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ESTIMATION OF EVAPOTRANSPIRATION UNDER A HISTORICAL CLIMATE SCENARIO IN UYO WATERSHED, SOUTH–SOUTH NIGERIA

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Abstract: Land evapotranspiration (ET_0) is a central process in the climate system and a nexus of the water, energy and carbon cycles. Estimating evapotranspiration is one of the first important steps for calculating crop water requirements that has a special economic importance in rationalization of water consumption in the agricultural field under current and future climate conditions. In this study the agro–meteorological data of the study area was obtained from Nigerian Meteorological (NIMET) station, Abuja, to determine the variation of evapotranspiration under recent climate conditions. The Penman Monteith (PM) equation was used to calculate reference evapotranspiration (ET_0) according to the agro–meteorological data. The results show that under recent climate condition, the highest (ET_0) was evident in the year 1983 while year 1999 gave the lowest (ET_0).

Keywords: Evapotranspiration, hydrological cycle, climatic conditions, temperature, water resources

1. INTRODUCTION

It is an established fact that precipitation and temperature are the major meteorological parameters that have a direct effect on the hydrological cycle. It infers therefore that the change in precipitation and temperature influence water resources, land cover, and ecological sustainability. Consequently, such changes have the potential of significantly affecting the spatial and temporal availability of water resources and the water balance (Leta *et al.,* 2016).

Prediction of evapotranspiration is usually carried out by direct measurement (i.e. using lysimeter, field plots, water balance, soil moisture depletion studies and evaporation plans), or indirectly using empirical formulae (models) obtained through climatological observations (e.g. Penman, Jensen–Haise, Blaney–criddle, Hargreaves, Thornwaite, Blaney–Marin–Nigeria, etc.) (Ayotamuno, 2003). Direct measurements naturally give the best assessment of ET; while indirect measurement gives a more rapid, though not necessarily accurate result (Jensen and Haise, 1963; and Ayotamuno, 2003). The formula used in the indirect method range from simple equations, expressing evapotranspiration as a function of temperature alone, to complex models requiring extensive data and much calculations. Evapotranspiration–based methods are used to provide valuable information on broad aspects such as ecology, hydrology, atmospheric science, agronomy, carbon science of a watershed (Fisher *et al.,* 2017).

According to the predictions of climate change models, ET_o is expected to increase over the coming years due to an expected temperature rise (Goyal 2004). However, decreasing trends of ETo have been detected in some regions of China (Wang *et al*. 2007), Korea (Song *et al.* 2014), the USA (Suat *et al.* 2012), and Australia (Roderick and Farquhar 2004). Therefore, global atmospheric temperature rise might not necessarily result in a rise of ETo in all cases. For example, the decrease in solar radiation could compensate for the impact of temperatures on ETo which has been observed in many places (Wild, 2014). Chen *et al*. (2006) concluded that the reduction of wind speed (WS) was the primary meteorological variable contributing to the observed decline of ETo rates on the Tibetan Plateau. Evapotranspiration–based research has been conducted in different countries

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(Zhang *et al.,* 2016); however, limited studies have been undertaken in Nigeria, especially in the Uyo watershed. Therefore, this research is aimed at investigating the characteristics of the meteorological variables and ET_o on annual scales under a historical (a 33–year) period, thus evaluating the variability of potential evapotranspiration in Uyo, as well as identify the primary variables controlling changes in ET_o. The investigative outcome of this research will help to design and establish smart and sustainable water resources management in Ikpa River Basin, Uyo, Nigeria.

2. MATERIALS AND METHODS

Study area

Figure 1 shows the map of Nigeria showing Akwa Ibom State. Uyo is the Headquarter of the state, and it is located between Latitude 5°1[1]N and 5°3[1]N and Longitudes 7°55[1] E and 8°05[1] E above sea level within the tropical rainforest belt with evergreen vegetation. Uyo covers a total land area of 8,412km^2. It has a mean annual temperature between 26° – 27° and has two distinct seasons: the wet season (April to October) and the dry season (November to March). The rainy season usually lasts for about 7 or 8 months (SLUK–AK, 1989).

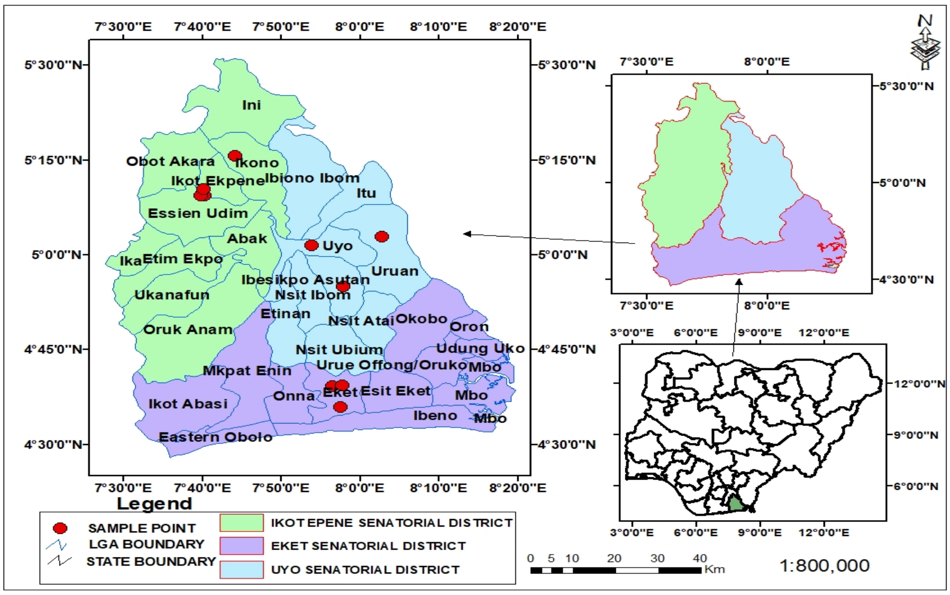

Figure 1: Map of Nigeria showing Akwa Ibom State
Source: ASTAL, Uyo (2021)

The rains are of high intensity and of bimodal pattern with two weeks' peaks in July and September, and a period of 2 – 3 weeks of little or no rain (called August Break) in between. The dry season gives rise to the post–season characteristic of a maximum rainfall regime in which the months with the heaviest rainfall are usually June and July for the first rainfall maximum and September for the second Maximum. The annual rainfall ranges from 2,000 mm to 3000 mm. The location of Akwa Ibom is just North of the equator and within the humid tropics and its proximity to the sea makes the state generally humid. Naturally, maximum humidity is recorded in July while the minimum humidity occurs in January (Essien and Essien, 2012).

Meteorology Data

Daily historical meteorology data used in this study includes: solar radiation, sunshine hour, Relative humidity (RH), temperature etc. The mean monthly rainfall (ρ_{mean}), minimum temperature(T_{min}), maximum temperature(T_{max}), mean temperature (T_{mean}), and sunshine hours (R_s) were obtained from NIMET for the purpose of computing PET in the model used. Mean monthly values of each of the parameters in the past thirty–three years (1981–2013) were inserted in the reference model to compute the PET using the model equations described below.

ET_O Computation Method

The methodology for ETo computation or measurement using the reference model selected for the study are as presented below:

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

where ET_o is the reference evapotranspiration (mm day^{-1}), R_n is the net radiation at the surface (MJm^{-2} day^{-1}), G is the ground heat flux density (MJm^{-2} day–1), T is the mean daily air temperature at 2m height (^{0}C), U_2 is the wind speed at 2m height (MS^{-1}), e_s is the saturation vapour pressure (KP_a), e_a is the actual vapour pressure (KP_a), Δ is the slope of the saturation constant ($kP_a{}^0C^{-1}$), and γ is the psychometric constant ($kP_a{}^0C^{-1}$).

The Penman–Monteith–FAO–56 method (Allen *et al.,* 1998) is a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters. The concept of reference evapotranspiration (ET_o) was introduced to avoid need to calibrate a separate evapotranspiration equation for each crop and stage of growth. Allen *et al.* (1998) defined reference evapotranspiration as the rate of evapotranspiration from a hypothetical crop with an assumed crop height (0.12 m) and a fixed canopy resistance (70 sm^{-1}) and albedo (0.23) which would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water". The method overcomes shortcomings of the previous FAO Penman Method and provides values more consistent with actual crop water use data worldwide. The PM FAO 56 method was used in this study as a reference model since it has been tested and proven to find application in all climate conditions across the globe.

Data Analysis

Minitab software was used for analyzing ETo. Means were separated by the least significant difference using the fisher's protected text at 5% probability.

3. RESULTS AND DISCUSSION

The result and discussion of this study are as presented in Table 1 and Table 2, respectively.

Computation of monthly reference evapotranspiration using the reference model

Monthly reference evapotranspiration (ETo) as shown in Table 1 revealed that PM reference evapotranspiration ranged from 1.4169–4.595 mm/day.

Table 1: Monthly evapotranspiration estimated by Penman Monteith method for Uyo Meteorological Station covering a 33 year period (1981 – 2013)

Model	Month	Total Count	Mean	SE Mean	Std. Dev.	Variance	Coefficient of variation	sum	Minimum	Maximum	Range
PM	January	33	3.8246	0.0916	±0.526	0.2766	13.75	126.2110	2.8147	4.9096	2.0949
	February	33	4.595	0.116	±0.665	0.444	14.50	151.623	2.857	6.088	3.231
	March	33	3.2773	0.0790	±0.454	0.2061	13.85	108.1509	2.4823	4.3110	1.8287
	April	33	2.5338	0.0589	±0.338	0.1146	13.36	83.6148	1.7147	3.2084	1.4937
	May	33	1.9383	0.0352	±0.202	0.0408	10.42	63.9631	1.4747	2.3133	0.8386
	June	33	1.7648	0.0341	±0.195	0.0383	11.09	58.2387	1.4101	2.2254	0.8153
	July	33	1.4169	0.0319	±0.183	0.0335	12.52	48.2439	0.8228	1.7398	0.9170
	August	33	1.4185	0.0331	±0.190	0.0361	13.40	46.8098	0.7620	1.7810	1.0190
	September	33	1.7456	0.0399	±0.229	0.0525	13.13	57.6060	1.0267	2.2842	1.2575
	October	33	2.0442	0.0424	±0.243	0.0593	11.91	67.4600	1.2843	2.5428	1.2585
	November	33	2.3323	0.0440	±0.252	0.0638	10.83	76.9665	1.6955	2.9392	1.2437
	December	33	2.8776	0.0721	±0.414	0.1716	14.40	94.9599	1.9447	3.8290	1.8843

Source :The researcher (2023)

The maximum PM reference evapotranspiration (4.595 mm) was recorded in the month of February, while the minimum PM reference evapotranspiration was registered in the month of July (1.41 mm/day). The result of this study is within the same range with the findings of Tekwa and Bwade (2011) who obtained the value of 4.35 mm/day using direct evapotranspiration measurement (Pan evaporation method). Moreover, the result of this study is in sync with the fact that climate variables and soil present a high spatio–temporal variability (FAO, 2016), as such, the lowest values are found when the weather is cool, humid and cloudy, which is a characteristics of the weather condition of the study area around the month of July. Uyo is known to have higher mean temperature and lower relative humidity in the month of February (SLUK–AK, 1989). Therefore, the higher ETo recorded for those months which have lesser relative humidity and higher temperature with little, and sometimes, no amount of rainfall were as expected since ETo increases with increase in temperature and with decrease in humidity.

Computation of Yearly Reference Evapotranspiration using the reference model

Table 2 shows the Reference evapotranspiration (ET_O) for all the years under study, in which the highest reference evapotranspiration was found in 1983 (2.87 mm/day) and the lowest Reference evapotranspiration was found in 1999 (1.931 mm/day) for the Penman–Monteith model, due to differential changes which occurs in the weather conditions like temperature, sunshine hours, humidity and wind speed.

Table 2: Yearly evapotranspiration estimated by Penman Monteith method for Uyo meteorological station covering a 33 year period (1981 – 2013)

Model	Year	Total Count	Mean	SE Mean	Std Dev	Variance	CV	Sum	Minimum	Maximum	Range
PM	1981	12	2.599	0.316	± 1.09	1.196	42.07	31.187	1.399	4.663	3.265
	1982	12	2.510	0.273	± 0.94	0.892	37.61	30.125	1.526	4.301	2.776
	1983	12	2.873	0.362	± 1.25	1.575	43.68	34.478	1.636	6.088	4.452
	1984	12	2.693	0.322	± 1.11	1.242	41.39	32.310	1.629	4.999	3.370
	1985	12	2.672	0.267	± 0.92	0.854	34.59	32.064	1.655	4.846	3.191
	1986	12	2.512	0.230	± 0.79	0.635	31.74	30.138	1.622	4.292	2.670
	1987	12	2.721	0.293	± 1.02	1.030	37.30	32.654	1.451	4.626	3.175
	1988	12	2.637	0.353	± 1.22	1.493	46.33	31.646	1.434	5.300	3.866
	1989	12	2.524	0.215	± 0.74	0.554	29.49	30.293	1.695	3.844	2.149
	1990	12	2.819	0.361	± 1.25	1.568	44.42	33.824	1.537	5.682	4.145
	1991	12	2.706	0.347	± 1.20	1.448	44.47	32.473	1.539	5.464	3.926
	1992	12	2.605	0.309	± 1.07	1.147	41.11	31.255	1.459	5.035	3.576
	1993	12	2.754	0.334	± 1.16	1.342	42.06	33.052	1.497	5.241	3.744
	1994	12	2.635	0.318	± 1.10	1.216	41.85	31.623	1.348	4.818	3.470
	1995	12	2.500	0.303	± 1.05	1.103	42.01	30.000	1.470	4.825	3.355
	1996	12	2.369	0.253	± 0.88	0.770	37.03	28.432	1.395	4.380	2.985
	1997	12	2.248	0.236	± 0.82	0.670	36.42	26.975	1.389	3.879	2.490
	1998	12	2.245	0.260	± 0.90	0.813	40.16	26.934	1.270	4.139	2.869
	1999	12	1.931	0.180	± 0.62	0.387	32.20	23.178	1.102	2.857	1.755
	2000	12	2.160	0.268	± 0.93	0.863	43.01	25.922	1.188	4.439	3.251
	2001	12	1.951	0.310	± 1.07	1.152	55.01	23.409	0.762	4.508	3.746
	2002	12	2.151	0.191	± 0.66	0.437	30.73	25.806	1.372	3.529	2.157
	2003	12	2.457	0.263	± 0.91	0.829	37.06	29.480	1.333	4.278	2.944
	2004	12	2.568	0.354	± 1.23	1.504	47.77	30.812	1.312	5.128	3.816
	2005	12	2.360	0.257	± 0.89	0.794	37.75	28.324	1.373	3.970	2.597
	2006	12	2.243	0.294	± 1.02	1.034	45.32	26.920	1.241	4.155	2.915
	2007	12	2.298	0.275	± 0.95	0.906	41.41	27.580	1.283	4.220	2.937
	2008	12	2.384	0.265	± 0.92	0.844	38.53	28.605	1.384	4.155	2.771
	2009	12	2.628	0.354	± 1.23	1.506	46.69	31.540	1.314	5.250	3.936
	2010	12	2.745	0.387	± 1.34	1.802	48.89	32.945	1.407	5.429	4.023
	2011	12	2.646	0.343	± 1.19	1.410	44.87	31.755	1.425	4.934	3.509
	2012	12	2.445	0.302	± 1.05	1.096	42.81	29.339	1.387	4.362	2.975
	2013	12	2.397	0.259	± 0.90	0.806	37.46	28.767	1.271	4.157	2.886

Source: The researcher (2023)

The fluctuation of ETo due to climate warming is expected to have important consequences because of its association with precipitation change. From precipitation data, ETo estimates, and accurate crop coefficients, adapted irrigation schedules could be defined and strategies could be developed optimizing water use as well as yield.

Changes in meteorological elements that are affected by climate change should be considered to formulate reasonable policies concerning the future agricultural crop production and water resources. Therefore, this study has successfully provided the significant baseline information on long–term trends in spatio–temporal climate variations that can be used for various agricultural crop management and water resources planning purposes in Uyo. Comparing this work with the findings of authors from other regions, the findings of this study provides ample information that is expected to obtain insight into regional climate changes over the past agricultural productivity problems and natural disasters such as drought and flood events in Uyo. Ultimately, it is believed that this study and our results demonstrate the need and importance of knowledge about the seasonal/regional meteorological patterns that will inform decision–making processes, adaptive management, and development to minimize the negative impacts of climate change on food production in Uyo in particular and Nigeria in general.

4. CONCLUSIONS

Since potential evapotranspiration is a key parameter for the determination of crop water demand and irrigation scheduling, the temporal trend of potential evapotranspiration is an important concern with reference to climate change. Due to climate change, status of the conditions needed to run the evapotranspiration will vary remarkably in future. In most cases, an increasing trend in atmospheric temperature, vapour pressure gradient and precipitation has been reported. The rate of evapotranspiration increases with the increase in temperature, precipitation and wind speed and decreases with the increase in humidity in the atmosphere. The accurate estimation of the ET_0 response to meteorological variables could be favourable for designing future irrigation systems and agricultural production practices in the studies area.

Evapotranspiration in the South part of Nigeria at Uyo area had the highest and lowest monthly ETo in the months of February and July, respectively. Regarding the annual potential evapotranspiration, the highest ETo were observed in the year 1983 and the lowest ET_O were observed in the year 1999. The comparison between potential evapotranspiration during the years (1983–1994) revealed a general increase in evapotranspiration within that period, after which there was a drop between 1995–2008. Water consumption under climate change in Uyo should be developed to mitigate the negative effects of climate change on evapotranspiration. Also, selection of better cultivar and the suitable irrigation level are the most important factors for maximizing crop yield.

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