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RESEARCH ARTICLE

ESTIMATING POTENTIAL EVAPOTRANSPIRATION OF A DATA SCARCE REGION: A CASE OF LAKE VICTORIA BASIN OF KENYA

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ABSTRACT

This paper examines potential evaporation over the Lake Victoria basin, a region with very few operational meteorological stations hence scarce data. Data stations within the Lake basin provided rainfall and temperature data covering periods of at least twenty years. Five methods of computing Potential Evapotranspiration (PET) (Penman, Hargreaves, Thornwaite, Blaney-Criddle and Pan Evaporation) were studied for their applicability under the same catchment. The homogeneity of rainfall was done using mass curve analysis and the filling of missing data using Markov Model. The averaging of historical data was used to interpolate the missing data. The stated empirical equations were applied to all stations over the 20 year period. C++ Program was developed and used to generate respective PET values using the stated empirical models. Based on the range of difference and average values of both the total absolute differences and the standard deviation, and using the Penman method as the basis of comparison, the Blaney-Criddle method predicted the monthly PET values better and Thornwaite was rated the poorest predictor. This showed that the Blaney-Cridle method could be applied in place of Penman as it predicted closer to Penman where the latter could not work.

INTRODUCTION

The Study Area

The study covered the Lake Victoria basin area of Kenya with more emphasis given to the areas around the shores of the Lake which are more commonly affected by droughts. The area lies between longitudes 34° E and 35° E and latitudes 1° 30' S and 1^0 20'N. The study area chosen often experiences harsh conditions due the effect of drought, and this may be likened to other areas in Kenya that are gazetted as arid and semi-arid lands. Due to lack of meteorological stations with enough data, the five stations, Kadenge, Kibos cotton research station, Kisumu Airport, Rusinga Island and Muhuru bay, were taken as a representative of the area under study, as shown in Figure 1. The major scarps are prominent at the study area. They form the Nandi, Nyando and the Mau escarpments. Along the margins of the escarpments, foot slopes extend gently undulating to rolling topography with slopes of 3-16%. The foot slopes have moderate to severe gully erosion and consists mainly of colluviums derived from granites and rhyolites. The river terraces and flood plains formed from recent alluvial materials are found along some of the rivers. They have in general flat topography potential for crop production. The climate of the area studied is influenced very much by the lake. The area is known to experience strong local circulation because of the breezes from both the land and the lake. The breezes are as a result of both heating and cooling of the land and water surfaces at different times of the day. According to Okeyo (1986), the day and night circulation induces low or high pressure over the lake during the night and day respectively. The five meteorological stations mentioned above are considered to give an indication of the climatic characteristics of the area of study. The climatic characteristics that are given more weight in this study are both rainfall and temperature and their relation to the potential evaporation and actual evapotranspiration. According to Koppen's classification, the climate of the Lake Victoria is sub-humid tropical Savannah (Sombroek *et al*., 1982). Evapotranspiration (ET) is an important process of the hydrologic cycle. Approximately 75% of the total rainfall on the continent is returned to the atmosphere through the combined evaporation from all surfaces and the transpiration of plants. Since this works to provide the planners with the necessary knowledge on spatial viability of droughts, for implementation of soil water management systems, discussing evapotranspiration along with the drought severity of the study area is vital. Evapotranspiration is an important process in the

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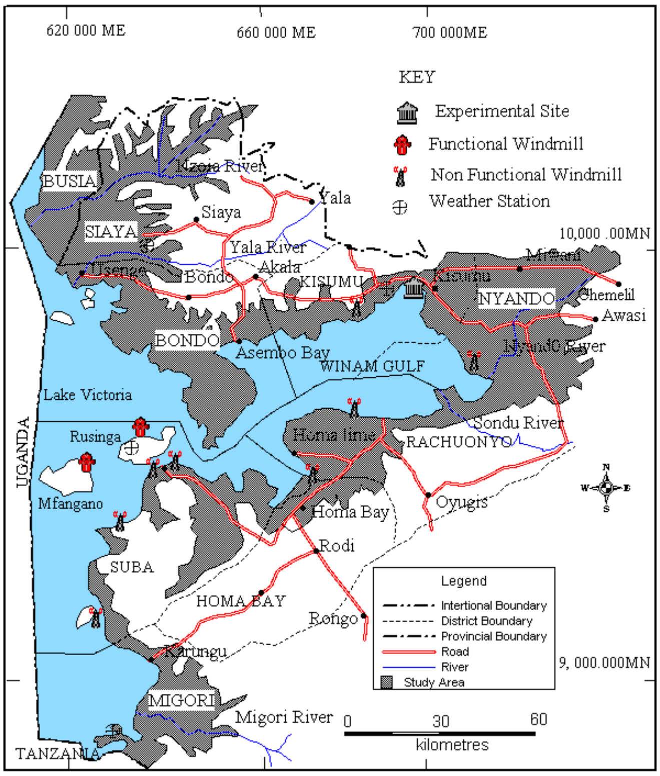

Figure 1: Map Showing the Study Area

study of agricultural watershed management. For this reason, several scholars have put forward numerous methods to estimate the same. According Shih *et al*. (1983), the choice of a method to be used in estimation of evapotranspiration depends on several factors, including data availability, the intended use and the time required by the problem. Shih *et al.* (1983) found the Penman method to be superior to most other empirical methods. The Penman's method requires a variety of data such as mean air maximum temperatures, mean air minimum temperatures, relative humidity, solar radiation and wind speed. Woodhead (1968) reports that Penman's method performs better in the East African region. Because some climatological data were not available to be used in estimation of evapotranspiration during this study, it was found necessary to use another alternative method that mainly uses both temperature and rainfall data. However, Shih (1985) cautions that while choosing an alternative technique, one needs to minimize the input of climatological data without affecting the accuracy of the estimates. For this study, the temperature-based methods were compared against Penman's results from which one was chosen for this work. The methods tested and subsequently compared were those of Blaney and Criddle (1950), Penman (1949), Hargreaves and Samani (1985), Thornwaite (1948) and Pan Evaporation.

MATERIALS AND METHODS

Rainfall and temperature data were collected from the meteorological stations near the shores of Lake Victoria on the Kenyan side, for which suitable data for the drought analysis were available. The data were stored at the Nyanza provincial water office, Kisumu and covered a period of at least twenty years for each station. This was because the stations began operation at different times. Apart from both rainfall and temperature, the other data used included soil parameters; Field capacity, wilting point and a constant or depth. The five meteorological stations from which these data had been collected were Kadenge, Kisumu Airport, Kibos Cotton Research Centre, Rusinga Island and the Muhuru Bay (Figure 1). Precipitation stations have short breaks in their records because of absence of an observer or because of instrument failures. During this study, it was necessary to estimate the missing records. Since the monthly rainfall values were used in the study, Markov Model was applied to estimate the missing data (Olwero, 1998). In filling the missing gaps of temperature, the method of averaging of historical data was used. The method uses the historical data available from the station to interpolate missing data for the same station. The quality of the rainfall data was tested using the double mass curve method for each rainfall station. This method is consistent and powerful and is thus best in testing the homogeneity of a given data series (Shaw, 1984). Based on this method, a station's cumulative records were plotted against time, and the mass curves were obtained. From the shape of the curves, the quality of the data was then inferred. If the curve approximated a straight-line, then the data was homogenous, otherwise it was heterogeneous. The mass curves of the rainfall data from the stations are shown in Figures 2 and 3. Inspection of these curves indicates that the data from the station are homogenous.

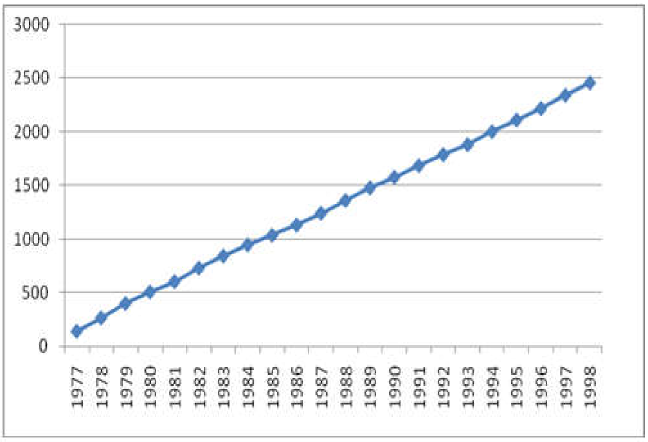

Figure 2: Mass curve using data from Kibos Cotton Research Station

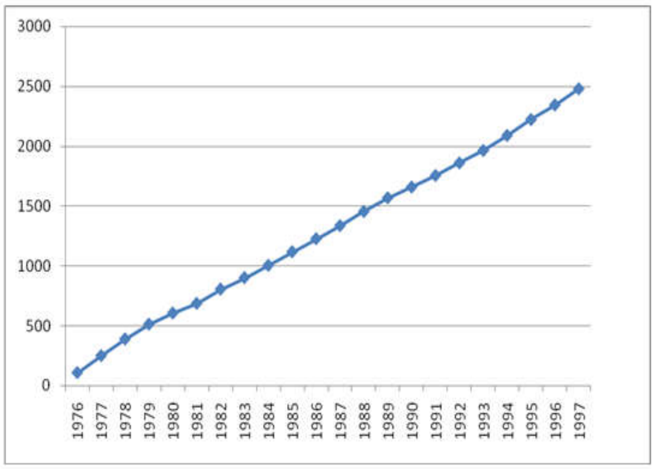

Figure 3: Mass curve using data from Kisumu Airport meteorological station

Potential Evapotranspiration Methods

The Thornwaite Method

The empirical formula for potential Evapotranspiration (PET) developed by Thornwaite was tested for this current study. While other methods make use of several climatological data, Thornwaite thought that temperature could serve as an index to potential evapotranspiration because there is a fixed relation between net radiation used for heating and that used for evaporation when conditions exist to achieve the potential rate (Thornwaite, 1948). A drawback of the method is that the calculation of PET ceases when temperature is below zero degrees centigrade (Papadopoulou *et al*., 2003). The potential evapotranspiration was calculated from the Thornwaite method as follows:

$$\mathbf{PET}m = \frac{16m(10\mathbf{T}m)}{1}a(mm)$$

$$\mathbf{I} = \sum_{im} \square = \boldsymbol{\Sigma}\left(\mathbf{T_m}\right)^{1.5}$$

Where

$a = 6.7 \times 10^{-7}\ I^3 - 7.7 \times 10^{-5}\ I^2 + 1.8 \times 10^{-2}\ I + 0.49$

$$E_m = \frac{16(10T_m)im}{I}$$

PET = Monthly potential evapotranspiration

i_m = the months 1, 2, 3, ………………………………12

N_m = Monthly adjustment factor related to hours of daylight, and obtained from tables of mean daily duration of maximum possible sunshine hours (N)

T_m = Mean monthly temperature ^{0}C

E_m = Unadjusted evaporation (mm).

The Blaney-Criddle Method (Original)

Climatological data, such as temperature, solar radiation, relative humidity and wind speed, have been widely used to estimate potential evapotranspiration. This work tests the Blaney and Criddle (1950) method that predicts monthly ET for arid climates from the percentages of daylight hours in the month and the average monthly temperatures. The formula utilizes a seasonal crop coefficient that depends on sowing date, rate of crop development, length of growing season and climatic conditions. The formula is of the form:

$$ET = K_2 * F$$

Where,

ET = Monthly ET in (mm)

K_2 = A coefficient for the Blaney and Criddle method For this current work the K_2 whose value is 1.0 and the crop being grass was adopted (Stigter, & Wartena, 1989).

F = Monthly ET factor, where;

$$F = 25.4 * PD * \frac{1.8T_m + 32}{100}$$

T_m = Mean monthly temperature in degrees centigrade

PD = Percent of annual daylight hours in the month

Hargreaves Method

Hargreaves and Samani (1985) suggested a method involving only temperature and radiation data. The equation is given by:

$$\mathbf{ET}_{Har} = (0.0023\ \mathbf{R}_a)(\mathbf{T}_m + 7.8)\sqrt{\mathbf{TD}}$$

Where Ra is extra-terrestrial radiation in equivalent mm of water evaporation for the time period, T_m, as the mean monthly temperature in ^{0}C and TD is the difference between maximum and minimum temperatures.

Penman Method

Penman (1949) developed a formula for calculating Potential Evapotranspiration (PET) based on fundamental physical principles, with some empirical concepts incorporated, to enable standard meteorological observations to be used. The method combines both the mass transfer (aerodynamic) method and the energy budget method. The four measurements required to calculate potential evapotranspiration are:

T_a = Mean air temperature for a month ^{0}C.

e_d = Mean vapour pressure for the same period, mm of mercury (Saturated vapour pressure at the dew point)

n = hours of bright sunshine over the same period, h/day

u_2 = Mean wind speed at 2 m above the surface, (cm/day)..

The other parameters that are also necessary for Penman method are obtained from the standard Meteorological tables, they include:

Δ = Slope of the curve of saturated vapour pressure plotted against temperature.

$$= \frac{(\mathbf{e_a} - \mathbf{e_d})}{\mathbf{t_a} - \mathbf{t_d}}$$

y = hygrometric constant,

e_a = Saturated vapour pressure at air temperature.

R_a = Solar radiation (fixed by latitude and season)

N = Maximum possible sunshine duration

δ = Stefan - Boltzman Constant

When all the net radiation measurements were available, the available heat (HT) was calculated from incoming (Ri) and outgoing (Ro) radiation determined from sunshine records, temperature and humility as follows:

$$\mathbf{HT} = 0.75\ \mathbf{R}_i - \mathbf{R}_o$$

The term E_{at} was obtained from the following:

$$E_{at} = \frac{0.35(1 + \mu_2)(e_a - e_d)}{100}$$

where

R_1, a function of R_a, the solar radiation modulated by a function of the ratio, n/N, measured to maximum possible sunshine duration, was given as:

$$R_1(1-r) = 0.75R_a * fa\left(\frac{n}{N}\right)$$

Where,

$$f_a\left(\frac{n}{N}\right) = \left(0.16 + \frac{0.62n}{N}\right)$$

(Outgoing radiation) was then calculated from the equation,

$$R_o = \delta T_a^4 (0.47 - 0.075\sqrt{e_d})\left(0.17 + \frac{0.83n}{N}\right)$$

Taking account of the increased albedo for vegetation and introducing multiplying factor 0.95 to δTa, since vegetation does not radiate as a percent black body, then, HT was calculated as:

$$\mathbf{HT = 0.75R_a\left(0.18 + 0.\frac{55n}{N}\right) - 0.95\delta T_a\left(0.1\right.}$$

From the above calculations, the potential evapotranspiration (PET) was then obtained as:

$$\mathbf{PET} = \frac{\left(\frac{\Delta}{\gamma}\right)\mathbf{HT} + \mathbf{E_a t}}{\left(\frac{\Delta}{\gamma}\right) + 1}$$

Comparison of Evapotranspiration Estimates

Five methods of computing potential evapotranspiration (Penman, Blaney & Criddle, Thornwaite, Hargreaves and Pan Evaporation) were studied under the same climatic condition. The Penman method was taken as the standard and the other four were compared against this method. This method is probably the most comprehensive approach to estimate potential evapotranspiration (PET) since it takes into account almost all the factors that are known to influence PET, such as Temperature, humidity, solar radiation and wind speed. Most of these meteorological parameters are not readily available in the current form in the Lake Victoria basin of Kenya. Pant and Rwandusaya (1971) and Cocheme and Brown (1969), compared both the Penman and the Lysimeter observations based on East African climatic conditions. They reported that the performance of the Penman model and the Field measurements were relatively close.Since no Lysimeter measurements of evapotranspiration are available at the location under study, the Penman method was taken as the standard against which other methods were compared. The purpose of this study of PET estimates was to select a method to be used in the Palmer's procedure for determination of drought severity (Chumo, 2011).Good correlation was obtained between the values estimated by the three methods and the Penman method, although difference in magnitude was found (Table 2). The Blaney and Criddle method, as apart from performing better than the Thornwaite method, still enjoys the advantage of low data requirement, contrary to other methods like Penman which requires numerous climatological data not readily available in most rural climatological stations in Kenya.

The Actual Evapotranspiration (AET)

Due to the scarcity of meteorological data for the catchment under study, it was found necessary to obtain a regression equation relating both AET and PET respectively. AET and PET were obtained by Morton model and Blaney and Criddle methods, respectively. They were linked through the method of least squares. According toSharma and Korongo (1996), the Morton model was recommended for estimation of actual evapotranspiration on a monthly basis in the tropical African catchments. In theMorton model the AET was explicitly determined using the following equations:

$$\mathbf{AET = 2E_{tw} - PET}$$
$$\mathbf{PET = F_T(V_P - V_D)}$$
$$\mathbf{E_{tw} = b_1 + b_2\left(1 + \frac{\gamma_P}{\Delta} * p\right)^{-1} * R_{TP}}$$

Where F_T is the vapour transfer coefficient (dimension less); V_p is the saturation vapourpressure of equilibrium temperature; V_D is the saturation pressure at dew point temperature; E_{tw} is the wet environment areal evapotranspiration in w/m$^{2;}$ b_1 and b_2 are constants; R_{TP} is the net radiation for soil plant surfaces; p is the atmospheric pressure in mbar, and Δp is the slope of the atmospheric pressure in mbar/°C. Using the method of least squares, a linear regression equation was obtained and subsequently used to calculate the AET on monthly basis.

RESULTS AND DISCUSSIONS

Monthly PET values from the Penman (Pen), Blaney-Criddle (BC), Hargreaves (HAR), Thornwaite (TH) and Pan Evaporation (PAN) methods were computed for the period January 1976 to December 1986 from the climatic records for the Kadenge, Kisumu Airport, Rusinga Island and Muhuru Bay stations. PET estimation in the Lake Victoria basin of Kenya has been hindered because climatic and water budget data has been either incomplete or not available at all. During this research, it was observed that some of the meteorological stations had been non-operational, because most instruments had been vandalized. Therefore, the foregoing research sought to present, among other objectives, some alternative methods of estimating PET in areas with less data. Despite the few stations being operational, the study attempted to show the applicability of the abovementioned methods of determining PET in this region. Evapotranspiration is often determined to show the peak water use by crops during the growing seasons, and also to show the total volume of water required for plant growth during the growing period. However, the relationship between rainfall and evaporation helps in identifying the agro-climatic zone in which the area lies. For example, the ratio between rainfall and potential evapotranspiration for Kadenge, a meteorological station along the Lake Victoria basin of Kenya, is 0.69 and therefore according to Sombroek *et al.* (1982), it is classified as semi-humid. The monthly mean potential evapotranspiration values being taken over the period (1976-1986) from the different methods are shown in Figures

4-7 for Rusinga Island, Muhuru Bay, Kadenge and Kisumu Airport, respectively. From Figure 4, it can be seen that for Rusinga Island the BC method follows the same trend as that of the Penman method with very little deviations compared to Hargreaves and Pan Methods. In Rusinga Island, the Pan was found to overestimate the PET whereas the Thornwaite underestimated the same taking Penman results as standard.

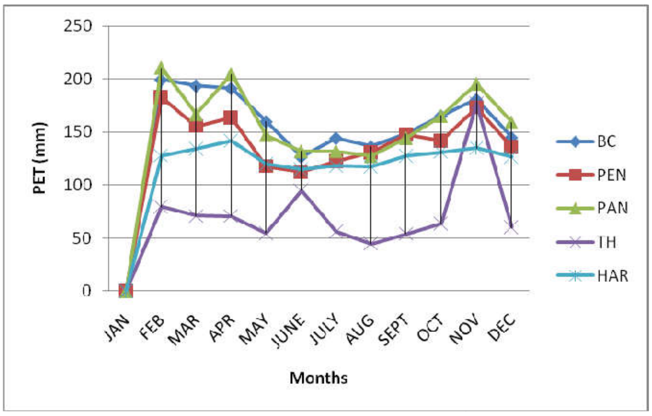

Figure 4: PET for Rusinga Island (1976-1986)

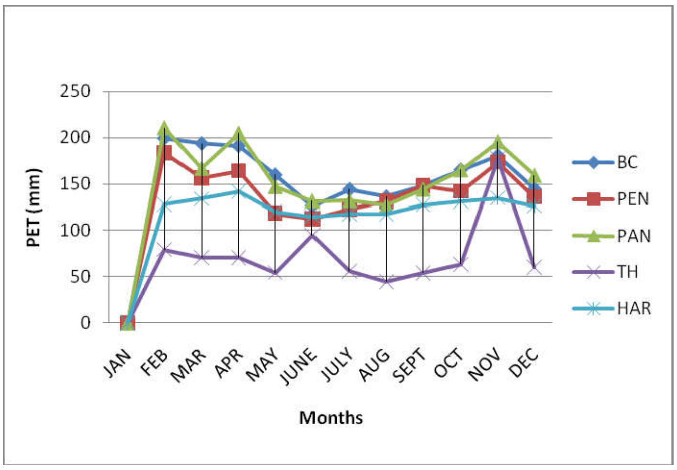

Figure 5: PET for Muhuru Bay (1976-1986)

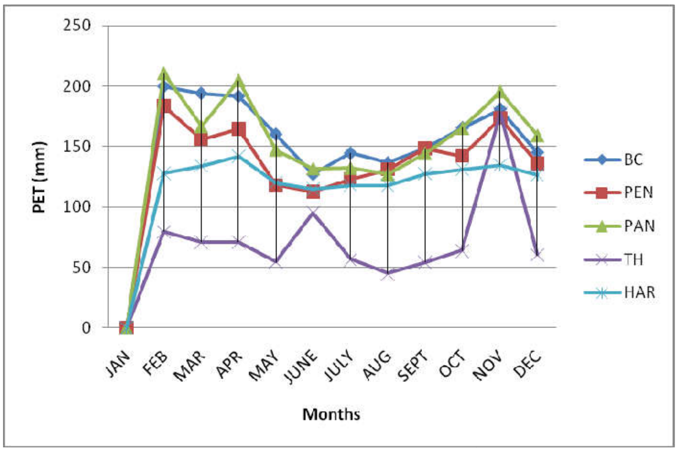

Figure 6: PET for Kadenge (1976-1986)

For Muhuru Bay (Figure 5) the Blaney-Criddle method continued to follow the same trend as that of Penman, except during the month of April where there was a large deviation noticed. However, the Pan method had much less deviation from the Penman method unlike in Rusinga Island. Both the Hargreaves and the Thornwaite methods underestimated the PET, while the Pan overestimated. From Figure 6, for the Kadenge station, the Hargreaves method performed somewhat closer to the Penman method throughout the months while the Blaney-Criddle method overestimated the PET values compared to the Pan. The Pan method overestimated only during the early months of the year, that is, during the months of March and April, after which it followed the trend of the Penman method very closely. It was also clear that the Thornwaite method underestimated the PET values as can be seen from the large deviation from those values obtained through the Penman method.

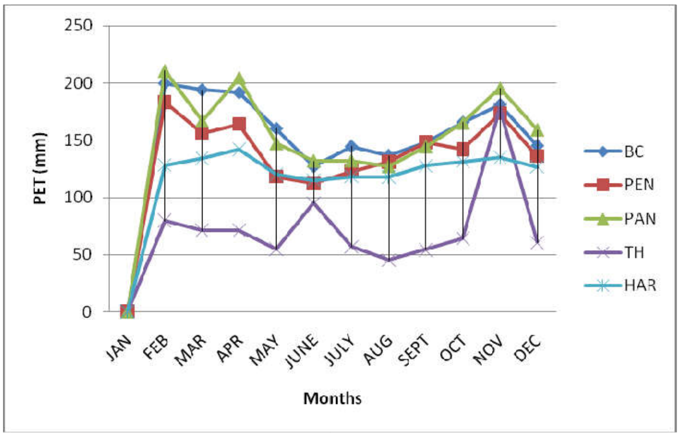

Figure 7: PET for Kisumu Airport (1976-1986)

For Kisumu Airport (Figure 7), the Hargreaves, Blaney-Criddle and Pan methods followed the same trend as that of the Penman method. Both the Pan and the Blaney-Criddle overestimated the PET despite following the trend as mentioned above. However, the Pan method was much closer to the Penman values compared to the Blaney-Criddle which followed so closely. In this station, the Thornwaite method underestimated just like in all other stations. From the behavioural trend of the methods discussed here, compared to the Penman method, it is clear that both the Pan and the Blaney-Criddle performed much closer, where as the Thornwaite was so much incomparable to the same. However, Thornwaite method underestimated the PET values throughout in all the stations and seasons. There are three distinct seasons in a year in the area studied. The seasons are classified according to the time they receive rainfall and the duration of the rainfall. Thus the dry season (January-March), long rains season (April-September) and short rains season (October-December). From the findings of this study, it was noted that during the January-March season, the PET values were highest, followed by October-December season and the least values were realized during the wet season (April-September). Table 1 shows the mean monthly PET estimates as obtained through the five conventional methods that were tested. While analyzing PET estimates by the Penman, Hargreaves, Pan, Thornwaite and Blaney-Criddle, it was observed that there was a general tendency for Blaney-Criddle estimates to be closer to the Penman values and the Pan method overestimated, while both the Thornwaite and the Hargreaves methods underestimated the values. The closeness of the Blaney-Criddle estimates to the Penman values was further affirmed by the annual mean values (combining all the

Table 1: Mean monthly PET in mm, by: Penman (PEN), Blaney-Criddle (BC), Thornwaite (TH), Class A Pan (PAN) and Hargreaves (HAR) Methods

MONTH	RUSINGA					MUHURU BAY					KADENGE					KISUMU AIRPORT				
	BC	PEN	PAN	TH	HAR	BC	PEN	PAN	TH	HAR	BC	PEN	PAN	TH	HAR	BC	PEN	PAN	TH	HAR
JAN	207.3	204.3	223.2	88.3	88	184.8	198.4	210.5	96.4	137.6	191.6	163.1	179.8	71.2	167.9	199.5	183.3	210.5	79.7	127.9
FEB	212.5	167.9	193.2	76.8	119	169.1	155.9	179.2	94.3	125.2	175	143.6	140	65.4	149.9	193.8	155.8	166.6	71.1	134
MAR	214	180.7	223.2	74.2	125.8	167.2	159	198.4	99.7	142.3	168.8	147.4	186	67.8	157.7	191.4	164	204.6	71	141.8
APR	185.3	140.3	168.2	62.3	111.6	188.9	211.7	162	92.2	158.1	133.8	95.8	126	47	128.8	160	118	147.1	54.7	120.1
MAY	132.3	126.7	148.8	53.5	111	113.9	101.6	170.5	84.2	124.7	121.5	97.8	114.7	41.4	118.7	126.9	112.3	131.8	95.1	114.9
JUNE	169.4	137.2	153	62.8	104.2	158.9	158.7	156	83.2	115.5	151.6	107.7	111	50.9	131.7	144.4	122.5	132	56.6	117.9
JULY	134	153.4	151.9	47.5	102.6	146	149.7	164.3	79.3	118.7	120.9	108.4	102.3	40.4	132.7	136.4	130.9	127.1	44.9	117.6
AUG	157.6	168.2	186	60.1	110.9	151.7	173.2	186	84.2	132.7	138.6	128.1	133	48.3	143.8	148.1	148.1	144.2	54.2	127.4
SEPT	175.4	200	186	70.1	118.8	164.8	177.1	177	88.1	138.9	155.5	123.2	144	57.3	143.6	165.4	141.9	165	64	131.2
OCT	181.1	151.3	223.3	92.1	134.6	175.1	181.6	210.8	99.7	147.2	180.6	146.8	167.4	72.7	150.4	180.8	173.4	195.3	177.4	134.7
NOV	140.5	151.3	183	63.1	118.2	151.7	156.1	174	89.2	148.2	149.5	120.6	135	57.1	134.8	145.0	135.9	159	60.4	126.5
DEC	180.4	175.6	201.5	76.8	126.2	173.5	160.9	186	91.2	179.7	167.9	124.7	167.4	65.6	145.3	174.2	150.2	184.5	71.2	135.7
TOTAL	2089.8	1956.9	2241.3	827.6	1370.9	1945.6	1983.9	2174.7	1081.7	1668.8	1855.3	1507.2	1706.6	685.1	1705.3	1965.9	1736.3	1967.7	900.3	1529.7

Table 2: Coefficient of correlation between PET estimates by Penman and other methods

Methods	Coefficient of Correlation (r)	Standard Error (SE) of different methods
BC	0.460	0.151
HAR	0.132	0.187
PAN	0.146	0.015
TH	0.653	0.204

Table 3: Difference of Monthly Evapotranspiration Estimations between Penman and other Methods

	KISUMU AIRPORT				RUSINGA ISLAND				MUHURU BAY				KADENGE			
DIFFERENCES	PAN	BC	HAR	TH	PAN	BC	HAR	TH	PAN	BC	HAR	TH	PAN	BC	HAR	TH
Mean Monthly Absolute Difference	19.82	19.10	27.99	87.11	13.2	12.95	49.56	95.62	24.64	19.30	33.29	75.22	18.26	29.02	31.9	68.52
Standard Deviation	11.00	12.23	14.98	33.39	9.356	8.94	23.92	14.79	19.05	14.57	31.66	24.14	12.76	10.17	53.22	11.94

stations) which were computed as 2020.4, 1900, 1798, 1569 and 846 mm by summing up the monthly values using Pan, Blaney-Criddle, Penman, Hargreaves and Thornwaite methods, respectively (Shih, 1991). While the Pan method provides a measurement of the integrated effect of radiation, wind, temperature and humidity on evaporation from a specific open water surface, plants respond to the same climatic variables but several major factors may produce significant difference in loss of water. Unlike other methods described above, the Pan method has some notable limitations. Water loss from pan and from crops can be caused by differences in turbulence, temperature and humidity of the air immediately above the surfaces. The other factors that may affect the performance of the Pan method, in estimating potential evaporation include, amongst others, the colour of the pan, use of the mesh screens, the siting of the pan and the general pan environment. However, with proper siting of the pan, regular renewal of water to eliminate extreme turbidity and if galvanized properly may further improve its performance.

Correlation between Methods

The computed monthly potential evapotranspiration values for ten years (1976-1986) from the different methods were analyzed with a view to finding a relationship between the other conventional methods and the standard model (Penman method). The Penman was chosen as a standard model because, despite using several meteorological parameters, Woodhead (l968) reports that the method performs better in the East African region. The correlation results between the standard Penman method and the other methods are summarized in Table 2. The correlation is significant at the 0.010 level. From Table 2, it can be observed that the Thornwaite (TH) estimates result in the highest correlation with that of Penman while Hargreaves method estimates have the lowest correlation. The standard error values with the Thornwaite (TH) methods are the highest among all the other methods and lowest with the Pan method. It can be observed that the Thornwaite method estimates are, in general, fairly well correlated with the Penman estimates. However, the Hargreaves method was observed to have the poorest correlation with the Penman's estimate. The analysis demonstrated poor degree of correlation between values estimated by the Penman and all other methods being tested here, apart from the Thornwaite (TH) which was relatively fair. The Penman method was taken as a standard because of its general application. The difference between the Penman method estimates and those by the other methods were calculated for the areas where data was available (between 1976 and 1986). To compare the performance of the methods being calibrated, the standard deviation was also computed for each station. Table 3 below shows the correlation results for the four stations from which data was obtained.

The above table also depicts the totals of the absolute values of the differences from the Penman method for each conventional method being tested. In making the judgment over the performance of each method against Penman, both the standard deviation and the absolute difference were used as the indicators. Therefore, if an estimation method is as good as the Penman method, both the standard deviation and the total absolute difference should be equal to zero. However, smaller differences are assumed to mean better prediction (Shih, 1991). Based on the above range of differences and the average values of both the total absolute differences and the standard deviation (Table 3), and using the Penman method as the basis for comparison, the Blaney-Criddle (BC) best predicted the monthly PET and Thornwaite was rated the poorest predictor. This is in agreement with other predictions which have shown the BC method as being superior, and the Thornwaite method consistently underestimating PET (Papadopoulou *et al*., 2003). The second and third best predictions were obtained from the evaporation Pan and the Hargreaves methods, respectively. This procedure shows that if the climatic data are not sufficient to use with the Penman method in the shores of the Lake Victoria region of Kenya, then the best method to be chosen, among the four discussed herein, is the Blaney-Criddle method, because it predicts closer to Penman's.

Conclusions and recommendations

Evapotranspiration aspects of the area of study were dealt with, with some models used to estimate the PET being tested. The methods that were tested included Thornwaite, Penman, Hargreaveas and Blaney-Criddle methods. The study found that PET is difficult to estimate accurately and therefore caution should be taken in determining the actual water loss from a natural system (Jianbiao *et al.*, 2005). The several PET models tested gave different values, showing differences in PET values across the Lake Victoria region. However, Blaney-Criddle was chosen because it gave the results at least as good as, or slightly better than, those obtained by other methods tested compared to Penman method. Because Blaney-Criddle method require less data and closely correlates with Penman method, the study concluded it was a better method compared to the others with respect to the current area of study. It was also clear that Penman method required more input data and had more involved calculations, factors which lead to uncertainties and errors in applying the equations, and geographical limitations due to scarcity of operational meteorological stations in the Lake Victoria basin of Kenya. The study has shown that in areas like the Lake Victoria basin of Kenya, where the meteorological data is scarce and hence insufficient to apply the Penman method in estimating potential evaporation, the Blaney and Criddle method may be used. With the evaporation estimates, it is possible to carry out water balance analysis to obtain quantitative estimates of the water in storage.

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