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Analyses of Potential Evapotranspiration of Two Major Towns in Enugu State, Nigeria

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Abstract
Evapotranspiration (ET) may account for up to 70% of the annual precipitation even in humid region. Understanding ET is essential for management of water resource, crop water requirement as well as irrigation designs/scheduling etc. Therefore, this study tries to analyze potential ET over Enugu State using meteorological data from weather stations and compared the results obtained with that from satellite remote sensed techniques. The meteorological data from 1999 to 2014 were collected from Nigerian Meteorological agency (NIMET) for two stations in Enugu State (Enugu town and Nsukka). The data were processed and ET calculated using CROPWAT software. Also, necessary data for ET were downloaded from global atmospheric reanalysis product by European Centre for Medium-Range Weather Forecast (ERA-Interim) and National Aeronautics and Space Administration (NASA). Daily and monthly potential ET results were estimated for Enugu and Nsukka. The potential ET obtained for both stations varies with month and seasons with higher values in dry season than rainy season. The potential ET obtained from NIMET, NASA and ERA-Interim have similar trend but varied in magnitude. Statistically, ET_{NIMET} was the most accurate followed by ET_{NASA}.

Keywords: Potential Evapotranspiration, Enugu town, Nsukka, NASA, NIMET and ERA-Interim

1.0 INTRODUCTION

The two distinctive mechanisms of water removal from the surface of the earth to the atmosphere have gained a lot of interest within the last few years. Evaporation as one of the mechanisms is the process where liquid water is removed from the earth surface in a gaseous state. Transpiration on the other hand, is the removal of water from plant through the stomata [1]. The term evapotranspiration (ET) was conceived due to difficulty in establishing a distinctive difference between these two mechanisms under field condition. ET is a major component of the catchment water balance and is affected by both environmental and biological factors. Important environmental factors affecting ET range from solar radiation, temperature, relative humidity, wind and soil moisture. The ET rate from a spatially-extensive vegetated surface having uniform physiological and structural characteristics given the condition of unlimited soil moisture is called Potential ET [2]. The main factor affecting potential ET are climatic parameters and it can be computed from data obtained from satellite and weather s station.

There are many methods for estimating ET, ranging from ground-based techniques to remote sensing products and process modelling [3]. ET and its components can be directly measured using lysimeter, energy balance by eddy covariance (EC) towers, scintillometers and soil volumetric water content etc. [4]. Similarly, ET can be calculated indirectly from environmental variables measured by weather sensors or the satellite remote sensing method [5]. Numerous models exist for estimating potential ET ranging from the single climatic variable driven equations (e.g., Priestley-Taylor, Blaney-Criddle, Jensen and Haise, Blaney-Morin-Nigeria [12], [13], Thornthwaite etc.) [14] to combination equations of energy balance and aerodynamic principle (e.g., Penman, Makkink, Penman-Monteith, Hargreaves-Samani, Ritchie's etc.). Among the combination methods, the Penman-Monteith equation is assumed to be the most suitable for various climatic conditions [6]. It requires meteorological data such as radiation, air-temperature, air humidity and wind speed data for estimation of ET and these meteorological data can be obtained from weather stations or satellite technologies.

Recently, there is increasing need to monitor hydrological variables spatially using multi-temporal and multi-spatial sensors estimations. Satellite remote sensing

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techniques is one of the indirect methods for estimating ET by predicting spatially distributed heat fluxes from point to large landscape. Obviously, spatial resolution is gaining more ground at the expense of lower temporal coverage [7]. However, there is need for estimation of ET both temporally and spatially at every point on earth surface without compromising accuracy. Studies on ET over the two major towns (Enugu and Nsukka) in Enugu state are still very few and there is also need for comparative analysis of existing ET data sources to ascertain the reliability of information obtained from them. Therefore, this study aims to analyze potential ET over two major towns (Enugu and Nsukka) in Enugu State using meteorological data from weather stations and compare the results obtained with that from satellite remotely sensed techniques.

1.1 CROPWAT

CROPWAT model developed by FAO is a decision support tool used by irrigation engineers and meteorologists to estimate crop water use and evapotranspiration. This study used CROPWAT 8.0 for windows to estimate evapotranspiration. CROPWAT 8.0 calculation procedures are based on the FAO publications of the Irrigation and Drainage Series namely: 1) No. 56 "Crop Evapotranspiration - Guidelines for computing crop water requirements"; and 2) No. 33 "Yield response to water". It uses Penman-Monteith equation (equation 1) to calculate ET [15]. Input data required to run the model include information on the meteorological station (country, station, altitude, latitude and longitude) together with climatic data (minimum temperature (°C), maximum temperature (°C), relative humidity (%), sunshine duration (hour) and wind speed (km/day). Once the parameters from meteorological station and climatic data were inputted, CROPWAT model automatically calculates the ET.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where

ET= evapotranspiration [mm day^{-1}],

R_n=net radiation at the crop surface [MJ m^{-2} day^{-1}],

G=soil heat flux density [MJ m^{-2} day^{-1}],

T=air temperature at 2 m height [°C],

u_2=wind speed at 2 m height [m s^{-1}],

e_s=saturation vapour pressure [kPa],

e_a=actual vapour pressure [kPa],

e_s-e_a=saturation vapour pressure deficit [kPa],

Δ=slope vapour pressure curve [kPa °C^{-1}],

γ=psychrometric constant [kPa °C^{-1}]

2.0 MATERIAL AND METHOD

2.1 Study Area

Enugu State is one of the states in south-eastern Nigeria (Figure 1) with a total area of 7,161km^2 (https://www.enugustate.gov.ng/index.php/elements-devices/). It is within the tropical rain forest zone with a derived savannah [8]. The state has humid tropical environment with maximum humidity between March and November [9]. There are two distinct seasons (wet and dry season) in the region with mean daily temperature of 26.7 °C (https://en.wikipedia.org/wiki/). The average annual rainfall in Enugu State is approximately 2,000 mm which arrives intermittently and becomes very heavy during the rainy season [10]. Because of availability of meteorological data, two stations were selected for this study namely: Nsukka and Enugu town (Figure 1) with coordinates of 6.856^{0}N, 7.410^{0}E and 6.340^{0}N and 7.390^{0}E respectively.

2.2 Data Collection and Processing

Basically, the data collected for this study were meteorological data from NIMET, satellite derived data from NASA and the downloaded ET data from ERA-Interim. Meteorological data from 1999 to 2014 were collected from the NIMET for Enugu town and Nsukka. The meteorological data (minimum temperature, maximum temperature, wind speed, relative humidity and solar radiation) collected were processed and ET calculated using CROPWAT software. CROPWAT software and ERA-Interim uses Penman-Monteith equation to calculate ET. The ET values were downloaded directly from ERA-Interim obtained at 80km spatial resolution. However, the downloaded ET data was in Network Common Data Form (NetCDF) file format which was later extracted using ARCGIS 10.1 software. Before comparison with other ET data, the downloaded ET from the ERA-Interim were converted to mm/day. In addition to the above, necessary data (minimum temperature, maximum temperature, solar radiation, wind speed and relative humidity) for calculation of ET were downloaded from NASA obtained at 60km spatial resolution. The data downloaded were also NetCDF files which were equally extracted using ARCGIS. Thereafter, ET were computed from the extracted data on excel spreadsheet using Penman-Monteith equation.

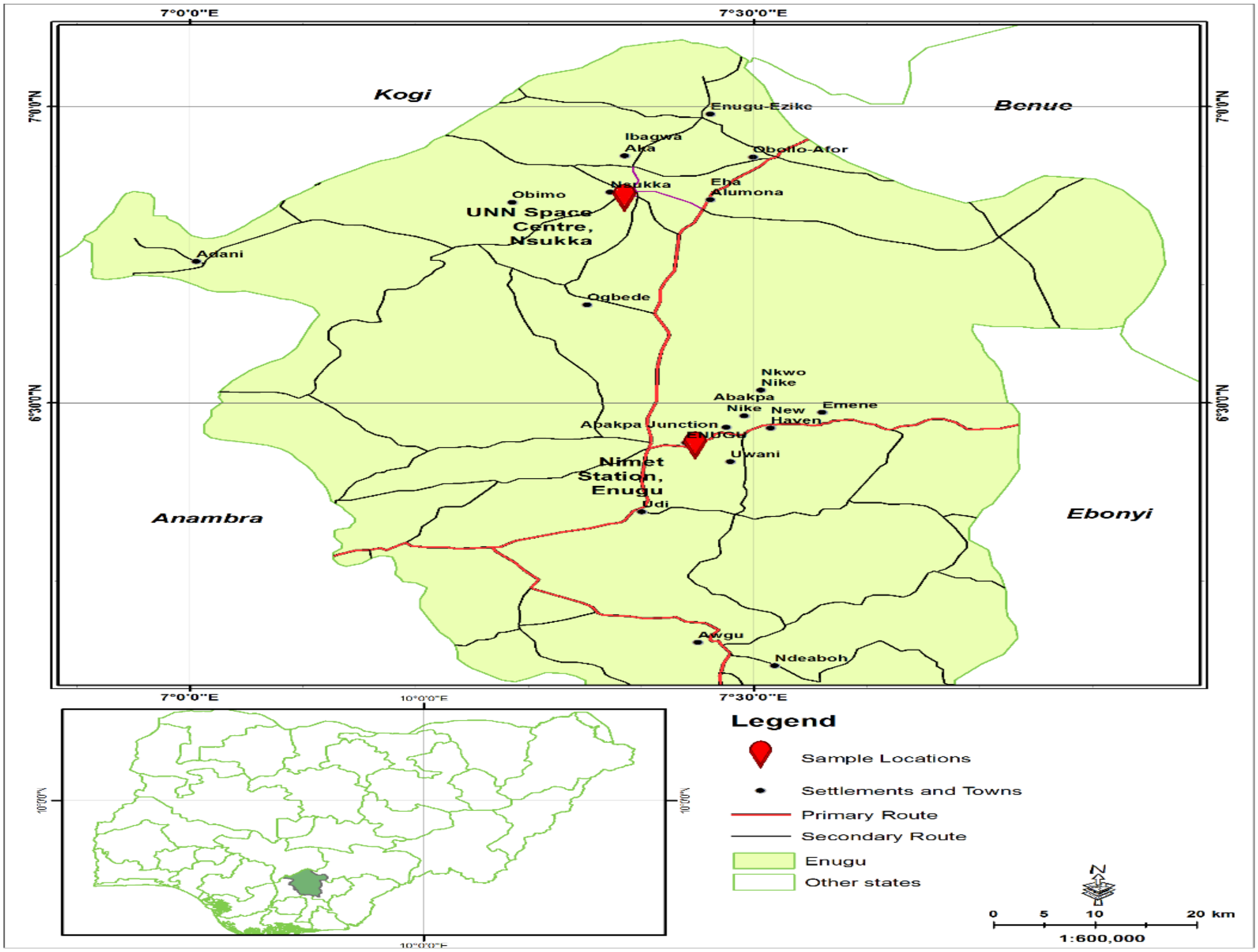

Figure 1: Maps showing the study area

2.2 *Statistical Analysis*

Statistical analyses were done using monthly averages of the potential ET obtained from the three data sources which were subjected to ANOVA test. The performance of the results was equally investigated using the following statistical tools: the root mean square error (RMSE) (equation 2), mean percentage error (MPE) (equation 3), mean absolute percentage error (MAPE) (equation 4), coefficient of determination (R^2) (calculated using excel).

$$RMSE = \sqrt{\frac{\Sigma_{k=0}^{n}(ET_{NASA} - ET_{NIMET})^2}{n}} \qquad (2)$$

$$MPE = \sqrt{\frac{\Sigma_{k=0}^{n} 1/n(ET_{NIMET} - ET_{NASA}) \times 100}{ET_{NIMET}}} \qquad (3)$$

$$MAPE = ABS\left[\sqrt{\frac{\Sigma_{k=0}^{n} 1/n(ET_{NIMET} - ET_{NASA}) \times 100}{ET_{NIMET}}}\right] \qquad (4)$$

where

ET_{NASA} and ET_{NIMET} are the estimated and measured values of ET;

ABS represents the absolute value of the expression.

3.0 RESULTS

3.1 *Potential ET Results for Enugu and Nsukka*

The daily potential ET for Enugu and Nsukka was obtained from 1999 to 2014 using the NIMET, NASA and ERA-Interim data. The mean monthly potential ET for Nsukka and Enugu obtained between 1999 and 2014 are shown in Table 1.

Table 1: Mean monthly potential ET for Enugu and Nsukka

	Enugu			Nsukka		
Month	**NIMET**	**NASA**	**ERA-Interim**	**NIMET**	**NASA**	**ERA-Interim**
January	6.36	4.22	0.98	6.51	4.17	0.98
February	6.85	4.05	1.04	7.03	4.05	1.038
March	7.28	3.72	1.12	7.60	3.76	1.12
April	6.17	3.35	1.10	6.56	3.36	1.13
May	4.75	3.14	1.10	5.09	3.14	1.13
June	3.55	2.72	1.02	3.73	2.73	1.08
July	3.00	2.38	1.01	3.04	2.38	1.06
August	3.03	2.36	1.01	2.99	2.36	1.07
September	3.09	2.47	1.01	3.07	2.47	1.05
October	3.44	2.70	1.09	3.43	2.70	1.14
November	4.20	3.10	1.22	4.24	3.10	1.25
December	5.31	3.53	1.14	5.44	3.56	1.16
Average	4.75	3.15	1.07	4.89	3.15	1.10

4.0 ANALYSIS AND DISCUSSIONS OF RESULTS

4.1 Potential ET Result for Enugu

Figure 2 shows some monthly averages of ET variation (1999-2014) for Enugu from NIMET, NASA and ERA-Interim. From the graph, it was observed that NIMET, NASA and ERA-Interim follow the same trend. NIMET has the highest ET values followed by NASA and then ERA-Interim for all the months. From the figure, ET varies across the months with highest ET values occurring between January and March and lowest values between June and August. Considering the two distinct seasons found in Enugu State, it shows that ET is more during the dry season and lower in the rainy season. This is in line with the report by [11] that the values of ET are generally lower in the rainy season (April to October) compared to dry season (November to March). Therefore, it can be said that the ET in Enugu varies with month as well as seasons. Graphically, the difference in the ET results from the three sources (NIMET, NASA and ERA-Interim) is lower in the rainy season than in the dry season. Figure 3 illustrates the average of the different sources. NIMET has its peak value as 7.28 in March, NASA has its peak value as 4.22 in January while ERA-Interim has its peak value as 1.22 in November for Enugu.

In addition, statistical analysis using ANOVA indicates that there was significant difference in the ET obtained from the three sources. However, correlation coefficient (R^2) between ET_{NIMET} and ET_{NASA} is high with value of 0.8728 compare to $ET_{ERA\text{-}Interim}$ with a value of 0.0415. This indicates that the ET_{NIMET}, ET_{NASA} analysis is acceptable than the ET_{NIMET}, $ET_{ERA\text{-}Interim}$ analysis.

Furthermore, error analysis was used to quantify the differences between the ET estimated using NIMET, NASA and ERA-Interim. The results obtained in the evaluation of the error analysis of the ET results for Enugu are summarized in Table 2. The result of RMSE showed that the ET derived from ET_{NIMET}, ET_{NASA} is better than that of ET_{NIMET}, $ET_{ERA\text{-}Interim}$ for Enugu.

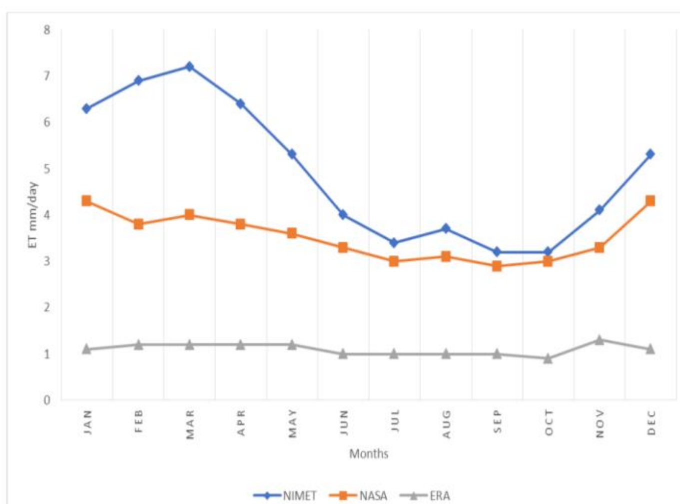

Figure 2 (a): Mean monthly ET for Enugu (1999)

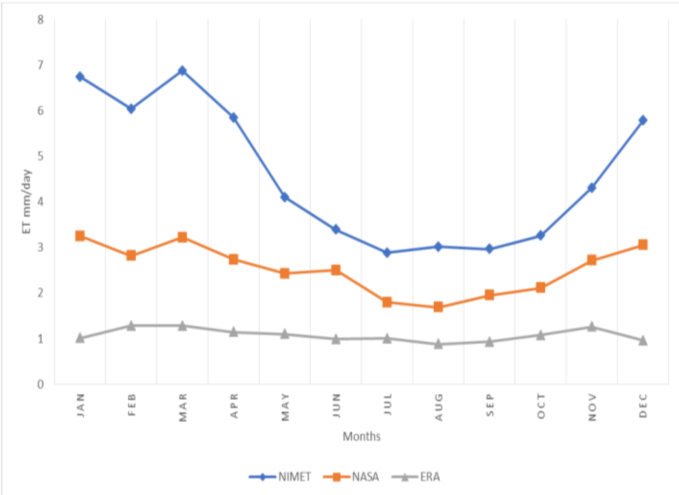

Figure: 2 (b): Mean monthly ET for Enugu (2011)

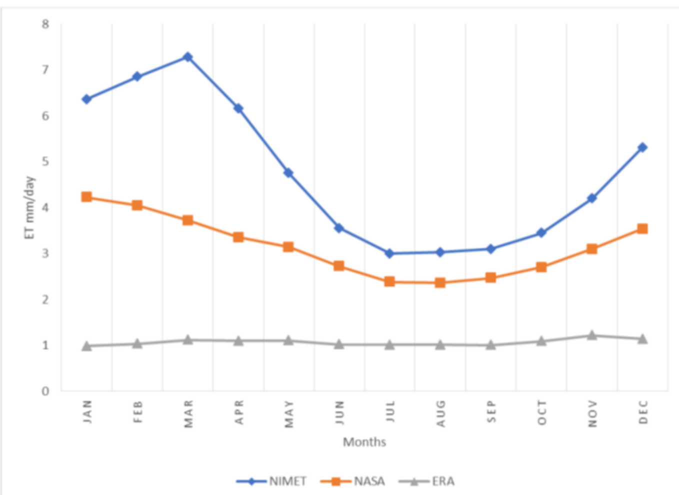

Figure 3: Mean averages of various sources for Enugu

Table 2: Summary of the evaluation statistics for Enugu.

	NIMET-NASA	NIMET-ERA Interim
RMSE (mm/day)	1.7154369	3.70395
MPE	30.96%	75.05%
MAPE	30.96%	75.05%
R^2	0.8728	0.0415

4.2 Potential ET result for Nsukka

Figure 4 shows the monthly averages of ET variation for Nsukka from NIMET, NASA and ERA-Interim. From the graph, it was observed that NIMET, NASA and ERA-Interim follow the same trend. ET by NIMET has the highest values followed by NASA and then ERA-Interim for all the months. From the figure, ET varies across the months with highest ET values occurring between January and March and lowest values between June and August. Generally, the ET variation in Nsukka is similar to that of Enugu indicating that the two stations are within the same climatic zone. Figure 5 illustrates mean averages of the different data sources. NIMET has its peak value as 7.598 in March; NASA has its peak value as 4.174 in January while ERA-Interim has its peak value as 1.252 in November across Nsukka.

Based on the analysis of variance, there were significant differences between the three sources ($P_{cal} \leq 0.05$). The correlation coefficient (R^2) between ET_{NIMET} and ET_{NASA} is 0.8637 while that of ET_{NIMET} and $ET_{ERA\text{-}Interim}$ is 0.0077. This indicates that the ET_{NIMET} ET_{NASA} analysis is better than the $ET_{NIMET,}$ $ET_{ERA\text{-}Interim}$ analysis.

The results obtained in the evaluation of the error analysis of the ET results for Nsukka are summarized in Table 3.

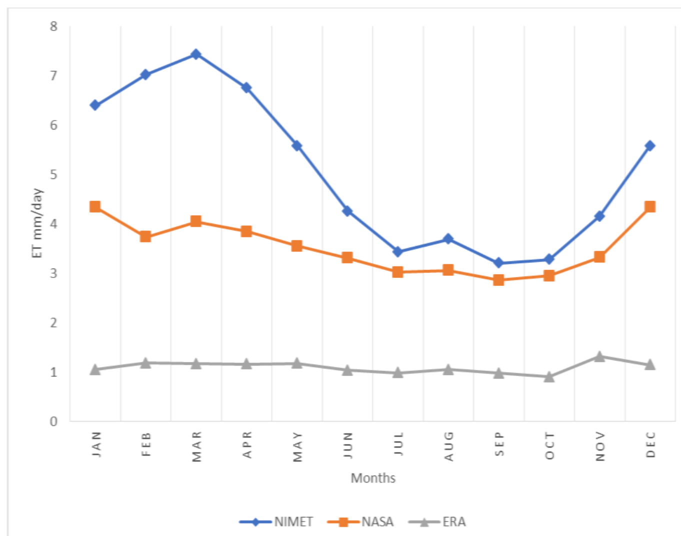

Figure 4 (a): Mean monthly ET for Nsukka (1999)

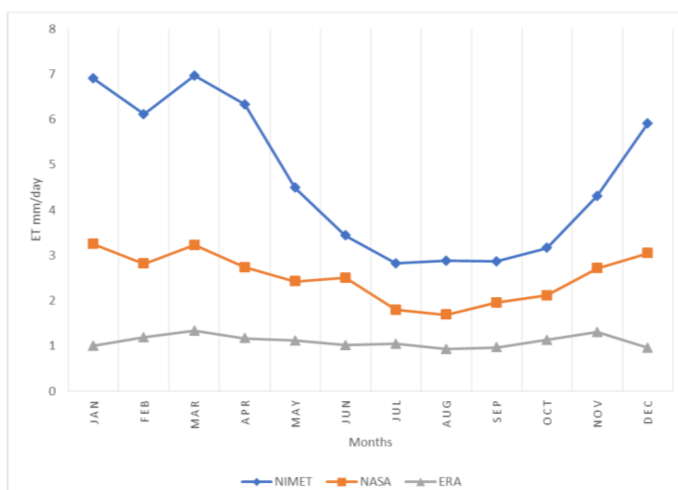

Figure 4 (b): Mean monthly ET for Nsukka (2011)

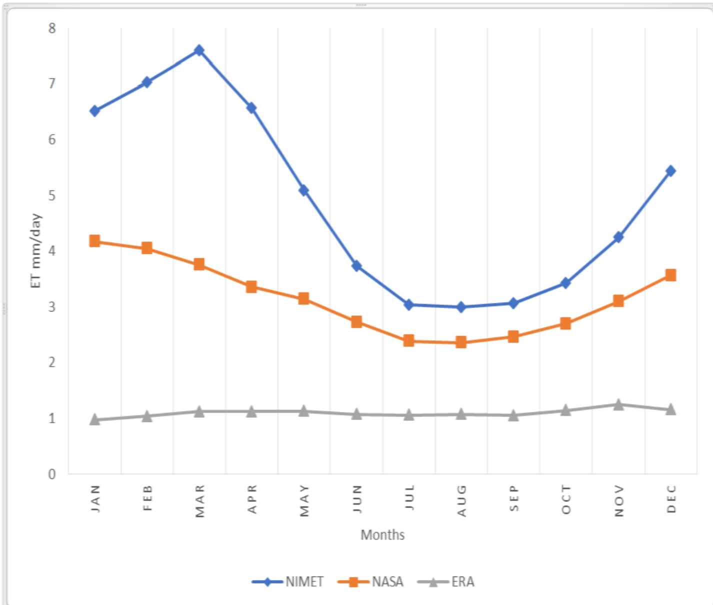

Figure 5: Mean averages of various sources for Nsukka

Table 3: Summary of the evaluation statistics for Nsukka

	NIMET-NASA	NIMET – ERA-Interim
RMSE	1.86	3.82
MPE	32.35	74.67
MAPE	32.35	74.67
R^2	0.86	0.007

5.0 CONCLUSION

Potential ET over Enugu town and Nsukka town in Enugu State varies with months and seasons with higher values in dry season than rainy season. The ET obtained from the three sources (NIMET, NASA and ERA-Interim) both in Nsukka and Enugu town have similar trend but vary in magnitude. Based on the statistical analysis carried out, ET_{NIMET} was the most accurate followed by ET_{NASA}. Recent versions of NASA and ERA-Interim data should be tested to ascertain the performance of these data sources in Enugu town and Nsukka town of Enugu State.

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