Figure 9 shows that as the mixing ratio decreases slightly from January to its minimum value in February and increases to May the relative humidity decreases from January to its minimum value of 17.9100 % in February and then increases to July and maintain almost similar value to September; the mixing ratio decreases from May to August and increases to September. The mixing ration and relative humidity decreases from September to December. The result further revealed that the mixing ratio depicts direct relationship with the relative humidity.

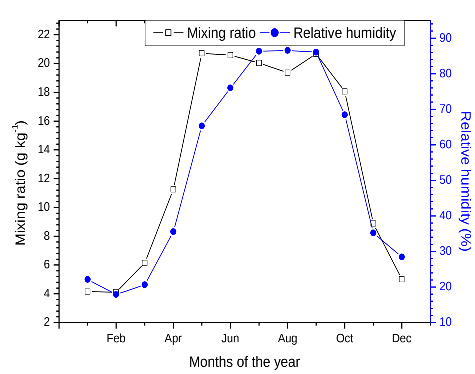

Figure 9: Monthly variation of mixing ratio with relative humidity during the period of thirty-eight years (1979 – 2016) for Potiskum

CONCLUSION

The saturation mixing ratio and mixing ratio are important atmospheric variables that are not measured in any of the meteorological stations in Nigeria including Potiskum. The saturation mixing ratio can be predicted from meteorological parameter such as temperature as there is a direct relationship as revealed in this study. Similarly, the mixing ratio depicts a direct relationship with relative humidity.

The saturation mixing ratio and mixing ratio decreases sharply from October to December, which coincides with the period when the climate of the study area is dominated by harmattan wind blowing dust from the Sahara which cause a fall in temperature and as a result, decrease the saturation mixing ratio and mixing ratio. The mathematical methods used in this study for saturation mixing ratio and mixing ratio estimations can be further explored for applications in the study of thermal processes of the atmosphere.

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