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Determination of the Evapotranspiration Parameters of Benin City Based on the Penman-Monteith Equation from 1979 to 2013

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Abstract

Evapotranspiration comprising the Reference evapotranspiration (ETo) and the standard crop Actual Evapotranspiration (ETc) was computed for Benin City using the Penman-Monteith equation for a period spanning 35years. The standard crop used in this study was Cassava. The input data of the equation consisted of meteorological data which were obtained from research-based institutions and government agencies. The results showed that the average daily ETo was between 2.643 and 3.162mm/day while similar data for the ETc was between 3.500 and 4.300mm/day. Peak ETo and ETc occurred in the month of March while the lowest values of these evapotranspiration constituents occurred in the month November and January.

1. Introduction

Evapotranspiration plays a critical role in crop life, groundwater balance studies and groundwater modelling operations [1]. It is the sum of all process by which water moves from the land surface to the atmosphere by means of evaporation and transpiration [2]. The impacts of evapotranspiration may be direct or indirect. The deep root movement of water constitutes the direct impact while the evaporation of surface water resources and unsaturated zone account for the indirect impact groundwater balance. Several methods abound for the determination of the evapotranspiration of a catchment. These include Penman-Monteith-FAO-56 method, Blaney-Criddle method, Hargreaves-Samani modified 2 method, Pan Evaporation method, Jensen-Haise method and Thornthwait method [3]. The Penman-Monteith-FAO-56 method is generally known to produced more reliable results than the other methods [3-5]. In the Penman-Monteith-FAO-56 method, three scenarios of evapotranspiration are considered namely reference evapotranspiration, standard crop evapotranspiration and non-standard crop evapotranspiration where water stress is factored into the evaluation. The expressions to determine the standard crop evapotranspiration and adjusted crop evapotranspiration are presented in equations 1 and 1a [1, 4, 6].

$$ET_c = K_C \times ET_o \quad (1.0)$$

$$ET_{c(adj)} = (K_C \times K_s) \times ET_o \quad (1.0a)$$

ET_c is the crop evapotranspiration under standard condition, K_c is crop coefficient, K_s is the coefficient caused by water stress in the soil; ET_o is the reference crop evapotranspiration (mm/day)

The reference crop evapotranspiration is the evapotranspiration from a reference surface with a hypothetical grass reference crop having abundant water. This parameter may sometimes be referred to as potential evapotranspiration. The reference evapotranspiration in this study was computed using the Modified Penman-Monteith method as enunciated in the FAO Irrigation and drainage paper No. 56 (1998) due to its reliability compared to the other methods. The Penman-Monteith method makes use of major meteorological parameters such as temperature, relative humidity, wind speed and solar radiation [3]. These data were obtained from secondary sources and, processed to obtain the evapotranspiration on a daily, monthly or yearly basis. Temporal Penman-Monteith equations [4] for the reference evapotranspiration is expressed as

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma\left(900/_{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2.0)$$

where ET_O is the reference evapotranspiration (mm/day), R_n net radiation at the crop surface $(\text{MJ m}^{-2}.\text{day}^{-1})$, G is soil heat flux density $(\text{MJ m}^{-2}.\text{day}^{-1})$, T is air temperature at 2m heigh; t $({}^{o}C)$, u_2 is wind speed at 2m height (m/s), e_s saturation vapour pressure (kPa), e_a is actual saturation vapour pressure (kPa), $e_s - e_a$ is saturated vapour pressure shortfall (kPa), Δ slope vapour pressure curve (kPa/^{o}C) and γ is the psychometric constant (kPa/^{o}C)

The aim of this study is to determine the reference evapotranspiration and the standard crop evapotranspiration for Benin City over a period of 35 years given its peculiar meteorological characteristics.

2.0 Materials and Methods

2.1 Description of Study Area

Benin City is one of the ancient cities in Nigeria that is fast expanding and soon-to-be-designated as a smart city in Nigeria [7]. It is located between longitude $5^0$30'E and $5^0$48'E and Latitude $6^0$17'N and $6^0$24'N (see figure 1). The city was decapitated from the former Midwestern region of Nigeria where it was administrative capital since 1963. Benin City is about 250km east of Lagos, 90km from the coastline and the Atlantic Ocean. The climatic condition of Benin City is defined by Koppen's climatic categorisation where rainfall is abundant almost all year round. The study area is located in the tropical monsoon (AM) climatic sphere, sandwiched in the tropical wet and dry climates [8]. Climatic elements in terms of the changes, variation and variability have considerable influence on anthropogenic activities which have also exerted a high level of alteration on the micro-climatic attributes of the study area [9-13].

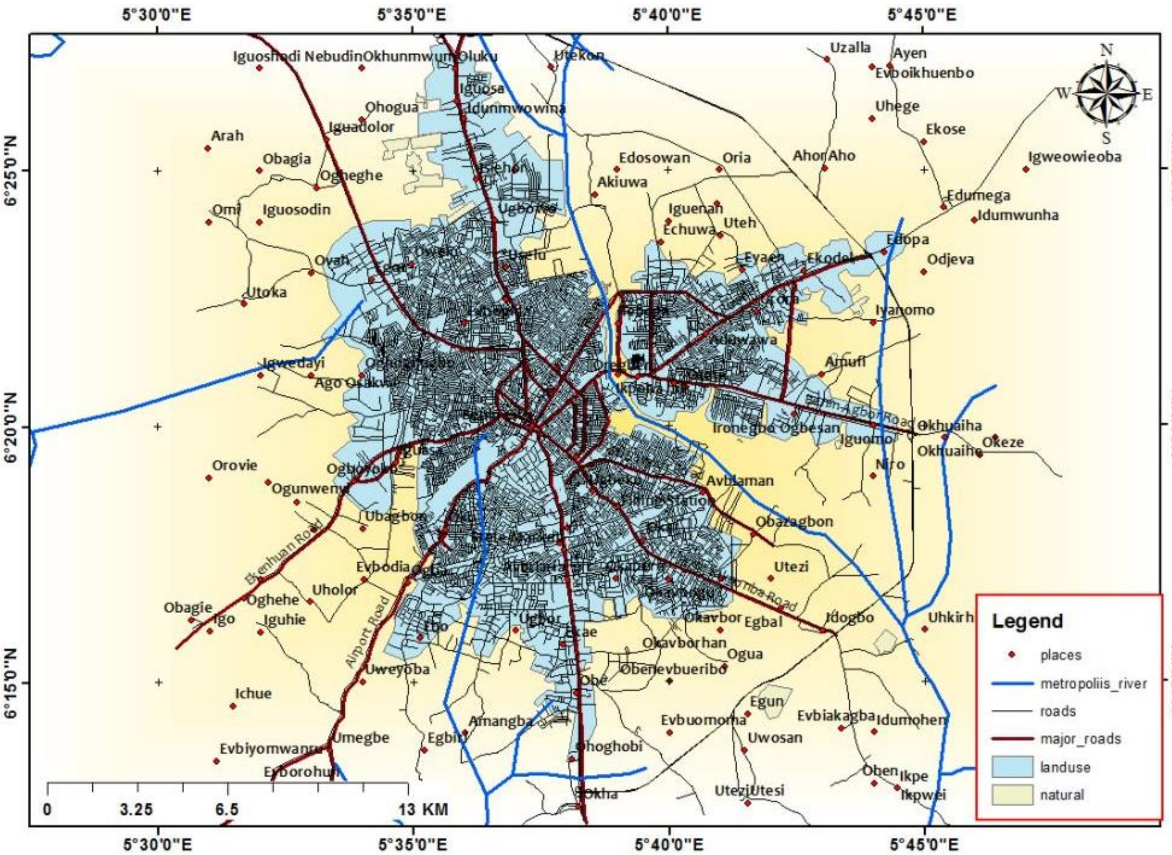

Figure 1: Location Map of Benin City [14]

2.2 Meteorological data

The critical data required for this study include meteorological data such as air temperature, wind speed, sunshine and relative humidity. Other parameters were obtained from models obtained from literature. Data span of about thirty-five (35) years are generally deemed sufficient for hydrological predictions both for surface and groundwater [15, 16].

2.2 Parameter Correction for Evapotranspiration Computation

2.2.1 Air Temperature

Air temperature is the most parameter of the FAO Penman-Monteith equation for the computation of the reference evapotranspiration. Temperature has a direct correlation with evapotranspiration as an increase in temperature, undoubtedly leads to an increase in evapotranspiration. The least temperature parameter required is the mean temperature was used in this study.

Allen, Pereira [4] permits assumptions and approximations principally from empirical relations for other parameters of the Penman-Monteith equation except for the air temperature for which data from agrometeorological stations must be obtained. Temperature as well as other climate data were collected at a measuring height ranging from 2m to 3m above the natural ground level in the agrometeorological station. This is unlike the normal meteorological station that collects climate data at a height of about 10m above the natural ground. The data obtained from typical meteorological station will therefore be converted to their 2m equivalent as in the case of the agrometeorological station using the expression in equation 3.

$$T_2 = T_z \frac{4.87}{\ln(67.8z - 5.42)} \quad (3.0)$$

where T_2 wind speed at 2m height, T_z is wind speed at elevation z above the natural ground

2.2.2 Solar Radiation

Solar radiation is one parameter that is rarely measured and for which relevant assumptions were made. Solar radiation provides the amount of energy required to change a large quantity of liquid into vapour. Solar radiation capacity to initiate evapotranspiration is determined by the Spatio-temporal characteristics of the location [17]. The solar radiation for this study emanates from temperature difference between the peak and the least values for the location using the Hargreaves' radiation formulae, adjusted and validated at several weather stations for a variety of climatic conditions and given as

$$\frac{R_s}{R_a} = K_{rs}\sqrt{T_{max} - T_{min}} \quad (4.0)$$

R_s is station radiation $(\text{MJ m}^{-2}\text{d}^{-1})$, R_a is exterrestial radiation $(\text{MJ m}^{-2}\text{d}^{-1})$, T_{max} is maximum The temperature, T_{min} is minimum temperature and K_{rs} is adjusted coefficient which depends on the proximity of the location to a water body.

adjusted coefficient is divided into interior and coastal locations. The coastal location has been adopted for Benin City considering that the south-westerly wind is the prevailing wind for the study area causing the heavy rainfall for the location, hence K_{rs} is taken as 0.19. Figure 2 shows the relationship between the fraction of extraterrestrial radiation that reaches the earth's surface, Rs/Ra, and the air temperature difference $T_{max} - T_{min}$ for interior (k_{Rs} = 0.16) and coastal (k_{Rs} = 0.19) regions

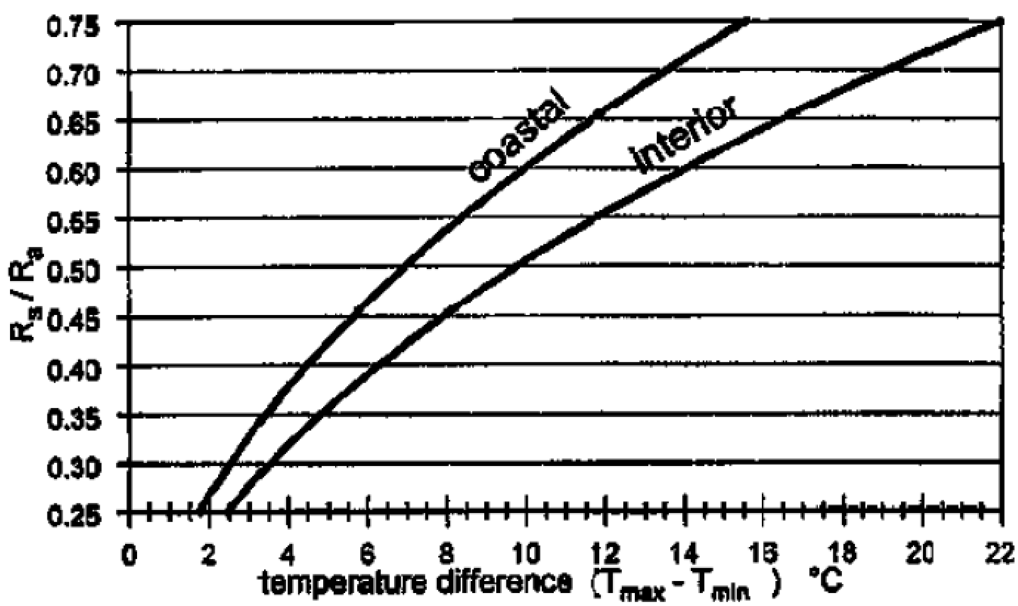

Figure 2: Rs/Ra vs Air Temperature Difference for Interior and Coastal Regions [4]

The extra-terrestrial radiation is obtained from the expression:

$$R_a = \frac{24(60)}{\pi} G_{SC} d_r \left[w_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(w_s) \right] \quad (5.0)$$

G_{sc} is solar constant taken as $0.0820\left(\text{MJ m}^{-2}\text{ min}^{-1}\right)$, d_r is inverse relative distance from the sun, w_s is sunset hours angle, (rad), φ is location latitude (rad), δ is solar decimation (rad)

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365} J\right) \quad (6.0)$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365} J - 1.39\right) \quad (7.0)$$

$$w_s = \cos^{-1}\left[-\tan(\varphi)\tan(\delta)\right] \quad (8.0)$$

For this work, the annual evapotranspiration was investigated by converting daily, weekly and monthly data to their yearly equivalent data. Evapotranspiration was computed for both the dry season as well as for the rainy season.

The net radiation R_n is the difference between the incoming shortwave radiation R_{ns} and the outgoing longwave radiation R_{ni} i.e.

$$R_n = R_{ns} - R_{ni} \quad (9)$$

The incoming shortwave radiation is dependent on the shortwave radiation R_s and the Albedo or the canopy reflection coefficient α (usually taken as 0.23) here expressed as

$$R_{ns} = (1-\alpha)R_s \quad (10)$$

while

$$R_s = 0.25 + 0.5\left(\frac{n\pi}{24w_s}\right) \quad (11)$$

where n is the measured duration of sunshine per day for the location

On the other hand, the net outgoing long radiation is dependent on the radiation of a clear sky R_{50}. The expressions for the clear sky radiation and the outgoing longwave radiation are presented in equations 12 and 13

$$R_{50} = \left(0.75 + 2\times10^{-5} z\right) R_a \quad (12)$$

$$R_{ni} = \sigma T_k \left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{50}} - 0.35\right) \quad (13)$$

σ is Stefan-Boltzmann constant taken as 4.903×10^{-9} $\left(\text{MJ K}^{-4}\ \text{m}^{2}\ \text{d}^{-1}\right)$

T_k is the mean absolute temperature in kelvin for the location within a 24hour period.

2.2.3 Soil Heat Flux Density

The soil heat flux density describes the heating of the soil by radiations especially from the sun and is principally caused by temperature effects. For a longer period of soil heat flux estimation, there abound in literature calculation procedures based on the assertion that the soil radiation follows from the air temperature over a time interval and is expressed as
Assuming a constant soil heat capacity of say 2.1MJ m^{-3} $^{o}C^{-1}$ for a suitable depth of soil, the monthly soil heat flux (which can be extended to yearly soil heat flux) is expressed as

$$G_{month,i} = 0.07\left(T_{month,i+1} - T_{month,i-1}\right) \quad (14)$$

$$G_{month,i} = 0.14\left(T_{month,i} - T_{month,i-1}\right) \quad (15)$$

$T_{month,i}$ is mean air temperature of month i$\left({}^{o}C\right)$, $T_{month,i-1}$is preceeding month i-1 mean air temperature i$\left({}^{o}C\right)$,

$T_{month,i+1}$ is mean air temperature of the next month i+1$\left({}^{o}C\right)$

The soil heat flux density is often regarded as infinitely small and was ignored for this study. The amount of energy gained or lost by the soil due to radiation from the sun should be arithmetically subtracted or added to the net radiation when estimating evapotranspiration.

2.2.4 Actual and Saturation Vapour Pressure

The actual and saturated vapour pressures play a critical role in the determination of reference evaporation for any given catchment. The FAO (1998) method has specified procedures for the termination of the actual and saturated vapour pressure given sparse data like in the case of our environment. The empirical relationships require records of the relative humidity of the location as well as the dew point temperature. The dew point temperature is the temperature at which moisture/liquid water in the air begins to condense or evaporate at the same rate at which it condenses. It is the temperature where the saturated vapour pressure (e_s) is equal to the actual vapour pressure (e_a). The expression for e_a and e_s are in given equations 16 and 17.

$$e_a = \frac{RH \times e_s}{100} \quad (16)$$

$$e_s = 0.610 e^{\left(\frac{17.27 T_d}{T_d + 237.3}\right)} \quad (17)$$

RH is relative humidity (%), T_d is the dew point temperature $\left({}^{o}C\right)$

Ukhurebor *et al.* [18] gave a relationship of the dew point and relative humidity from which the required values of relative humidity were obtained (see Figure 3). The regression equation depicting the relationship between the relative humidity and dew point for Benin City is given as

$$RH = 21.076e^{0.0566T_d} \qquad (18)$$

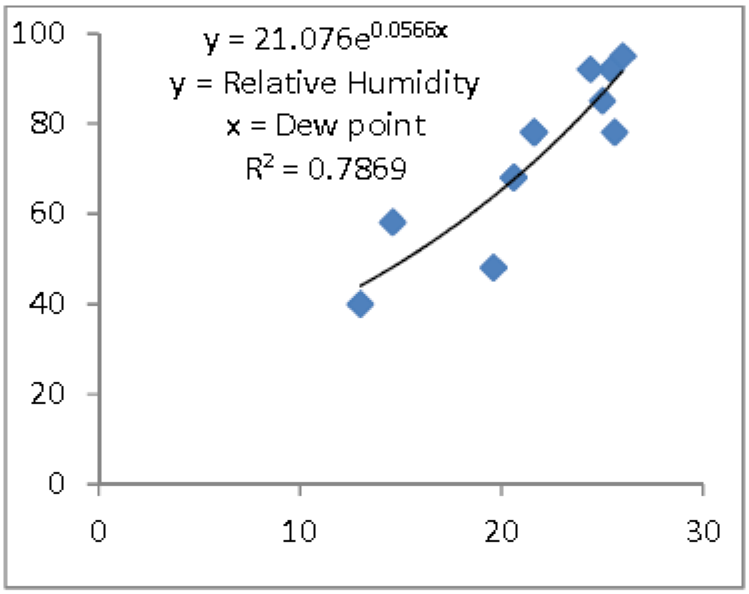

Figure 3: Regression Plot Between Relative Humidity and Dew Point Temperature For Benin City [18]

2.2.5 Psychrometric Constant γ

The psychrometric constant is an expression comprising the specific constant pressure c_p, atmospheric pressure (P), molecular weight of water vapour/dry air and the latent heat of vaporisation of a mass of air. Using minimum values specified by FAO [4], the psychrometric constant as a function of atmospheric pressure P is as presented in equations 19 to 21.

$$\gamma = 6.65 \times 10^{-4} P\left[kPa^{o}C^{-1}\right] \qquad (19)$$

$$P = 101.3\left(\frac{293 - 0.065z}{293}\right)^{5.26} \qquad (20)$$

$$\gamma = 0.0674\left(\frac{293 - 0.065z}{293}\right)^{5.26} \qquad (21)$$

While equation (19) is the psychrometric constant in relation to the atmospheric pressure (P), equation (21) is a relationship between the psychrometric constant and the elevation of the study location. The simplicity of equation 21 is the sole criteria for its adoption in this study.

2.2.6 Slope of Saturation Vapour Pressure (Δ)

This is the ratio of the saturation vapour pressure and temperature prevalent in the catchment. The slope of saturation vapour pressure is a parameter that is required for the computation of the evapotranspiration of the catchment using the Penman-Monteith equations [4]. The expression for the slope of the saturation as a function of dew point temperature is presented in equation 22

$$\Delta = \frac{4098\left[0.6108e^{\left(\frac{17.27T_d}{T_d+237.3}\right)}\right]}{\left(T_d + 237.3\right)^2} \quad \left(kPa^oC^{-1}\right) \qquad (22)$$

Preferable values of the slope of saturation vapour pressure are calculated using the mean air temperature as obtained from the catchment.

2.2.7 Wind Speed

The speed and direction of wind play a critical role in the estimation of the evapotranspiration of a catchment in determining the groundwater balance. Paramount importance between the wind speed and direction is the wind direction. The wind speed values for this study were obtained from literature [19, 20] some of which have been presented in the preceding chapter. Since most of the wind data were obtained from weather stations where the anemometers are typically placed at 10m above the natural ground, the conversion relationship to derive the wind speed at 2m depth for the study location is given as

$$u_2 = u_z \frac{4.87}{\ln\left(67.8z - 5.42\right)} \qquad (23)$$

where u_2 wind speed at 2m height, u_z is wind speed at elevation z above the natural ground

Given that z is 10m, the conversion factor to the wind speed at 2m height and for which was used in this study is given in equation 25

$$u_2 = 7.24 \times 10^{-3} u_{10} \qquad (24)$$

2.3 Determination of the Standard Crop and Crop Coefficient

The expression for the ET_c is as shown in equation 1.0. The coefficients of evapotranspiration vary with the type of crop being cultivated in an area. Some of the arable crops that do well in Benin City include but not limited to Yam, Cassava, Sweet Potato, Water Melon, Pineapple, Maize, Plantain, Banana, Pumpkin and Bitter Leaf [7, 8]. Tree crops that produce good yield include Citrus, Pawpaw, Mango, Cashew to mention but a view. According *to* Fabolude and Aighewi [21], *only about 27%* of the land in Benin City are available for viable and repetitive agriculture. The mentioned crops stages of development are presented in Table 1.0. The lengths of crop development stages more peculiar to Benin City as obtained in Shiru, Shahid [22] are presented in Figure 4. The crop coefficients of evapotranspiration for the different crops for three major stages of development such as the initial, mid and last stages are presented in Table 2.

Table 1: Lengths of Crop development stage for various planting periods [4].

	Crop	Crop groupings	L_{int}	L_{dev}	L_{mid}	L_{Last}	Total
1	Cassava	Roots and Tubers	150	40	110	60	360

2	Yam	Roots and Tubers	150	40	110	60	360
3	Maize	Cereals	20	35	40	30	125
4	Watermelon	Vegetable - Cucumber Family	20	30	30	30	110
5	Pineapple	Tropical Fruits and Trees	60	120	600	10	790
6	plantain/Banana	Tropical Fruits and Trees	120	90	120	60	390
7	Pumpkin/Bitter leaf	Vegetable - Cucumber Family	20	30	30	20	100
8	Sugarcane	Sugarcane	50	70	220	140	480
9	Sweet Potato	Roots and Tubers	15	30	50	30	125

Table 2: Crop Coefficient for Evapotranspiration Computation [4]

	Crops	$K_{c\ int}$	$K_{c\ mid}$	$K_{c\ end}$	Max. Crop Height (m)
1	Cassava	0.3	1.1	0.5	1.5
2	Yam	0.3	1.1	0.5	1.5
3	Maize	1.0	1.2	0.6	1.5
4	Watermelon	0.4	1.0	0.75	0.4
5	Pineapple	0.5	0.3	0.3	1.0
6	plantain/Banana	1.0	1.2	1.1	4.0
7	Pumpkin/Bitter leaf	1.0	1	0.8	0.4
8	Sugarcane	0.4	1.25	0.75	3.0
9	Sweet Potato	1.0	1.15	0.65	0.4

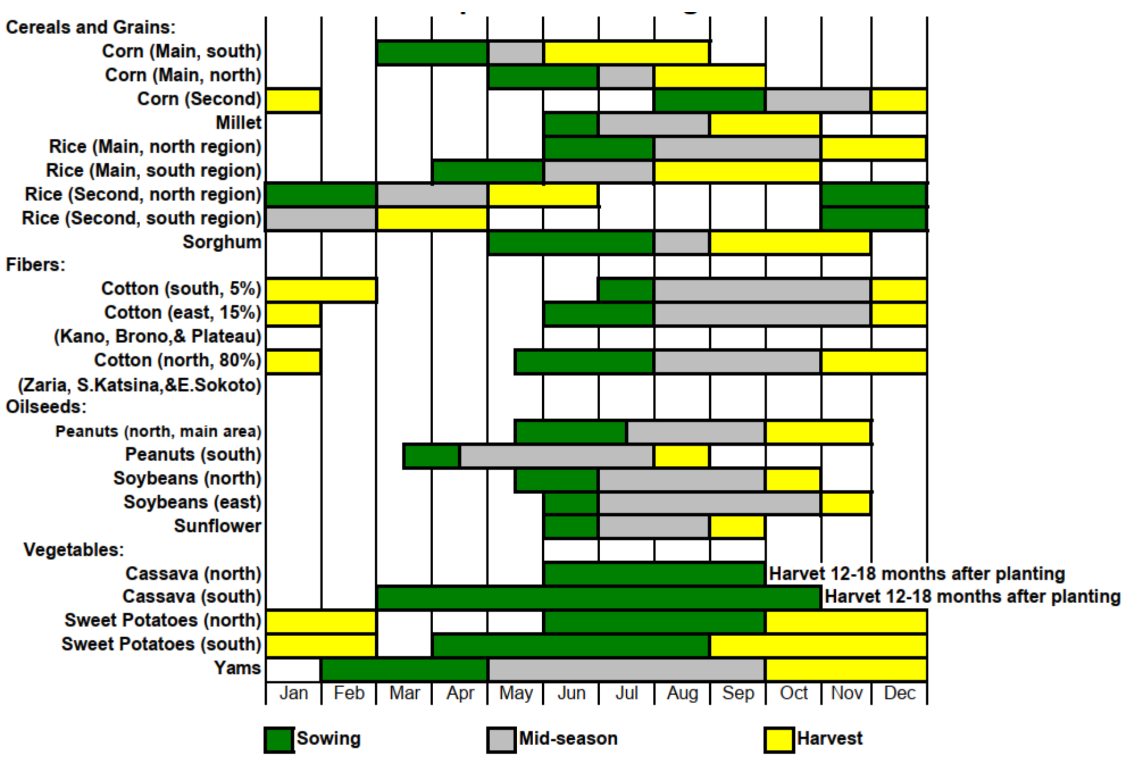

Figure 4: Crop calendar for Nigeria [22]

From figure 4, it is clear that outside November to January, at least one of the mentioned crops in the study area can be planted. The period between November and January constitute the dry season of the study area when harvesting and land preparation for the next planting season takes place. For this study, cassava was chosen as the standard crop upon which to determine the crop coefficient towards computing the standard crop evapotranspiration devoid of water stress. This is based on the fact that the planting season of these crops are usually in the rainy season when there is plenteous water to aid crop growth. The Kc value will therefore be for a single crop in this study.

2.3.1 Adjustment of $K_{c\ int}$

The initial growth stage development crop coefficient in Table 1 was adjusted using the wetting time interval obtained from the precipitation data of the study area. The wetting time interval for the study area was 2days interval and the average infiltration depth, obtainable from the rainfall depth was between 5 and 12mm indicating medium shower using the initial growth period of Cassava. Figure 5 was used to extrapolate the Kc value from the reference evapotranspiration for the initial stage of crop development.

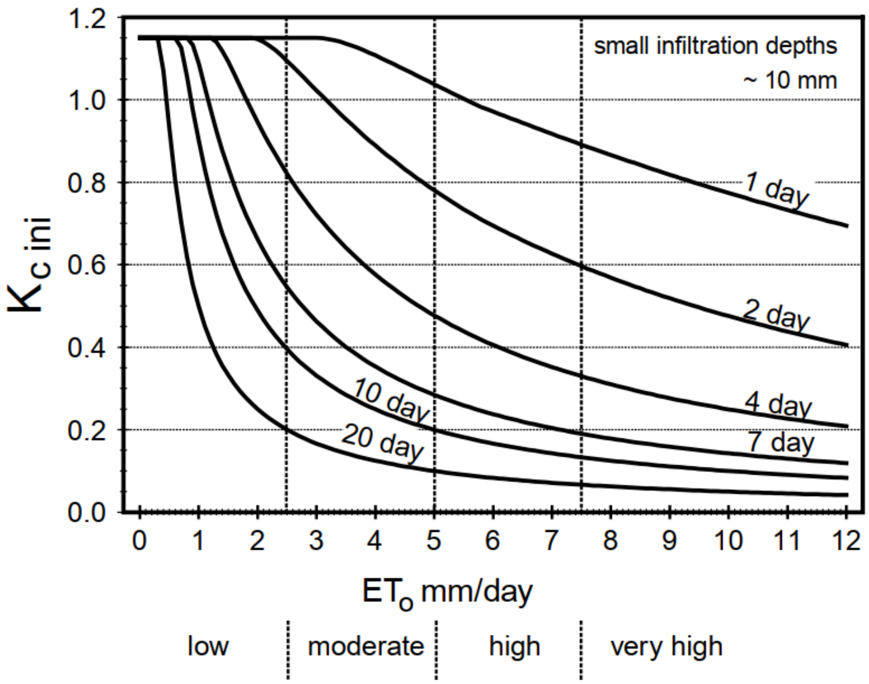

Figure 5: Light - Medium Infiltration Depth $K_{c\text{-}int}$ Chart

2.3.2 The determination of $K_{c\ mid}$ and $K_{c\ end}$

Benin City can generally be described as a sub-humid region due to its abundance rainfall. The mid-season and end-season growth stage crop coefficient used for the computation of the ET_c can be obtained from equation 25.

$$K_{c\ mid} = K_{c\ (Tab)} + \left[0.04\left(u_2 - 2\right) - 0.004\left(RH_{min} - 45\right)\right]\left(\frac{h}{3}\right)^{0.3} \quad (25)$$

where $K_{c\ (Tab)}$ is the Table value $K_{c\ mid}$ or $K_{c\ end}$;

RH_{min} - mean value for daily minimum relative humidity during the mid – season growth stage [%],

for $20\% \le RH_{min} \le 80\%$,

u_2 - mean value for daily wind speed at 2 m height over grass during the mid-season growth stage

Cassava at mid-season is between 0.8 and 1m height and the examined wind speed at the stated period in Benin City was less than 2m/s indicating that for mid and end seasons, typical table values of the crop coefficients are used. The duration of the mid-season incorporates the development phase and, for cassava, this amounts to another 150 days. The duration of the end-season for cassava as obtained in Table 1 was 60days.

2.3.3 Construction of the K_c curve

The crop coefficient for all the stages of crop growth will be plotted against the three adjusted K_c defining each stage of crop development. The steps for the construction of the Kc curve as follows: [4, 5]

a) Divide the growing period into four general growth stages that describe crop phenology viz: initial, crop development, mid-season, and late season stages and identify the three K_c values that correspond to $K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$ from Table X3.
b) Adjust the Kc values to the frequency of wetting and/or climatic conditions of the growth stages as outlined in the previous section.
c) Construct a curve by connecting straight line segments through each of the four growth stages. Horizontal lines are drawn through $K_{c\ ini}$ in the initial stage and through Kc mid in the mid-season stage. Diagonal lines are drawn from $K_{c\ ini}$ to $K_{c\ mid}$ within the course of the crop development stage and from Kc mid to Kc end within the course of the late season stage.

3.0 Results and Discussion

3.1. Reference evapotranspiration RE

The Reference evapotranspiration between 1979 to 2013 are presented in Figures 6 to 12. In figure 6, on average, the range of the Reference evapotranspiration ranges from 3.003 to 3.516mm/day with the maximum occurring in March while the minimum evapotranspiration occurring in November. For the period of 1979 to 1983, two crest points with potential evaporation of about 3.7m comprising 1980 and 1983 are visible in the graph. While the latter crest point occurred in March, the former took place in September.

Figure 7 shows the Reference evapotranspiration between the period of 1984 and 1988. On average, RE is between 3.1251 and 3.7233mm/day also at September and March respectively. There were noticeable spikes in PE in each year of the period under review.

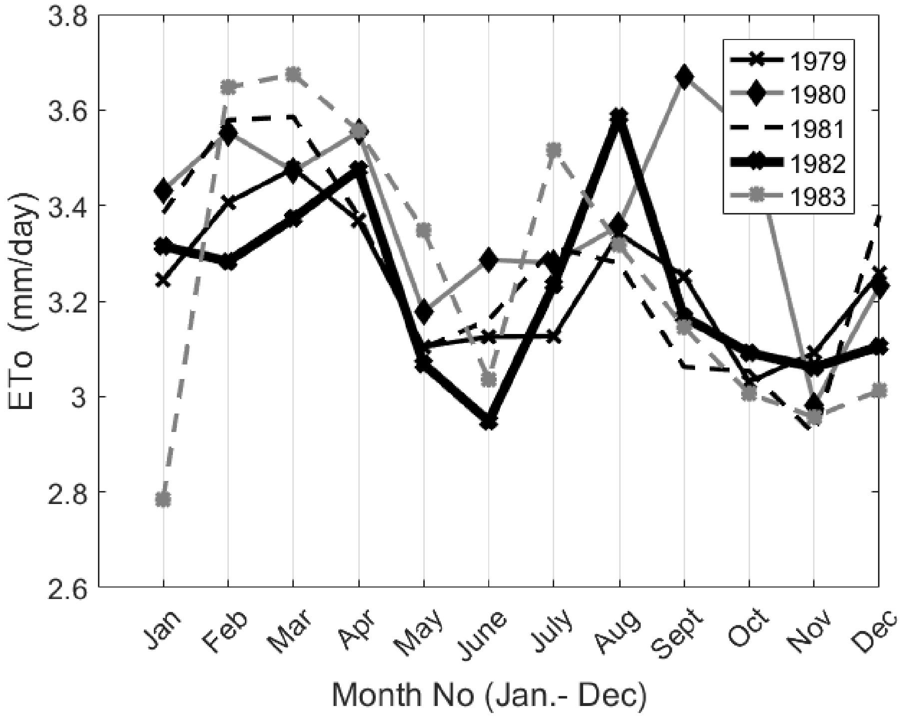

Figure 6: Reference evapotranspiration between 1979 – 1983

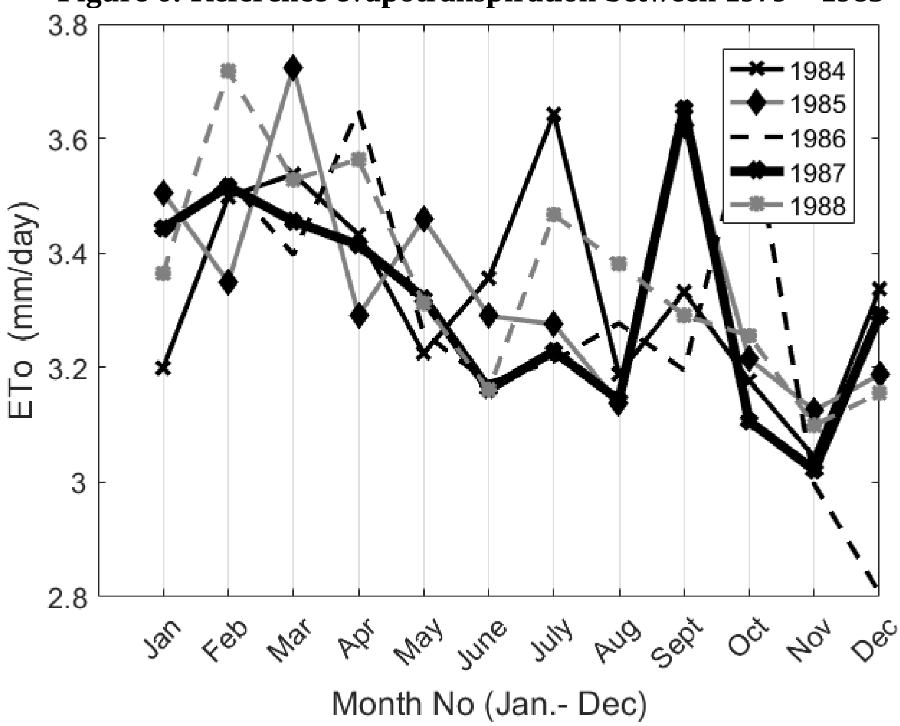

Figure 7: Reference evapotranspiration between 1984 – 1988

Figure 8 shows the Reference evapotranspiration between the period of 1989 and 1993. On average, RE is between 3.0479 and 3.5634mm/day occurring at November and March respectively. There were noticeable spikes in RE in the months of March, April, June and September within the period under review.

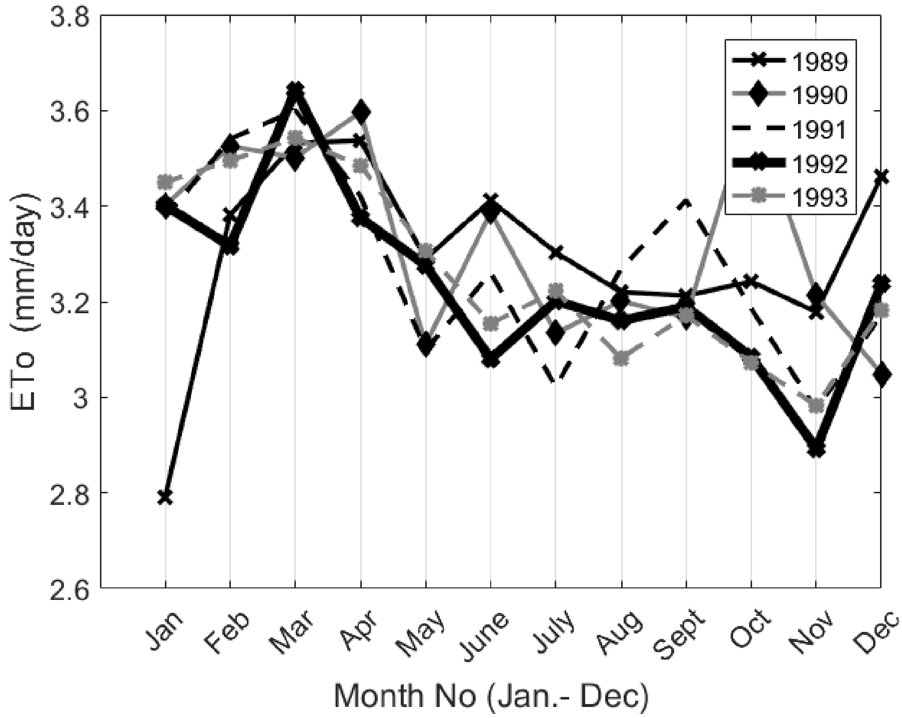

Figure 8: Reference evapotranspiration between 1989 – 1993

Figure 9 shows the Reference evapotranspiration between the period of 1994 and 1998. On average, ETo is between 3.0139 and 3.5884mm/day occurring at October and March respectively. There were noticeable spikes in ETo in the months of February to April and August for the period under review.

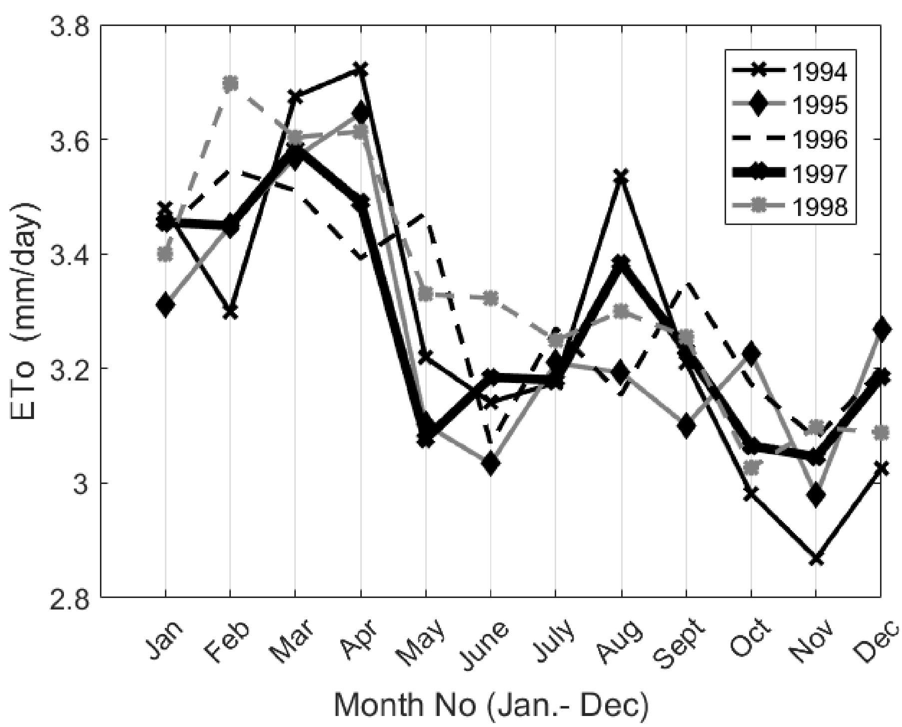

Figure 9: Reference evapotranspiration between 1994 – 1998

Figure 10 shows the Reference evapotranspiration between the period of 1999 and 2003. On average, ETo is between 3.0221 and 3.6306mm/day occurring at November and March respectively. There were noticeable spikes in ETo in the months of February to April and August for the period under review.
Figure 11 shows the Reference evapotranspiration between the period of 2004 and 2008. On average, RE is between 3.0884 and 3.6142mm/day occurring at October and March respectively. There were noticeable spikes in ETo in the months of February to April and July for the period under review.
Figure 12 shows the Reference evapotranspiration between the period of 2004 and 2008. On average, ETo is between 3.0652 and 3.4857mm/day occurring within the same period as in Figure 11. There were noticeable spikes in ETo in the months of February, March and August for the period under review. Figure 13 shows a general summary of the Reference evapotranspiration which has it that the average ETo for the period of 35yrs is between 2.6435 and 3.1620mm/day with the extreme values occurring at November and March respectively. The standard deviation of the mean ETo values was 0.151mm/day

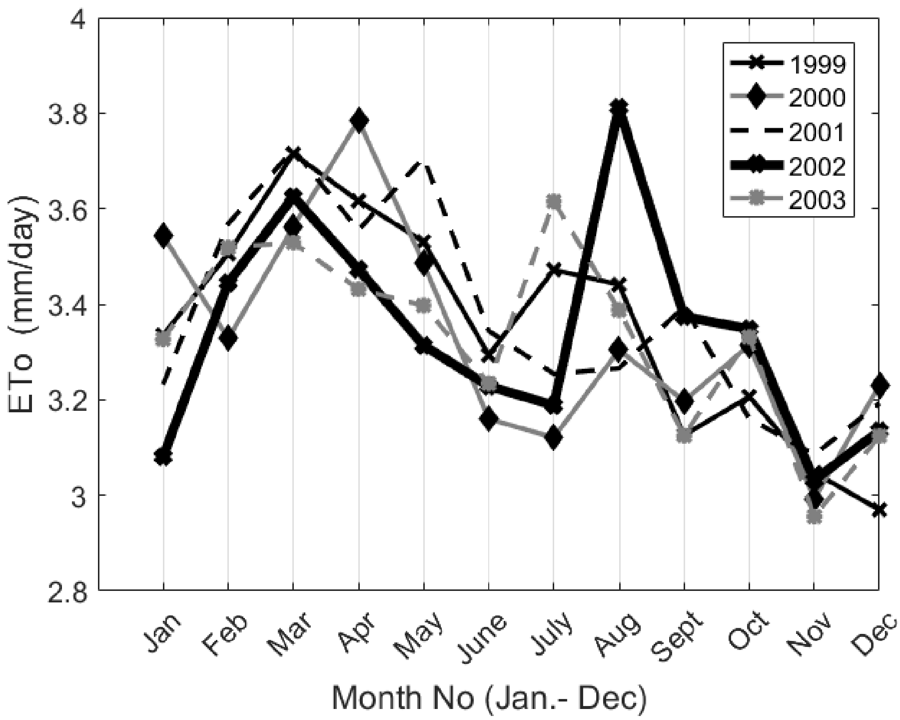

Figure 10: Reference evapotranspiration between 1999 – 2003

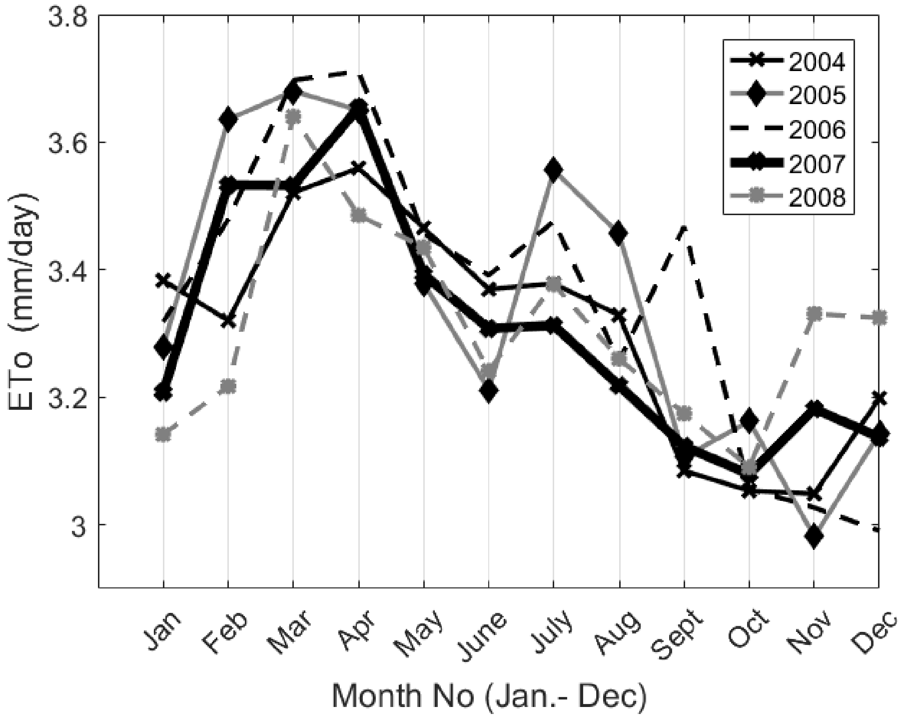

Figure 11: Reference evapotranspiration between 2004 – 2008

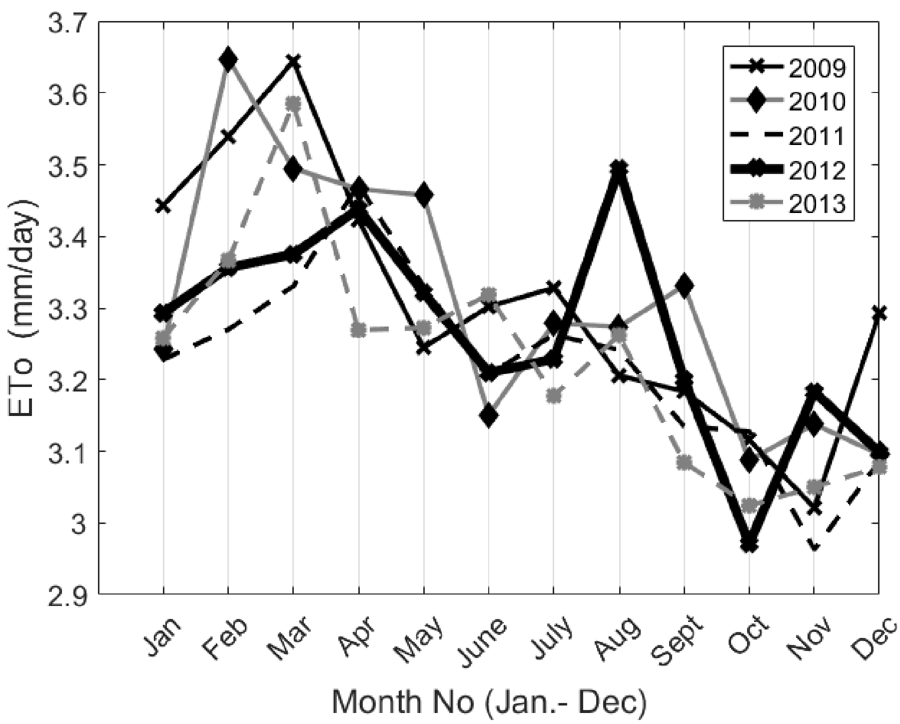

Figure 12: Reference evapotranspiration between 2009 – 2013

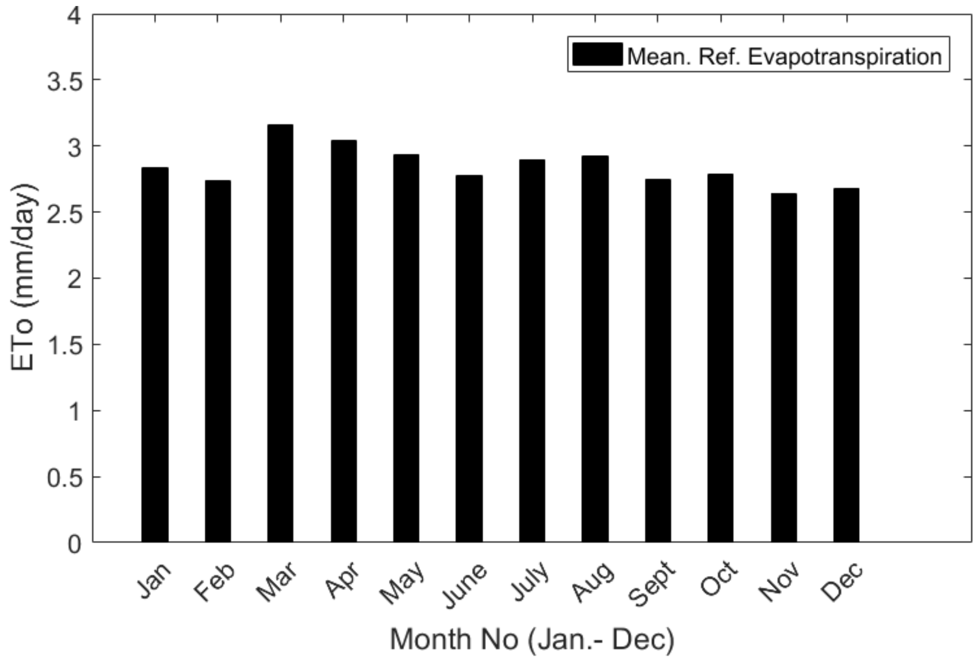

Figure 13: Mean Reference Evapotranspiration (1979 – 2013)

3.2 Generalized Crop coefficient (K_c) Curve

The generalised Kc curve of the study area is presented in Figure 12. The sample crop was cassava whose crop coefficients from the initial stage to the mid stage were uniform with a value of 1.1. The crop coefficient at the end stage which extends from December to January ending have a crop coefficient of 0.5 as presented in Table 2.

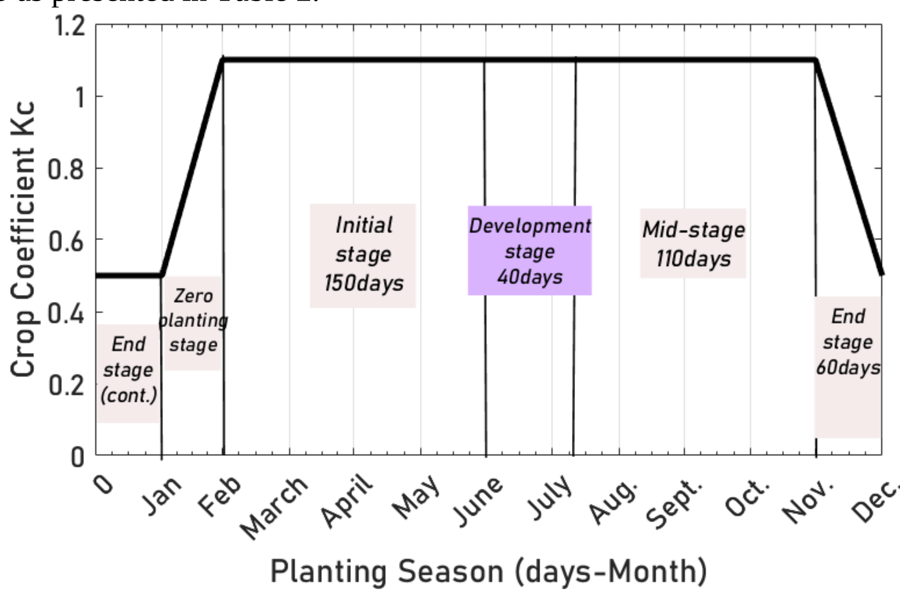

Figure 14: Generalised K_c Curve for the Sample Crop

3.3 Single Crop Evapotranspiration ET_c

Figures 15 to 21 show the results of the $\mathbf{ET_c}$ computed for the study area. Figure 22 is a summary of the average month standard crop evapotranspiration for the study area. The standard crop evapotranspiration between 1979 and 1983 are presented in Figure 15. The maximum ET_c were in the months of March and September with a value of about 4mm/day while the minimum occurred between May and June commencing from the initial stage to the mid stage of crop development. the highest ET_c occurred in 1980.

Figure 16 show a fairly uniform ET_c of 3.8mm/day within the initial to mid stage. The end stage was similar to figure 15 with a value of 1.6mm/day. The ET_c between 1989 and 1993 are presented in figure 17. Peak periods occurred in 1990 (September) and 1992(March) with values of 4mm/day. The lowest point from the initial to the mid stage of crop development was in the month of June in 1992.

Figure 18 shows the ET_c between 1994 and 1998. The peak period was in the months of April (4.2mm/day) and August (3.7mm/day) while the lowest point occurred in March 1995 (June) with a value of 3.4mm/day. The lowest point ET_c was about 1.5mm/day. The maximum ET_c in figure 19 occurred in the month of April (2000) and August (2002) with values of 4.2mm/day and 4.35mm/day respectively. The lowest points within the initial to mid stage was 3.5mm/day at July (2000). Figure 20 shows the ET_c for the period spanning 2004 and 2008. The figure has semblance with those between 1984 and 1988. The maximum ET_c was 4.1mm/day in April while the lowest within the active development stage of the crop (initial - mid stage) was 3.5mm/day in the month of October.

Figure 21 has striking semblance to figure 15. The peak ET_c occurred in the month of February and slopes downwards to November which marks the end of the active stage of crop development with a value 3.35mm/day. From Figure 22, the highest standard crop evapotranspiration generally occurs in the month of March annually.

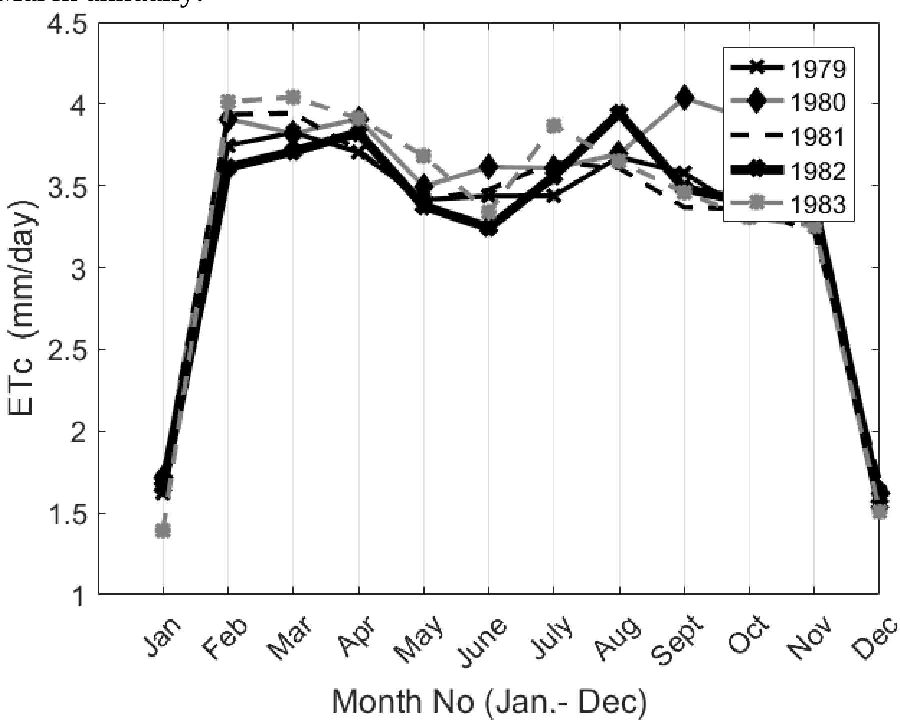

Figure 15: Standard Crop Evapotranspiration between 1979 – 1983

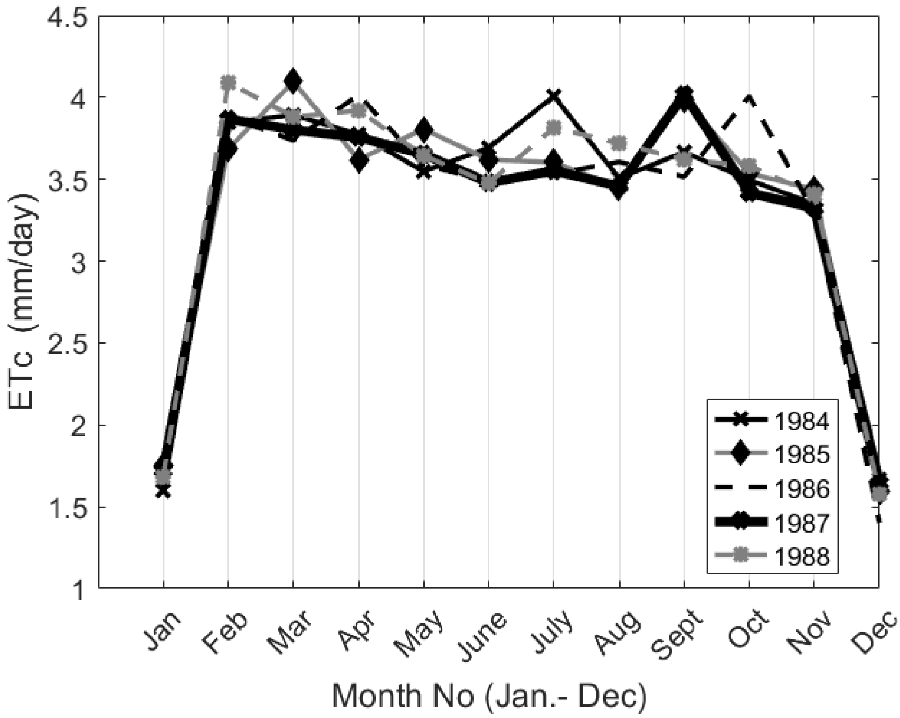

Figure 16: Standard Crop Evapotranspiration between 1984 – 1988

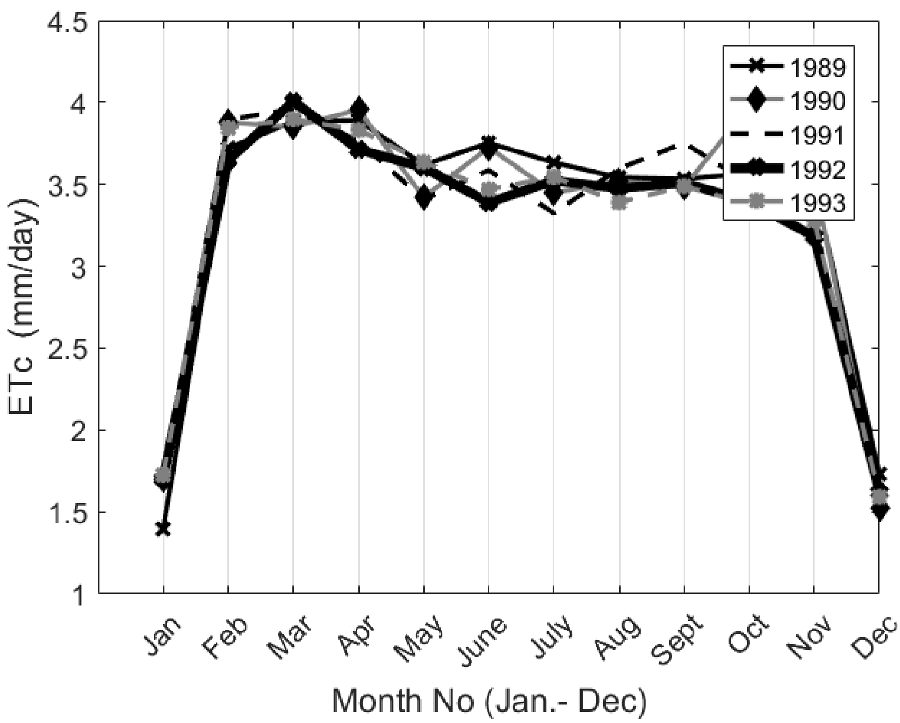

Figure 17: Standard Crop Evapotranspiration between 1989 – 1993

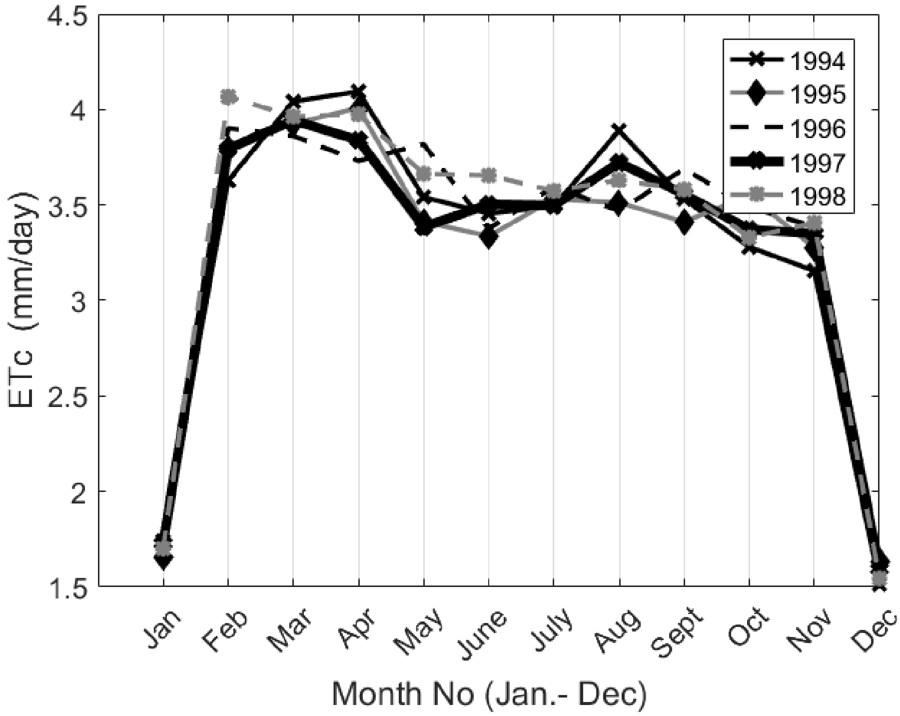

Figure 18: Standard Crop Evapotranspiration between 1994 – 1998

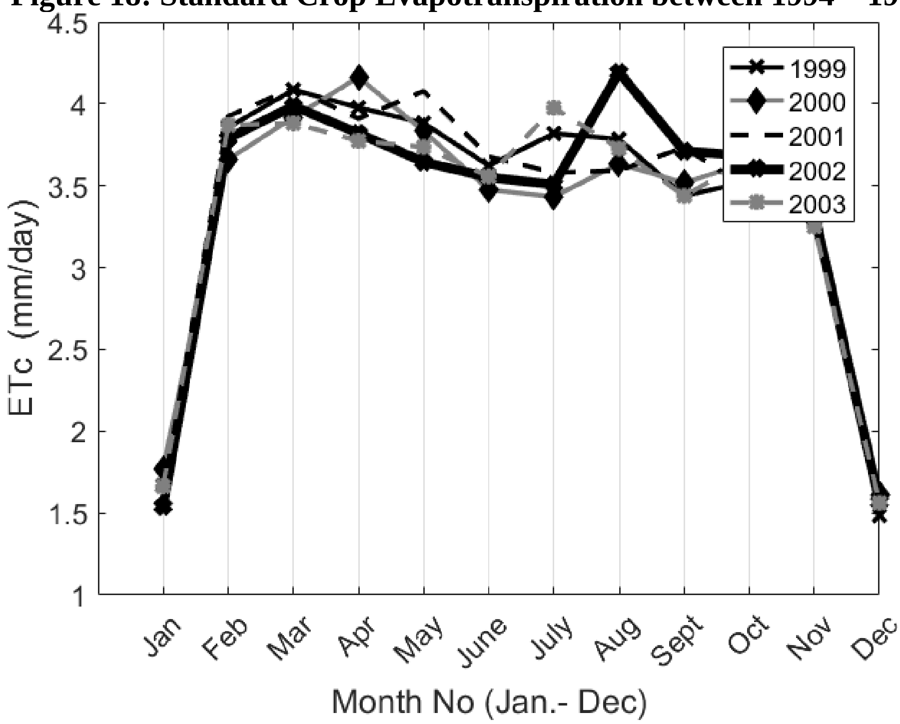

Figure 19: Standard Crop Evapotranspiration between 1999 – 2003

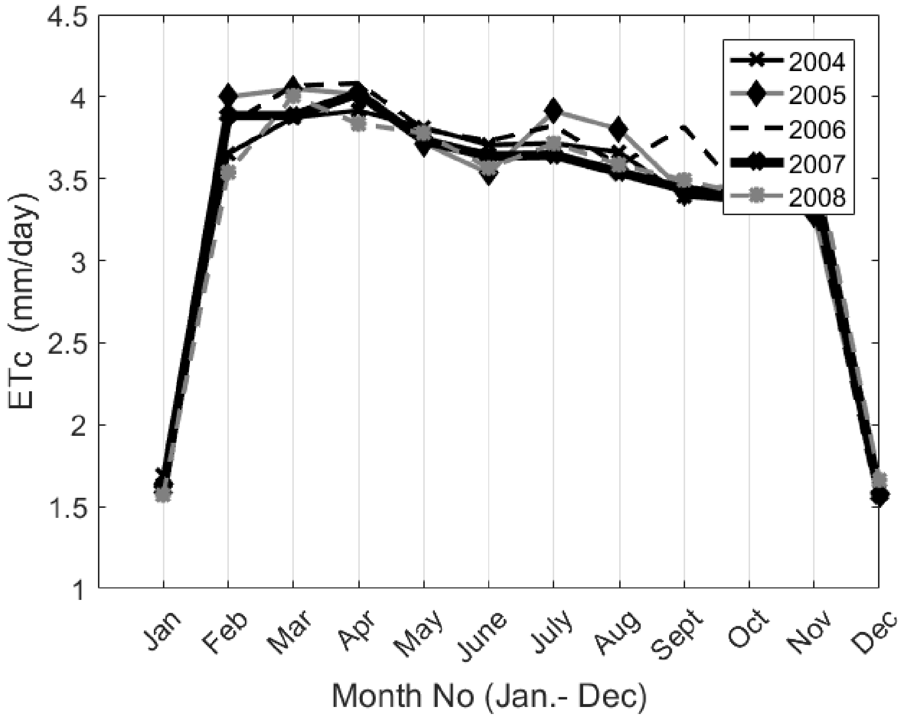

Figure 20: Standard Crop Evapotranspiration between 2004 – 2008

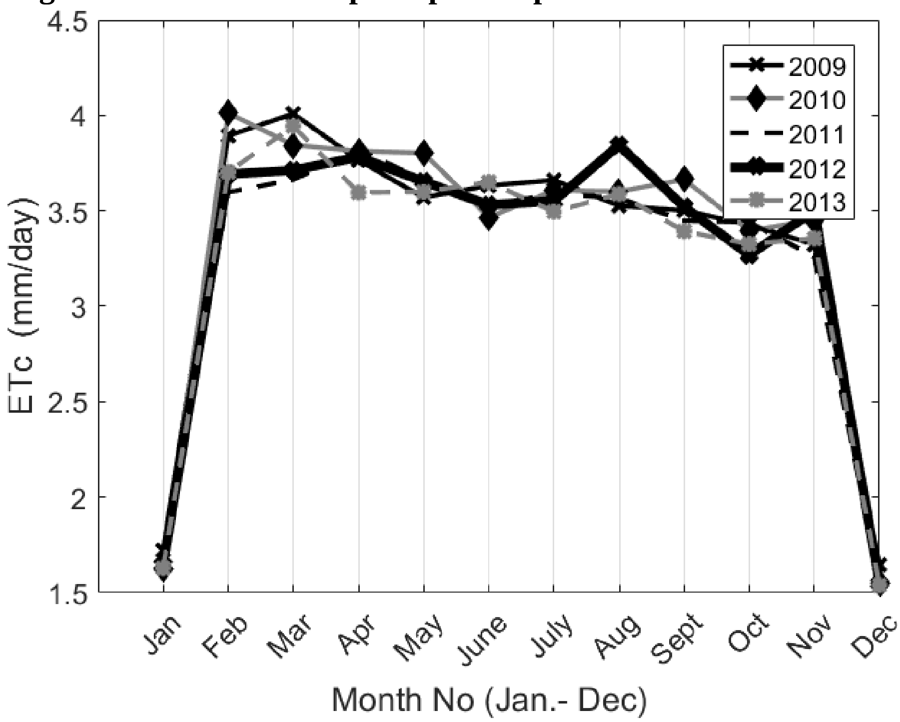

Figure 21: Standard Crop Evapotranspiration between 2009 – 2013

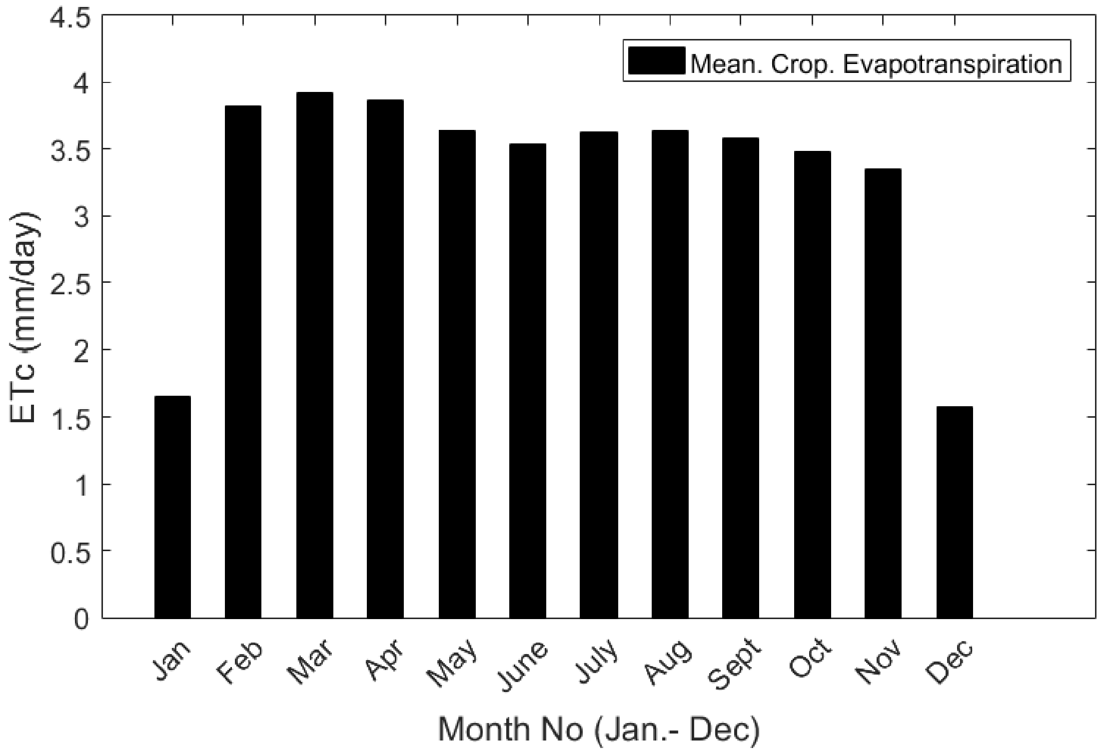

Figure 22: Average Standard Crop Evapotranspiration 1979 -2013

4.0 Conclusion and Recommendation

The evapotranspiration values for Benin City was computed using the **Penman-Monteith** equation for a period of 35years spanning 1979 to 2013. The Reference evapotranspiration (ET_o) and the Standard Crop evapotranspiration (ET_c) constitute the investigated evapotranspiration parameters in this study. While the reference evapotranspiration is the evapotranspiration of a hypothetical surface for which grass is cultivated, the single standard crop used for which evapotranspiration was determined in this study is Cassava. Aside being the most common crop cultivated in Benin City, Cassava is known to have a span of about a year which makes it a veritable ‘specimen’ for analysis. Meteorological data such as precipitation, sunshine, relative humidity and wind speed among others, form the input of the **Penman-Monteith** equation. The average ET_o for the 35years period ranges between 2.643 and 3.162mm/day. In some years, the ET_o could be as high as 3.7mm/day. The peak ET_o, in the majority of instances, occurred in the month of March while the lowest ET_o occurred between the months of June and November. The crop coefficient for the specimen crop was flat between the initial stage and mid stage of crop development with a value 1.1. The least single crop coefficient in the study area occurs at the end of the crop development stage with a crop coefficient of 0.5. The Standard Single Crop evapotranspiration (ET_c) for the catchment is between 3.5 and 4.3mm/day for the period under review in the active stages of crop development (initial to mid stages), whereas the end stage occurring between November and January has ET_c value of about 1.5mm/day. Overall, the peak value of ET_c tends to occur in the month of March annually even as the end stages of crop development often experience the lowest evapotranspiration values.

It is recommended that other models and experimental approaches are conducted to give credence to results provided by the Penman-Monteith equation.

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