MODELING MONTHLY RELATIVE HUMIDITY FOR EVAPOTRANSPIRATION ESTIMATION IN OHAJI-EGBEMA, IMO STATE AND ANINRI, ENUGU STATE

BY

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CERTIFICATION

This is to certify that this work "Modelling Monthly Relative Humidity for Evapotranspiration Estimation in Ohaji-Egbema, Imo State and Aninri, Enugu State" was carried out by **Iwuchukwu, Emmanuel Ikechukwu** with registration number (**20144916578**) in partial fulfillment of the requirements for the award of Master of Engineering (M.Eng) Degree in Agricultural and Bioresources Engineering (Soil and Water Engineering option).

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List of Abbreviations Used

Δ: slope of saturation vapor pressure with air temperature, kPa/°C.

γ: psychrometric constant, kPa/°C.

φ: latitude of site, radians.

ET: evapotranspiration rate, mm/h or mm/d or inches/d.

PET: potential ET rate, mm/h or mm/d or inches/d.

ET_0: reference evapotranspiration rate from a grass surface, mm/h or mm/d or inches/d.

ET_{SZ}: reference evapotranspiration rate from a standardized surface, mm/h or mm/d.

ET_C: crop evapotranspiration, mm/h or mm/d.

u: monthly consumptive use (ET), inches/mon. or mm/mon.

U: seasonal consumptive use (ET), inches/season or mm/season.

K_C: crop coefficient developed by FAO 56 method.

k: empirical crop coefficient for monthly period.

K: empirical crop coefficient for irrigation season or growing period.

T_a: mean monthly/daily/hourly air temperature, °C.

T_F: mean monthly/daily/hourly air temperature, °F.

t: difference between actual canopy temperature and canopy temperature in wet conditions, °C.

u_2: wind speed at 2m height, m/s.

r_c: canopy surface resistance, s/m.

r_a: aerodynamic resistance, s/m.

r_l: daily average stomata resistance: s/m.

r_i: climatological resistance, s/m.

r*: climatic resistance, s/m. RH: relative humidity, %.

R_n: net radiation, MJ/m^2/d or MJ/m^2/h.

R_s: incoming solar radiation, MJ/m^2/d or MJ/m^2/

Ra: extraterrestrial radiation, MJ/m^2/d or MJ/m^2/h.

e_a: actual vapor pressure, kPa.

e_s: saturation vapor pressure, kPa.

D: vapor pressure deficit, kPa.

p: monthly percentage of daytime hours of the year, %.

f: monthly consumptive use (ET) factor.

F: sum of monthly consumptive use (ET) factors for the period.

i: heat index.

I: sum of the 12 monthly heat index i.

S: measured sunshine hours times 100 divided by the number of possible sunshine hours. K_{RS}: calibration coefficient.

TD: mean maximum minus mean minimum temperature, °C.

K: dimensionless constant developed empirically from data analysis. C: dimensionless coefficient related to climatic parameters.

G: soil heat flux, $MJ/m^2/d$ or $MJ/m^2/h$.

f(u) = wind speed function. J: Julian day of the year.

λ: latent heat of evaporation, MJ/kg.

ρ: air density, kg/m^3.

C_p: specific heat capacity of air at constant pressure, J/kg/K.

D: zero plane displacement height, m.

hc: crop height, m.

z_m: height of wind measurements, m.

z_h: height of humidity measurements, m.

z_{om}: roughness length governing momentum transfer, m.

z_{oh}: roughness length governing heat transfer.

k:von-Korman's constant (0.41).

U_z: wind speed at height z, m.

LAI: leaf area index, m^2/m^2.

C_n: numerator constant that changes with reference type and calculation time step, K mm s^3 M/g/d or K mm s^3M/g/h.

C_d: denominator constant that changes with reference type and calculation time step, s/m.

W_{aero}: empirical weighted factor.

ABSTRACT

Monthly Relative humidity (RH) models for Enugu and Imo States were developed using statistical analysis (SPSS) based on stepwise method. In this study, the independent variables: sunshine hours, minimum temperature, maximum temperature, rainfall and vapour pressure and the dependent variable (monthly relative humidity) were obtained from Nigeria Meteorological Agency (NIMET) for the years 1991 to 2010. The data for 1991 – 2007 were used to develop the models. High coefficients of determination R^2 *= 0.845 and 0.753 for estimating monthly relative humidity for Enugu and Imo respectively were obtained during model building. The developed models were used to predict a monthly relative humidity value for the remaining three years using data obtained from NIMET from 2008-2010 that was not used in building the model. It was observed that the Imo model predicted fairly accurate, judging from the low percentage error in year 2008 got from the monthly RH that was not used in building the model; (ranging from 0.46 to 45.94) but for 2009 and 2010, the percentage errors were fairly higher than that predicted for year 2008 whereas that of the Enugu model predicted fairly accurate, judging from the low percentage error in year 2008 got from the monthly RH not used in building the model;(ranging from 0.59 to 32.42) and also for 2009 and 2010, the percentage errors were fairly accurate as that predicted for year 2008. Thus the smaller the percentage error values between measured and predicted results, the better the model developed. Blaney-Morin-Nigeria(BMN) model was used as a test case because it dealt with Evapotranspiration estimation in Nigeria. By applying the two models into* ***equation 1.1,*** *The error margin for RH model for Enugu state used in Blaney-Morin-Nigeria(BMN) gave 0.0295 – 0.1864 whereas the error margin for RH model for Imo state used in BMN gave 0.0312 – 0.1322. By applying the developed monthly relative humidity in BMN model to estimate the monthly evapotranspiration from 1991 to 2010 gave a high significant difference. These results are clear evidence of the test of goodness of fit of the models between predicted and measured parameters for monthly relative humidity for Imo and Enugu states using BMN.*

Keywords: Modeling, Relative humidity, Evapotranspiration Estimation, Blaney-Morin Nigeria(BMN) and Statistics

CHAPTER ONE
INTRODUCTION

1.1 Background of Study

In Nigeria the occupation of the rural dwellers is predominantly agricultural practices. They engage in planting of crops such as yams, cocoyam, potatoes, vegetables and some other food crops. Two States in South-Eastern Nigeria that would be considered in this study are Imo and Enugu.

Modeling is a proven and well accepted engineering technique; it is being built or developed so that one can better understand the systems that are being developed. A model represents often in considerably idealized form the data generating process. It is usually specified by mathematical equations that relates one or more random variables or factors and possibly other non-random variables. Thus, a model is a formal representation of a theory, (Ader, 2008).

Relative humidity (RH) is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature. Relative humidity depends on temperature (maximum and minimum), Vapor pressure, Rainfall intensity, sunshine hours, and wind speed of the system of interest. It requires less water vapor to attain high relative humidity at low temperatures; and more water vapor is required to attain high humidity in warm or hot air.

Water availability is one of the important factors considered in Agriculture. Water is provided to crop through natural precipitation and subsurface moisture. In many areas of the world where rainfall is insufficient to meet the crop water demand, irrigation system is often used to offset the water deficit. Water is lost from crops through evaporation and transpiration.

Evaporation is the process of liquid water conversion to water vapour and removal from the evaporating surface. Transpiration includes the vaporization of liquid water contained in plant tissues and the water removal to the atmosphere. Evapotranspiration (ET), which is the combination of evaporation and transpiration, is also known as the consumptive use or actual evapotranspiration (Allen *et al*., 1998).

The rate of ET is determined using different approaches. As indicated by Ilesanmi *et al*. (2012), these approaches may be broadly classified into direct and indirect measurement. The direct measurement include the use of lysimeters (Ayoade, 1988, 1988a; Meissner *et al*., 2010), energy balance/budget approach (Adeboye *et al*., 2009), the soil water budget method (Phene *et al*., 1990; Evett and Parkin, 2005), the use of pan evaporimeters (Ayoade, 1988,1988a; Howell *et al*., 1991; Young *et al*., 1996), satellite remote sensing (Bastiaanssen *et al*., 2005; Tang et al., 2009) and the Eddy-Covariance method (Shuttleworth, 1993, 2007).

Direct measurement of evapo-transpiration is usually not feasible in many situations because it is expensive and relatively time consuming (Igbadum *et al*., 2006). The indirect measurement involves the use of empirical models developed to estimate ET using meteorological data. These models range from simple expressions which relate ET to temperature and/or radiation to models having extensive data requirement. The models may be classified into three: Temperature-based models (Thornthwaite, Blaney-Cridle, Blaney-Morin and McCloud models); radiation-based models (Turc, Hargreaves, Hargreaves-Samani, Priestly-Taylor and the Makkink Formula) and a combination approach based on original Penman model which consists of radiation and aerodynamic part (Jacobs and Satti, 2001; Alexandris *et al*., 2008, Ilesanmi *et al*., 2012).

Penman's model has been modified over the years because it produces good results when applied over different climatic regions (Allen *et al*., 1998). One of its modifications is the FAO56 Penman-Monteith model (FAO56-PM) which has been adjudged to be the best estimator of Reference Evapo-transpiration (ET_O) and has been recommended as the model to be used for the estimation of ET_O from meteorological data (Allen *et al.*, 1998; Alexandris *et al.*,2008) if all meteorological data is available.

In Nigeria, as in most developing countries, the meteorological data needed for the calculation of ET_O using models such as the FAO56-PM are most of the time not readily available (Adeboye *et al.*, 2009). For Nigeria, therefore, a temperature based model - the Blaney-Morin-Nigeria (BMN) - developed by Duru (1984) has been adjudged to be the best for the Nigerian condition by the Nigerian Institute of Agricultural Engineers (NIAE).

In the development of this model, there are some perceived shortcomings which are believed to affect its reliability for ET estimation in Nigeria. These shortcomings have been exhaustively discussed by Idike and Aneke (2002), Idike (2005) and Ilesanmi *et al* (2012) among other researchers.

This study was therefore carried out to generate a modified version of the BMN model that is specific for Imo and Enugu states, South Eastern Nigeria.

Duru (1984) presented a modified form of the Blaney-Morin potential evapotranspiration equation christened Blaney-Morin-Nigeria (BMN) Evapotranspiration (ET) model for use in Nigeria. In the work, the very wide variability of relative humidity in Nigeria and consequently the very important role this parameter is bound to play in the evapo-transpiration process in this geographical region (Nigeria) was recognized. The author correctly surmised that any evapo-transpiration model that would reasonably estimate potential evapo-transpiration (PET) in Nigeria must involve humidity term as a crucial parameter.

The BMN model in (Eqn1.1) as stated by Idike (2005) is currently the only evapo-transpiration model specifically developed for the Nigerian condition and, as would be expected, is enjoying wide use in the country. Eqn 1.1

$$\mathbf{Etp} = \mathbf{r_f} * \frac{(\mathbf{0.45t + 8})(\mathbf{520 - R^{1.31}})}{\mathbf{100}} -------- (\mathbf{1.1})$$

Where

Etp = Potential evapo-transpiration (mm/day).

r_f = ratio of maximum possible radiation to the annual maximum.

t = temperature (^{0}C)

R = relative humidity (%)

Blaney-Morin-Nigerian (BMN) model was developed to determine the evapo-transpiration but the advantage the relative humidity model when applied into BMN to determine evapo-transpiration is that relative humidity parameter in BMN model is just a direct measurement of relative humidity.

1.2: Statement of the Problem:

There are so many Evapo-transpiration (Etp) models here and there and the

and the reason is that Etp is climatic dependent. And since there are varieties of climatic conditions all over the world; we will have a lot of Etp models.

In Nigeria, many models has been known which includes Blaney-Morin-Nigeria (BMN), Blaney-criddle, Thornthwaite, Penman, Jansen and Hetz etc. Since Etp is climatic dependent, BMN being an indigenous Etp model can be assumed to be the best model in Nigerian climatic conditions. However some people like Idike and Aneke (2002), Idike (2005) and Ilesanmi *et al* (2012) have questioned the authenticity of this claim. Blaney-Morin-Nigeria (BMN) was produced based on data from various parts of Nigeria which includes different climatic conditions (Humid, Subhumid and Arid) climatic conditions but the data was collected from all of these climatic conditions. It is the intention of this work to collect data from only rainfall/humid zone of the country and build an Etp models based on these which will be used in computing Etp from these zone and later compare Etp from BMN for these same zone.

1.3: Objectives of the study:

The main objective of this study is to model the Monthly Relative Humidity of *Ohaji-Egbema*, Imo and *Aninri*, Enugu States.

The specific objectives are to:

1. Develop mathematical (statistical) models using statistical method to predict relative humidity using the factors climatic factors obtained from Nigeria Meteorological Agency from (1991-2010).
2. Validate the models.

3. Apply the relative humidity models into Blaney-Morin Nigeria (BMN) model to estimate evapotranspiration.

1.4: Justification of the study

The importance of Relative Humidity in Evapo-transpiration justifies the objective. The weather parameters used in developing the Relative Humidity models in both states will make the Evapo-transpiration estimation easier.

The monthly relative humidity model will help the farmer to estimate the evapo-transpiration at any point in time. Relative humidity depends majorly on maximum and minimum temperatures, vapor pressure, rainfall intensity, sunshine hours and wind speed. Thus, developing a model for monthly relative humidity with these factors could give better results for estimating evapo-transpiration using Blaney-Morin-Nigeria model because Blaney-Morin Nigerian (BMN) model was developed to determine the evapo-transpiration but the advantage the relative humidity model when applied into BMN to determine evapo-transpiration is that relative humidity parameter in BMN model is just a direct measurement of relative humidity but the relative humidity model comprises of sunshine hours, minimum temperature, maximum temperature, rainfall, and vapour pressure which will make it predict evapo-transpiration better.

1.5: Scope of the study:

The scope of this project is limited to development of a mathematical model to determine the monthly relative humidity of *Ohaji-Egbema* in Imo State and *Aninri*, Enugu State respectively using the following parameters for twenty (20) years. The selected Weather parameters chosen for the study are as follows: Maximum and Minimum Temperatures, Vapor pressure, Rainfall intensity, sunshine hours and wind speed.

CHAPTER TWO

LITERATURE REVIEW

Water is the basis of life. In the modern world, the demand of water is increasing because of the growing population as well as the increased urbanization and industrialization. As a result, water for agriculture is becoming limited. For this reason, accurate estimation of crop water requirement is very important. The problem of over irrigation or under irrigation will be minimized if we are able to accurately estimate crop water requirement or crop evapo-transpiration (ET, mm/d). Various methods have been developed so far to estimate the evapo-transpiration. John Dalton (1766-1844) was the pioneer in developing an equation for evaporation from large water bodies, such as lakes and reservoirs. This chapter two reviews various ET estimation models that have been developed to date.

Among these models, the Penman-Monteith (PM) equation is found to be more consistent over a wide range of climatic conditions (Allen *et al*., 2005), The most challenging part in the PM equation is to calculate the canopy surface resistance. The FAQ 56 PM equation (Allen *et al*., 1998) and ASCE-EWRI (Environmental and Water Resources Institute of American Society of Civil Engineers) 2005 Standardized PM equation (ASCE-EWRI, 2005) are based on the fixed canopy surface resistance approach. These two methods calculate the reference crop ET, which along with the crop coefficient (Ks) is used to calculate ET. Or the actual crop FT (or ET). Recently, some researchers have pointed out flaws in this technique of estimating ET,, so there have been attempts to calculate ET directly using variable surface resistance values, without requiring crop coefficients. Todorovic (1999), and Shuttleworth (2006) are notable researchers in variable surface resistance approach, which are described later in the manuscript. The subsequent sections describe different ET estimation techniques in a chronological order.

2.1 *Blaney-Criddle Method*

The Blaney-Criddle method was first developed in 1942. It is an empirical equation and very simple to use. They developed a simple mathematical model as given by Equation (1), (Blaney &.Criddle, 1962). Eqn 2.1 & 2.2

$$U = kf \tag{2.1}$$

$$u = kf = KF \tag{2.2}$$

Where,

u = monthly consumptive use, in inches;

f= T_F x p / 100 is the monthly consumptive use factor;

T_F = mean monthly temperature, in degrees Fahrenheit (°F);

p monthly percentage of daytime hours of the year;

k = empirical consumptive use crop coefficient for monthly period;

U = seasonal consumptive use (or evapotranspiration), in inches;

F = sum of the monthly consumptive use factors for the period (sum of the products of mean monthly temperature and monthly percentage of daytime hours of the year);

K= empirical consumptive use crop coefficient for irrigation season or growing period. Eqn 2.3

In metric units,

$$U=kp\ \left(\frac{45.7T_a+813}{100}\right) \qquad (2.3)$$

where,

U = monthly consumptive use, in millimeters;

T_a = mean monthly temperature, in degrees Centigrade/Celsius (°C).

Although the method was originally developed to compute ET on a monthly basis, it can be modified to estimate daily values of ET with mean daily temperature (ASCE, 1990). As temperature methods tend to underestimate ET in arid regions while overestimating ET in humid regions, local calibration of the empirical coefficients is required to produce reliable estimates of ET (ASCE, 1990). The advantage of this method is the simplicity and disadvantage is that it underestimates ET grossly compared to the measured El' values (Sammis *et al.*, 2011).

2.2 *Thornthwaite Method*

In 1948, Thornthwaite and Penman both developed potential evapotranspiration equation independently. Potential ET here refers to the maximum ET that can occur from a given crop surface. Penman's equation was more mechanistic while Thornthwaite's equation was more empirical. The Thornthwaite (1948) equation is simpler than Penman's equation because the method requires less climatic data. Thornthwaite's equation is as follows:Eqn 2.4

$$PET = 16(10\,T_a/I)^a \qquad 2.4$$

where,

PET = potential evapotranspiration rate, in mm per month;

Ta = mean monthly air temperature, in degrees Celsius (°C);

I = summation of the 12 monthly heat index i, where i $(T_a / 5)^{1.514}$;

o = an empirical coefficient, which is calculated using the following equation: Eqn 2.5

$$a = 0.675*10^{-6}/1^3 - 77.1*10^{-6}/1^2 + 0.017921 + 0.49239 \qquad (2.5)$$

This method is not based on strong mathematical and physical principles as it is purely empirical. However, as it is simple to use and gives acceptable result, in many parts of the world the method is still used to estimate irrigation water requirement.

Kurnar *et al.* (1987) compared the Thornthwaite and Penman methods, in India, to calculate potential ET. They found that Penman's method seemed more realistic in estimating the mean annual potential evapotranspiration distribution over India. They also reported that Penman's potential evapotranspiration estimates were higher than Thornthwaite's estimates during the winter and pre-monsoon months and lower during the monsoon months, at most of the Indian stations. Pereira and De Carnargo (1989) concluded that Thornthwaite's method was not appropriate for estimating ET in advective condition; however, they indicated that the method could be used for irrigation scheduling purposes when the fetch requirement is met, Bautista *et al*. (2009) concluded that Thornthwaite's method worked very well during the rainy months in both of their research sites; however, for drier months the use of Thornthwaite's method was not recommended without the adjustment of its coefficient"16",

2.3 *Hargreaves Equation*

Hargreaves (1975) developed an equation for estimating ET which doesn't require wind speed data, His equation is as follows: Eqn 2.6

$$ET_0 = 0.0075R_ST_F \qquad (2.6)$$

where,

ET_o =potential ET for a grass reference surface in the same units as R_S:

R_s=global solar radiation at the surface in equivalent water evaporation, usually mm of evaporation;

T_F = mean air temperature in degrees Fahrenheit (°F).

For degrees Celsius, the equation is modified as: Eqn 2.7

$$ET_O = 0.0135R_S(T_a +17.8) \qquad (2.7)$$

Hargreaves (1977) developed the equation for R as shown below, R units as Ra units: Eqn 2.8

$$R_s =0.075R_a^{S0.50} \qquad (2.8)$$

Hargreaves (1977) developed the equation for S to be applicable for Central America as: Eqn 2.9

$$S= 12.5(100—RH)^{0.50} \qquad (2.9)$$

where, RH = mean monthly relative humidity, %.

Hargreaves and Samani (1985) developed an equation to determine R_S from extraterrestrial radiation (Ri,) and the air temperature range (TD): Eqn 2.10

$$R_S = K_{RS} R_a TD^{0.50} \qquad (2.10)$$

where, R, and Ra are in the same units as indicated above, K_{RS} is a calibration coefficient and TD is mean maximum minus mean minimum daily temperatures, in degree Celsius, for a given period (generally one week).

Later on, Hargreaves and Samani (1985) obtained the following equation for ET_0. Eqn 2.11

$$E7_o = 0.0022Rs\,(T_a + 17.8)TD_{0.50} \qquad (2.11)$$

For months of peak demand, Hargreaves and Samani (1985) recommended that the coefficient (0.0022) be increased to 0.0023. ASCE-EWRI (2005) and Allen *et al.* (1998) recommended using Equation (2.11) when solar radiation, relative humidity and/or wind speed data are missing.

Hargreaves equation is also empirical, simple, and easy to use, Bautista *et al.* (2009), in a study, compared the results of the Hargreaves equation (Equation 2.11) with those of the FAO 56 PM equation (Allen *et al*., 1998), considering the latter equation as the standard method (reference), They found that the Hargreaves method compared well with the FAO 56 PM method with a resulting coefficient index (of determination) of 0,82. However, the coefficient index improved to 0,91 after adjusting Hargreaves equation coefficient “0.0022” in Equation (2.11) from 0.0021 to 0.0024 (based on seasons) for tropical sub humid climate sites and from 0,0022 to 0.0026 for semiarid climate sites, Ravazzani *et al*. (2012) also compared the Hargreaves and Samani (1985) equation (HS) to FAO 56 PM equation for daily time steps in alpine river basins ad found that the HS equation didn’t perform well. The HS method showed overestimation of ET_0 at lower elevation sites and underestimation at higher elevation sites. However, after using a correction factor, they found that the HS equation was in very good agreement with the FAQ 56 PM equation.

2.4 Christiansen Method

Christiansen (1968) developed a simple method to estimate pan evaporation and crop evapotranspiration. According to Christiansen, the reasons for using pan evaporation data were: they were more consistent, already considerable work had been done to relate pan evaporation data with crop consumptive use and the pan evaporation data were readily available. The mathematical model that he developed was as follows: Eqn 2.12

$$E = K\, R_a\, C \qquad (2.12)$$

where E is used in a general sense to apply to evaporation or evapotranspiration, K is a dimensionless constant developed empirically from data analysis, and C is a dimensionless coefficient related to climatic parameters, and Ra is the extraterrestrial radiation, expressed as equivalent depth of evaporation in the same units as E. The coefficient C is expressed as the product of any number of sub coefficients that are functions of specific climatic parameters that are found to have a significant effect on the evaporation or evapotranspiration (Christiansen, 1968). Eqn 2.13

Mathematically,

$$C=C_TC_WC_HC_SC_E \tag{2.13}$$

where, $C=C_TC_WC_HC_H$ and C_E, represent the coefficients for air temperature, wind speed, relative humidity, sunshine percentage and elevation, respectively. The value of K was adjusted so that all coefficients were equal to unity for standard and approximate mean values of the parameter they represent (Christiansen, 1968). Christiansen (1968) described in detail how to calculate the different parameters in Equation (2.13) using Tables in his article.

This method is purely empirical as it is not based on any physical equation. This method can somehow accurately estimate ET on a monthly basis. However, this method cannot be used to calculate ET on a daily basis or for shorter time steps.

Wai *et al*. (2004) evaluated the performance of the Christiansen method and Penman methods with respect to the measured pan evaporation in Malaysia. They found that the Penman method ET results compared better than the Christiansen's method ET results to measured values (Pan) of potential evapotranspiration.

2.5 Penman Related Equations

2.5.1 Original Penman equation

Penman (1948) developed a mechanistic approach to calculate ET. He used a combination approach by combining the surface energy balance equation with an aerodynamic equation. Several ET estimation models, for example, FAO 56 PM equation, ASCE-EWRI Standardized PM equation, CIMIS Penman method (as described in Temesgen *et al*., 2005) have been based on Penman equation.

The original Penman equation is as follows: Eqn 2.14 & Eqn 2.15

$$ET = \frac{(\Delta(R_n - G) + K_w(e_s - e_a)f(u)\gamma)}{\lambda(\Delta + \gamma)} \qquad (2.14)$$

$$F(u) = a_w + b_w u_2; \qquad (2.15)$$

where,

f(u) = wind speed function

k_w= unit coefficient (6.43 for ET in mm/d or 0.268 for ET in mm/h).

Penman (1948) recommended the value of a and b as 1.0 and 0.537, respectively, for clipped grass. Doorknobs and Pruitt (1977) in the FAO 24 paper recommended a constant of 6.61 in place of 6.43. They also recommended the values of a_w and b_w as 0.75 and 0.993 for full cover alfalfa. Wright (1987) as cited by Allen *et al.* (1989) derived an improved form of the variable wind function by using the normal probability density function equation to approximate the change in a\ and b. coefficients as a function of the Julian day (J) or day of the year for an alfalfa reference surface at Kimberly, Idaho.

The equations for a_w and b_w are: Eqn 2.16 & 2.17

$$a_w = 0.4 + 1.4 \exp\left[-\left(\frac{(J-173)}{58}\right)^2\right] \quad (2.16)$$

$$b_w = \left\{0.007 + 0.004 EXP\left[-\left(\frac{[J-243]}{80}\right)^2\right]\right\}(86.4) \quad (2.17)$$

Equations (2.14) and (2.15), with a and b, calculated with Equations (2.16) and (2.17) were termed 1982 Kimberly Penman equation by Allen *et al*. (1989).

2.5.2 CIMIS Penman method

The CIMIS Penman method calculates grass reference ET (ET0) using the Penman combination equation, as modified by Pruitt and Doorenbos (1977), with a wind function that was developed at the University of California, Davis (Ventura *et al.*, 1999 and Temesgen *et al*., 2005). The CIMIS Penman method uses a_w = 0.29 and b_w 0.53 for R_w > 0 and a_w = 1,14 and b_w = 0,40 for $R_n \leq 0$. These coefficients are applied hourly using Equation (14) where ET_0 is in mm/h, R_n is in $MJ/m^2/h$ and k_w 0.268 (ASCE-EWRI, 2005). Temesgen *et al*. (2005) showed that the CIMIS Penman method correlated well with the FAO 56 PM equation for daily time step and with the ASCE Standardized equation (ASCE EWRI, 2005) for both daily and hourly time steps for 37 different studied sites in the state of California, USA. The limitation of this method is that this method may not be applicable in different climatic conditions as the coefficients were mainly developed for the climatic condition of California.

2.5.3 Penman-Monteith equation

Monteith (1965) introduced some crop resistance terms in the original Penman equation and the equation later became the well-known "Penman-Monteith" (PM) FT equation. This equation is physically based and its robustness has been demonstrated as it does not require local calibrations, provided there are complete input data (Temesgen *et al*., 2005; Allen *et al*., 1999). This equation does not have any wind function; rather it has aerodynamic and surface resistance terms. The wind function in the Penman equation is calculated empirically whereas the aerodynamic and surface resistance terms are calculated using physically based and semi-empirical equations, respectively. Aerodynamic resistance (r_o) is the resistance to molecular and turbulent diffusion of water vapor between leaf surfaces and the air above the canopy at a reference height (Robins, 1974). Surface resistance (r_o) is the resistance to the diffusion of water vapor within the evaporating surface (Monteith *et al*,, 1965). The popular reference FT equations like the FAO 56 PM equation and the ASCE Standardized Reference PM ET equations are also based on the Penman Monteith equation. Equation (2.18) is the so called Penman-Monteith (1965) equation: Eqn 2.18

$$\lambda E = \frac{(\Delta(R_n - G) + PC_p(e_a - e_a)/e_a}{\Delta + \gamma(1 + r_c/r_a)} \qquad (2.18)$$

In the PM equation, all other parameters except r are relatively straightforward to calculate. A procedure has been developed to calculate r for grass and alfalfa surfaces, For this reason, to calculate the actual crop ET, the procedure is to first calculate the reference crop ET considering the grass or alfalfa as the reference crop surface and then multiplying the reference ET by the an appropriate crop coefficients. Direct use of the PM equation (Equation 18) to calculate actual crop ET (for any crop type is very rare in practice, although some researchers have tried this recently, which will be discussed in subsequent paragraphs.

2.6 Priestley and Taylor Method

Priestley and Taylor (1972) developed a semi-empirical equation to calculate potential evaporation (λE or ET), which is applicable for partial equilibrium conditions. Their equation is as follows: 2.19

$$\lambda E = a \frac{\Delta(R_n - G}{\Delta + \gamma} \qquad (2.19)$$

where a is a variable that can range from 1.15 to 1.50 depending on the surface type, climate and season. For water surfaces under condition of minimal advection, Priestley and Taylor (1972) approximated the value of a as 1.26. The value of a will be different for different crops and open water bodies. Researchers are still working on finding appropriate value of a different surface. Hobbins *et al*. (2001) found he value of a as 1.3 177 for vegetation while using a calibration subset of 92 basins. This method is more suitable to find the ET rate on a large scale which is more applicable in hydrology. The disadvantage of this method is that it is not applicable in advective condition. This method is simpler to use than the PM equation as it has less parameters and variables.

2.7 Fixed Surface Resistance Approach

Allen *et al*. (1998) developed guidelines for computing crop water requirements or ET0, in the FAO 56 PM paper. They recommended using the PM equation to

calculate reference grass ET based on surface canopy resistance and aerodynamic resistance, they also tabulated the crop coefficient (K_s) values for the initial, mid and end stages for various crops based on previous researchers' findings. The FAQ 56 PM equation was modified mainly to calculate daily crop ET; however, the authors claimed that it can also be used to calculate hourly crop ET if the needed input hourly weather data are available. The FAO 56 PM method assumes a fixed surface resistance of 70 s/m for the entire day or 24 hours. The fixed surface resistance value for 24 hours has been used for the daily or hourly FAO 56 PM equation.

In many parts of the world, including the US, alfalfa is used as another reference crop instead of clipped grass. Alfalfa can tolerate harsh weather conditions compared to the grass surface cover, Keeping this in mind, in 1999, the Irrigation Association (IA) requested the Evapotranspiration in Irrigation and Hydrology task Committee of the American Society of Civil Engineers (ASCE)-Environmental and Water Resources Institute (EWRI) to establish and define a benchmark reference evapotranspiration equation. Later, the ASCE EWRI ET task committee, in 2005, developed a reference evapotranspiration equation which is applicable for both tall (alfalfa) and short (grass) reference crops. As part of the standardization, the ASCE Penman-Monteith (ASCE-PM) equation and associated equations for calculating aerodynamic and bulk surface resistance have been combined and condensed into a single equation that is applicable to both surfaces (ASCE-EWRI, 2005). For the ASCE standardized PM equation, there is one fixed surface resistance for daytime and another fixed surface resistance for nighttime for each reference crop, hence this method is an improved version over the FAO 56 PM (Allen *et al*., 1998) equation.

2.7.1 FAQ 56 Penman-Monteith equation

The FAO 56 PM equation was based on the Penman-Monteith equation. The FAO 56 PM method defines the reference crop as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s/m and an albedo of 0.23, closely resembling the evaporation of an extensive surface of green grass of uniform height, actively growing and adequately watered. Equation (18) can be approximated to Equation (2.20) after using the aerodynamic and surface resistance equations, which is the FAO 56 PM equation. Eqn 2.20

$$ET_0 = \frac{0.408\Delta(R_n - G) + \left[\frac{\gamma 900}{T_a + 273}\right] 2_2\ (a_s - e_a)}{(\Delta + \gamma(1 + 0.34u_2)} \qquad (2.20)$$

where,

FT_0 grass reference ET (mm/d);

R_n = net radiation at the crop surface ($MJ/m^2/d$);

G = soil heat flux density ($MJ/m^2/d$).

The equations used for aerodynamic and surface resistances while deriving FAQ 56 PM equation are as follows: Eqn 2.21

$$R_a = \frac{ln\left[\frac{Z_m - d}{Z_{mom}}\right] ln\left[\frac{Z_h - d}{Z_{oh}}\right]}{K^2 U_z} \quad (2.21)$$

where r_a is the aerodynamic resistance (s/rn) for neutral atmospheric conditions, z_m is height of wind speed measurements (m), zh, is height of humidity measurements (in), d is zero plane displacement height (in) = 0.67h_c, h_c is the crop height (m), z_{om} = 0.123 h_c. is the roughness length governing transfer of momentum (m), z_{oh}, = 0.1 Z_{om} is the roughness length governing transfer of heat and water vapor (m), (Allen *et al.*, 1998), k is von-Karman's constant (taken as 0.41), and u is wind speed at height z (m/s).Eqn 2.22

$$r_c = \frac{r1}{0.5\ LAI} \quad (2.22)$$

where r_c is the canopy resistance (s rn^{-1}), r_1 is the daily average stomata resistance (which is assumed as 100 s m^{-1} for clipped grass and full cover alfalfa), and LAI is leaf area index (rn^2/m^2). k'

Lopez-Urrea *et al*. (2006) found that the FAO 56 PM equation performed better under semiarid climatic conditions of Albacete, Spain, as it agreed well with

measured lysimeter ET compared to other versions of Penman equations and Hargreaves and Sarnani (1985) equation.

2.7.2 ASCE-EWRJ Standardized Penman Monteith evapotranspiration equation

The ASCE Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005) is based on the Penman-Monteith equation, with some simplification and standardization on the aerodynamic and surface resistances. This equation is applicable for both tall (alfalfa) and short (grass) reference surfaces. A grass reference crop is defined as an extensive, uniform surface of dense, actively growing, cool-season grass with a height of 0.12m, and not short of soil water; whereas a full cover alfalfa reference crop is defined as an extensive, uniform surface of dense, actively growing alfalfa with a height of 0.50 m, and not short of soil water (ASCE-EWRI, 2005). The equation is as follows: Eqn 2.23

$$ET_{Sz} = \frac{0.408\Delta(R_n - G) + \gamma C_n U_2 \frac{e_s - e_a}{T_a + 273}}{\Delta + \gamma\,(1 + C_d U_2)} \qquad (2.23)$$

where,

ET_{sz} = standardized reference crop evapotranspiration for short crop (grass) (EL_{os}) or tall crop (alfalfa) (ET_{ts}) surfaces (mm/d for daily time steps or mm/h for hourly time steps);

Rn= calculated net radiation at the crop surface ($MJ/m^2/d$ for daily time steps or $MJ/m^2/h$ for hourly time steps); G = soil heat flux density at the soil surface ($MJ/m^2/d$ for daily time steps or $MJ/m^2/h$ for hourly time steps);

The values for C_n for the short and tail references are 900 and 1600, respectively, for the daily time steps whereas the C_n are 37 and 66 for hourly time steps for both crops, respectively. Similarly the values for C_d for the short and tall reference crops are 0.34 and 0.38 for daily time steps whereas the C_d values for a short crop are 0.24 and 0.96 for daytime and for night time, respectively. For a tall alfalfa reference crop, the C_d values are 0.25 and 1.7 for daytime and night time, respectively. C_n is a function of the time step and aerodynamic resistance whereas C_d is a function of the time step, surface resistance and aerodynamic resistance (ASCE-EWRI, 2005).

Irmak *et al*. (2005) found a good correlation between the ASCE Standardized ET_o equation results and the FAO 56 PM EL results calculated on hourly time steps. However, the FAO 56 PM method estimated 5% to 8% lower ET. compared to the ASCE Standardized ET_o . According to Inmak *et al*. (2005) the results may be due to the higher surface resistance values during daytime periods in the FAO 56 PM equation. The authors also compared the daily ET_o given by the ASCE Standardized daily ET_o equation with the sum of the hourly ET_o calculated using the ASCE Standardized hourly equation. They observed that the daily ET_0 values were generally higher than the sum of the hourly ET_o and they recommended to use the hourly ET_o, values especially in advective condition.

2.7.3 Valiantzas Model

Valiantzas (2006) developed a set of equations to determine the ET_o rate based on simplifications made to the Penman (1963) equation. His purpose was to enable ET_o computation with limited meteorological data. Valiantzas (2013a) then improved these equations and claimed that his model performed equivalent in accuracy to the Penman (1963) equation. 1-us simplified equation to calculate grass reference ET is as follows: 2.24

$$ET_o \approx 0.0393 R_s \sqrt{T_a + 9.5} - 0.19 R_s^{\ 0.6} \varphi^{0.15} + 0.048 (T_a + 20)\left(1 - \frac{RH}{100}\right) U_2^{\ 0.7} \quad (2.24)$$

where, ET_{sz} is the grass reference ET (mm/d), R, is the measured or estimated incoming solar radiation ($MJ/m_2/d$), T_a is the mean daily air temperature (°C), φ is the latitude of the site (radians), RH is the relative humidity (%) and u_2 is the mean wind speed at 2 in height (m/s). He also developed an equation to calculate reference ET when the wind speed data is not available.

The equation is as follows: Eqn 2.25

$$ET_o = 0.0393 R_s \sqrt{T_a + 9.5} - 0.19 R_s^{\ 0.6} \varphi^{0.15} + 0.078 (T_a + 20)\left(1 - \frac{RH}{100}\right) \quad \text{-----}(2.25)$$

Valiantzas (2013b) also developed a set of equations to calculate reference ET for arid and humid regions. His equation to calculate reference ET with two different aerodynamic term weighted factors is as follows: Eqn 2.26

$$ET_a= \quad 0.0393R_s\sqrt{T_a + 9.5}-2.4\left(\frac{R_s}{R_a}\right)^2-0.024(T_a + 20)\left(1 - \frac{RH}{100}\right) + w_{aero}0.066(T_a + 20)(1-\frac{RH}{100})u^{0.6} \qquad (2.26)$$

where, R_a is the extraterrestrial radiation ($MJ/m^2/d$) and W_{aero} is an empirical weighted factor. The value of W_{aero} is as follows:

W_{acro} = 0,78 when RH> 65%; W_{aero} = 1.067 when RH ≤ 65%.

when the wind speed data is not available, the following equation applies: Eqn 2.27

$$ET_0 =0.0393R_s\sqrt{T_a + 9.5} – 2.4 \left(\frac{R_s}{R_a}\right)^2+C_u (T_a + 2)\left(1 - \frac{RH}{100}\right) \qquad (2.27)$$

where, C_u = 0.054 when RH > 65% and 0.083 when RH ≤ 65%.

Valiantzas' model might be a good substitute when some weather data are missing. However, when there are good quality data available, the use of the mechanistic Penman-Monteith equation are more appropriate than the empirical methods.

2.8 Variable Surface Resistance Approach

All of the above mentioned equations, in section 2.7, calculate ET for a reference crop surface; which is either grass or alfalfa. In order to calculate the actual crop ET, the current practice is to multiply the reference crop ET with a crop coefficient

(K_c). Crop coefficients have been developed for different crop growth stages for various crops. However, Katerji and Rana (2006) have pointed out that the difference of ± 40% could be observed between the K0 values reported by Allen *et al*. (1998) and the experimentally obtained K_c values from different researchers. Based on findings from previous researchers (Rana *et al*, 1994; Ventura *et al*., 1999; Pereira, 2005; De Medeiros *et al*., 2006). Katerji and Rana (2006) indicated that there is up to 18% of underestimation and 13.4% of overestimation in ET_0 in semi-arid regions and humid regions, respectively, due to the use of fixed r0 values. Hence, the cumulative error from reference ET_o calculation and the use of K_c may be significant which could be a concern for irrigation water management purposes. In order to address this problem, some researchers have started to use variable surface resistance instead of fixed surface resistance to calculate actual crop ET directly without using the crop coefficient approach. This new approach is also called the one step crop ET estimation approach as there is no need of using the crop coefficients (a two-step approach). The variable surface resistance approaches that have been developed so far are discussed below:

2.8.1 Jarvis model

Jarvis (1976) developed a multiplicative model to calculate stomata resistance from weather parameters including air temperature, vapor pressure deficit, leaf water potential and ambient carbon dioxide ($C0_2$) concentration. However, the

Penman-Monteith equation requires the bulk surface resistance and hence the knowledge of stomata resistance only may not be enough to calculate ET. The ups calling of the stomata resistance to the canopy level is required to calculate the bulk surface resistance. Alves and Pereira (1999) objected the methodology adopted by Jarvis, as they questioned the validity of the multiplicative model and also they expressed doubt in the assumption of weather parameters acting independently.

2.8.2 Katerji and Perrier (KP) model

Katerji and Perrier (1983) found that a linear relationship can be established between the two ratios r_c/r_a and r^*/r_a, where r* is a climatic resistance term. They developed the following empirical relationship. Eqn 2.28

$$\frac{r_c}{r_a} = a\frac{r}{r_a} + b \qquad (2.28)$$

where, a and b are empirical calibration coefficients requiring experimental determination. The resistance, r*, is defined as: Eqn 2.29

$$r^* = \frac{\Delta+\gamma}{\Delta\gamma} \; \frac{pc_pD}{R_n - R} \qquad (2.29)$$

where D is the vapor pressure deficit (kPa), the units of R_n and G are W/m^2.

Katerji and Rana (2006) reported that the coefficients a and b have already been developed for alfalfa, rice, grass, lettuce, sweet sorghum, sunflower, grain sorghum, soybean, clementine orchard and sloping grassland. The coefficients have also been adapted for water stress conditions (Rana *et al*, 1997, 2001).

Rana *et al*. (1997) claimed that the coefficients "a" and "b" have multi-local validity (i.e. they do not change with the site but only with the crop species).

The downside of this method is that there seems to be no physical meaning for these coefficients. In addition, the coefficients need to be tested for different crop species. Alves and Pereira (1999) indicated that Equation (2.28) is only valid for periods where the Bowen ratio varies between -0.3 and 0.3,

2.8.3 Todorovic model

Todorovic (1999) presented a mechanistic approach to calculate surface resistance using weather variables. His summarized methodology is as follows: Eqn 2.30

$$t = \frac{\gamma}{\Delta}\frac{D}{(\Delta+\gamma)} \qquad (2.30)$$

Firstly, t which is the difference between actual canopy temperature and canopy temperature (°C) in wet conditions is calculated using Equation (30). Then, using a quadratic Equation (2.31), X, which is the ratio of surface resistance (r_c) to climatological resistance (r_i) is calculated. Eqns. 2.31- 2.34

$$X= \frac{a+\sqrt{b^2-4_{ac}}}{2a} \qquad (2.31)$$

where,

$$a \quad = \frac{\Delta+\gamma\Delta}{\Delta+\gamma}\ \gamma D \tag{2.32}$$

$$b \quad = b = -\gamma Yt \tag{2.33}$$

$$c \quad = -(\Delta+\gamma)t \tag{2.34}$$

The climatological resistance (ri) can be calculated using: Eqn 2.35

$$r_i = \frac{pc_p D}{\gamma(R_n - G)} \tag{2.35}$$

In Equation (2.33), Y is the ratio of climatological resistance (r_i) to aerodynamic resistance (r_a). The units of all the resistances, which is the reciprocal of conductance, are in slim Rn and C in Equation (2.35) are in $W1m^2$.

Secondly, after finding X, r_c is calculated by multiplying X by r_i .The calculated r will be inserted in the Penman-Monteith Equation (2.18) to calculate the actual crop ET. The actual crop ET can be defined as the rate of ET that occurs under field-environmental-surface condition which may depart from the ideal “standard” conditions.

Shi *et al.* (2008) found that the KP model agreed better with the measured eddy covariance ET values for half-hourly and daily ET by summing the half-hourly ET values. They reported that the Todorovic model overestimated ET by about 30% in their experimental site in China.

2.8.4 Li, L., Yu, Q., Su, Z., & Tol, C. Van der. model

Li *et al*. (2009) found sonic errors in the Todorovic model in the derivation of ”t”. Li *et al*. (2009) derived “t” as: Eqn 2.36

$$t = \frac{\gamma DC}{\Delta(\Delta+\gamma)} \qquad (2.36)$$

Li *et al* (2009) proved that Todorovic’s method missed the term C while deriving “t”. The missing parameter C was described as shown in Equation (2.37):

$$C = \frac{\left(\frac{\Delta}{\gamma}\right)\left(\frac{1}{r_i}\right)+\left(\frac{1}{r_a}\right)}{\left(1+\frac{\gamma}{\Delta}\right)\left(\frac{1}{r_c}\right)+\left(\frac{\gamma}{\Delta}\right)\left(\frac{1}{r_a}\right)} \qquad (2.37)$$

In their article, Li *et al*. (2009) replaced C with $(1 + D/D_0)$, where D_0 is a parameter which accounts for the response oft to vapor pressure deficit (D). They used D+ as 1.5 kPa for their research, which they claimed was applicable for the winter wheat crop in the North China Plain. They also mentioned that the value of D_0 can vary with crops and climatic conditions.

Li *et al*. (2009) showed that Todorovic model severely underestimated the canopy temperature and sensible heat flux and severely overestimated the latent heat flux. On the other hand, their model gave acceptable results for latent heat flux at both half-hourly and hourly time scales. The limitation of this method is that there seems to be no physical meaning of D_0 and the value of D_0 is needed to compute "t" and ultimately "rc".

2.8.5 Shuttleworth model

Shuttleworth (2006) introduced the concept of the crop independent blending high (50 m) to use as a reference height instead of 2m reference height to enable the one step ET (ET_a) calculation for different crops.

Shuttleworth(2006) used the existing PM equation and then calculated r_c, as a function of weather variables and K_c values documented in FAO 56 PM publication (Allen *et al*., 1998). They worked on a daily time step instead of hourly; hence their model is not applicable for hourly ET estimation. They concluded that the use of fixed crop coefficients (K_c) to calculate actual crop ET can be problematic. The authors mentioned that the recommended K values are said to be appropriate for wind speeds of 2 m/s and "humid" conditions with 45% relative humidity. Whenever the weather conditions differ then the reported values of K cannot provide reasonable estimates of ET. The authors also mentioned that the FAO 56 PM equation and the Priestley-Taylor equation with a = 1.26 give identical ET values in "humid" conditions, They showed from their Equation (2.11) that the ambient weather changes the value of the K_c via the values of the climatological resistance and wind speed. They developed a relationship between r_c and K_c where r_c was a function of k_c, r_s^i and r_s^2, where r_s^1 and r_s^2 could be calculated using their Equations (14) and (15) or performing interpolation from their Table 1 (See Appendix). The authors concluded that use of their approach will yield estimates of ET as good as those given by the FAO 56 PM model in humid conditions whereas it improves ET estimation for arid climates and for taller crops.

2.8.6 Irmak and Mutiibwaa model

Irmak *et al*. (2008) were able to upscale stomata resistance (leaf scale) to the whole canopy surface resistance for maize using photosynthetic photon flux density (PPFD), leaf area index (LAI) for sunlit and shaded leaves, solar zenith angle, direct and diffuse solar radiation. They measured the stomata resistance using parameters. They developed their model for corn and then successfully validated it for soybean with recalibration of some parameters (Irmak & Mutiibwa, 2008; Irmak *et al*., 2008; Mutiibwa & In Irmak, 2010, 2012; Irmak *et al*., 2013). Irmak and Mutiibwa (2009) showed that the estimation of crop ET using the one step approach was better (an improvement) compared to the two step approach (i.e. using the reference crop ET multiplied by the crop coefficients). The one step approach ET was within 2 per cent of measured ET using the Bowen Ratio instrument whereas for the two step ET calculation, there was no distinct pattern of over or under estimation. On the other hand, the two step ET method underestimated actual ET (measured) especially when there was high evaporative demand according to the authors. This result suggests that the use of fixed surface resistance while calculating the reference ET is not appropriate (Irmak & Mutibwaa, 2009).

Irmak and Mutibwaa (2009) were able to modify the Jarvis model, which they referred to as Modified-Jarvis-model (NMJ) and showed that their model is an improvement to the older version, as NMJ model improved the stomata resistance estimation by 10% in RMSD (root mean square deviation) when compared to the measured stomata resistance using a dynamic diffusion pyrometer. Irmak and Mutiibwa (2010) developed a set of empirical equations for no stressed maize crop to calculate r_0 from weather variables. They used the measured ET from a Bowen Ratio instrument, and then inverted the PM equation to back calculate r. Then, they used a linear regression technique to find the relationship between r_o and a_o set of weather variables. Irmak *et al.* (2013) also developed similar set of empirical equations for soybean crop to calculate r from weather variables

2.8.7: BLANEY-MORIN-NIGERA (BMN) MODEL

Duru (1984) presented a modified form of the Blaney-Morin potential evapo-transpiration equation christened Blaney-Morin-Nigeria(BMN) evapotranspiration (ET) model for use in Nigeria. In the work, the very wide variability of relative humidity in Nigeria and consequently the very important role this parameter is bound to play in the evapo-transpiration process in this geographical region (Nigeria) was recognized.

The author correctly surmised that any evapo-transpiration model that would reasonably estimate Potential evapo-transpiration (PET) in Nigeria must involve humidity term as a crucial parameter.

The BMN model (Eqn1.1) is currently the only evapo-transpiration model specifically developed for the Nigerian condition and, as would be expected, is enjoying wide use in the country. Eqn 2.38

$$\mathbf{Etp = r_f * \frac{(0.45t + 8)(520 - R^{1.31})}{100}} \quad ------(\mathbf{2.38})$$

Where

Etp = Potential evapotranspiration (mm/day).

r_f = ratio of maximum possible radiation to the annual maximum.

t = temperature (^{0}C)

R = Relative humidity (%)

Conclusively, the above models did not directly talk about Relative Humidity models but this work focuses on the development of relative humidity model that can be applied to Blaney-Morin Nigeria model to estimate evapo-transpiration.

Effect of Relative Humidity on Crop Production.

According to Tamil Nadu Agricultural University (TNAU-2006), Relative Humidity (RH) directly influences the water relations of plant and indirectly affects leaf growth, photosynthesis, pollination, occurrence of diseases and finally economic yield.

The dryness of the atmosphere as represented by saturation deficit (100-RH) reduces dry matter production through stomata control and leaf water potential.

Very high Relative Humidity reduces evapo-transpiration, Increases heat load of plants, Stomata closure, Reduced $C0_2$ uptake, Reduced transpiration influences translocation of food materials and nutrients, Moderately high RH of 60-70% is beneficial and Low RH increases the evapo-transpiration.

CHAPTER THREE

MATERIALS AND METHODS

3.1: Study Area

The study area is Ohaji-Egbema Local Government Area of Imo State; South Eastern Nigeria. It lies on the geographical coordinates of 06° 8' 5" N, 5° 22' 53" E. Aninri also located in Southern Nigeria, lies on the geographical coordinates of 6^0 03'N 7° 35'E / 6.050^0N 7.583^0E respectively. Ohaji-Egbema covers about $890km^2$ of land. The population is 182,538 at the 2006 census. Aninri on the other hand has an area of $364km^2$ and a population of 133,723 at the 2006 census.

Plates 3.1 and 3.2 is the location maps of Imo and Enugu States in which the Ohaji-Egbema and Aninri Local Government Areas are found.

Plate3.1: Location map of Imo the study Area

Source is www.researcchgate.net

Plate 3.2: Location map of Enugu the study Area

Source is www.researcchgate.net

3.2 Materials:

The weather measuring equipment utilized by Nigerian Meteorological Agency (NIMET) are as follows: Thermometer (Casella Inc.), Barometer (Lambert Inc.), Rain Gauge (Casella Inc.), Sunshine Recorder (Casella Inc.), Wind Vane (Lambert Inc.) and Hygrometer (Casella Inc.) were used to generate data from year 1991 – 2010 for Maximum and Minimum Temperatures, Vapour Pressure, Rainfall Intensity, Sunshine Hours, Wind Speed and Relative Humidity respectively.

3.3 Methods:

Using SPSS (Statistical Package for Social Sciences), multiple linear regression was run to predict relative humidity (monthly) from minimum temperature, maximum temperature, rainfall, Sunshine hours, Wind speed and vapour pressure, but the effective variables that influenced monthly relative humidity are: Minimum temperature, Maximum Temperature, rainfall, Sunshine hours and vapour pressure of the locations. These independent variables were statistically significant and predicted monthly relative humidity.

After developing the model, The Validation of the model was done using the Percentage Error (PE) Technique. Thus:

$$\textbf{Percentage Error (PE)} = \left|\frac{\textbf{Measured RH} - \textbf{Caculated RH}}{\textbf{Measured RH}}\right| * \mathbf{100\%} \text{ ....}\mathbf{3.1}$$

For three remaining years (2008-2010), the values of the parameters not used in developing the model, was utilized in estimating Monthly Relative humidity.

The statistical analysis was described using Microsoft Excel 2007 version and Statistical Package for Social Sciences (SPSS). The relative humidity data for 20 years for both Imo and Enugu were collected from Nigerian Meteorological Agency, NIMET, Oshodi, Lagos, Nigeria. The data was recorded on monthly basis using the standard time of Greenwich Meridian Time (GMT). The Standard deviation was computed for each month of the year. Out of the 20 years data obtained from NIMET, 17 years data was used to develop the model and the remaining 3years data was used to validate the model.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

The Table 4.1.1 below is the mean values of the raw data for the climate properties in Enugu State.

Table 4.1.1: Mean Values of the raw data for the climate properties in Enugu State

Month	R.H	Min. Tempt.	Max. Tempt.	Rainfall Intensity	Sunshine Hours	Windspeed	Vapour Pressure
Jan.	54.588	20.977	33.594	6.9471	5.9000	6.1471	20.1882
Feb.	58.882	22.718	35.588	12.4353	5.9824	6.1647	22.9588
Mar.	68.824	24.259	35.129	60.4824	5.4588	6.8353	27.1529
Apr.	75.706	23.959	33.735	174.529	5.9529	6.5118	29.1118
May.	80.177	23.077	31.894	254.818	5.9000	5.6765	29.1235
June	82.529	22.771	30.777	281.953	5.1471	5.4647	28.3000
July	83.765	22.288	29.700	277.953	3.7294	5.9824	27.5824
Aug.	83.824	22.288	29.388	236.041	3.3118	5.6471	27.5824
Sept.	84.177	22.206	30.212	277.100	4.0588	5.3059	27.8824
Oct.	82.000	22.247	31.065	210.835	5.4941	4.9118	28.3353
Nov.	72.7647	21.9059	32.7647	20.0059	7.0588	4.6059	27.1882
Dec.	59.7647	20.2235	33.1765	2.0882	6.7941	5.6294	21.8412

The Table 4.1.2 below is the mean values of the raw data for the climate properties in Imo State.

Table 4.1.2: Mean Values of the raw data for the climate properties in Imo State

Month	R.H	Min. Tempt.	Max. Tempt.	Rainfall Intensity	Sunshine Hours	Windspeed	Vapour Pressure
Jan.	66.882	22.894	33.835	34.0000	4.9824	3.7118	24.0353
Feb.	71.529	24.294	35.071	42.8235	4.9647	3.6000	27.9059
Mar.	76.882	24.382	34.012	118.853	4.6588	3.6647	30.2118
Apr.	78.177	24.247	33.247	192.794	4.9059	3.9235	30.7529
May.	79.588	23.735	32.194	285.924	5.2529	3.5353	30.2941
June	83.706	23.406	30.888	363.294	4.1118	3.7294	29.5588
July	87.059	22.959	29.335	359.270	3.0353	3.3235	28.8353
Aug.	86.882	22.924	29.482	343.694	3.0235	3.5882	28.7294
Sept.	84.706	23.129	30.365	369.812	3.2000	3.4059	29.1529
Oct.	82.235	23.135	31.177	215.088	3.8647	3.1588	29.5412
Nov.	76.1765	23.5882	32.9824	73.5941	5.3176	2.9118	29.2882
Dec.	70.8235	22.5824	33.6000	17.6625	5.3765	3.2765	26.5529

The test of homogeneity of variance for Enugu data is as shown in Table 4.1.3below.

Table 4.1.3: Test of homogeneity of variance for Enugu data.

	Levene Statistic	df1	df2	Sig.
VapourPressure	18.951	11	192	0.000
Windspeed	.970	11	192	0.475
RelativeHumidity	16.581	11	192	0.000
Sunshine Hours	2.219	11	192	0.015
Rainfall Intensity	8.410	11	192	0.000
Tmax	1.975	11	192	0.033
Tmin.	8.065	11	192	0.000

The test of homogeneity of variance for Enugu data is as shown in Table 4.1.4 below.

Table 4.1.4: Test of homogeneity of variance for Imo State data.

Property	Levene	df1	df2	Sig.
Vapour Pressure	15.945	11	192	0.000
Wind speed	1.668	11	192	0.083
Relative Humidity	13.316	11	192	0.000
Sunshine Hours	1.019	11	192	0.431
Rainfall Intensity	5.762	11	191	0.000
Tmax	1.124	11	192	0.344
Tmin	3.883	11	192	0.000

Tables 4.1.5 and 4.1.6 respectively are the mean comparison technique using DMRT method.

Table 4.1.5: Mean comparison table using Duncan's Multiple Range test (DMRT) for Enugu State model

Properties/months	RH	Minimum Temperature	Maximum Temperature	Rainfall Intensity	Sunshine Hours	Wind speed	Vapour pressure
JAN.	54.5882[a] (12.23243)	20.9765[b] (1.56146)	33.5941[f] (.71891)	6.9471[a] (14.45355)	5.9000[d] (1.13633)	6.1471[def] (1.00568)	20.1882[a] (4.65630)
FEB.	58.8824[ab] (11.96287)	22.7176[de] (1.45569)	35.5882[h] (.63333)	12.4353[a] (15.02073)	5.9824[d] (.97162)	6.1647[def] (1.05708)	22.9588[b] (4.74184)
MAR.	68.8235[c] (4.96532)	24.2588[e] (.61039)	35.1294[h] (1.02881)	60.4824[b] (47.22829)	5.4588[cd] (.94674)	6.8353[f] (.84701)	27.1529[c] (2.61561)
APR.	75.7059[de] (2.51905)	23.9588[f] (.61549)	33.7353[f] (1.21601)	174.5294[c] (67.37813)	5.9529[d] (.55013)	6.5118[ef] (1.00616)	29.1118[c] (.67164)
MAY.	80.1765[ef] (1.84510)	23.0765[f] (.50686)	31.8941[e] (.80891)	254.8176[e] (75.83542)	5.9000[d] (.53385)	5.6765[bcd] (.99971)	29.1235[c] (.53797)
JUNE.	82.5294[f] (1.28051)	22.7706[de] (.35314)	30.7765[cd] (.62102)	281.9529[e] (61.91416)	5.1471[c] (.59804)	5.4647[bcd] (.96238)	28.3000[c] (.47958)
JULY.	83.7647[f] (1.88843)	22.2882[cd] (.48203)	29.7000[ab] (.54083)	277.9529[e] (77.22232)	3.7294[ab] (.77117)	5.9824[cde] (.64152)	27.5824[c] (.70466)
AUG.	83.8235[f] (3.64409)	22.2882[cd] (.49356)	29.3882[a] (.45122)	236.0412[de] (98.49780)	3.3118[a] (.75489)	5.6471[bcd] (1.66813)	27.5824[c] (1.12763)
SEPT.	84.1765[f] (1.84510)	22.2059[cd] (0.5344)	30.2118[bc] (.48847)	277.1000[e] (66.08499)	4.0588[b] (.49378)	5.3059[abc] (.83925)	27.8824[c] (.53995)
OCT.	82.0000[f] (1.41421)	22.2471[cd] (0.3393)	31.0647[d] (.80307)	210.8353[cd] (84.75808)	5.4941[cd] (.50925)	4.9118[ab] (.75571)	28.3353[c] (.69367)
NOV.	72.7647[cd] (5.65165)	21.9059[c] (1.10988)	32.7647[f] (.73988)	20.0059[ab] (25.76324)	7.0588[e] (.75669)	4.6059[a] (.93171)	27.1882[c] (2.74246)
DEC.	59.7647[b] (11.93487)	20.2235[a] (1.17714)	33.1765[fg] (1.47416)	2.0882[a] (5.25914)	6.7941[e] (1.00590)	5.6294[bcd] (1.20248)	21.8412[b] (3.67050)

NB: 1. Group means with different superscript(s) in same column are significantly different from each other.
2. Values in parenthesis represent the standard deviation for each mean value.

Table 4.1.6: Mean comparison table using Duncan's Multiple Range test (DMRT) for Imo State model

Properties/months	RH	Minimum Temperature	Maximum Temperature	Rainfall Intensity	Sunshine Hours	Wind speed	Vapour pressure
JAN.	66.8824[a] (11.58600)	22.8941[ab] (1.65472)	33.8353[fg] (.68002)	34.0000[a] (30.60864)	4.9824[e] (.85676)	3.7118[bc] (1.43217)	24.0353[a] (5.12225)
FEB.	71.5294[b] (9.70256)	24.2941[e] (1.02620)	35.0706[fg] (.89076)	42.8235[a] (38.61260)	4.9647[e] (.78735)	3.6000[bc] (.55227)	27.9059[bc] (4.08648)
MAR.	76.8824[c] (2.80362)	24.3824[e] (.64249)	34.0118[g] (.90200)	118.8529[b] (62.79734)	4.6588[cde] (1.14677)	3.6647[bc] (.57221)	30.2118[de] (.90890)
APR.	78.1765[c] (1.87867)	24.2471[de] (.63553)	33.2471[ef] (.87758)	192.7941[c] (75.69899)	4.9059[de] (1.15080)	3.9235[c] (.69510)	30.7529[e] (.64335)
MAY.	79.5882[cd] (1.62245)	23.7353[cde] (.59890)	32.1941[d] (.66094)	285.9235[d] (116.70657)	5.2529[e] (1.55367)	3.5353[bc] (.48340)	30.2941[e] (.78060)
JUNE.	83.7059[ef] (1.57181)	23.4059[bc] (.54253)	30.8882[bc] (.66791)	363.2941[e] (92.21455)	4.1118[cd] (1.13186)	3.7294[bc] (.65457)	29.5588[cde] (.48484)
JULY.	87.0588[f] (1.19742)	22.9588[ab] (.55233)	29.3353[a] (.76725)	359.2706[e] (122.97227)	3.0353[a] (.94799)	3.3235[abc] (.65434)	28.8353[cd] (.61739)
AUG.	86.8824[e] (1.36393)	22.924[ab] (0.4423)	29.4824[a] (.89109)	343.6941[de] (93.71588)	3.0235[a] (1.75589)	3.5882[bc] (.84844)	28.7294[cd] (.59975)
SEPT.	84.7059[ef] (1.92888)	23.129[abc] (0.5588)	30.3647[b] (.82458)	369.8118[e] (150.73888)	3.2000[ab] (.49875)	3.4059[abc] (.65524)	29.1529[cde] (.64043)
OCT.	82.2353[de] (2.22288)	23.135[abc] (0.7416)	31.1765[c] (.88849)	215.0882[c] (102.31798)	3.8647[bc] (.94402)	3.1588[ab] (.69468)	29.5412[cde] (.78347)
NOV.	76.1765[c] (5.93965)	23.588[bcd] (1.0331)	32.9824[e] (1.08814)	73.5941[ab] (73.51663)	5.3176[e] (1.13316)	2.9118[a] (.60196)	29.2882[cde] (2.10828)
DEC.	70.8235[b] (8.50173)	22.582[a] (1.6471)	33.6000[fg] (.88034)	17.6625[a] (25.31179)	5.3765[e] (.93309)	3.2765[ab] (.82351)	26.5529[b] (3.78618)

NB: 1. Group means with different superscript(s) in same column are significantly different from each other.
2. Values in parenthesis represent the standard deviation for each mean value.

Table 4.1.7 shows the result of the correlation analysis of the monthly relative humidity value against the weather/climate parameters/properties.

Table 4.1.7: Correlation Analysis for Enugu State

Air properties	Coefficient of Correlation, r	p-value	Meaning
RH & Max. Tempt	-0.642**	0.000	Significant
RH & Min. Tempt	0.239**	0.000	Significant
RH & Rainfall Intensity	0.721**	0.000	Significant
RH & Sunshine hours	-0.456**	0.000	Significant
RH & Windspeed	-0.281**	0.000	Significant
RH & Vapour Pressure	0.827**	0.000	Significant

Note: ** means correlation is significant at 0.01 probability level

Table 4.1.8 shows the result of the correlation analysis of the monthly relative humidity value against the weather/climate parameters/properties.

Table 4.1.8: Correlation Analysis for Imo State

Air properties	Coefficient of Correlation, r	p-value	Meaning
RH & Max. Tempt	-0.671**	0.000	Significant
RH & Min. Tempt	0.154**	0.014	Significant
RH & Rainfall Intensity	0.638**	0.000	Significant
RH & Sunshine hours	-0.391**	0.000	Significant
RH & Windspeed	0.039^{ns}	0.290	Not Significant
RH & Vapour Pressure	0.572**	0.000	Significant

Note: ** means correlation is significant at 0.01 probability level

From the **Table 4.1.9** below, the fourth equation seems to be the optimum of the fit using statistical analysis. Thus,

Table 4.1.9: Step wise Regression for Enugu State model

S/N	Equation	R	R^2	R^2_{adj}	F	S.E
1	2.819 + 2.689VP	0.827	0.684	0.682	436.916	6.928
2	87.701 + 2.226VP – 2.252Tmax	0.905	0.819	0.817	453.774	5.260
3	70.680 + 1.993VP – 1.626Tmax + 0.020R	0.916	0.839	0.836	347.171	4.970
4	70.262 + 2.028VP – 1.477Tmax + 0.016R – 0.869SH	0.919	0.845	0.842	270.776	4.891

NB: VP = Vapour Pressure; Tmax = Maximum Temperature; R= Rainfall Intensity and SH= Sunshine Hours

From the **Table 4.1.10** below, the fourth equation seems to be the optimum of the fit using statistical analysis. Thus,

Table 4.1.10: Step wise Regression for Imo State model

S/N	Equation	R	R^2	R^2_{adj}	F	S.E
1	168.048 – 2.775Tmax	0.671	0.450	0.447	164.179	6.119
2	119.614 – 2.573Tmax + 1.459VP	0.843	0.710	0.707	244.936	4.452
3	100.235 – 3.029Tmax + 1.080VP + 1.916Tmin	0.864	0.746	0.743	195.197	4.175
4	99.283 – 3.030Tmax + 1.105VP + 1.805Tmin + 0.828W	0.867	0.753	0.748	150.502	4.134

NB: VP = Vapour Pressure; Tmax = Maximum Temperature; W= Windspeed; Tmin = Minimum Temperature and SH= Sunshine Hours

VALIDATION OF THE DEVELOPED MODEL USING 2008, 2009 AND 2010 DATA FOR ENUGU STATE

The table 4.1.11 below is the validation between Measured and Calculated Monthly RH using Enugu State 2008 Data.

Table 4.1.11: 2008 Validation Table between measured and calculated Monthly RH

Year 2008	Month	Measured RH	Calculated RH Using Equation 3.1	% Error
	Jan.	50.00	52.04	+4.08
	Feb.	58.00	66.80	+15.17
	March	76.00	67.64	-11.00
	April	76.00	72.74	+4.29
	May	78.00	74.96	-3.89
	June	81.00	77.63	-4.16
	July	81.00	80.52	-0.59
	August	81.00	81.99	+1.22
	Sept.	80.00	78.36	-2.05
	Oct.	81.00	77.08	-4.84
	Nov.	77.00	68.89	-10.53
	Dec.	77.00	52.04	-32.42

The table 4.1.12 below is the validation between Measured and Calculated Monthly RH using Enugu State 2009 Data.

Table 4.1.12: 2009 Validation Table between measured and calculated Monthly RH

Year 2009		**Measured RH**	**Calculated RH Using Equation 3.1**	**% Error**
	Jan.	60.00	65.55	+9.25
	Feb.	62.00	73.91	+19.21
	March	70.00	77.91	+11.30
	April	75.00	81.29	+8.39
	May	79.00	81.66	+3.37
	June	81.00	79.51	-1.84
	July	74.00	82.13	+10.99
	August	83.00	83.13	+0.16
	Sept.	81.00	83.24	+2.77
	Oct.	74.00	81.48	+10.11
	Nov.	72.00	80.41	+11.68
	Dec.	75.00	71.64	-4.48

The table 4.1.13 below is the validation between Measured and Calculated Monthly RH using Enugu State 2010 Data.

Table 4.1.13: 2010 Validation Table between measured and calculated Monthly RH

Year 2010		**Measured RH**	**Calculated RH Using Equation 3.1**	**% Error**
	Jan.	77.00	64.47	-16.27
	Feb.	71.00	69.93	-1.51
	March	70.00	73.48	+4.97
	April	74.00	78.95	+6.69
	May	76.00	78.73	+3.59
	June	79.00	82.18	+4.03
	July	85.00	87.17	+2.55
	August	84.00	90.23	+7.42
	Sept.	81.00	88.59	+9.37
	Oct.	78.00	82.09	+5.24
	Nov.	73.00	80.52	+10.30
	Dec.	60.00	75.16	-25.27

VALIDATION OF THE DEVELOPED MODEL USING 2008, 2009 AND 2010 DATA FOR IMO STATE

The table 4.1.14 below is the validation between Measured and Calculated Monthly RH using Imo State 2008 Data.

Table 4.1.14: 2008 Validation Table between measured and calculated Monthly RH

Year 2008	**Month**	**Measured RH**	**Calculated RH Using equation 3.1**	**% Error**
	Jan.	52.00	75.89	+45.94
	Feb.	55.00	62.81	+14.20
	March	75.00	72.84	-2.88
	April	78.00	80.19	+2.81
	May	80.00	82.78	+3.48
	June	83.00	78.23	-5.75
	July	85.00	84.61	-0.46
	August	86.00	82.23	-4.38
	Sept.	89.00	82.36	-7.46
	Oct.	83.00	81.53	-1.77
	Nov.	78.00	76.42	-2.03
	Dec.	68.00	75.34	+10.79

The table 4.1.15 below is the validation between Measured and Calculated Monthly RH using Imo State 2009 Data.

Table 4.1.15: 2009 Validation Table between measured and calculated Monthly RH

Year 2009		**Measured RH**	**Calculated RH Using Equation 3.1**	**% Error**
	Jan.	18.00	65.55	+264.17
	Feb.	15.00	73.91	+392.73
	March	24.00	77.91	+224.63
	April	42.00	81.29	+93.55
	May	50.00	81.66	+63.32
	June	62.00	79.51	+28.24
	July	75.00	82.13	+9.51
	August	76.00	83.13	+9.38
	Sept.	72.00	83.24	+15.61
	Oct.	59.00	81.48	+38.10
	Nov.	26.00	80.41	+209.27
	Dec.	18.00	71.64	+298.00

The table 4.1.16 below is the validation between Measured and Calculated Monthly RH using Imo State 2010 Data.

Table 4.1.16: 2010 Validation Table between measured and calculated Monthly RH

Year 2010		**Measured RH**	**Calculated RH Using Equation 3.1**	**% Error**
	Jan.	16.00	64.47	+302.94
	Feb.	15.00	69.93	+366.20
	March	17.00	73.48	+332.24
	April	25.00	78.95	+215.80
	May	47.00	78.73	+67.51
	June	61.00	82.18	+34.72
	July	71.00	87.17	+.77
	August	77.00	90.23	+17.18
	Sept.	71.00	88.59	+24.77
	Oct.	54.00	82.09	+52.81
	Nov.	27.00	80.52	+198.22
	Dec.	60.00	75.16	+25.27

4.2 DISCUSSION

4.2.1 Discussion of Test Mean Values of the raw data for the climate properties in Enugu State

The mean result of the Enugu State data obtained from Nigerian Meteorological Agency (NIMET) Oshodi, Lagos for the study on Monthly Relative Humidity (R.H) is as shown in Table 4.1.1.

4.2.2 Discussion of Test Mean Values of the raw data for the climate properties in Imo State

The mean result of Imo State data obtained from Nigerian Meteorological Agency (NIMET) Oshodi, Lagos for the study on Monthly Relative Humidity (R.H) is shown in Table 4.1.2.

4.2.3 Discussion of Test of homogeneity of variance for Enugu State Data

From Table 4.1.3 above, The Levene statistic test helps in making decision for the homogeneity of variance of the climatic proper ties in Enugu. It showed that the variability of monthly relative humidity, minimum temperature, rainfall, sunshine, vapour pressure were significantly different in Enugu across the months for 17 years of study, as p-value <0.05. More so, it also showed that the variance of Wind speed and Maximum Temperature in Enugu across the months of study for 17 years are not significantly different as $p \geq 0.05$.

4.2.4 Discussion of Test of homogeneity of variance for Imo State Data

From Table 4.1.4 above, The Levene statistic test helps in making decision for the homogeneity of variance of the climatic properties in Imo state. It showed that the variability of monthly relative humidity, minimum temperature, rainfall, vapour pressure were significantly different in Imo across the months for 17 years of study, as p-value <0.05. More so, it also showed that the variance of sunshine, Wind speed and Maximum Temperature in Imo across the months of study for 17 years are not significantly different as $p \geq 0.05$.

Testing the null hypothesis as stated in Appendix 3, it showed that all the climatic factors/properties considered in the study are highly significantly different from their means between months of the year as p –value < 0.01 ($p<0.01$). This means that the monthly vapour pressure observed at say January for instance is statistically different from that observed at February, March, April, May, June, July, August, September, October, November, December, for the two States.

Likewise that observed for sunshine hour in March is different from that observed in June and other months of the year.

Testing the null hypothesis as stated in Appendix 4, it showed that all the climatic factors/properties considered in the study are highly significantly different from their means between months of the year as p –value < 0.01 ($p<0.01$). This means that the monthly relative humidity observed at say

January for instance is statistically different from that observed at February, March, April, May, June, July, August, September, October, November, December, in Imo.

Likewise that observed for rainfall in March is different from that observed in June and other months of the year.

4.2.5 Discussion of Mean comparison table using Duncan's Multiple Range test (DMRT) for Enugu and Imo State models

From Tables 4.1.5 and 4.1.6, based on the mean comparison technique using DMRT method to discover which of the Monthly climatic/weather factors are similar to the other. It was observed that Monthly relative humidity in February is significantly similar to Relative humidity in December but different from Monthly Relative humidity in March. Similarly, Monthly Relative humidity in June is significantly similar to Monthly Relative humidity in October. Also, Monthly Relative humidity in July, August and September are statistically similar to each other. More so, for Sunshine hours, the months of January, February, March and April are significantly similar to each other but different from the months of June, July, August, September, October, November and December. Similarly, for Wind Speed, the months of January, February, June and July are not significantly different from each other but are significantly different from wind speed in the months of October and November. Also, Rainfall in the months of June, July, August, September and October are not significantly different from each other but are significantly different from that in the Months of January, February, March, April, May and December. Likewise for Maximum Temperature in the month of January, April and December are not significantly different but are significant from the month of February, March, May, June, July and August. Furthermore, the Month of July and August are not significant as well as the month of October and November are not significantly different from one another, as compared with Ngwangwa, *et al* (2014).

4.1.7 Discussion of Correlation Analysis for Enugu State

From the Table 4.1.7 above, the r-value between RH & Vapour pressure exceeds both the tabular r-values at 5% and 1% probability levels. Therefore, it was concluded that the simple linear correlation coefficient is significantly different from zero at 1% probability. This significance (r-value) indicates that there is strong association between RH and the independent variables in a linear function. Also, with an r-value of 0.827, the implication is that 68.39% $\{100r^2=100\ (0.827)^2= 68.39\%\}$ of the variation in RH can be accounted for by the linear function of the vapour pressure in the location of the study. As observed in above Table 4.1.7, the Significant high positive r-value between RH and Rainfall Intensity indicates that there is strong evidence that RH and Rainfall Intensity in Enugu is highly associated with one another in a linear function. Conversely, the significantly high negative r-value indicates that there is strong evidence that the Relative humidity and Maximum Temperature, sunshine hours and wind speed in Enugu is highly associated with one another in a linear function. This linear association shows that the climatic conditions of Enugu with high Relative humidity will have a lower Maximum Temperature and vice versa.

4.1.8 Discussion of Correlation Analysis for Imo State

From the Table 4.1.8 above, the r-value between RH & Vapour pressure exceeds both the tabular r-values at 5% and 1% probability levels. Therefore, it was concluded that the simple linear correlation coefficient is significantly different from zero at 1% probability. This significance (r-value) indicates that there is strong association between RH and the independent variables in a linear function. Also, with an r-value of 0.572, the implication is that 32.7% $\{100r^2=100\ (0.572)^2= 32.7\%\}$ of the variation in RH can be accounted for by the linear function of the vapour pressure in the location of the study.

As observed in Table 4.1.8, the significant high positive r-value between RH

and Rainfall intensity indicates that there is strong evidence that RH and Rainfall Intensity in Imo are highly associated with one another in a linear function. Conversely, the significantly high negative r-value indicates that there is strong evidence that the Relative humidity, Maximum Temperature and sunshine hours in Imo are highly associated with one another in a linear function. This linear association shows that the climatic conditions of Imo with high Relative humidity will have a lower Maximum Temperature and vice versa.

4.1.9 Discussion of Step wise Regression for Enugu and Imo States models

The Tables 4.1.9 and 4.1.10 respectively, listed the best fit equations of the stepwise regression for the different number of model variables including their test characteristics such as correlation, coefficient, R, Coefficient of determination, r^2, adjusted coefficient of determination, R^2_{adj}, F-test and standard error estimates, S.E. for Enugu and Imo States models respectively. Using SPSS software, multiple linear regressions was run to predict monthly relative humidity from Maximum temperature, minimum temperature, Vapour pressure, rainfall, Wind speed and sunshine hour, but the effective variables that influence monthly relative humidity and was retained in the model

Include; vapour pressure, Maximum temperature, rainfall Intensity and Sunshine hours of the Enugu climate. These variables generally were statistically significant and predicted monthly relative humidity as stated in the Table 4.1.9 above. The coefficient of determination, R^2 increased gradually (**Table 4.1.9 above**) until it gets to a point where R^2, which shows that the best model fit has been achieved.

From Table 4.1.9, the Step-wise regression showed the four models with its corresponding coefficient of regression, R, coefficient of determination, R^2, adjusted R^2 , Fisher's estimate and standard error. With four independent variable used in generating the model, the fourth equation seems to be the optimum of the fit using statistical analysis since it is the model with the highest R, R^2, Adjusted R^2 and with the lowest standard error (S.E) as compared with Ngwangwa *et al* (2014). The model stopped at the fourth regression since there are **only** six independent variables for the study of which two (Tmin and Wind speed) were excluded and as such the best fit model is given below.

In stepwise regression analysis, the predictor variables (i.e Vapour pressure, Maximum Temperature, Rainfall intensity and sunshine hours) are inputted in the regression, one at a time, to see the response each predictor variables has on the response variable (Monthly Relative humidity).

Equation 4.1 below, showed that with vapour pressure data values, the correlation coefficient, R =0.827 showed a strong linear correlation with RH. Also, the coefficient of determination, R^2 =0.684, showed a 68.39% variation accounted for, in the regressed equation 4.1

RH = 2.819 + 2.689VP ------------------------------(4.1)

Adding another response variable (Maximum Temperature) gave equation 4.2 This added predictor variable increases the, R=0.905 and R^2 = 0.819 as compared with equation 4.1 above. Thus,

RH = 87.701+ 2.226VP - 2.252Tmax -------------------------(4.2)

Rainfall data was added to the stepwise regression equation and the values of R and R^2 increased to 0.916 and 0.839 respectively. Thus increment in R and R^2 values showed that with the added predictor variables, the equation developed becomes better than the previous one. Thus, with rainfall data added, gave equation 4.3 below.

RH = 70.680 +1.993VP – 1.626 Tmax + 0.020R--------------(4.3)

Equation 4.4 below, gave a better result when Sunshine hours data was added to the regressed equation 4.3. With increased R and R^2 values, equation 4.3 gave:-

RH = 70.262 + 2.028VP – 1.477 Tmax + 0.016R - 0.869SH.-----(4.4)

Finally, adding sunshine hours to the stepwise regression, gave equation 4.4, which is the best of all since wind speed is not significant in the model developed.

Using SPSS software, multiple linear regression was run to predict monthly relative humidity from Maximum temperature, minimum temperature, Vapour pressure, rainfall, Wind speed and sunshine hour, but the effective variables that influence monthly relative humidity and was retained in the model include; Vapour pressure, Maximum and Minimum temperature and Rainfall intensity of Imo climate. These variables generally were statistically, significant and predicted monthly relative humidity as stated in the Table 4.1.10 above.

The coefficient of determination, R^2 increased gradually (**Table 4.1.10 above**) until it gets to a point where R^2, is high which shows that the best model fit has been achieved. From Table 4.1.10, the Step-wise regression showed the four models with its corresponding coefficient of regression, R, coefficient of determination, R^2, adjusted R^2, Fisher's estimate and standard error. With four independent variable used in generating the model, the fourth equation seems to be the optimum of the fit using statistical analysis since it is the model with the highest R, R^2, Adjusted R^2 and with the lowest standard error (S.E) as compared with Ngwangwa *et al* (2014). The model stopped at the fourth regression since there are **only** six independent variables for the study of which two (Sunshine hours & Rainfall intensity) were excluded and as such the best fit model is given in equation 4.8 below.

In stepwise regression analysis, the predictor variables (i.e Maximum Temperature, Vapour pressure, Minimum Temperature and Wind speed) are inputted in the regression, one at a time, to see the response each predictor variables has on the response variable (Monthly Relative humidity).

Equation 4.5 below, showed that Tmax data values, the correlation coefficient, R =0.671 showed a strong linear correlation with RH. Also, the coefficient of determination, R^2 =0.450, showed a 45.02% variation accounted for, in the regressed equation 4.5 below.

RH = 168.048-2.775Tmax ------------------------------(4.5)

Adding another response variable (Vapour Pressure) gave equation 4.6. This added predictor variable increases the, R=0.843 and R^2 = 0.710 as compared with equation 4.5 above. Thus,

RH =119.614 - 2.573Tmax + 1.459Vp -------------------------(4.6)

Tmin data was added to the stepwise regression equation and the values of R and R^2 increased to 0.864 and 0.746 respectively. Thus increment in R and R^2 values showed that with the added predictor variables, the equation developed becomes better than the previous one. Thus, with Tmin data added, gave equation 4.7 below.

RH = 100.235-3.029Tmax+1.080VP+1.916Tmin --------------(4.7)

Equation 4.8 below, gave a better result when minimum temperature data was added to the regressed equation 4. 7 With increased R and R^2 values, equation 4.7 gave:-

RH = 99.283 – 3.030 Tmax + 1.105VP + 1.805Tmin + 0.828W----(4.8)

Finally, adding Wind speed, sunshine hours and Rainfall parameters were excluded and to the stepwise regression, gave equation 4.8 which is the best of all since wind speed is not significant in the model developed.

The Fig. 4.1 below shows the plots of Measured and Calculated Monthly RH for 2008, 2009 and 2010 in Enugu State.

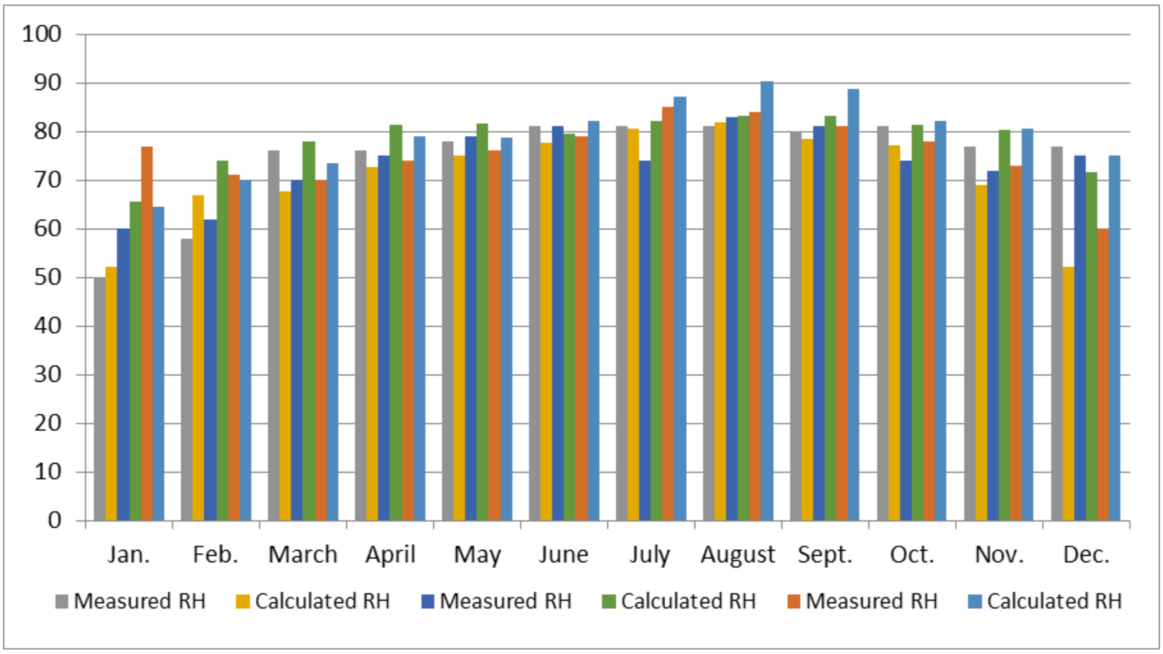

Fig. 4.1: Graph showing the plots of Measured and Calculated Monthly RH for 2008, 2009 and 2010 in Enugu State.

Table 4.1.11 depicts that the Enugu model predicted fairly accurate, judging from the low percentage error in year 2008 got from the monthly RH that was not used in building the model; (4.08, 15.17, 11.00, 4.29, 3.89, 4.16, 0.59, 1.22, 2.05, 4.84, 10.53 and 32.42) and also for 2009 and 2010, the percentage errors were fairly accurate as those predicted for year 2008. Also, as seen from Fig. 4.1, the plots of the predicted and measured monthly relative humidity against the months of year 2008, 2009 and 2010 showed a better uniform trend which indicated that the developed equation is good, which is in agreement with the finding of Ngwangwa, *et al.* 2014 which states that the smaller the percentage error values between measured and predicted results, the better the model developed. The Fig. 4.2 below shows the plots of Measured and Calculated Monthly RH for 2008, 2009 and 2010 in Imo State.

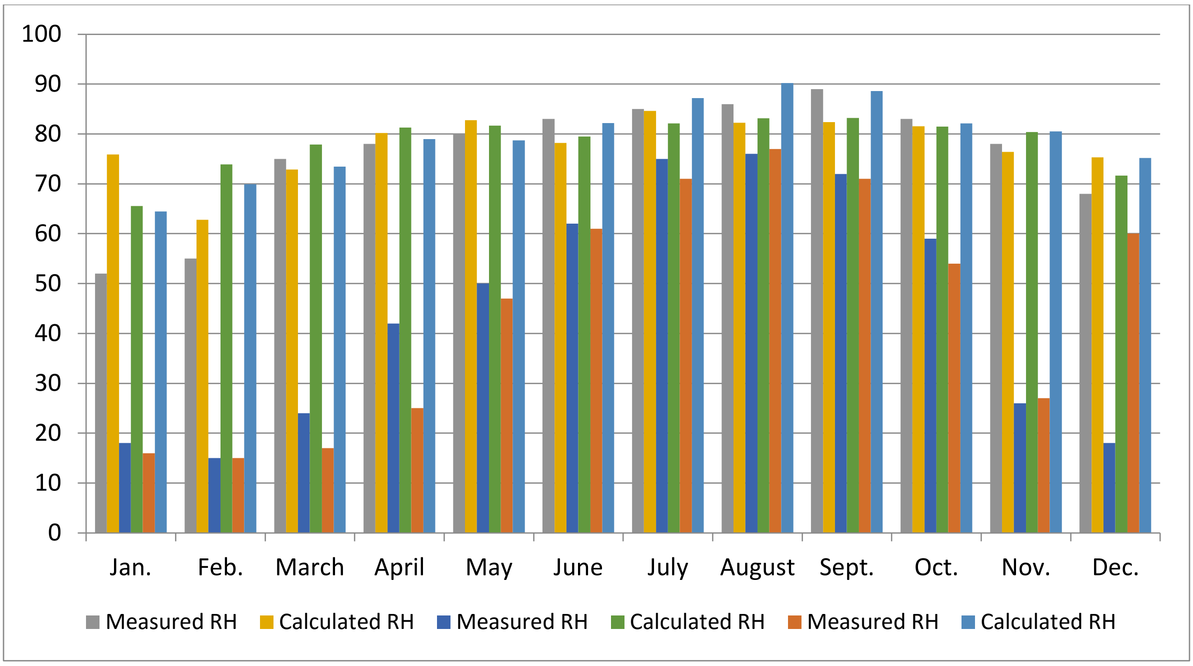

Fig. 4.2: Graph showing the plots of Measured and Calculated Monthly RH for 2008, 2009 and 2010 in Imo State.

Tables 4.1.14 depicts that the Imo model predicted fairly accurate, judging from the low percentage error in year 2008 got from the monthly RH not used in building the model; (45.94, 14.20, 2.88, 2.81, 3.48, 5.78, 0.46, 4.38, 7.46, 1.77, 2.03, and 1.79) but for 2009 and 2010, the percentage errors were fairly higher than that predicted for year 2008. Also, as seen from Fig. 4.2, the plots of the predicted and measured monthly relative humidity against the months of year 2008, 2009 and 2010 showed a fairly uniform trend which indicated that the developed equation is fairly good, which is in agreement with the finding of

Ngwangwa, *et al.* 2014 which states that the smaller the percentage error values between measured and predicted results, the better the model developed.

APPLICATION OF MONTHLY RELATIVE HUMIDITY MODELS OF IMO AND ENUGU STATES INTO BLANEY-MORIN NIGERIA (BMN) MODEL TO ESTIMATE MONTHLY EVAPOTRANSPIRATION

Blaney-Morin-Nigeria(BMN) model was used as a test case because it dealt with Evapotranspiration estimation in Nigeria. By substituting the developed Monthly Relative humidity model into BMN Model in **Equation 1.1** to evaluate the Monthly evapo-transpiration for the study area, the Table 4.1.17 below shows the Average Monthly Evapo-transpiration, Mean values, Standard Deviation and Standard error across the study area from 1991-2010.

Table 4.1.17 $BMN_{Predicted}$ Monthly Evapo-transpiration, Mean values, Standard Deviation and Standard error for Imo State from 1991-2010

Months of the year	N	Mean	Std. Deviation	Std. Error
January	17	4.6382	0.47365	0.1148
February	17	4.5432	0.54546	0.1322
March	17	4.0284	0.25587	0.0620
April	17	3.7583	0.19874	0.0482
May	17	3.5798	0.12868	0.0312
June	17	3.3022	0.13289	0.0322
July	17	3.0134	0.14741	0.0357
August	17	3.0494	0.20229	0.0490
September	17	3.2442	0.17971	0.0435
October	17	3.4496	0.19959	0.0484
November	17	3.9452	0.35419	0.0859
December	17	4.4183	0.36171	0.0877

The Table above shows that Evapotranspiration for the Months of January, February, March, December where higher than for the months of July, August, September, June, October, May, April, and November. This is in agreement with the weather changes, across the study area.

Also, from Table 4.1.16, the Monthly Evapotranspiration mean values were subjected to analysis of variance. From the result obtained the P-value of $0.000 < 5\%$ probability level.

Table 4.1.18 Analysis of variance of Imo State Monthly Evapotranspiration Estimates.

ANOVA					
Monthly Evapotranspiration estimates					
	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	61.015	11	5.547	63.263	0.000
Within Groups	16.834	192	0.088		
Total	77.849	203			

This depicts that the monthly evapo-transpiration estimates is highly significant at P=0.05. Thus, evapo-transpiration of each month is different from another which clarifies that evapo-transpiration changes is as a result of the weather changes across the study area. Inferentially, the relative humidity model developed predicted better evapo-transpiration when applied to Blaney-Morin Nigeria model because it considered many parameters such as maximum and minimum temperatures, vapour, Rainfall intensity, sunshine hours whereas the relative humidity in Blaney-Morin Nigeria model is just the direct measurement of relative humidity.

The Table below shows that Evapo-transpiration for the Months of January, February, March, December where higher than for the months of July, August, September, June, October, May, April, and November. This is in agreement with the weather changes, across the study area.

The Table 4.1.19 below shows the Average Monthly Evapo-transpiration, Mean values, Standard Deviation and Standard error across the study area from 1991-2010.

Table 4.1.19 $BMN_{Predicted}$ Monthly Evapotranspiration, Mean values, Standard Deviation and Standard Error for Enugu State from 1991-2010

Months of the year	N	Mean	Std. Deviation	Std. Error
January	17	5.3396	0.68907	0.1671
February	17	5.3628	0.76861	0.1864
March	17	4.6303	0.49472	0.1199
April	17	3.9636	0.23822	0.0577
May	17	3.5278	0.15834	0.0384
June	17	3.3883	0.12190	0.0295
July	17	3.2285	0.14821	0.0359
August	17	3.2044	0.27985	0.0678
September	17	3.2792	0.15769	0.0382
October	17	3.5191	0.21859	0.0530
November	17	4.2820	0.45010	0.1091
December	17	5.0622	0.60085	0.1457

The Table 4.1.20 below Shows Analysis of variance of Enugu State Monthly Evapo-transpiration Estimates.

Table 4.1.20. Analysis of variance of Enugu State Monthly Evapo-transpiration Estimates.

ANOVA					
Monthly Evapotranspiration estimates					
	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	132.305	11	12.028	67.33	0.00
Within Groups	34.297	192	0.179		
Total	166.601	203			

Also, from Table 4.1.20, the Monthly Evapo-transpiration mean values were subjected to analysis of variance. From the result obtained the P-value of 0.000 $<$ 5% probability level. This depicts that the monthly evapo-transpiration estimates is highly significant at P=0.05. Thus, evapo-transpiration of each month is different from another which clarifies that evapo-transpiration changes is as a result of the weather changes across the study area. Inferentially, the relative humidity model developed predicted better evapo-transpiration when applied to Blaney-Morin Nigeria model because it considered many parameters such as maximum and minimum temperatures, vapour, Rainfall intensity, sunshine hours whereas the relative humidity in Blaney-Morin Nigeria model is just the direct measurement of relative humidity.

The Table 4.1.21 below shows the Average Monthly Evapo-transpiration, Mean values, Standard Deviation and Standard error across the study area from 1991-2010

Table 4.1.21 BMN_{Actual} Monthly Evapotranspiration, Mean values, Standard Deviation and Standard error for Imo State from 1991-2010

Months of the year	N	Mean	Std. Deviation	Std Error
January	17	4.5141	0.86241	0.20916
February	17	4.2762	0.80347	0.19487
March	17	3.7980	0.26567	0.06444
April	17	3.6529	0.19755	0.04791
May	17	3.4733	0.16342	0.03963
June	17	3.0696	0.15481	0.03755
July	17	2.7254	0.11684	0.02834
August	17	2.7439	0.13814	0.03350
September	17	2.9592	0.18280	0.04434
October	17	3.1929	0.21279	0.05161
November	17	3.7788	0.50389	0.12221
December	17	4.1837	0.58827	0.14268

The Table 4.1.22 below shows the Average Monthly Evapo-transpiration, Mean values, Standard Deviation and Standard error across the study area from 1991-2010

Table 4.1.22 BMN_{Actual} Monthly Evapotranspiration, Mean values, Standard Deviation and Standard error for Enugu State from 1991-2010.

Months of the year	N	Mean	Std. Deviation	Std Error
January	17	5.3462	0.90798	0.22022
February	17	5.2357	0.91606	0.22218
March	17	4.5158	0.41973	0.10180
April	17	3.8668	0.19783	0.04798
May	17	3.3872	0.15922	0.03862
June	17	3.1411	0.11827	0.02868
July	17	2.9856	0.16382	0.03973
August	17	2.9695	0.30848	0.07482
September	17	2.9663	0.15621	0.03789
October	17	3.1761	0.12599	0.03056
November	17	3.9769	0.46407	0.11255
December	17	4.9013	0.91803	0.22266

The Fig.4. 3 is the graph showing the relationship between BMN actual and BMN predicted for Imo State.

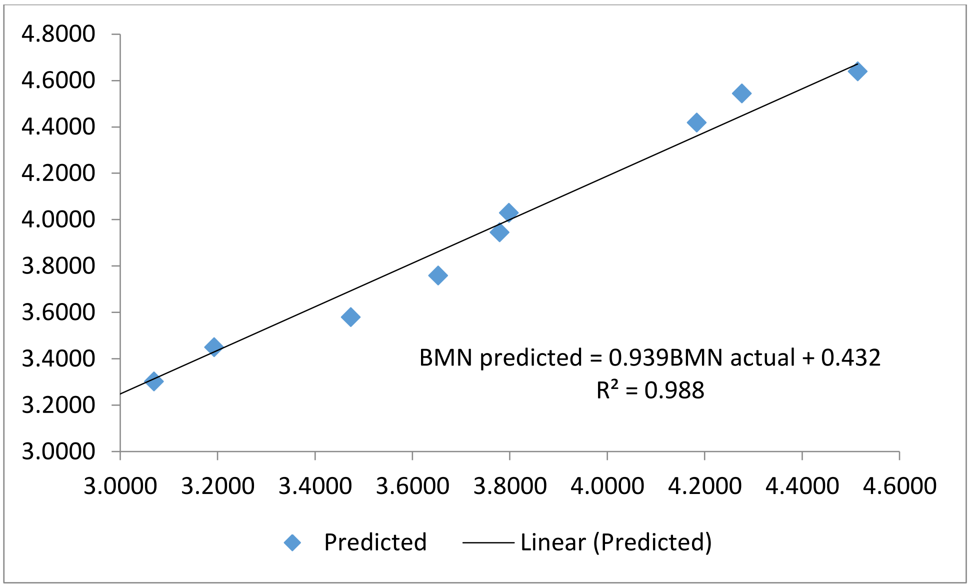

Fig.4. 3: Graph showing the relationship between BMN actual and BMN predicted for Imo State.

The Fig.4.4 below is the graph showing the relationship between BMN actual and BMN predicted for Enugu State.

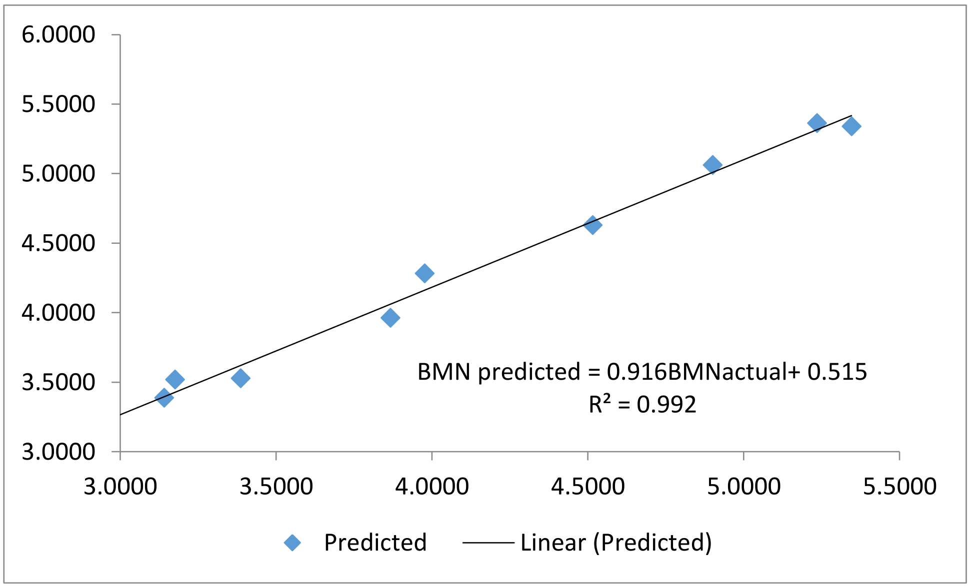

Fig.4.4: Graph showing the relationship between BMN actual and BMN predicted for Enugu State.

OBSERVATION BETWEEN THE TWO MODELS

RH(Enugu State) = 70.262 + 2.028VP – 1.477 Tmax + 0.016R - 0.869SH

(R^2 =0.845)

RH(Imo State) = 99.283 – 3.030 Tmax + 1.105VP + 1.805Tmin + 0.828W

(R^2=0.753)

- In the model developed for Enugu state, minimum temperature and wind-speed were not significant contributors in the model and as such were removed in the stepwise regression process during the model development. In contrast, rainfall and sunshine hours were removed from the model developed for Imo state since they weren't significant contributors in the model development.
- Also, the coefficient of determination, R^2 gave a higher value (84.5%) in the model developed for Enugu State compared to that for Imo State which is 75.3%. This factor depicts that the model developed for Enugu State accounted for more variates error than that of Imo State.
- The error margin for RH model for Enugu state used in BMN gave 0.0295 – 0.1864 whereas the error margin for RH model for Imo State used in BMN gave 0.0312 – 0.1322.
- The model developed for Enugu state gave better result than the Imo state model as seen in Fig.4.3 and Fig.4.4.above.

From Fig.4.4 (Enugu State) the R^2 –value (99.2%) is higher compared to R^2-value of 98.8% (Imo state). This depicts that RH model (Eqn 4.4) for Enugu statistically represents the measured value of RH

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Using statistical methods to build the model for monthly Relative humidity for the two states (Imo and Enugu) of southeastern Nigeria. The following result summary is as follows:

- Seventeen years (1991-2007) data obtained from NIMET was used to develop the Monthly Relative humidity model statistically as:

RH(Enugu) = 70.262 + 2.028VP – 1.477 Tmax + 0.016R - 0.869SH

(R^2 =0.845)

RH(Imo) = 99.283 – 3.030 Tmax + 1.105VP + 1.805Tmin + 0.828W

(R^2=0.753)

With a high coefficient of determination, R^2 = 0.753 for Imo model, which depicts that the developed model accounted for 75.3% of the unexplained variation. Also, a high coefficient of determination, R^2 = 0.845 for Enugu model was observed, which depicts that the developed model accounted for 84.5% of the unexplained variation. These high R^2 – values show that the models are in conformity with that presented by Nwangwa, *et al* (2014).

The developed model was used to predict Monthly Relative humidity values for the remaining three years (2008-2010) data obtained from NIMET that was not used in building the model. It was observed from the predicted Monthly Relative humidity values compared to the Measured Relative humidity values that low percentage error (45.94, 14.20, 2.88, 2.81, 3.48, 5.78, 0.46, 4.38, 7.46, 1.77, 2.03 and 1.79) but for 2009 and 2010, the percentage errors were fairly higher than that predicted for year 2008. Also, the plots of the predicted and measured monthly relative humidity against the months of year 2008, 2009 and 2010 showed a fairly uniform trend which indicated that the developed equation is fairly good, which is in agreement with the finding of **Ngwangwa, *et al.* 2014 which states that the smaller the percentage error values between measured and predicted results, the better the model developed.**

Similarly, Enugu model predicted fairly accurate, judging from the low percentage error in year 2008 got from the monthly RH not used in building the model; (4.08, 15.17, 11.00, 4.29, 3.89, 4.16, 0.59, 1.22, 2.05, 4.84, 10.53 and 32.42) and also for 2009 and 2010, the percentage errors were fairly accurate as that predicted for year 2008. Also, the plots of the predicted and measured monthly relative humidity against the months of year 2008, 2009 and 2010 showed a better uniform trend which indicated that the developed equation is good, which is in agreement with the finding of **Ngwangwa, *et al.* 2014 which states that the smaller the percentage error values between measured and predicted results, the better the model developed.**

The error margin for RH model for Enugu state used in Blaney-Morin-Nigeria(BMN) gave 0.0295 – 0.1864 whereas the error margin for RH model for Imo state used in BMN gave 0.0312 – 0.1322.

The model developed for Enugu state gave better result than the Imo state model as seen in Fig.4.3 and Fig.4.4

From Fig. 4.4 (Enugu State) the R^2 –value (99.2%) is higher compared to R^2 –value of 98.8% (Imo state). This depicts that RH model (Eqn 4.4) for Enugu statistically represents the measured value of RH.

Applying the two developed Monthly Relative humidity in Blaney-Morin Nigeria model to estimate the Monthly Evapotranspiration from 1991 to 2010 gave a high significant difference. This observation shows that the evapotranspiration for January, February, and March is different from that obtained in April, May, June, July and August. This is in conformity with the varied changes in weather properties which directly affects the value of evapotranspiration across the months of the year.

5.2 RECOMMENDATIONS

Due to the challenges posed during this project work, the following recommendations were advised:

- There should be more research in this area of study to optimize the models.
- There should be in-situ test for relative humidity and evapo-transpiration (Modified BMN) to make comparison with the developed models.
- There should be more weather stations spread across the study areas to ascertain credible data.

5.3 CONTRIBUTIONS TO KNOWLEDGE

- ✓ The monthly relative humidity model will help the farmer to estimate the evapo-transpiration at any point in time.
- ✓ Developing a model for monthly relative humidity with factors such as - Sunshine Hours, minimum temperature, maximum temperature, rainfall, and vapour pressure gave a better result for estimating evapo-transpiration using Blaney-Morin-Nigeria (BMN) model.

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APPENDIXES

Appendix 1: Test of Analysis of Variance (ANOVA) for Enugu State

ANOVA						
		Sum of Squares	Df	Mean Square	F	Sig.
Vapour Pressure	Between Groups	1691.536	11	153.776	24.437	0.000
	Within Groups	1208.201	192	6.293		
	Total	2899.737	203			
Windspeed	Between Groups	75.845	11	6.895	6.583	0.000
	Within Groups	201.086	192	1.047		
	Total	276.930	203			
Relative Humidity	Between Groups	22260.877	11	2023.716	46.219	0.000
	Within Groups	8406.706	192	43.785		
	Total	30667.583	203			
Sunshine	Between Groups	252.735	11	22.976	37.619	0.000
	Within Groups	117.265	192	0.611		
	Total	370.000	203			
Rainfall	Between Groups	2699415.222	11	245401.384	65.884	0.000
	Within Groups	715150.238	192	3724.741		
	Total	3414565.460	203			
Tmax	Between Groups	801.045	11	72.822	101.668	0.000
	Within Groups	137.525	192	0.716		
	Total	938.569	203			
Tmin	Between Groups	232.450	11	21.132	27.610	0.000
	Within Groups	146.951	192	0.765		
	Total	379.400	203			

Appendix 2: Test of Analysis of Variance (ANOVA) for Imo State

ANOVA						
		Sum of Squares	Df	Mean Square	F	Sig.
Vapour Pressure	Between Groups	646.665	11	58.788	10.759	.000
	Within Groups	1049.056	192	5.464		
	Total	1695.722	203			
Windspeed	Between Groups	14.841	11	1.349	2.336	.010
	Within Groups	110.868	192	.577		
	Total	125.709	203			
Relative Humidity	Between Groups	8062.956	11	732.996	24.139	.000
	Within Groups	5830.118	192	30.365		
	Total	13893.074	203			
Sunshine	Between Groups	154.186	11	14.017	11.240	.000
	Within Groups	239.438	192	1.247		
	Total	393.624	203			
Rainfall	Between Groups	3658910.984	11	332628.271	40.798	.000
	Within Groups	1557231.629	191	8153.045		
	Total	5216142.613	202			
Tmax	Between Groups	673.038	11	61.185	86.038	.000
	Within Groups	136.539	192	.711		
	Total	809.576	203			
Tmin	Between Groups	69.706	11	6.337	7.309	.000
	Within Groups	166.462	192	.867		
	Total	236.168	203			
Mean temperature	Between Groups	242.922	11	22.084	41.745	.000
	Within Groups	101.571	192	.529		
	Total	344.493	203			

Appendix 3

VAPOUR PRESSURE
(Hpa)

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
owerri	1991	24.7	31	31.1	30.2	30.3	30.1	29	28.6	29	28.6	30.1	23.1
owerri	1992	18	24	29.9	30.8	30	28.7	28	27.8	28.3	29	25.5	26.4
owerri	1993	19	27.5	27.8	30.3	30.2	29.6	28.7	28.8	28.9	29.1	30	25.5
owerri	1994	23.9	29.2	31	30.5	29.9	29.7	28.7	28.5	29.2	29.1	28.2	16.4
owerri	1995	20.8	28.1	30.4	31	30.8	29.8	29.2	29.3	29.5	29.4	30.4	28.8
owerri	1996	31.3	31.7	31.2	31	30.8	29.6	28.8	28.3	29.1	29.4	29.4	31.3
owerri	1997	19.2	21.8	29.4	30.3	30.7	29.5	29	29	29.7	30.1	30.4	30.8
owerri	1998	18.8	29.9	30.8	32.8	32.6	30.8	29.9	29.9	29.9	30.3	31.4	27.1
owerri	1999	27.1	30.9	30.7	30.7	30	29.8	29	29	29.1	29.3	30.3	26.5
owerri	2000	27.9	20.5	29.4	30.5	30.4	29.6	29.3	28.6	29.4	29.6	30.6	25.3
owerri	2001	26.1	24.3	30.7	30.3	30.3	29.4	28.7	28.5	28.8	29.9	30.7	30.4
owerri	2002	26.1	31.8	30.9	31.1	30.5	29.8	29.2	28.8	30	30.8	24.4	30.1
owerri	2003	32.5	32.1	30.8	30.7	29.6	29.6	29.5	29.4	30.5	31.4	25.6	28.6
owerri	2004	27.9	30.0	29.5	30.9	29.5	28.9	27.7	27.5	28.1	28.3	29.2	20.8
owerri	2005	27.3	30.5	30.0	31.2	30.4	29.0	29.5	29.5	29.1	29.8	31.0	27.3
owerri	2006	24.6	30.7	30.8	30.7	30.2	29.5	27.8	28.4	28.7	29.0	30.2	26.0
owerri	2007	13.4	20.4	29.2	29.8	28.8	29.1	28.2	28.5	28.3	29.1	30.5	27.0
owerri	2008	28.9	25.0	29.6	30.0	30.3	28.9	28.5	28.6	28.5	28.6	29.7	29.7
owerri	2009	20.8	28.8	30.0	29.8	29.4	28.4	27.4	27.1	27.9	28.2	28.9	25.1
owerri	2010	25.5	29.6	29.7	29.5	29.3	28.1	26.9	26.6	27.5	28.5	27.8	27.3

Appendix 4

VAPOUR PRESSURE (Hpa)

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Enugu	1991	19.7	28.6	28.9	28.7	29.2	28.8	28	27.7	27.7	27	29.3	17.7
Enugu	1992	14.5	18.7	28.2	30	29.4	27.9	27.1	26.6	27.4	28.3	24.7	22.7
Enugu	1993	15.3	18.9	25.7	29.1	28.8	28.3	27.2	29.9	28	28.6	28.7	19.5
Enugu	1994	21.4	25.6	28.3	28.9	29.3	28.3	27.7	28.1	28.7	28.9	25.7	12.9
Enugu	1995	14.6	24.1	28.6	29.3	29.5	28.6	28.3	29	28.5	28.1	23.9	25.4
Enugu	1996	27.5	27.9	29.2	29.5	29.7	28.8	27.5	27.4	27.7	27.7	23.4	26.8
Enugu	1997	23.8	11.9	26.7	28.9	28.7	28.5	29.2	30	28.9	29.3	30.6	23.6
Enugu	1998	16.3	24.3	19	31	30.4	29.4	28.1	27.1	28.2	29.6	30.2	22
Enugu	1999	23.5	28.2	28.6	28.9	29	28.7	27.9	27.4	27.6	27.9	28.9	21.2
Enugu	2000	24.5	16.4	25.2	28.4	29.4	27.9	27.6	27.4	28.4	28.4	29	19.4
Enugu	2001	17.9	19.2	28.4	29.4	29.3	28.1	27.2	27	27.9	29	29.1	26.3
Enugu	2002	12.5	23.3	29.9	29.2	29.5	28.6	28.5	27.5	27.6	28.8	28.7	19
Enugu	2003	23.4	28.1	28.6	29.1	29.1	28.1	27.5	27.5	28.3	28.9	29.6	19.8
Enugu	2004	24.0	27.5	28.1	29.1	28.5	27.7	27.1	27.0	27.2	27.7	27.5	20.0
Enugu	2005	15.7	24.0	27.8	28.9	28.6	28.0	26.7	27.2	27.3	28.2	21.8	24.9
Enugu	2006	23.0	21.1	26.4	28.6	28.3	27.6	26.4	26.1	27.1	27.6	23.7	25.2
Enugu	2007	25.6	22.5	24.0	27.9	28.4	27.8	26.9	26.0	27.5	27.7	27.4	24.9
Enugu	2008	18.0	25.0	27.2	28.0	28.1	27.7	27.5	27.6	27.0	27.7	26.6	18.7
Enugu	2009	27.1	20.4	27.5	28.7	28.7	27.4	26.7	27.4	26.8	27.7	29.5	17.4
Enugu	2010	23.2	27.8	27.7	29.3	27.8	27.5	26.3	25.8	26.9	27.2	27.4	15.9

Appendix 5

WIND SPEED (mtrs./s)

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
owerri	1991	2.9	3.6	3.4	3.5	2.8	3.3	2.5	2.5	2.9	2.6	2.3	2.6
owerri	1992	3.1	2.7	3	2.8	2.9	2.8	2.5	2.3	2.7	2.5	2.6	2.2
owerri	1993	2.7	2.7	3.2	3.2	3	2.9	2.4	2.1	2.9	2.6	2.7	3.2
owerri	1994	4.3	4.1	4.9	4.6	4.2	4	2.9	5.3	4.9	2.7	2.6	2.7
owerri	1995	2.8	3.3	3.5	4.5	3.9	3.4	3	4.2	4	4	2.3	2.9
owerri	1996	3.6	4	3.2	3.7	3.5	3.7	3.2	4.2	4	4	2.5	2.4
owerri	1997	8.1	4.1	3.3	3.8	3.4	3.3	3.2	2.9	2.5	2.2	2.8	4.3
owerri	1998	3.1	4.1	4.1	3.8	3.5	3.7	3.4	3	2.8	2.6	3.1	4.6
owerri	1999	3.6	3.3	3.8	3.6	3.8	3.8	3.8	3.7	3.4	3.3	2.8	3.2
owerri	2000	3	3.7	3.9	3.6	3.5	4.1	5.2	4.7	4.2	4.3	3.9	4.1
owerri	2001	3.7	3.5	2.4	2.9	2.7	3.5	3.5	3.7	2.9	2.3	2	3.1
owerri	2002	2.7	2.8	3.6	3.6	3.5	3.6	3.1	3.5	3.1	2.8	2.6	2.2
owerri	2003	2.2	3.9	4.2	5.3	3.3	4.9	3.2	3.3	3.3	2.9	2.7	2.5
owerri	2004	3.3	3.6	3.7	4.4	4	3.6	3.8	4	4.1	3.8	3.2	3.7
owerri	2005	6.1	4.2	4.2	4.9	4.3	3.7	3.6	4.1	3.3	3.4	3.5	3.6
owerri	2006	3.7	4.5	3.9	4.6	4	3.6	3.5	3.5	3.8	4.1	4.1	3.6
owerri	2007	4.2	3.1	4	3.9	3.8	5.5	3.7	4	3.1	3.6	3.8	4.8
owerri	2008	6.5	5.3	4.1	4.7	5	4.4	3.9	3.8	3.8	3.7	3.4	3.9
owerri	2009	3.6	5.1	3.7	5.7	4.7	3.5	3.9	6.6	4.2	3.5	3.2	4.1
owerri	2010	3.2	3.5	3.5	2.9	3.7	4.2	4.5	3.1	3.3	4.5	4	3.3

Appendix 6

WIND SPEED (mtrs./s)

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Enugu	1991	6.1	6.7	6.9	6.1	5.1	5.9	5	5.9	4.7	4.6	3.4	6.1
Enugu	1992	7.2	5.9	5.1	4.6	4.2	4.5	5.6	7.1	5.2	4.8	5.6	5.8
Enugu	1993	6.7	5.2	7.1	6.7	5.3	5.2	6.2	5.4	4.6	4.6	4.6	5.9
Enugu	1994	6.1	3.9	7	5.9	4.9	5.3	5.8	6	5.1	4.2	4.9	7.2
Enugu	1995	5.8	4.8	6.3	5.6	4.7	5.4	5.4	4.6	4.7	4.5	5.5	4.5
Enugu	1996	4.7	5.9	6.5	6.2	6.3	5.6	5.8	5.5	5.4	5	5.6	4.1
Enugu	1997	5.1	7.8	5.6	5.6	4.3	5.2	6.5	5.6	5.4	4.7	3.9	5
Enugu	1998	7.2	5.9	6.4	6.9	5.8	5.2	6.4	0.7	5.7	4.6	3.8	5.3
Enugu	1999	5.9	6	8	6.4	5.8	5.2	5.9	6	5.1	4.6	3.7	5.7
Enugu	2000	5.6	6.8	6.6	7.4	5.7	5.4	6	6.1	5.6	4.5	4.3	6.3
Enugu	2001	5.9	6.6	6.7	6.5	5.7	5.5	5.8	6.3	5.5	4.4	4	4.8
Enugu	2002	7.2	6.3	7	6.8	5.7	5.5	5.3	5.7	5.2	4	4	6
Enugu	2003	6	6	7	7	6	3	5	3.1	3	5	3	3
Enugu	2004	4	5	6	5	5	5	6	6	6	5	5	6
Enugu	2005	7	7	8	8	8	7	7	7	6	7	6	5
Enugu	2006	6	7	8	8	7	7	7	7	6	6	6	8
Enugu	2007	8	8	8	8	7	7	7	8	7	6	5	7
Enugu	2008	7	7	7	7	6	6	7	6	5	5	5	5
Enugu	2009	4	5	5	6	5	5	5	6	4	4	3	5
Enugu	2010	5	5	5	5	5	5	5	6	4	3	4	4

Appendix 7

RELATIVE HUMIDITY (%)

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Owerri	1991	66	78	79	79	80	84	87	88	84	81	80	63
Owerri	1992	51	60	77	79	78	83	86	88	85	83	69	70
Owerri	1993	52	69	72	77	78	84	89	87	85	80	79	67
Owerri	1994	62	72	77	77	79	85	88	88	86	83	77	45
Owerri	1995	60	71	78	78	82	83	87	87	85	82	77	74
Owerri	1996	82	80	79	79	80	81	85	87	88	82	75	79
Owerri	1997	82	53	76	80	80	86	86	87	87	83	82	76
Owerri	1998	49	70	72	77	79	83	88	86	85	83	79	72
Owerri	1999	71	79	79	78	77	82	85	86	81	86	81	84
Owerri	2000	72	53	71	77	78	83	87	88	85	84	82	68
Owerri	2001	69	59	77	76	80	82	88	89	83	83	79	76
Owerri	2002	65	79	79	80	80	86	88	87	84	78	61	75
Owerri	2003	80	79	76	79	83	85	86	85	81	80	65	70
Owerri	2004	71	75	78	80	80	86	88	87	83	79	77	71
Owerri	2005	49	78	79	77	78	83	88	83	85	81	75	75
Owerri	2006	81	77	77	74	79	82	86	87	87	84	76	64
Owerri	2007	75	84	81	82	82	85	88	87	86	86	81	75
Owerri	2008	52	55	75	78	80	83	85	86	89	83	78	68
Owerri	2009	18	15	24	42	50	62	75	76	72	59	26	18
Owerri	2010	16	15	17	25	47	61	71	77	71	54	27	60

Appendix 8

RELATIVE HUMIDITY (%)

	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Enugu	1991	55	71	73	80	83	83	86	86	84	80	78	50
Enugu	1992	42	49	73	78	80	82	84	83	85	82	67	59
Enugu	1993	42	52	67	76	79	81	83	87	85	82	75	88
Enugu	1994	60	66	68	76	82	84	85	88	86	83	69	36
Enugu	1995	41	62	72	75	82	84	85	89	84	82	64	68
Enugu	1996	74	70	74	77	80	82	85	86	82	82	61	70
Enugu	1997	64	31	68	81	80	82	81	85	85	82	80	62
Enugu	1998	43	57	59	75	79	83	81	81	85	83	78	59
Enugu	1999	64	72	73	74	82	82	86	83	84	83	78	58
Enugu	2000	65	43	62	75	80	83	84	86	84	83	74	52
Enugu	2001	50	49	73	77	81	80	83	85	85	81	73	67
Enugu	2002	36	59	74	77	79	84	85	84	81	84	76	48
Enugu	2003	61	69	68	73	76	84	82	82	84	80	75	54
Enugu	2004	51	55	60	74	80	81	81	84	85	81	76	70
Enugu	2005	42	67	72	71	79	84	87	81	84	81	77	70
Enugu	2006	75	76	70	75	83	83	84	82	88	85	65	48
Enugu	2007	63	53	64	73	78	81	82	73	80	80	71	57
Enugu	2008	50	58	76	76	78	81	81	81	80	81	77	77
Enugu	2009	60	62	70	75	79	81	74	83	81	74	72	75
Enugu	2010	77	71	70	74	76	79	85	84	81	78	73	60

Appendix 9

SUNSHINE HOURS

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Owerri	1991	5.3	4.2	4.9	4.1	2.6	2.6	1.9	8.8	2.6	4.4	6.3	6.6
Owerri	1992	5.5	4.8	5.1	4.5	1.1	2.4	2.2	2.6	2.7	3.3	5.8	5.1
Owerri	1993	6	3.7	4.6	5.1	4.4	2	2.9	2.3	3	4.2	5.3	6.3
Owerri	1994	5.6	4.4	4.5	5.6	5.9	4.9	3.3	1.8	2.9	4	5.1	5.3
Owerri	1995	5.7	5.4	4.4	5.5	5.7	5.2	2.9	1.5	2.8	3.9	5.1	5.1
Owerri	1996	5.7	5.3	5	4.2	5.5	4.5	3.3	4.6	4	3.2	5.7	4.8
Owerri	1997	2.9	4.9	6.6	5.7	5.2	2.3	1.9	1.5	2.8	3.9	5.6	5.9
Owerri	1998	4	4	4.9	5	5.6	3.9	3.6	4.6	4	3.2	5.1	5.3
Owerri	1999	4.6	3.9	4.1	4.7	5.9	4.3	3	3.1	3.8	2.9	5.1	5.1
Owerri	2000	5.9	5.4	5.3	6.2	5.6	5.1	1.9	3.1	3.2	4.2	5.7	4.8
Owerri	2001	5.3	5.4	4.7	5.3	5.9	5.5	4.8	3.3	3.8	4.7	6.3	6.9
Owerri	2002	3.9	6.1	4.8	6.1	5.7	4.8	4	3.3	2.9	3.9	6.3	3.4
Owerri	2003	4.5	4	5.3	4.4	5.5	4.9	4.5	2.6	2.7	1.5	1.3	3.9
Owerri	2004	4.2	5.6	1.2	1.2	8.3	5.2	4.2	2.3	3	4	5.1	5.2
Owerri	2005	5.7	5.6	5	5.5	4.3	4.5	3	2.2	3.3	3.9	5.1	5.8
Owerri	2006	5	6	3.1	4.6	6.3	3.7	2.2	1.7	3	4.4	6.1	6.7
Owerri	2007	4.9	5.7	5.7	5.7	5.8	4.1	2	2.1	3.9	6.1	5.4	5.2
Owerri	2008	5.8	5.2	5.8	5.4	5.5	3.7	3.3	3.4	3	4.6	6.6	7
Owerri	2009	5.2	6.3	4.7	5.7	5.8	5.1	2.9	3.2	3.6	4.4	6.6	6.1
Owerri	2010	5.9	6.5	4.6	5.4	5.7	4.8	2.7	1.8	2.9	3.5	6.6	5.4

Appendix 10

SUNSHINE HOURS

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Enugu	1991	5.1	3.4	4.1	5.1	6.5	5.2	4.5	3.7	4	6	8.5	7.8
Enugu	1992	7.6	6.8	6.7	5.1	6.8	5.6	3.4	3.8	3.8	5.7	7.9	8.1
Enugu	1993	7.8	6.1	5.2	6.1	6.3	5.4	4.4	2.9	4.7	4.7	6.3	7.2
Enugu	1994	6.9	5.2	5.5	5.9	5.4	5.6	3.2	3.5	4.4	4.6	6.6	6.6
Enugu	1995	5.5	6.9	5.7	6.5	5.7	5.7	3.4	3.2	3.9	5.8	6.7	7.9
Enugu	1996	6.5	5.4	6.2	6.7	5.7	4.9	3.7	2.5	3	5.1	6.5	7.1
Enugu	1997	4.4	6.8	4.9	6.4	5.8	4	3.6	2.6	4.3	5.2	6.8	7.1
Enugu	1998	4.9	6	4.8	5.2	6.2	6.3	5.4	4.8	4.4	5.5	6.4	6.2
Enugu	1999	5.6	4.9	5.2	5.6	6.1	4.8	4	4.6	4.5	6	6.8	5.3
Enugu	2000	5.8	6.2	5.5	6.5	6.3	5.4	2.7	3.9	4.3	5.9	7.1	5.5
Enugu	2001	5.7	4.9	5.4	6.1	6.2	5.1	5.3	4.3	4.7	6.1	7.6	7.6
Enugu	2002	4	6.9	5.2	6.2	6.2	5.3	3.5	2.9	3.8	5.7	8.5	5.1
Enugu	2003	8	6.9	6.2	6.8	5.8	4.5	3.7	2.8	4	5.5	7.9	7.4
Enugu	2004	5.6	5.8	7.3	6.2	5.5	5.3	3	3.1	3.8	6	6.1	5.6
Enugu	2005	5.8	6.3	5.7	5.6	4.8	5.3	3	2.6	3.5	4.8	6.7	6.4
Enugu	2006	5.2	7	3.2	5.4	4.9	3.9	3.1	2.5	3.3	4.9	7.2	8.2
Enugu	2007	5.9	6.2	6	5.8	6.1	5.2	3.5	2.6	4.6	5.9	6.4	6.4
Enugu	2008	5.6	5.1	6.7	6.1	6.2	4.8	2.7	2.6	3.5	5.6	8.3	7.8
Enugu	2009	6.6	5.9	6.5	6.3	7.1	5.4	5.3	4.8	4.3	5.2	6.8	7.1
Enugu	2010	7.5	6.6	5.7	6.2	7	5.1	3.5	4.6	4.4	5.5	6.4	6.2

Appendix 11

RAINFALL INTENSITY (mm)

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Owerri	1991	Trace	42.5	107.1	182.6	245.2	498.3	402.9	521.1	193.9	349.8	24	0
Owerri	1992	0.9	2.8	157.5	216.8	248.1	373	489.9	289.4	333.7	214.9	79.5	17.6
Owerri	1993	0	58.7	90.2	177.8	291	293.9	464.3	315.5	218.8	176.6	73.7	22.3
Owerri	1994	37.1	34.3	45.9	99.6	298.8	185.9	468	438.2	622.2	284.3	111.7	0
Owerri	1995	59.6	12.5	72.2	115.9	361.5	339.2	484	381.6	460.9	292.4	26.7	15.8
Owerri	1996	21.1	74.6	68.7	238.4	252.7	395.3	350	502	573.2	228	1.5	Trace
Owerri	1997	31.7	0	215.1	309.8	542.7	504.8	311.9	304.3	242.5	262.5	137.4	28.7
Owerri	1998	14.6	0	48.7	130.5	253.7	289.4	288.9	168.5	254.2	179.2	12.4	0
Owerri	1999	49.1	73.9	118.7	161.5	256.7	218.3	270.5	302.7	609	354.5	100.5	0
Owerri	2000	39.1	0	53.2	354.2	47.3	391.8	382.7	356.4	344	246.5	116.5	5.5
Owerri	2001	5.5	62	206.4	172.2	140.8	385.4	301.7	348.7	430.8	213.4	22.6	14.8
Owerri	2002	27.9	90.4	241.7	265.6	198.3	391.5	131.5	293.5	372.4	40.9	53.8	102.6
Owerri	2003	92.6	136.9	73.3	278.1	277.4	439.5	379.2	476.4	123.8	50.6	88.3	30.2
Owerri	2004	73.5	32.4	173.3	163.1	225.2	240.4	185.4	309.1	322.9	37	0.2	25.4
Owerri	2005	35.5	58.4	102.6	194.3	469.8	367	260	302.4	232.9	199.8	13.9	Trace
Owerri	2006	89.8	1.8	167.9	81.9	358.2	454.7	625.5	286.7	479.4	360.6	302.6	
Owerri	2007	0	46.8	78	135.2	393.3	407.6	311.2	246.3	472.2	165.5	85.8	19.7
Owerri	2008	0.2	0	256.4	238.2	165.4	230.8	328.8	362.8	445.3	183.3	14.8	10.1
Owerri	2009	21.9	58.5	40.1	152.2	282.2	304.3	328.3	569.9	210.9	270.1	115.4	Trace
Owerri	2010	47.3	51	35	198.8	326.4	292	145.5	488.9	322.8	208.3	36.6	Trace

Appendix 12

RAINFALL INTENSITY (mm)

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Enugu	1991	0	37.6	63.4	197.1	346.4	244.8	320.2	264.5	230.5	253.5	2.5	0.7
Enugu	1992	Trace	0	111.5	200.9	194	354	313	149.3	249.7	105.3	28.8	Trace
Enugu	1993	0	5.1	62.8	148.9	109.9	263.7	186.7	389.8	243.5	72.9	82.9	11.6
Enugu	1994	33.8	0	9.7	144.5	211.2	140	216	187.2	331.9	181.6	Trace	0
Enugu	1995	1.6	Trace	90.2	194.1	263.9	356.7	340.2	432.1	192.4	261.7	35	0
Enugu	1996	Trace	26.7	48.6	160.9	277.2	289.6	368.3	268.4	176.3	303.4	0	0
Enugu	1997	Trace	0	111.6	261.3	376.1	344.9	226.8	235	392.3	242.2	68.1	4.1
Enugu	1998	0	6.1	25.8	161.1	188.7	285.9	259.2	96.2	256.6	217.4	0	0
Enugu	1999	0	15.7	30	103.6	223.5	316.8	206.4	101.2	195.1	291.6	24.3	0
Enugu	2000	32.4	0	32.3	202	357.5	206.1	289.5	331.8	339.7	226.5	Trace	0
Enugu	2001	0	28	72.5	305.5	273.8	188.8	152	130.6	407.9	118.1	Trace	0
Enugu	2002	0	46.5	10.4	159.1	219.7	296.4	263.3	121.9	270.9	332.5	1.5	0
Enugu	2003	Trace	0	2.9	74.6	234.3	286.9	400.4	290.2	334.4	227.4	39.8	0
Enugu	2004	6.4	4.8	186.8	305.5	222.3	284.7	174.1	272.3	258	22.1	33.1	0
Enugu	2005	Trace	26.9	20.8	115.6	170	258.3	277.6	292	283.6	228.5	24.1	19.1
Enugu	2006	43.9	4.6	78.9	138.4	375	369.2	402.5	188.3	261.8	233.7	0	0
Enugu	2007	0	9.4	70	93.9	288.4	306.4	329	261.9	286.1	265.8	Trace	0
Enugu	2008	1.2	0	56.7	191.6	281.2	250.6	221.3	338.4	300.2	97.2	11.2	43.4
Enugu	2009	Trace	Trace	11.1	112.4	199.3	206	281.1	193.6	204.7	393.3	32.1	0
Enugu	2010	Trace	Trace	2.2	162.8	187.4	403.4	130.3	153.2	439	234.9	1	Trace

Appendix 13

						TMAX							
STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Owerri	1991	33.6	34.1	33.8	32.3	31.6	30.9	29.2	28.4	30	30.1	32	32.7
Owerri	1992	35.2	35.9	33.9	32.3	32.3	29.6	28.1	27.9	29.6	30.5	32	33.3
Owerri	1993	33.3	35	33.3	33	32.1	30.5	28.4	28.7	30.2	31.7	32	32.5
Owerri	1994	33.2	35	34.2	33.3	32	30.4	28.9	29.9	29.2	30.3	32.1	32.5
Owerri	1995	32.8	34.5	33.6	33.2	31.8	30.9	29.1	29.5	30.2	30.3	33.3	33.5
Owerri	1996	34	34.3	33.5	33.1	32.8	31.2	30	29.8	30	31.5	34.4	35
Owerri	1997	33.6	36.5	34	32.7	32.3	30.6	29.7	29.2	31	31.9	32.2	33.6
Owerri	1998	33.8	36.4	36.6	35	33.5	32.2	30.4	30.9	30.8	31.3	33.3	33.3
Owerri	1999	33.3	33.3	33.7	33	32.4	31	29.9	30.3	29.6	29.8	31.9	33.9
Owerri	2000	33.6	35.1	35.8	33.2	32.5	31	29.3	29	30.2	30.9	32.3	33.2
Owerri	2001	34.3	35.9	33.8	33.9	32.3	30.9	29.6	28.3	30	31.8	32.9	34.4
Owerri	2002	34.2	35.6	33.6	32.7	32.6	31.1	29.8	29.3	30.3	30.8	33	34.5
Owerri	2003	35.3	34.5	33.9	32.6	30.4	30.3	29.9	30.3	32.3	32.7	33.3	32.9
Owerri	2004	34	36	33	32	31.8	30	28	31	32	32.5	35	33.3
Owerri	2005	33.9	35.2	34	34.3	32.9	31.4	29.7	30.2	31	32.1	34.6	34.3
Owerri	2006	34.1	34.8	34.3	35	32.2	32.2	30.4	29.5	30	31.6	34.6	35.5
Owerri	2007	33	34.1	33.2	33.6	31.8	30.9	28.3	29	29.8	30.2	31.8	32.8
Owerri	2008	33.5	36.9	35	33.3	32.1	31.2	30.3	30.5	30.6	31.3	33.9	33.5
Owerri	2009	33.7	35.4	33.6	32.9	32	31.6	30.3	30.6	30.2	30.7	32	32.8
Owerri	2010	33.1	35.2	34.6	32.5	32.3	30.8	28.5	27	28.1	31	31.9	32.4

Appendix 14

TMAX

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Enugu	1991	32.2	35.8	36.5	36.7	30.3	30.2	29.4	29.8	31.5	33.7	33.2	32.9
Enugu	1992	34.4	35.9	34.8	32.7	31.9	31	29.5	29.8	29.9	30.6	31.8	32.2
Enugu	1993	34.2	35.4	34.2	32.1	32.3	30.3	30.2	29.6	29.9	31.2	33.3	32.4
Enugu	1994	34.4	35.8	33.2	34.3	32.1	31.4	29.4	29.2	29.9	30.9	32.1	32.3
Enugu	1995	34.4	34.9	35.2	35.4	33.9	30.8	31.2	29.9	31.2	32.1	34.4	34.2
Enugu	1996	34.2	36.9	35.2	34.3	32.4	30.8	29.9	29.7	30.3	31.1	33.2	32.4
Enugu	1997	33.3	35.2	35.9	33.8	31.1	31.4	29.9	29.4	29.8	30.5	33.3	33.2
Enugu	1998	33.9	35.3	37.5	34.4	32.1	30.7	29	29.3	29.8	30.7	32.2	32.1
Enugu	1999	33.5	35.3	34.5	32	31.2	31.1	29.3	29.2	30.2	30.3	32.4	32.1
Enugu	2000	32.5	35.9	34.4	33.2	31.9	29.8	29.3	28.8	30	30.8	31.6	38.3
Enugu	2001	33.3	35.4	34.3	33.3	32.1	30.7	29.6	29.1	30.3	31.1	32.4	31.9
Enugu	2002	32.6	35.1	35.7	33.3	31.7	30.9	29.6	28.2	30	30.9	32.7	32.8
Enugu	2003	33.6	35.5	35	33.9	31.6	30.5	29.5	29.4	30.6	30.8	32.2	33.5
Enugu	2004	34.4	35	34.4	32.8	31	31.2	29.7	29.3	30.4	30.7	32.4	33.5
Enugu	2005	33.3	36.1	35	32.7	31.6	29.4	29	29.2	29.8	31.4	33	33.4
Enugu	2006	33	36.9	36.4	35	33	32	30.3	29.6	30	31	33.9	33.5
Enugu	2007	33.9	34.6	35	33.6	32	31	30.1	30.1	30	30.3	32.9	33.3
Enugu	2008	34.3	34.3	36	34	32.6	31.1	30.1	29.3	30.4	31	33.4	33.3
Enugu	2009	34.2	35.5	34.6	33.3	32	31	29.8	28.8	30	31.4	34.1	34.6
Enugu	2010	33.8	35.7	35	33.3	32.8	31.1	30.5	29.7	30	30.8	33	34.1

Appendix 15

TMIN

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Owerri	1991	23.3	24.5	24.6	23.4	23.9	23.6	22.9	22.8	23.3	22.7	24	22.4
Owerri	1992	21.5	23.9	24.6	24.5	24	22.8	21.9	21.8	22.2	22.8	22.5	22.4
Owerri	1993	22	23.7	23.4	23.8	23.5	23.1	22	22.8	23	22.9	23.5	22.1
Owerri	1994	22.7	24	23.7	23.2	22.5	22.3	22.6	22.5	22.4	21.9	21.5	17.8
Owerri	1995	19.2	21.9	23.1	23.4	22.4	22.6	22.5	22.6	22.5	22	22.9	23.2
Owerri	1996	23.9	24.6	24.5	24.1	23.8	24.3	22.9	22.7	22.5	21.9	21.2	20.1
Owerri	1997	22.5	23	24.6	24	23.5	23.4	23	23.2	23.5	23.3	23.6	24
Owerri	1998	20.1	24.9	23.9	25.1	24.7	23.8	23.5	23.1	23.4	23.7	24.4	23.1
Owerri	1999	23.3	24.8	24.5	24.4	23.9	24	23	23	22.8	23.1	23.8	23.2
Owerri	2000	23.9	23.4	25.1	24.2	24.4	23.4	23.3	23	23.4	23.4	23.9	22.2
Owerri	2001	22.8	24.1	24.5	24.5	24	23.5	22.9	23.1	23.2	23.7	24.5	24.9
Owerri	2002	22.7	23.7	25.2	24.4	23.6	23.4	23.5	23.5	23.3	23.5	24.4	23.5
Owerri	2003	25.4	25.2	25	24.3	23.6	23.3	23.5	23.3	24.1	24.4	24.2	23.3
Owerri	2004	25	26	24	24	23.7	23	23	23	24	23.9	24	23.1
Owerri	2005	22.3	25.5	25.2	25.4	24	24.1	23.5	23.3	23.7	23.8	24.6	24.2
Owerri	2006	25.3	25.6	24.9	25.4	24.5	24	23.9	23.6	23.3	23.7	24.7	22.9
Owerri	2007	23.3	24.2	23.7	24.1	23.5	23.3	22.4	22.4	22.6	22.6	23.3	21.5
Owerri	2008	22.6	24	24.1	24.8	23.9	21	23.5	22.5	22.8	23.5	24.5	23
Owerri	2009	23.5	25.4	24.5	24.4	23.8	23.1	22.8	22.8	22.8	22.8	24.1	22.5
Owerri	2010	19.2	23.1	24	23.9	23.2	23.1	22.6	22.6	22.9	23	24.3	22.8

Appendix 16

TMIN

STN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Enugu	1991	19.4	22.1	23.9	23.1	22.2	22.9	21.8	21.9	22.2	21.9	20.3	20.3
Enugu	1992	22.2	22.9	23.7	23.6	23.1	23.2	22.2	22.9	21.8	21.9	21.7	20.3
Enugu	1993	19.2	23.1	23.8	25.5	23.6	22.8	21.9	21.7	22.6	22.8	23.1	22.1
Enugu	1994	20.1	23.9	24.8	23.7	22.9	21.9	21.7	21.8	21.1	22.3	22.1	20.2
Enugu	1995	23.1	21.3	23.9	23.5	22.7	22.9	21.7	21.6	21.5	22.2	23.1	20.3
Enugu	1996	22.2	23.9	23.7	23.8	22.6	22.8	21.8	21.8	21.9	22.6	22.1	19.3
Enugu	1997	21.3	23.4	23.6	24.6	23.7	22.6	22.9	22.7	22.5	22.6	23.1	20.2
Enugu	1998	22.3	24.9	24.7	24.6	22.5	22.7	21.9	22.7	21.6	21.9	22.1	21.2
Enugu	1999	17.2	21.3	24.6	23.5	22.6	22.7	21.9	21.5	21.6	21.7	22.2	19.3
Enugu	2000	22.7	22.2	24.2	24.2	23.7	22.5	22.5	22.8	22.6	22.7	23.6	23.1
Enugu	2001	21.4	25	25.2	23.9	23.9	23.6	22.9	22.6	22.1	21.9	22.3	19.3
Enugu	2002	19.8	21	24.8	24.5	23.3	22.5	22.4	22.5	22.4	22.5	21.1	19.3
Enugu	2003	20.4	21.5	23.9	24	23.6	22.8	22.8	22.5	22.5	22.5	22.8	20
Enugu	2004	21.4	23	25.1	23.7	23	22.7	22.7	21.9	22.7	22.4	21.1	17.8
Enugu	2005	19.8	22.1	24.9	24.3	22.7	22.6	22.8	22.6	22.7	22.1	20.3	20.4
Enugu	2006	21.7	24.6	24.5	23.8	23.4	23.1	22	22.5	22.9	22.3	19.7	20.4
Enugu	2007	22.4	20	23.1	23	22.8	22.8	23	22.9	22.8	21.9	21.7	20.3
Enugu	2008	21	24.5	24.9	26	25	23	23.1	23.2	23	23	23.5	20.9
Enugu	2009	22.2	24.9	21.6	24.3	23	23	22.5	22.7	22.3	22.4	23	19.1
Enugu	2010	22.6	21.4	23.4	24	23.8	22.5	22.8	21.9	22.9	22.7	23.4	19.8