*FUDMA Journal of Sciences (FJS)*
*ISSN online: 2616-1370*
*ISSN print: 2645 - 2944*
*Vol. 4 No. 1, March, 2020, pp 235 – 245*

# INVESTIGATING THE EFFECT OF HIGH AND LOW WIND SPEED ON SURPLUS NET RADIATION IN MAKURDI, NIGERIA: AN IMPLICATION TO ENERGY IMBALANCE

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## ABSTRACT

This study aims at investigating the effect of wind speed on net radiation by conditioning the chance occurrence of surplus net radiation on high and low wind speed in Makurdi, Nigeria. A two – state (surplus net radiation conditioned on high wind speed and surplus net radiation conditioned on low wind speed) Markov Chain model was developed and used in the course of this work. The result revealed; net radiation is surplus all through the year, no definite linear trend between net radiation and wind speed and two extreme results of the Markov Chain model. This include; a steady state or long run chance of 62% surplus net radiation conditioned on low wind speed and 38% surplus net radiation conditioned on high wind speed occurring in the month of January and April. Further analysis with the model showed that it takes 2.44 days for surplus net radiation conditioned on high wind speed and 1.69 days for surplus net radiation conditioned on low wind speed on the average to reoccur from January – December. Thus, resulting to increase in air temperature in Makurdi all through the year.

**Keywords:** Surplus net radiation, steady state, Markov Chain, wind speed, Penman-Monteith.

## INTRODUCTION

The imbalances between the shortwave radiation, longwave radiation and the rotation of the earth, results to complex but organized patterns of energy and water transfer in the atmosphere. These imbalances drive the global circulation of winds (general circulation) and determine the climates in different parts of the earth. As a result of the rotation of the earth, winds do not move directly to the north or south but are deflected towards the left in the Southern Hemisphere to become the southeast trade winds, and towards the Northern Hemisphere known as the northeast trade winds. Where the southeast trade and northeast trade wind meet is called the Intertropical Convergence Zone (ITCZ) (Sturman and Spronken-Smith, 2001).

The imbalance between shortwave and longwave radiation on a particular day (day and night) results to diurnal changes in energy balance between the surface and atmosphere. When the values (radiation) of the atmosphere and earth surface are summed up, it clearly defined areas where the net radiation is positive (surplus) or negative (deficit). Net radiation is the difference between the incoming solar (shortwave) radiation that reaches the earth's surface and the total terrestrial (longwave) radiation that is been emitted from the earth's surface. According to Allen et al. (2007), net radiation is one of the input parameter used in computing leaf wetness period and reference evapotranspiration in physical models.

Net radiation is a vital parameter in the energy budget and it's essential for the study of climate change, agricultural meteorology, estimation of evapotranspiration and monitoring weather. The rate at which incoming solar energy is received from the sun by the earth's surface and the rate at which terrestrial radiation is emitted back to space, determines the air temperature of a place. Normal air temperature equals zero net radiation. A shift in net radiation (either surplus or deficit) can result to an increase or decrease in air temperature. According O'Hare (2002), increase in air temperature can result to extreme weather events such as drought, severe heat, intense rainfall, serious flooding, and violent storm, to mention few. Surplus net radiation must be transferred to deficit net radiation region by evaporation, condensation of water and atmospheric circulation, thus moderating the climate (air temperature) on earth.

The heat transfer necessary for transferring surplus net radiation to areas experiencing deficit net radiation is accomplished by global winds organized into what is known as the general circulation of the atmosphere. These processes of heat transfer maintain steady-state equilibrium within the climate system of the earth. Wind carries warm air and water vapour away from energy-surplus region to energy-deficit region around the globe. Latent heat energy (energy in water vapour) is transferred from regions of the world where there is much evaporation (such as the warm tropical oceans) to regions where there is much condensation (such as in mid latitudes during storms), in order to warm the air (Sturman and Spronken-Smith, 2001).

According to D'Amico et al. (2012), Wind speed is stochastic in nature for which a satisfactory model is still lacking. It is difficult to model environmental (climatic) variables deterministically due to their random (stochastic) behavior (Nortazi, 2013). So many authors have worked on either wind speed or net radiation separately or wind speed and solar irradiance combined using the deterministic approach. Mehrens and Bremen (2016) investigated the correlation of spatial wind speed and solar irradiance variability above the North Sea; Kassem et al. (2018) studied the economic assessment of renewable power generation based on wind speed and solar radiation in urban regions (Northern Cyprus); Sahin and Sen (2001) proposed the First Order Markov Chain model in their study for the synthetic wind speed generation; Hocaoglu et al. (2008) studied the effect of Markov Chain state size for synthetic wind speed generation. However, only few have applied the stochastic approach. According to Crommelin and Khouider (2015), climate predictions and weather forecasts should be expressed in terms of probabilities due to their random (stochastic) behavior. This study seeks to apply the Markov Chain model (stochastic process) in investigating the effect of high and low wind speed on surplus net radiation which differ from previous works, as they rarely modeled the chance of occurrence of surplus net radiation conditioned on high and low wind speed in Makurdi, Nigeria.

Makurdi is the capital of Benue State situated in the north-central region of Nigeria. It's located at latitude 7.74°N and longitude 8.51°E. Makurdi is known for its harsh weather / climate, with an average air temperature of about 33°C (Audu et al., 2014). This high air temperature is ascribed to the existence of the second largest river (River Benue) in Makurdi. This is because the river has a tremendous capacity of storing heat for a long time of the day before emitting the heat back into space.

## Theoretical Framework

### Penman-Monteith (FAO-56) Model.

Due to high cost and constant maintenance of recording instruments such as net radiometers, net radiation (*$R_n$*) measurements are difficult to collect. The Penman-Monteith (FAO-56) step by step method was used to compute the daily net radiation. This includes:

The inverse relative distance Earth-Sun $(\partial r)$ is given as (Spencer, 1971):

$$\partial r = 1 + 0.033\cos[\frac{2\pi}{365} j] \qquad (1)$$

where $j$ is number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

The solar declination (δ) can be found from the approximate equation of Cooper (1969),

$$\delta = 23.45\sin(360\frac{284+j}{365}) \qquad (2)$$

The sun angle $(\omega_s)$ is given by (John and William, 2013):

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)] \qquad (3)$$

where $\varphi$ is the latitude of a particular location.

The extraterrestrial radiation $(R_a)$, for each day of the year can be estimated using;

$$R_a = \frac{24\times3600}{\pi} G_{sc}\partial r(\cos\varphi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\varphi\sin\delta)$$

(4)

where $G_{sc}$ is solar constant =1367w/m$^2$ (lgbal, 1983).

The actual vapor pressure $(e_a)$ can be computed (Lincoln et al., 2015);

$$e_a = \frac{e_{(T_{\min})}[\frac{RH_{\max}}{100}] + e_{(T_{\max})}[\frac{RH_{\min}}{100}]}{2}.$$

$$e_{(T_{\max})} = 0.6108\exp(\frac{17.27T_{\max}}{T_{\max}+237.3})$$

$$e_{(T_{\min})} = 0.6108\exp(\frac{17.27T_{\min}}{T_{\min}+237.3}) \qquad (5)$$

where $e_{(T_{\min})}$ and $e_{(T_{\max})}$ are daily saturation vapour pressure at minimum and maximum temperature, and $RH_{\max}$, $RH_{\min}$ are maximum and minimum relative humidity.

The clear-sky radiation $R_{so}$ is given by (Lincoln et al., 2015):

$$R_{so} = (0.75 + 2E10 - 5Z)R_a \qquad (6)$$

where *Z* is the elevation above sea level.

The net terrestrial (long wave) radiation $(R_T)$ is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law as given below:

$$R_T = \sigma[\frac{(T_{\max}+273.16)^4 + (T_{\min}+273.16)^4}{2}](0.34 - 0.14\sqrt{e_a})[1.35\frac{R_s}{R_{so}} - 0.35] \qquad (7)$$

where $\sigma$ is Stefan-Boltzmann constant [4.903x10$^{-9}$MJ K$^{-4}$ m$^{-2}$day$^{-1}$] and $R_s$ is incoming solar radiation, MJm$^{-2}$ day$^{-1}$.

Lastly, the net radiation **(** $R_n$ **)** which is the difference between the incoming net shortwave radiation ( $R_{ns}$ ) and the outgoing net terrestrial radiation ( $R_T$ ) is given by;

$$R_n = R_{ns} - R_T \tag{8}$$

$$R_{ns} = (1-a)R_s \tag{9}$$

where $R_{ns}$ is net solar radiation (MJ m$^{-2}$ day$^{-1}$) and $a$ is albedo = 0.3 (John and Willam, 2013).

**Simple Linear Regression**

The simple linear regression model is given by:

$$y_j = B_0 + B_1 x + e_j \tag{10}$$

where $y_j$ , $x_i$ , $e_j$ are dependent variable (net radiation), independent variable (wind speed) and residual term respectively. $B_0$ and $B_1$ are the unknown parameters that are to be estimated, and $j$ is 1, 2, ... ,$n$. The coefficient of determination $(R^2)$ which is a measure of the degree of fit of the linear trend equation is used to determine the level of fit of the regression line relating net radiation and wind speed. The estimated regression model is afterward used for the prediction of the independent ($x_j$) variable given one or several future observations of the dependent variable ($y_j$).

**Markov Chain**

Markov chain is a stochastic process $\{X_n,\ n = 0,1,2, \dots \dots\}$ that takes on a finite or countable number of possible values and if $X_n = i$, then the process is said to be in state $i$ at time $n$. Supposing that the process is in state $i$, there is fixed probability $P_{ij}$ that it will next be in state $j$. That is;

$$P\{X_{n+1} = j | X_n = i, X_{n-1} = i_{n-1}, \dots, X_1 = i_1, X_0 = i_0\}$$
$$= P\{X_{n+1} = j | X_n = i\} = P_{ij} \tag{11}$$

For all states $i_0, i_1, \dots, i, j$ and $n \geq 0$.

For a first-order Markov chain, the future state $X_{n+1}$ is independent of the previous states $(X_0, X_1, \dots\dots, X_{n-1})$, but depends only on the present state $X_n$ (Ross, 2010).

**1.1.3.1 Transition Probability Matrix**

A Markov chain transition matrix is a square array describing the probabilities of the chain transiting from one state to another. This transition probability $P_{ij}$ is given as (Balzter, 2000):

$$P_{ij} = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{pmatrix} \tag{12}$$

The elements $P_{ij}$ are also called stationary probabilities. They are defined by:

$$P(X_n = j / X_{n-1} = i) = p_{ij} \tag{13}$$

Considering the long period of the daily net radiation (34 years) used in this work, the $P_{ij}$ 's are assumed stationary.

**N-Step Transition Probability Matrix**

For any value of $n$ ( $n = 2, 3 \dots$ ), the $n^{th}$ power of the matrix $P$ specify the probabilities $p_{ij}^n$ that the chain will move from state $x_i$ to $x_j$ is called the n-step probability matrix. This is based on the Chapman Kolmogorov equation, which states as follows;

For any $r \leq n$,

$$P_n = (P_{ij})_n = P^{(n)} = \sum_{k=0}^{\infty} P_{ik}^r P_{kj}^{n-r} \tag{14}$$

where $P_n$ denotes the matrix of n-step transition probability (Udom, 2010).

**Steady State Probabilities of a Markov Chain**

Consider a Markov chain with Z-states and the row vector

$$\pi = (\pi_1\ \pi_2 \dots \dots \dots \dots \pi_z) \tag{15}$$

such that

$$\text{(i) } \pi_i \geq 0 \quad \text{(ii) } \sum_{i=1} \pi_i = 1 \qquad \text{(iii) } \pi_j = \lim_{n\to\infty} p_{ij}^{n} \tag{16}$$

where $P\{X_{n+1} = j | X_n = i\} = P_{ij}$, $(\pi_1\ \pi_2 \ldots\ldots\ldots\ldots \pi_z)$ is called the steady state vector of the Markov Chain. $\pi$ can be obtained by solving the relation;

$$\pi = \pi P_{ij} \tag{17}$$

where $P_{ij}$ are the stationary probabilities.

## METHODOLOGY

### Source of Data

The daily maximum and minimum Relative-Humidity, maximum and minimum air temperature, solar radiation and wind speed data were obtained from the International Institute of Tropical Agriculture (IITA**)** Ibadan, Nigeria for the period of thirty-four (34) years (1977-2010). The daily data were used in computing the daily Actual vapor pressure ($e_a$), and Terrestrial (long wave) radiation $(R_T)$. The daily inverse relative distance Earth-Sun $(\partial r)$, Solar declination (δ), sun angle $(\omega_s)$, extraterrestrial radiation $(R_a)$ ,Clear sky solar radiation ($R_{so}$ ), and Net radiation ($R_n$ ) were also computed using the step by step Penman-Monteith model (equation 1-9). Lastly, the daily net radiation was arranged monthly over the period of the thirty four years (1977-2010) and the monthly average was computed.

### Data transformations employed in the modeling process

The daily wind speed data and the daily computed net radiation over the period (1977-2010) was transformed into a sequence of binary events. For any $K^{th}$ day, a random variable $R_{nk}$ is defined to represent this event with the realization; 0 if the daily net radiation *($R_n$)* is negative (deficit) and with realization '1' if the daily net radiation *($R_n$)* is positive (surplus). We also define a random variable $W_k$ for daily wind speed (*W*) with realization; 0 if '*W*' is below monthly grand average ($\overline{W}$) and with realization '1' if the daily wind speed (*W*) is above monthly grand average ($\overline{W}$). This is termed low and high wind speed respectively. Mathematically we have;

$$W_k = \begin{cases} 0, if\ W_k < \overline{W}(low\ wind\ speed). \\ 1, if\ W_k \geq \overline{W}(high\ wind\ speed). \end{cases} \tag{18}$$

$$R_{nk} = \begin{cases} 0, if\ R_{nk} < 0 \ \text{(deficit net radiation ).} \\ 1, if\ R_{nk} > 0 \ \text{(surplus net radiation).} \end{cases} \tag{19}$$

where $k\ is\ 1, 2, \ldots, n$ (days); $W\ and\ \overline{W}$ are daily wind speed and grand monthly average wind speed respectively.

It is observed that net radiation is completely surplus all through the year in Makurdi, Nigeria as presented in Figure 1. Therefore, in order to model the relationship between net radiation and wind speed, we define a new transformation as follows. For any $K^{th}$ *day*, we capture a sequence of binary events using a random variable $X_k$ with the realizations '1' if $R_{nk}$ is 1(surplus) and $W_k$ is 1 (high) and '2' if $R_{nk}$ is 1 (surplus) and $W_k$ is 0 (low). Conditioning surplus net radiation on high and low wind speed was done daily for each month. Mathematically, we have;

$$X_k = \begin{cases} 1, if\ net\ radiation\ is\ 1\ and\ wind\ speed\ is\ 1\ (S/H) \\ 2, if\ net\ radiation\ is\ 1\ and\ wind\ speed\ is\ 0\ (S/L). \end{cases} \tag{20}$$

where S/H and S/L are Surplus net radiation conditioned on high and low wind speed. The Microsoft Excel Package (2007) was used to implement this transformation, for accuracy and computational ease.

In this study, the steady state probabilities for the first order Markov chain model were determined using the computational formula:

$$\pi_1 = \frac{p_{01}}{1 + p_{01} - p_{11}} \tag{21}$$

$$\pi_2 = 1 - \pi_1 \tag{22}$$

$$1 = \pi_1 + \pi_2 \tag{23}$$

where $\pi_1$ and $\pi_2$ are steady state probabilities of surplus net radiation conditioned on high wind speed and surplus net radiation conditioned on low wind speed respectively.

The mean recurrence time (in days) for each state is modeled as:

$$\frac{1}{\pi_1} \text{ and } \frac{1}{\pi_2} \tag{24}$$

Due to the huge amount of data involved in this work, a computer program was written in Pascal programming language version 1.5 for obtaining the transition counts, transition probabilities, N-step transition matrix and steady state probabilities.

**Statistical indicator functions of Energy balance.**

The following indicators of energy balance were developed in this study.

Energy balance occurs when the chance (steady state probabilities) of surplus net radiation conditioned on high wind speed is equal to the chance of surplus net radiation conditioned on low wind speed daily, otherwise it is considered energy imbalance.

$$I_{Eb}(P) = \begin{cases} Energy\ imbalance\ (if\ P(S/H) < P(S/L)\ or\ P(S/H) > P(S/L)) \\ Energy\ balance \qquad (if\ P(S/H) = P(S/L)) \end{cases} \tag{25}$$

where $I_{Eb}$ *(P)* is Indicator function of energy balance; $P(S/H)\ and\ P(S/L)$ are probabilities of surplus net radiation conditioned on high and low wind speed respectively.

## RESULTS AND DISCUSSION

### Monthly Net radiation and Wind speed

Net radiation is a basic factor that governs the climate of the troposphere (lower layers of the atmosphere). The difference between incoming solar radiation and terrestrial (long wave) radiation is known as net radiation. Net radiation is surplus in Makurdi from January to December as presented in Figure 1. Surplus net radiation occurs when net radiation is positive (greater than zero), that is, the amount of incoming solar radiation absorb by the earth's surface (Makurdi) is greater than the amount of terrestrial radiation emitted into the atmosphere, thereby increasing the air temperature of the atmosphere which agrees with the work of Ajon et al., (2018).

There must be a transfer of excess surplus net radiation between two regions so that the magnitude of the whole earth's net surplus radiation equals that of the deficit radiation. The heat transfer necessary for transferring surplus net radiation to areas experiencing deficit net radiation is accomplished by global winds organized into what is known as the general circulation of the atmosphere. Average monthly wind speed in Makurdi decreases from January to May, increases from May to June (highest peck), decreases from June to October (lowest wind speed) and finally increases to December as shown in Figure 1. The high wind speed transfer surplus net radiation from Makurdi to regions experiencing deficit net radiation so that the air temperature in Makurdi becomes favorable for the populace.

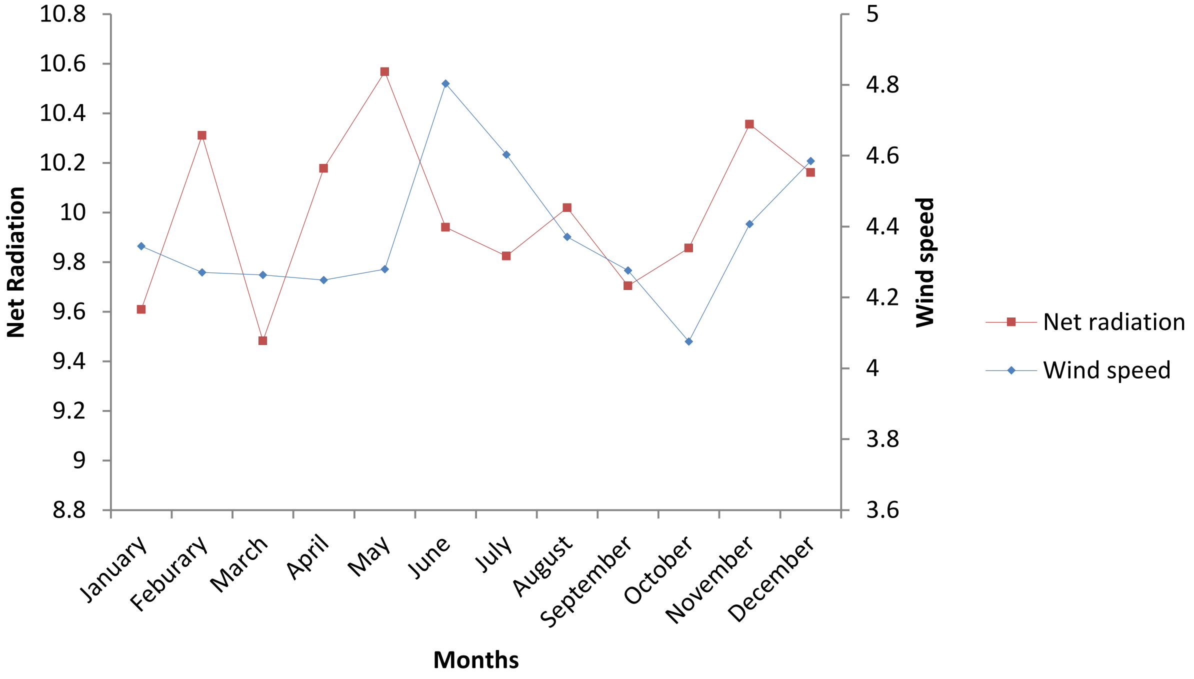

Fig. 1: Average monthly net radiation and wind speed.

The Linear regression (deterministic) model was applied to model the relationship between net radiation and wind speed. It was observed that, there is no definite linear trend between net radiation and wind speed, having a coefficient of determination $R^2$= 0.006 or 0.6% as shown in Figure 2. The negative slope value (-0.158) indicates that as net radiation is increasing, wind speed is decreasing as shown in Figure 2.

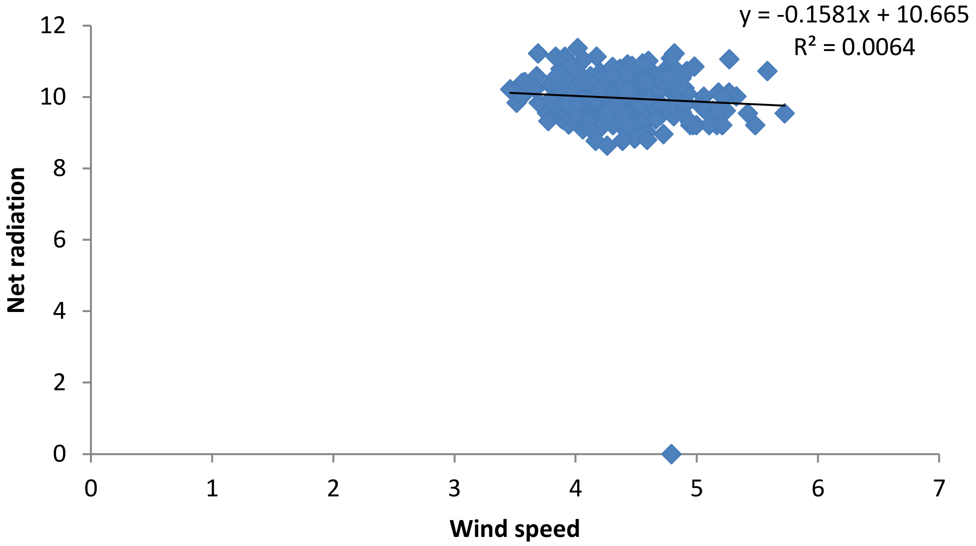

Fig. 2: Linear trend of net radiation against wind speed

The coefficient of determination ($R^2$) of 0.006 or 0.06% indicates a very poor fit, hence using the linear regression (deterministic) model, the relationship between net radiation and wind speed would yield a very poor result.

**First order transition probability matrix**

The first order transition probability matrix is obtained by dividing each transition counts as presented in Table 1 by the total transition row wise in a matrix form.

**Table 1: Transition Counts of surplus net radiation conditioned on high and low wind speed.**

| SEQ. | JAN. | FEB. | MAR. | APR. | MAY | JUNE | JULY | AUG. | SEPT. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S/H-S/H | 236 | 226 | 290 | 240 | 261 | 263 | 234 | 271 | 246 | 310 | 249 | 267 |
| S/H-S/L | 160 | 153 | 166 | 152 | 177 | 144 | 183 | 173 | 167 | 164 | 154 | 174 |
| S/L-S/H | 161 | 153 | 166 | 153 | 178 | 144 | 183 | 173 | 167 | 163 | 153 | 174 |
| S/L-S/L | 496 | 427 | 431 | 474 | 437 | 468 | 453 | 436 | 439 | 416 | 463 | 438 |

S/H is surplus net radiation conditioned on High wind speed; S/L is surplus net radiation conditioned on low wind speed; - is transition

The transition probabilities of surplus net radiation conditioned on low wind speed transiting into the same state dominates all through the year, having its peck in April and June (0.76 or 76%) as presented in Figure 3. Equal transiting probabilities of surplus net radiation conditioned on low wind speed transiting into the same state is observed in the months of March, August, September, October and December have (0.72 or 72%); also in the months of May and July (0.71 or 71%); lastly, the months of January and November (0.75 or 75%) as shown in Figure 3. This implies that there is a 75% chance of surplus net radiation conditioned on low wind speed transiting into the same state in the months of January and November, that is, 75% of surplus net radiation is retained in Makurdi, thereby increasing the air temperature.

Similarly, the transition probabilities of surplus net radiation conditioned on high wind speed transiting into the same state are the same in the months of January, February, May, and September (0.60 or 60%); also April, August, and December (0.61 or 61%); June and October (0.65 or 65%); differ in March (0.64 or 64%) and November (0.62 or 62%) as shown in Figure 3. This implies that there is a 65% chance of surplus net radiation condition on high wind speed transiting into the same state in the months of June and October.

The transition probabilities of surplus net radiation conditioned on high wind speed transiting into a surplus net radiation conditioned on low wind speed and surplus net radiation conditioned on low wind speed transiting into a surplus net radiation conditioned on high wind speed is below 0.5, meaning the chance of this transitions occurring is less than 50% as presented in Figure 3. Surplus net radiation conditioned on low wind speed transiting into the same state has the highest chance of occurring from January to December, resulting to an increase in air temperature in Makurdi monthly.

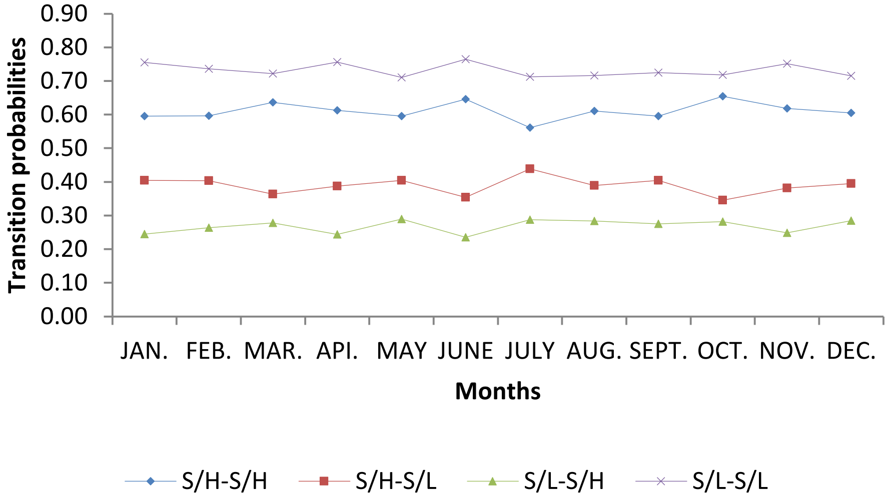

Fig. 3: Transitions probabilities of a particular state transiting into another state.

**N-step probabilities.**

The elements of the N-step transition probability matrix ‘$P^n$’ provides the various probabilities of surplus net radiation conditioned on high or low wind speed transiting from its current state to another state after n-steps. The higher order of transition probabilities are computed by raising the power “n” of the matrix P. The power matrix ($P^{(2)}$-$P^{(31)}$) are the daily probabilities of surplus net radiation conditioned on high and low wind speed transiting into the same state are presented in Table 2.

**Table 2: N-steps transition probabilities of surplus net radiation conditioned on high and low wind speed for January - June.**

| N-step | JAN. S/H | JAN. S/L | FEB. S/H | FEB. S/L | MAR. S/H | MAR. S/L | APR. S/H | APR. S/L | MAY S/H | MAY S/L | JUN. S/H | JUN. S/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.46 | 0.66 | 0.46 | 0.65 | 0.51 | 0.62 | 0.47 | 0.67 | 0.48 | 0.62 | 0.51 | 0.66 |
| 3 | 0.41 | 0.65 | 0.42 | 0.62 | 0.46 | 0.54 | 0.41 | 0.64 | 0.44 | 0.59 | 0.45 | 0.62 |
| 4 | 0.39 | 0.62 | 0.4 | 0.61 | 0.45 | 0.55 | 0.41 | 0.64 | 0.43 | 0.58 | 0.42 | 0.6 |
| 5 | 0.39 | 0.62 | 0.4 | 0.61 | 0.44 | 0.56 | 0.39 | 0.63 | 0.42 | 0.58 | 0.41 | 0.6 |
| 6 | 0.39 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.39 | 0.62 | 0.42 | 0.58 | 0.41 | 0.6 |
| 7 | 0.39 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 8 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 9 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 10 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 11 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 12 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 13 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 14 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 15 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 16 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 17 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 18 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 19 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 20 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 21 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 22 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 23 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 24 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 25 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 26 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 27 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 28 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 29 | 0.38 | 0.62 | 0.39 | 0.61 | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 30 | 0.38 | 0.62 |  |  | 0.44 | 0.56 | 0.38 | 0.62 | 0.42 | 0.58 | 0.41 | 0.59 |
| 31 | 0.38 | 0.62 |  |  | 0.44 | 0.56 |  |  | 0.42 | 0.58 |  |  |

The N-step transition probabilities attain steady state when $^{(n)}$ is equal to 4 (January, July and August), 5 (March, May, and September), 6 (February, April, November and December) and 7 (June and October) as presented in Table 2. This means that, the current state of a particular day is been affected by the previous state, but as the number of days increases (n-power), the effect reduces and a steady state is achieved.

**Steady states probabilities**

Surplus net radiation conditioned on low wind speed has the highest monthly steady state probabilities (long run dependence) from January to December as shown in Figure 4. The steady states probabilities of surplus net radiation conditioned on low wind speed are the same in the months of March and October (0.56 or 56%); May, August and December (0.58 or 58%); June and September (0.59 or 59%); July and November (0.60 or 60%); lastly January and April (0.62 or 62%) as revealed in Figure 4.

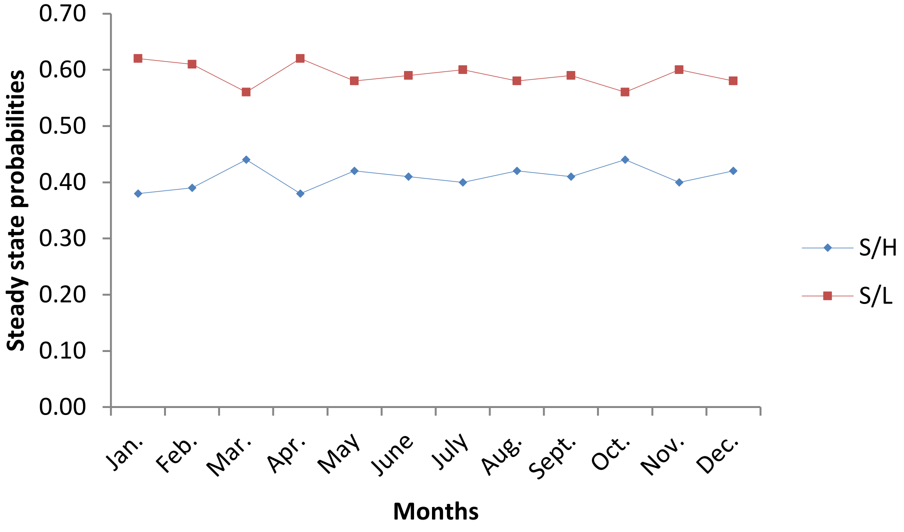

Fig.4: Monthly steady state probabilities of surplus net radiation conditioned on High and Low wind speed *(S/H and S/L)*

Similarly, it is also observed that equal steady state probabilities of surplus net radiation conditioned on high wind speed occurs in the months of March and October (0.44 or 44%); May, August and December (0.42 or 42%); June and September (0.41 or 41%); July and November (0.40 or 40%); and lastly January and April (0.38 or 38%) as presented in Figure 4. This signify that, at the long run there is a chance of 62% surplus net radiation conditioned on low wind speed and 38% surplus net radiation conditioned on high wind speed taking place daily in the months of January and April; 56% surplus net radiation conditioned on low wind speed and 44% surplus net radiation conditioned on high wind speed occurring daily in the months of March and October. The months of January and April would be warmer compare to the months of March and October because more heat is been retained in such months.

There is a 62% chance that, the air temperature at Makurdi would be hot and a 38% chance of it been cold in the months of January and April. Also there is a 56% chance that, the air temperature would be hot and 44% of it been cold in the months of March and October. These are the two extremes revealed in the study. It is also observed that in Figure 1, surplus net radiation occurs all through the year, while Figure 4 revealed that 38% of surplus net radiation is transferred by high wind speed to areas experiencing deficit net radiation in the month of January and April leaving 62% surplus net radiation in Makurdi, resulting to high air temperature. These transfers of energy are known as sensible heat transfer (warm air) and latent heat transfer (water vapour), respectively. Water vapour carries surplus energy (from Makurdi) in the form of latent heat where there is much evaporation and releases the energy when water condenses in deficit energy region.

On the average, 40% of the surplus net radiation is transferred to areas experiencing deficit net radiation in order to maintain thermal equilibrium, while 60% of the surplus net radiation conditioned on low wind speed is retained in the Makurdi as presented in Figure 4. Lastly, we have been able to model net radiation and wind speed using the Markov chain model as presented in Figure 4, unlike the linear trend model in Figure 2 which is so poor ($R^2$=0.006 or 0.6%)

**Mean Reoccurrence Time (days)**

The mean reoccurrence times (days) is the number of days it takes for a given state to reoccur. It takes 2.38 days for surplus net radiation conditioned on high wind speed, and 1.72 days for surplus net radiation conditioned on low wind speed to reoccur in the months of May, August and December; 2.63 days for surplus net radiation conditioned on high wind speed, and 1.61 days for surplus net radiation conditioned on low wind speed to reoccur in the months of January and April; 2.27 days for surplus net radiation conditioned on high wind speed, and 1.79 days for surplus net radiation conditioned on low wind speed to reoccur in the months of March and October; 2.44 days for surplus net radiation conditioned on high wind speed, and 1.69 days for surplus net radiation conditioned on low wind speed to reoccur in the months of June and September; lastly 2.50 days for surplus net radiation conditioned on high wind speed, and 1.67 days for surplus net radiation conditioned on low wind speed to reoccur in the months of July and November as presented in Figure 5.

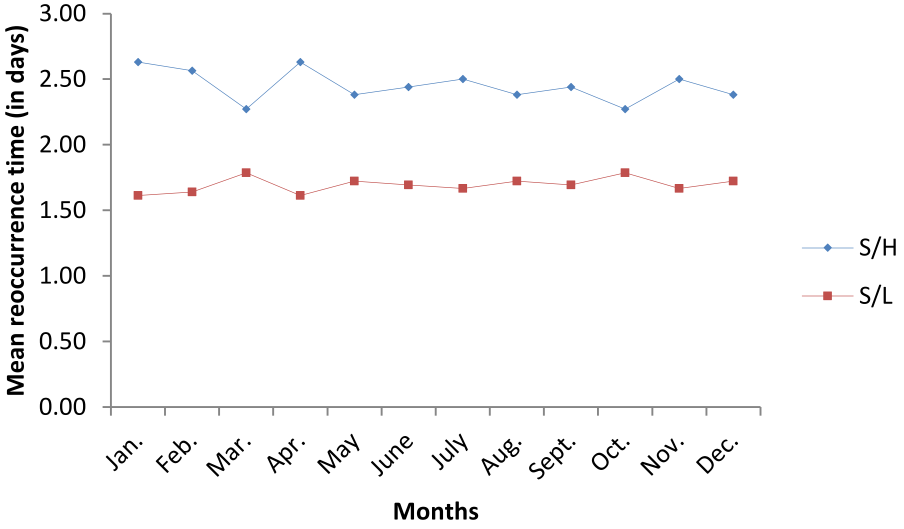

Fig. 5: Monthly mean reoccurrence times (days) of surplus net radiation conditioned on High and Low wind speed (S/H and S/L). On the average, the mean reoccurrence times (days) for surplus net radiation conditioned on high wind speed to reoccur is 2.44 days, while it takes 1.69days for surplus net radiation conditioned on low wind speed to reoccur. This indicates, that surplus net radiation conditioned on low wind speed would occur for 2.44 days and surplus net radiation conditioned on high wind speed for 1.69 days on the average resulting to a hot weather / climate.

**Implication to energy imbalance**

Since the monthly steady state probabilities are not equal, that is, steady state probabilities of surplus net radiation conditioned on low wind speed is greater than that of surplus net radiation conditioned on high wind speed from January to December, the indicator function of energy balance of equation 25 reveals that energy is imbalance in Makurdi. This implies that the amount of surplus net radiation transferred to areas experiencing deficit net radiation is less than the amount of surplus net radiation retained, thereby resulting to a warmer (extreme) weather/climate in Makurdi, from January to December as presented in Figure 4. The imbalance between surplus net radiation conditioned on low wind speed and surplus net radiation conditioned on high wind speed is rectified by latent heat flux and sensible heat flux. These imbalances and the rotation of the earth lead to complex but organized patterns of energy and water transfer in the atmosphere and also determine the weather/climates in Makurdi. This process of heat transfer maintains steady-state equilibrium within the climate system in Makurdi and greatly moderates its air temperature.

**Effect of high and low wind speed on surplus net radiation**

The monthly net radiation is surplus from January – December, that is, the amount of incoming solar radiation absorb is far greater than the amount of terrestrial radiation emitted by the earth's surface (Makurdi) as shown in Figure 1. Surplus net radiation will increase the air temperature of Makurdi, thereby increasing the rate of evaporation of energy, water vapour, evapotranspiration and affecting every aspect of life (human, plants and animals). Water vapour carries energy (different proportion) in the form of latent heat from Makurdi, where there is much evaporation and releases it when water condenses in deficit net radiation regions, in order to keep the air warm as presented in Figure 4. Thus any time the atmospheric circulation causes air to move from surplus to deficit regions, there is an outbreak of cold air in the surplus regions as a result of evaporation. This helps to explain the changeable and vigorous nature of the weather / climate of Makurdi. Figure 4 reveals that 38%, 39%, 44%, 38%, 42%, 41%, 40%, 42%, 41%, 44%, 40% and 42% of the surplus net radiation in Figure 1 is transferred by high wind speed from Makurdi to deficit regions in the months of January, February, March, April, May, June, July, August, September, October, November and December respectively, thereby maintaining air temperature in Makurdi. The surplus net radiation that is been transferred is less compared to the surplus net radiation retained in Makurdi as presented in Figure 4, thereby resulting to energy imbalance and increases in air temperature.

## CONCLUSION

Net radiation is surplus from January to December and no definite linear trend between net radiation and wind speed in Makurdi. The transition probabilities of surplus net radiation condition on low wind speed transiting into the same state dominates from January to December. Also the monthly steady state probabilities (long run dependence) of surplus net radiation conditioned on low wind speed dominate all through the year. Since the monthly steady state probabilities are not equal, the indicator function of energy balance reveals that energy is imbalance in Makurdi. On the average, it takes 2.44 days for surplus net radiation conditioned on high wind speed and 1.69 days for surplus net radiation conditioned on low wind speed to reoccur from January to December. By applying Markov Chain model in the study, we have been able to investigate the effect of high and low wind speed on surplus net radiation in Makurdi, probabilistically based on Crommelin and Khouider (2015).

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