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Comparative study of some estimation methods of evapotranspiration in the tropical zone: case of the region of Pointe-Noire (Congo)

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Abstract

Sustainable management of water resources needs a perfect command of the terms of the hydrological balance among them evapotranspiration. This work deals with the comparison of some methods assessing potential evapotranspiration in the tropical zone. It is made using climatic data (temperature, rainfall, relative humidity, sunshine duration, wind speed and Piche evaporation) collected during the period 1990 to 2016 at Pointe-Noire airport in the south-west of Republic of Congo. The results show that, on the monthly scale, the values of potential evapotranspiration (ETP) obtained by the Penman-Monteith method, are closes to those obtained with the measured Piche evaporation. However, during the dry season (August-September), this method of calculation overestimates potential evapotranspiration up to 27.4%. Moreover, the application of the different approaches for estimating the annual ETP, highlights that the Penman-Monteith method, leads also to a better estimate of this climatic component. Nevertheless, this method overestimates Piche ETP in the year 1992, with a relative deviation up to 40.5%.

Keywords: Water resources, climate change, water balance, evapotranspiration, tropical zone, pointe-Noire.

Introduction

Evapotranspiration is one of the most difficult components of the hydrological cycle to quantify because of its complexity in the subsoil-soil-plant system[1,2]. In addition, the study of this parameter presents a large interest for assessment of irrigation water requirements and of fluctuation of groundwater piezometric levels, following climate change[3]. However, the important socio-economic development of Pointe-Noire region, its industrial reputation and its investment in farming projects (fruit and vegetable crops, fruit trees, eucalyptus plantations) require increasingly abundant water resources.

This abundant consumption of the resource also requires rational management which integrates the establishment of a water balance equation defined by:

$$P = ETR + R + In + \Delta S$$

where P(mm) is rainfall, ETR(mm) is actual evapotranspiration, R(mm) is runoff, In(mm) is infiltration and ΔS(mm) is variation of water reserve which can be a negative value.

The phenomenon of evaporation corresponds to the part of the precipitated waters which evaporates either under the effect of temperature variation and sunshine, either under the action of plant transpiration. One distinguishes the actual evapotranspiration (ETR) which designates the quantity of water really evaporated, and potential evapotranspiration (ETP) that is the amount of water likely to be evaporated for a plant cover well supplied with water over a given time period. ETR depends on P, ETP and soil water.

The ETP component is often estimated experimentally from the Picheevaporimeter, Wild evaporimeter, lysimeter and porous cup atmometer, or calculated empirically, in particular by the methods of Thornthwaite, Haude and Bouchet, or calculated by methods based on energy balance such as the methods of Turc, Penman and Penman-Monteith.

In the case of Pointe-Noire region, few studies have been made essentially in the savannah of littoral Congolese and in the dense plantations of eucalyptus[4,5]. The objective of this work is to calculate the ETP (on monthly time scale), based on a series of hydro climatic data, obtained at the meteorological station of Pointe-Noire Airport located downtown, from 1990 to 2016 and to make a comparative and statistical analysis of the results of the different models compared to the ETP Piche obtained with Bouchet equation. This will allow to appreciate the appropriate calculation method in the climatic context of the study area.

Geographical location, geology and vegetation: The study focuses on the region of Pointe-Noire, which is an agglomeration located on the Atlantic coast of Central Africa, at the southwestern of the Republic of Congo. Its geographical coordinates are between the meridians 11°30 and 12° east and the parallels 4°30 and 5° south. Its area is approximately 15,660 hectares and is spread over a radius of 15 kilometers (Figure-1).

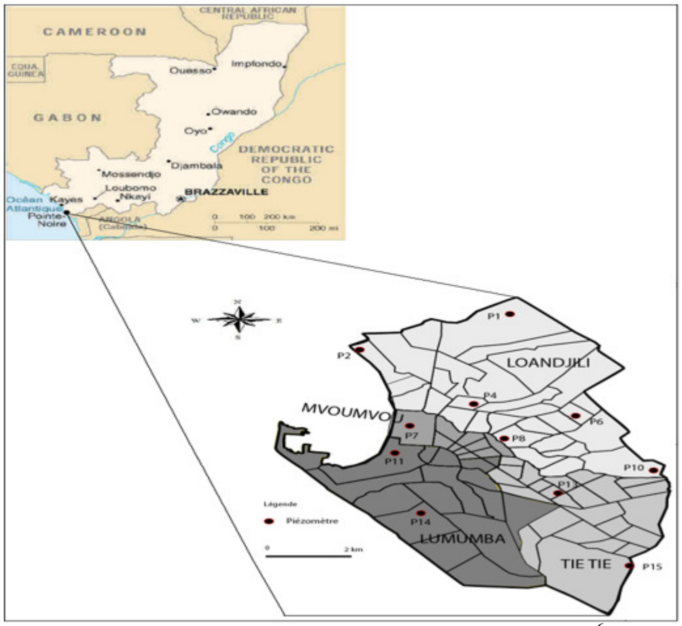


Figure-1: Geographical location of the study area[6].

Belonging to the coastal sedimentary basin of cretaceous and tertiary age, the area of Pointe-Noire is covered by formations with age pliopleistocenes formations other than of series of circuses made of very permeable sands including multiple resistant horizons. The FAO classification arranges the ground of the region of Pointe-Noire in the Ferralitic Arenosols group with a sandy texture (80-90%) on most than 1m[6].

The natural vegetation is savannah that is the dominant formation in the region of Pointe-Noire. This savannah is formed with grass of reduced sizes (heights between 0.5 to 1.5m) that do not cover the soil homogeneously. Some parts of the original savannah have undergone afforestation with some species with fast growth (eucalyptus, pines, and acacias). Savannah and eucalyptus plantations constitute the most representative plant cover of the region of pointe-Noire.

Climatic context

The network of climatic data measurements in the Congolese coast has more than seven scattered stations throughout the region. The study is limited to a synoptic station (Altitude: 16 m, Latitude: 04°49'S, Longitude: 11°54'E), of Pointe-Noire Airport belonging to the Meteorology Service of the National Agency of Civil Aviation (ANAC).

Rainfall: The results presented here are of a short series (1990-2016) where the annual average rainfall is 1283mm. The rainfall regime (Figure-2) makes it possible to highlight two main annual rainfall periods. These periods are characterized by two seasons. The first is the rainy season that starts in October and extends through April and which is characterized by heavy rainfall. This period corresponds to the recharge of the groundwater with maxima in February and November. The second is the dry season that is between May and September.

The precipitation at Pointe-Noire undergoes some variations on different time scales and sometimes, the rainy season has the same duration as the dry season.

Temperature: The Figure-3 shows that the highest temperatures are observed during rainy periods and the lowest during the dry periods, hence the rainy periods are hot and the dry periods are cool. The monthly average minimal temperatures are between 19.8°C and 24.2°C.

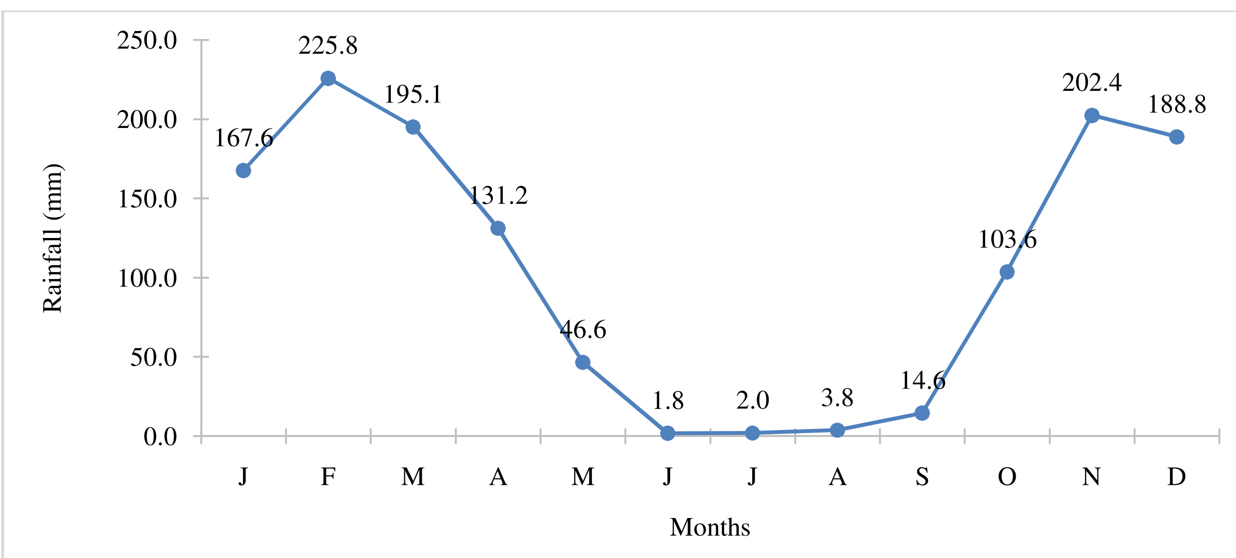


Figure-2: Monthly average rainfall (1990-2016).

Monthly average maximal temperatures are not generally very high, they vary between 25.8°C and 31.3°C (Figure-3).

Relative humidity: The climate of Pointe-Noire is generally characterized by a high monthly average humidity whatever the season. The monthly average maximal relative humidity is 95.1% (92.4% min and 95.9% max). Monthly averages are highs between February and May and can reach 95.9% in April (Figure-4). They are never weak but fall back to values of 92.8% during the dry season in June-October because of the cold waters of the Benguela current which stabilizes low levels of the atmosphere[7].

The monthly average minimal relative humidity is 68.3% (66.4% min and 71% max).Monthly averages are highs between October and December and can reach 71% in December (Figure-4). They are never weak but fall back to values of 66.4% during the dry season in June-August.

Sunshine hours or daylight: The monthly average duration of sunshine is 132 hours in the Pointe-Noire region (Figure-5). The annual average is low (1582hours) and hardly exceeds 2000 hours because of cloudiness[8]. It intensifies the evaporating power of air and therefore represents an essential parameter of solar radiation. It affects hydrological balance and takes part in the process of the water cycle.

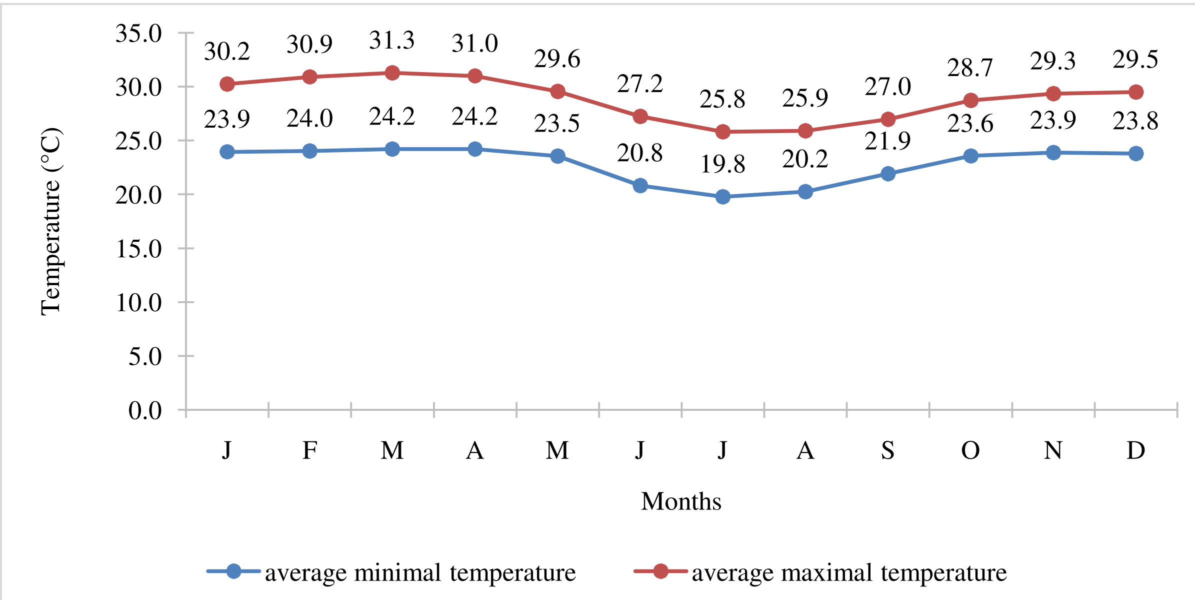


Figure-3: Monthly average minimal and maximal temperatures (1990-2016).

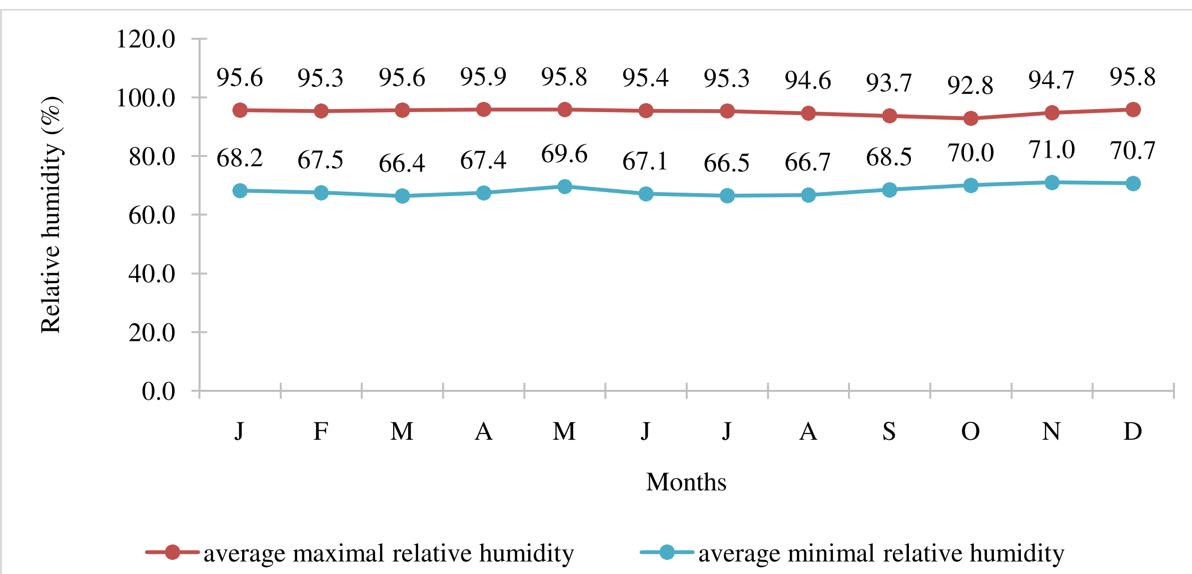


Figure-4: Monthly average maximal and minimal relative humidity (1990-2016).

Piche evaporation: Table-1 and Figure-6 show the variations of the monthly average of Piche evaporation in Pointe-Noire. Its annual average is 600.8mm. During the dry period the evaporation undergoes a slight decline, but it is still high whatever the season.

Methods used for the estimation of ETP

Since 1950, several authors have developed some methods estimating potential evapotranspiration, among them Thornthwaite, Turc, Haude, Penman, Christiansen and FAO Penman-Monteith.

The use of these models requires the knowledge of some climatic data such as, precipitation heights, maximal and minimal air temperature, maximal and minimal relative humidity, duration of sunshine and wind speed[9-11].

Thornthwaite method: The Thornthwaite method is used when only temperature is available among the climatic data. It expresses the ETP by the following formula[11-13]:

$$ETP = 16.\left(\frac{10.T}{I}\right)^{a}.f(\rho) \qquad (1)$$

where T is average temperature in the shade for the period considered, I is annual thermal index, that is sum of twelve monthly indices, $f(\rho)$ is a corrective term depending on the theoretical sunshine duration, latitude and month and a is a complex function of the index I.

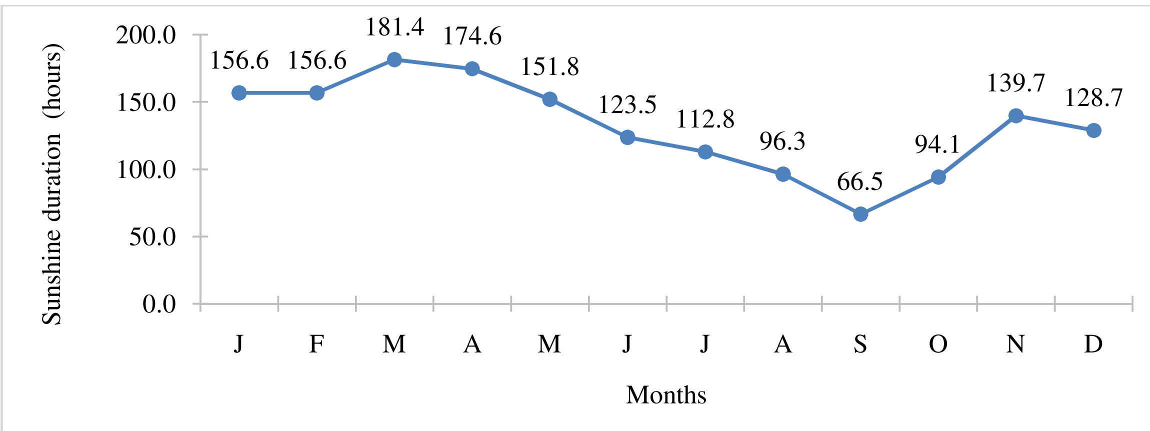


Figure 5: Monthly average duration of sunshine in Pointe-Noire (1990-2016).

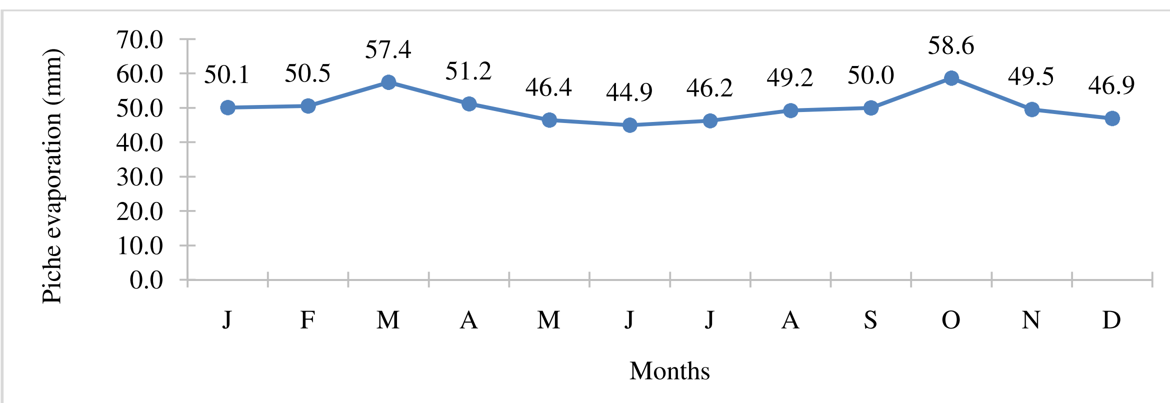


Figure 6: Monthly average Piche evaporation at Pointe-Noire (1990-2016).

Table-1: Monthly Piche evaporation (mm) in Pointe-Noire (1990-2016).

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
Average	50.1	50.5	57.4	51.2	46.4	44.9	46.2	49.2	50.0	58.6	49.5	46.9	600.8
Standard deviation	10.7	11.1	12.1	10.5	9.7	9.6	9.9	11.0	11.1	14.4	11.1	10.2	131.5

Turc method: the Turc method is based on the monthly average temperature T (°C), the relative humidity RH (%), the incoming solar or shortwave radiation (R_s) of the considered month and the relative sunshine duration[11,14]. In this case, the ETP on monthly time scale is expressed in mm/month according to the following formulas:

$$ETP = 0.40\frac{T}{T+15}(R_s + 50)\text{if } \ RH > 50\% \quad (2)$$

$$ETP = 0.40\frac{T}{T+15}(R_s + 50)\left(1 + \frac{50-RH}{70}\right)\text{if } RH < 50\% \quad (3)$$

In these relations, the regression equation obtained by Riou for Brazzaville, a city located at the neighbor latitude of Pointe-Noire, has been used.

$$R_s = n.R_a\left(0.31 + 0.69\frac{h}{300}\right) \quad (4)$$

With R_a the extra terrestrial radiation or the solar radiation at the entry of the atmosphere (cal/cm^2 /day), h the real duration of sunshine for the month considered and n a coefficient that depends on the month[15].

Haude method: The method proposed by Haude for evaluation of daily evapotranspiration is defined as follows[16,17]:

$$ETP = P_{14h}\left(1 - \frac{F_{14h}}{100}\right) \quad (5)$$

Where: P_{14h} is the saturation water vapor pressure (for air temperature at 14 hours) in mm Hg, given by the expression:

$$P_{14h} = 45.25\frac{7.4475T}{234.67+T} \quad (6)$$

with T the air temperature at 14 hours in °C, and F_{14h} the relative humidity at 14 hours in %[17].

If measurements at 14 hours are not available, one can use the values of maximal temperature and minimal relative humidity. Values calculated from formula (5) must be corrected according to the length of the day (duration of sunshine). Thus, to obtain the monthly cumulative ETP, the daily values calculated from formula (5) must be multiplied by the number of days in the month considered and by a coefficient K of correction of the length of the day in this month:

$$ETP_{corrected} = K.L.ETP \quad (7)$$

Where: K is coefficient of correction of the length of the days in the considered month (in this study, the values K = 0.26 for the months between May and September, and K = 0.37 for the months between October and April have been chosen), and L is the length of the month in days (($L_{january} = 31; L_{february} = 28; \ldots\ldots$)

Penman method: Penman has developed an expression combining the energy component needed to support evapotranspiration and the mass balance component linked to the saturation vapor gradient[18,19,15]. It try to make a weighted average of both components:

$$ETP = \frac{\Delta R_n + \gamma E_a}{\Delta + \gamma} \quad (8)$$

Where: ETP is evapotranspiration (mm/day), R_n is net radiation (mm/day), E_a is evaporation due to mass balance (mm/day), Δ is the slope of the saturation water vapor pressure at air average temperature (kPa/°C), and γ is the psychrometric constant γ= 0.065kPa /°C.

The slope of the saturation water vapor pressure at the average temperature of the air can be estimated using the following expression where the units are given in kPa/°C:

$$\Delta = \Delta(T) = \frac{2504e^{\left(\frac{17.27T}{T+237.3}\right)}}{(T+237.3)^2} \quad (9)$$

with T the daily average temperature of air (°C).

FAO-Penman-Monteith method: researchon evapotranspiration has made it possible to better define some terms and coefficients of the Penman expression. The evolution of the Penman equation has been known by the names of FAO-Penman, Penman-Monteith and the American Society of Civil Engineering (ASCE) adopted a daily step version[9,10]. It estimates the potential evapotranspiration by the following expressions[9]:

$$ETP = \frac{\frac{1}{\lambda}\Delta(R_n - G) + \gamma E_0}{\Delta + \gamma(1 + C_d V_2)} \quad (10)$$

$$E_0 = \frac{C_n}{T+273}(e_s - e_r)V_2 \quad (11)$$

Where: R_n is net radiation ($MJm^{-2}day^{-1}$); G is soil heat flux ($MJm^{-2}day^{-1}$); T is air average temperature (°C); e_s is average saturation water vapor pressure at the air average temperature at a height of 1.5 to 2.5m (kPa); e_r is average saturation vapor pressure at the temperature of the dew point at a height of 1.5 to 2.5m (kPa); Δ is slope of saturation water vapor pressure at the air average temperature (kPa/°C); V_2 is average wind speed at a height of 1.5 to 2.5m (m/s); C_n is constant depending on the reference culture C_n=900; C_d is constant depending on reference culture C_d=0.34; γ is psychrometric constant (kPa/°C); λ is latent heat of vaporization (2.45$MJkg^{-1}$ of water=$MJm^{-2}mm^{-1}$) at 20°C or

$$\frac{1}{\lambda} = 0.408.$$

This expression is valid on hourly, daily, 10 days and monthly time steps, provided that the parameters are well estimated[9].

The net radiation Rn has been estimated using the correlation expression obtained by Riouat Brazzaville, with an albedo coefficient of α = 0.23 that is to say

$$R_n = (1 - \alpha)R_s - R_{nl}$$

with R_s the incoming solar radiation and R_{nl} the outing net longwave radiation for which he proposes the relation

$$R_{nl} = 48.10^{0.0317A}$$

Where: R_{nl} is in cal/m^2.day and A (°C) is the range of temperature[15].

The soil heat flux G at the monthly time step has been estimated according to the method described by Allen and the saturation water vapor pressure at temperature T(°C) is given in kPa by[9]

$$e_s(T) = 0.6108e^{\frac{17.27T}{T+237.3}} \quad (12)$$

Bouchet equation: This equation makes it possible to evaluate the evapotranspiration from a measurement of evaporation with a Picheevaporimeter, for the period considered (day, decade, month)[20,11]. Bouchet has suggested the following Piche ETP relation:

$$ETPp = \eta(1 + \lambda(\theta))E_p \quad (13)$$

With, E_p: measured Picheevaporation (mm/day, decade, month); θ: average temperature between the air temperature and the temperature of the dew point θ_r (°C); $\lambda(\theta) = \Delta(\theta)/\gamma$, where $\Delta(\theta)$(kPa/°C) is the slope of saturation water vapor pressure at the temperature θ (°C) and γ the psychrometric constant; η: a coefficient depending on season and on region. The values calibrated by Riou for Brazzaville have been used[15].

Christiansen equation: The equation proposed by Christiansen is written as[21]:

$$ETP = 0.473R_a.C \quad (14)$$

With, R_a: the solar radiation at the entry of the atmosphere (cal/cm^2.day); C: the coefficient of the average temperature T (°C) defined by

$$C(T) = 0.393 + 0.5592\left(\frac{T}{20}\right) + 0.9722\left(\frac{T}{20}\right)^2 \quad (15)$$

This method has been developed in the United States of America. For the study area considered here in the tropical zone, a slight modification has been made by dividing the temperature T by 29, that is to say

$$C(T) = 0.393 + 0.5592\left(\frac{T}{29}\right) + 0.9722\left(\frac{T}{29}\right)^2 \quad (16)$$

Results and discussion

The results obtained by applying the different approaches estimating ETP on monthly and annual scales were compared with Piche evapotranspiration ETP_P, by using the values of relative deviation (RD). Thus, linear correlations will be established between the results of the different models and the Piche ETP. It should be noted that the relative deviation is defined by:

$$RD = \frac{[ETP_i - ETPp] \times 100\%}{ETPp} \quad (17)$$

ETP_i being the different ETP calculated by the methods of Thornthwaite, Turc, Haude, Christiansen, Penman and Penman-Monteith. The lower the absolute values of RD, the more the estimation method of the ETP gives a realistic estimate of this component.

Comparison of different methods on annual scale: The results obtained by applying the different approaches to estimate ETP during the period (1990-2016) are illustrated in Figure-7.

The comparative analysis of the different ETP values calculated with that of ETP_P makes it possible to highlight that ETP calculated by the Penman-Monteith method leads to a best estimate of this climatic component, with a relative deviation ranging between 2 and 40.5%. One can note that the period 1990-1992 shows a significant difference, between 21.6 and 40.5% (Table-4). During the study period the Turc ETP values (RD ranging between 2 and 53.4%) are between the values of the Penman ETP (RD ranging between 0.3 and 56%) and those estimated by ETP_P (Table-4).

Comparison of different methods on monthly scale: The results obtained by applying the different methods estimating the monthly average ETP are shown in Figure-8. The ETP values obtained by the Penman-Monteith method approximate those of ETP_P with RD ranging between 0.2 and 27.4%. Note that during the dry season RD is large, from 0.2 to 27.4% (Table-5). In addition, Turc ETP values (RD ranging between 3.7 and 48.1%) fall between the Penman ETP values (RD ranging between 5.3 and 43.3%) and those estimated by the Picheor Bouchet method. It should be noted that the Thornthwaite ETP values are significantly higher than those of ETP_P (Table-5), this shows that the Thornthwaite method can overvalue the ETP, with a gap up to about 67.2%.

Correlation between the Piche ETP with the other ETP methods: The relations between the monthly average Piche ETP and those estimated by the different methods, allow to obtain some linear correlations between them with some coefficients of correlation greater than 0.7 (Figure-9). It should be noted that the best correlation is obtained between the Piche ETP and Penman-Monteith ETP, with a coefficient of correlation of $R^2 = 0.90$ (Table-6).

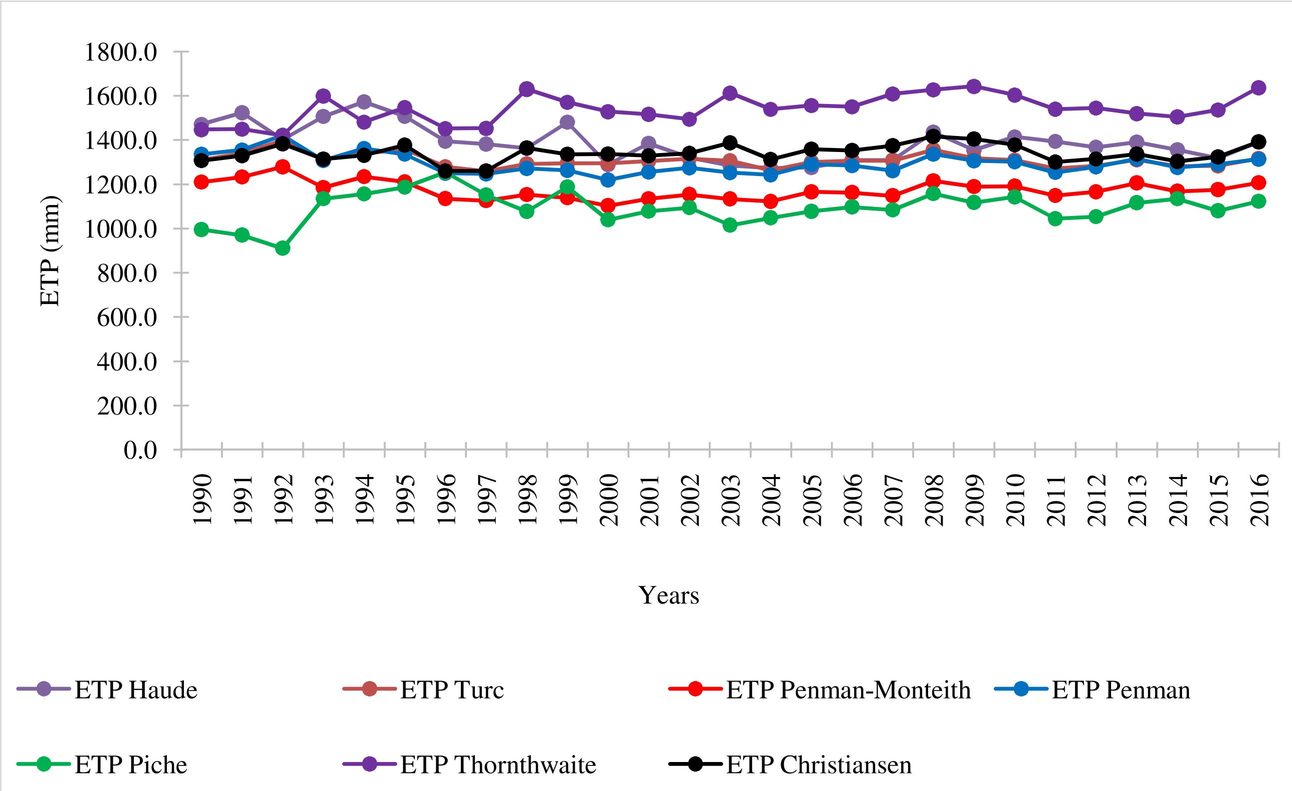


Figure-7: Annual ETP values estimated by the different methods (1990-2016).

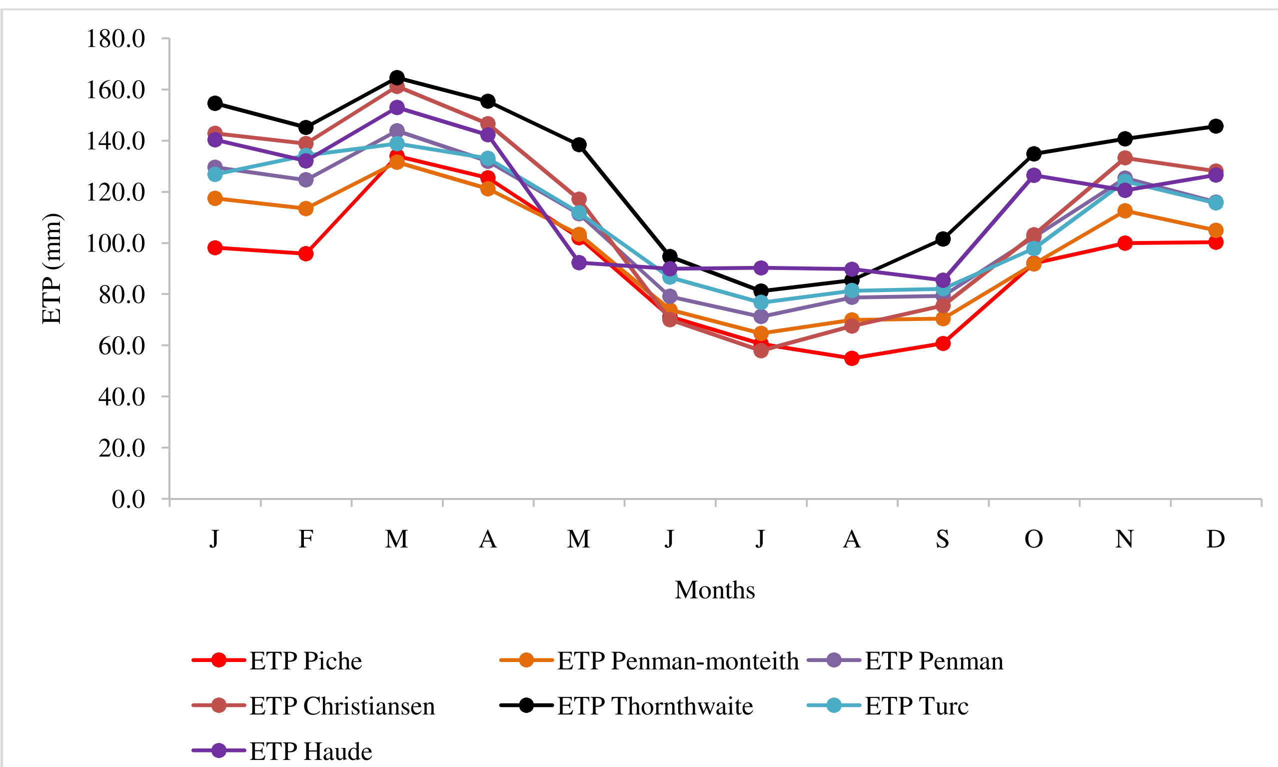
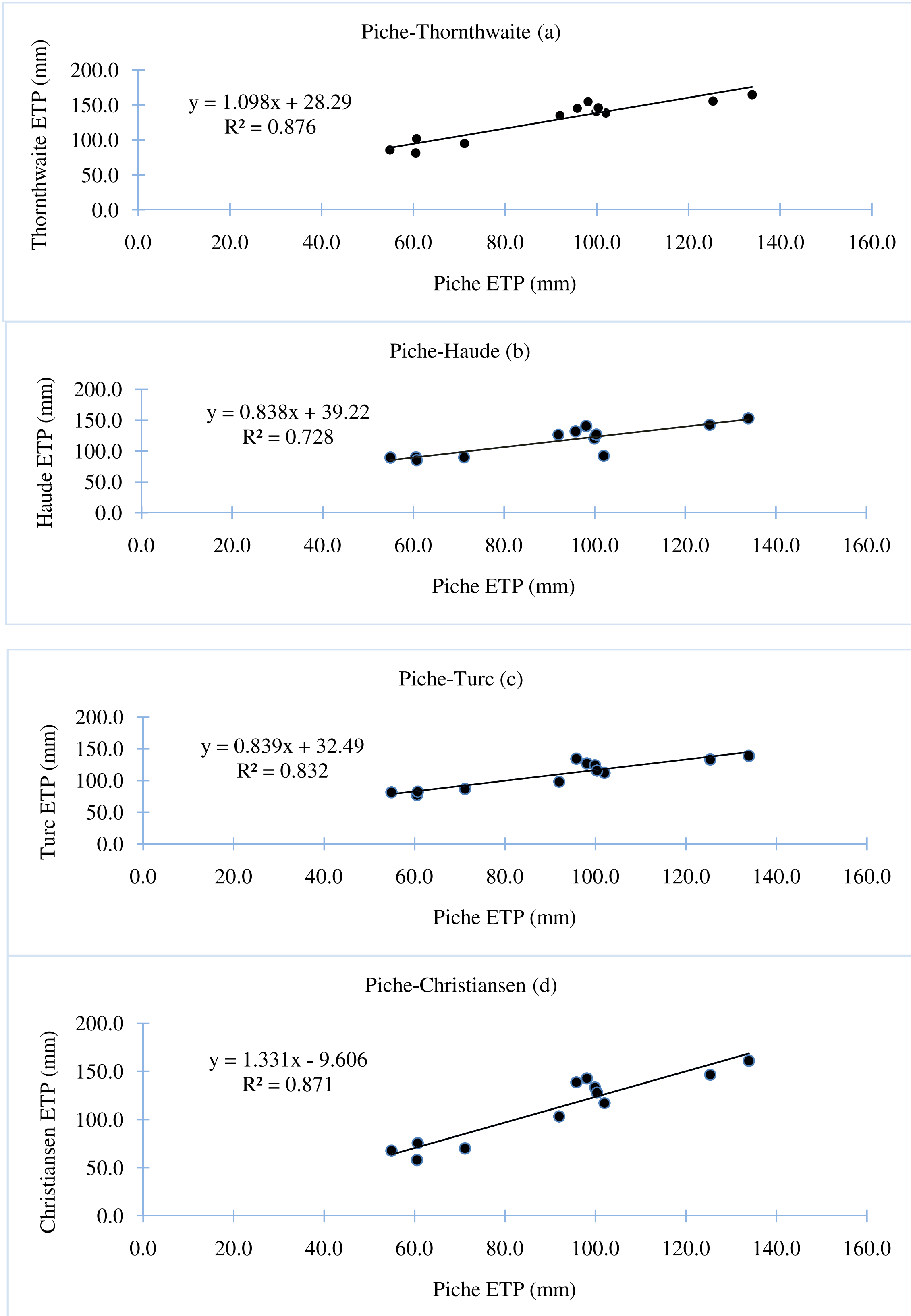
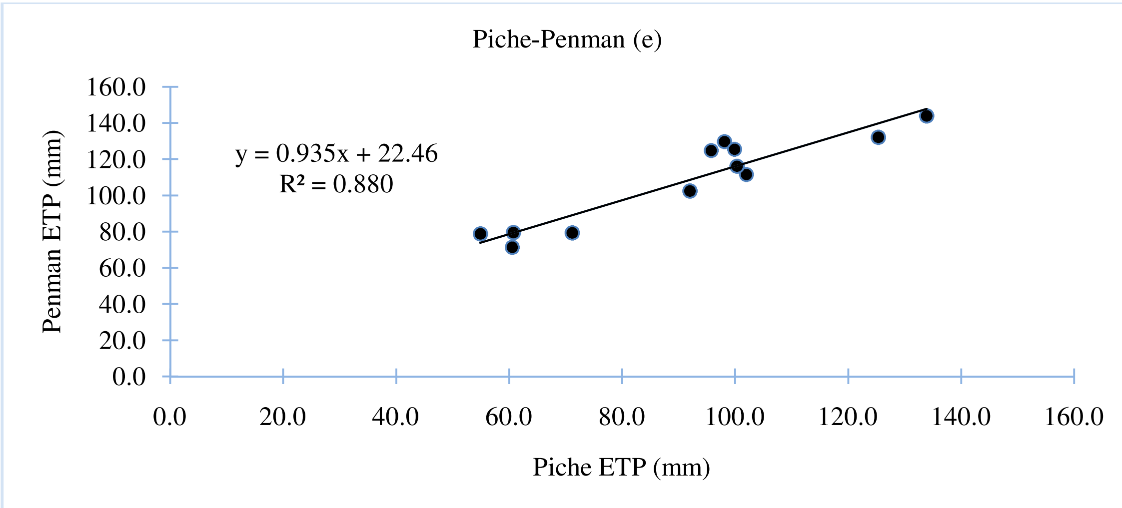


Figure-8: ETP monthly average values estimated by the different methods (1990-2016).


Piche-Thornthwaite (a)
y = 1.098x + 28.29
R² = 0.876
Thornthwaite ETP (mm)
Piche ETP (mm)
Piche-Haude (b)
y = 0.838x + 39.22
R² = 0.728
Haude ETP (mm)
Piche ETP (mm)
Piche-Turc (c)
y = 0.839x + 32.49
R² = 0.832
Turc ETP (mm)
Piche ETP (mm)
Piche-Christiansen (d)
y = 1.331x - 9.606
R² = 0.871
Christiansen ETP (mm)
Piche ETP (mm)



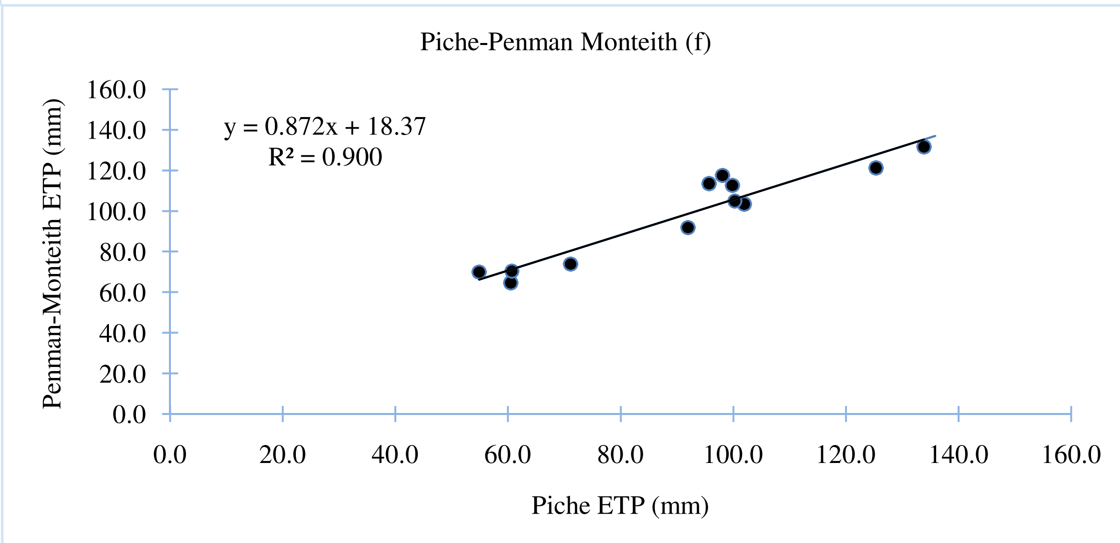


Figure-9: Curves of the linear correlations between monthly average Piche ETP with the other methods.

Table-2: Statistical parameters of the monthly average climatic data.

Climatic variables	Max	Min	Extent	Average	Standard deviation	Coefficient of variation
Rainfalls (mm)	671.1	0	671.1	106.9	89	0.83
Wind speed (m/s)	3.8	1.1	2.7	2	0.32	0.16
Relative humidity (%)	98	88	10	95	0.95	0.01
Piche Evaporation (mm)	441	1.8	439.2	55	8	0.15
Sunshine duration (h)	225.4	3.1	222.3	132	34.85	0.26
Maximal Températures (°C)	32.4	24.7	7.7	29	2	0.07
Minimal Températures (°C)	25.7	17.5	8.2	23	2	0.09

Table 3: Annual values of ETP (mm) calculated by the different methods (1990-2016).

Years	Thornthwaite	Haude	Turc	Christiansen	Penman	Penman-Monteith	Piche
1990	1448.3	1471.5	1311.8	1307.4	1336.7	1211.0	996.0
1991	1449.9	1524.6	1340.0	1329.5	1355.8	1234.4	971.3
1992	1421.5	1402.2	1398.4	1383.0	1421.6	1280.1	911.4
1993	1599.8	1507.6	1312.6	1314.3	1308.2	1185.8	1135.5
1994	1482.0	1573.8	1341.2	1331.7	1362.7	1235.6	1157.2
1995	1547.7	1508.6	1357.8	1377.1	1336.7	1211.6	1187.8
1996	1452.6	1395.3	1280.2	1260.3	1251.1	1135.9	1255.3
1997	1454.1	1381.9	1259.7	1260.5	1247.5	1126.9	1153.0
1998	1631.0	1362.6	1293.1	1365.0	1272.3	1154.5	1078.0
1999	1571.7	1481.5	1295.4	1336.2	1263.6	1140.4	1188.9
2000	1529.0	1289.1	1295.7	1337.3	1220.4	1103.8	1040.7
2001	1517.0	1384.9	1306.1	1329.2	1255.9	1135.3	1079.1
2002	1494.9	1321.6	1316.2	1339.7	1274.8	1154.8	1095.5
2003	1613.0	1284.5	1307.8	1387.2	1254.2	1134.8	1016.0
2004	1540.0	1273.1	1264.0	1312.4	1243.9	1123.4	1049.3
2005	1557.0	1276.0	1301.8	1358.2	1291.6	1166.9	1078.5
2006	1551.6	1310.1	1307.5	1352.8	1284.8	1163.6	1098.3
2007	1609.4	1310.1	1306.9	1374.5	1262.7	1149.0	1084.6
2008	1628.0	1436.0	1356,3	1416.6	1336.9	1216.0	1158.5
2009	1643.7	1353.9	1319.1	1404.9	1307.6	1190.2	1118.5
2010	1604.5	1415.0	1310.1	1378.4	1302.9	1192.6	1143.4
2011	1540.3	1394.2	1272.0	1300.8	1254.3	1150.1	1045.1
2012	1545.8	1368.2	1284.8	1314.8	1279.3	1166.8	1054.2
2013	1520.7	1390.5	1311.6	1336.9	1316.1	1206.9	1117.3
2014	1505.4	1356.2	1282.4	1304.1	1276.8	1169.3	1135.5
2015	1537.1	1317.6	1284.0	1324.1	1291.0	1176.4	1080.8
2016	1637.5	1392.5	1318.0	1391.6	1313.8	1207.9	1123.7
Average	1542.0	1388.3	1308.7	1341.8	1293.5	1175.0	1094.6

Table-4: Relative deviation (RD (%)) between different estimated ETP with Piche ETP (annual scale).

Years	Thornthwaite	Haude	Turc	Christiansen	Penman	Penman-Monteith
1990	45.4	47.7	31.7	31.3	34.2	21.6
1991	49.3	57.0	38.0	36.9	39.6	27.1
1992	56.0	53.9	53.4	51.8	56.0	40.5
1993	40.9	32.8	15.6	15.8	15.2	4.4
1994	28.1	36.0	15.9	15.1	17.8	6.8
1995	30.3	27.0	14.3	15.9	12.5	2.0
1996	15.7	11.2	2.0	0.4	-0.3	-9.5
1997	26.1	19.8	9.3	9.3	8.2	-2.3
1998	51.3	26.4	20.0	26.6	18.0	7.1
1999	32.2	24.6	9.0	12.4	6.3	-4.1
2000	46.9	23.9	24.5	28.5	17.3	6.1
2001	40.6	28.3	21.0	23.2	16.4	5.2
2002	36.5	20.6	20.1	22.3	16.4	5.4
2003	58.8	26.4	28.7	36.5	23.4	11.7
2004	46.8	21.3	20.5	25.1	18.6	7.1
2005	44.4	18.3	20.7	25.9	19.8	8.2
2006	41.3	19.3	19.0	23.2	17.0	5.9
2007	48.4	20.8	20.5	26.7	16.4	5.9
2008	40.5	23.9	17.1	22.3	15.4	5.0
2009	47.0	21.0	17.9	25.6	16.9	6.4
2010	40.3	23.7	14.6	20.6	14.0	4.3
2011	47.4	33.4	21.7	24.5	20.0	10.1
2012	46.6	29.8	21.9	24.7	21.3	10.7
2013	36.1	24.5	17.4	19.7	17.8	8.0
2014	32.6	19.4	12.9	14.8	12.4	3.0
2015	42.2	21.9	18.8	22.5	19.4	8.8
2016	45.7	23.9	17.3	23.8	16.9	7.5
Average	41.4	27.3	20.1	23.2	18.8	7.9

Table-5: Relative deviation (RD (%)) between different estimated ETP with Piche ETP (monthly scale).

Months / ETP	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Average
Thornthwaite	57.6	51.6	22.9	24.0	35.7	33.1	34.0	55.6	67.2	46.5	40.8	45.2	42.9
Haude	43.0	37.9	14.2	13.4	-9.6	26.3	49.0	63.4	40.6	37.4	20.6	26.2	30.2
Turc	29.3	40.1	3.7	6.1	9.6	21.7	26.7	48.1	35.1	6.3	24.2	15.3	22.2
Christiansen	45.5	44.9	20.4	16.9	14.8	-1.5	-4.3	23.1	24.3	12.2	33.4	27.6	21.4
Penman	32.1	30.2	7.4	5.3	9.2	11.2	17.6	43.3	30.7	11.2	25.5	15.6	19.9
Penmanmonteith	19.7	18.5	-1.8	-3.3	1.3	3.8	6.8	27.4	15.9	-0.2	12.7	4.5	8.8

Table-6: Linear correlation between the PicheETP and the others ones.

Relation	Linear correlation	R^2
$ETP_{Thornthwaite}$ - ETP_P	$ETP_{Thornthwaite}$ = 1.0985ETPp+28.296	0.8766
$ETP_{Penman-Monteith}$ - ETP_P	$ETP_{Penman-Monteith}$ = 0.872ETPp+18.371	0.9002
ETP_{Penman} - ETP_P	ETP_{Penman} = 0.9354ETPp+22.467	0.8802
ETP_{Turc} -ETP_P	ETP_{Turc} = 0.8394ETPp+32.494	0.8322
ETP_{Haude} - ETP_P	ETP_{Haude} =0.8383ETPp+39.221	0.7286
$ETP_{Christiansen}$ - ETP_P	$ETP_{Christiansen}$ = 1.3312ETPp–9.6069	0.8718

Discussion: The results show that the best estimates of the ETP are obtained with the methods based on energy balance, and especially with that of Penman-Monteith, which is the best in the tropical zone. This observation confirms that the results obtained above in the Pointe-Noire region (Congo) are in agreement with the conclusions of the previous work carried out on the climate variability in Africa including the recent ones made by Papa Malick in West Africa, Bouteldjaoui in North Africa, Nizinski and Moukandi Nkayain Congo[4,8,22,23]. In the region of Pointe-Noire, these results show that the determination of ETP by the Penman-Monteith method is an effective approach with a relative deviation varying between 0.2 and 27.4% (monthly scale) or between 2 and 40.5% (annual scale). The Penman method comes in second place, the Turc method in third place and the methods of Christiansen, Haude and Thornthwaite come in fourth, fifth and sixth place respectively (Table-5).

The average annual values of ETP obtained in this study by the Penman-Monteith method during the period 1990-2016 is 1175 mm/year (Table-3). This is close to that given by Allen at Cabinda (Angola), a neighbor city of Pointe-Noire located at 5°33 south and 11°11 east where ETP calculated with Penman-Monteith method in the year 1998 were 3.1mm/day or 1131,5 mm/year[9]. Similarly, the average annual values of ETP obtained in this study with the Penman method during the period 1990-2016 is 1293.5mm/year (Table-3). This is close to that obtained by Moukandi Nkayaat Pointe-Noire during the period 1998-2009 with the same method, that is to say 1280.8mm/year[8]. Recall that the ETP value obtain with Penman method in all the coastal region of republic of Congo during the period 1992-1998 were 1390.4mm/year[4]. This is greater than the value obtain in this work, because of the abundance of the plant cover in this coastal region.

Concerning Thornthwaite method, Riou shown during the period 1968-1971 that it can overvalue ETP up to 25% at Brazzaville (city in Congo located at the similar latitude)[15]. This study confirms the bad quality of this method at Pointe-Noire with an annual average relative deviation of 41.4% during the period 1990-2016. This explains why Thornthwaite has limited his method for the average air temperature lower than 26.5°C.

Conclusion

This work aimed to compare some methods estimating evapotranspiration in the tropical zone (case of Pointe-Noire) and to validate the best ones. To achieve this objective, the ETP calculated by the methods tested were compared to that provided by the method of Bouchet using the measured Piche evaporation. The comparative analysis of the results obtained by the application of the different models allows to highlight that on the annual scale, the Penman-Monteith method leads to a satisfactory estimate with a relative error (absolute value of RD) ranging between 2 and 40.5%, while the Thornthwaite method greatly overvalues ETP, with a relative error which can reach 58.8%. Similarly, on the monthly scale, the estimation of the ETP by the Penman-Monteith also leads to a better approximation of this component, with a relative error ranging between 0.2 and 27.4%. In addition, the values of Thornthwaite method are clearly above those of the Piche ETP with a significant difference which can reach 67.2%.

Nowadays, many works on estimation of ETP including meteorological satellite imagery, remote sensing and nonlinear modeling are developped[24]. It will be interesting to apply them in the study zone considered here.

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