Comparative Study of Potential Evapotranspiration in Different Geopolitical Zones; A Case Study of Nigeria

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ORIGINAL RESEARCH

Abstract—The dearth of information on crop water requirements through the evaluation of climatic characteristics cannot be over-emphasized, making water management and crop production a herculean task. This study was designed to estimate the ETo of states in each geopolitical zone of Nigeria using the Penman-Monteith method for proper crop growth and water management. The study also addresses difficulties experienced in sourcing climatological data in different geopolitical zones of Nigeria. The study is limited to comparative analysis of potential evapotranspiration estimates in states such as Southeast (Enugu State), South-south (Cross River State), Southwest (Ogun State), Northcentral (Kogi State) Northeast (Adamawa State) Northwest (Jigawa State). The estimated potential evapotranspiration (ETo) was calculated by applying Penman-Monteith method CROPWAT model. Cumulative daily ETo for the year were 1266mm, 1231.26mm, 1173.87mm, 1360.79mm, 1260.38mm, and 1332.35mm for Enugu, Abeokuta, Calabar, Dutse, Ilorin, and Yola cities, respectively. The results show that crop water consumptive use was higher in the northwest and northeast compared to other parts of the country. Estimated ETo values in the North-central region were similar to values obtained in the southern part. In the southern part, February, March April, and May recorded higher ETo values compared to July and August with the lowest ETo values.

Keywords— Crop water requirement, cumulative evapotranspiration, penman-monteith method, potential evapotranspiration,

1.0 Introduction

When considering the world's hydrologic cycle, evapotranspiration, abbreviated as ET is an essential factor in the plant growth process. It is a complex process that combines different processes of such as soil and vegetation evaporation and vegetation transpiration; (1) soil and vegetation evaporation, (2) vegetation transpiration. There are several important concepts crucial for understanding evapotranspiration processes namely: (1) according to Thompson, (1998), potential evapotranspiration (ETo), is referred to as evaporation occurring at its peak provided it occurs in a climatic condition where soil moisture is sufficient. (2) The term reference evapotranspiration implies the evapotranspiration occurring in a hypothetical reference crop of 0.12m height, with a bulk surface resistance and albedo measuring $70sm^{-1}$ and 0.23, respectively, provided the soil moisture is sufficient (3) crop evapotranspiration occurs when water losses under standard or non-standard conditions occur from the cropped field, (4) actual or real evapotranspiration are water losses that occur when the vegetation or crops are affected by hydrological, meteorological, and also vegetation or crop phenology (Anwar et al, 2023; Ehumadu et al., 2024).

ET which also can be described as a process comprising of evaporation and transpiration, which is crucial in the design and management of scarce water resources during agricultural production for man's use (Yingjie et al, 2023). Evaporation entails the removal of liquid water to gaseous form from the earth's surface while Transpiration entails water removal from the stomata of plants (Allen et al., 1998). ET is a major cause of water loss during various crop growth stages, which is equivalent to water demanded by the crop, thus, bringing to the conclusion that crop ET is equivalent to crop water requirement (Anyanwu et al., 2016; Ehumadu et al., 2024). The application of empirical ET estimation methods has an advantage over other methods because of its accuracy, ease of usage, and accuracy considering the suitability of the model applied (Yusuf et al., 2020). Accurate ET estimations are applied for proper studies and decision-making. It is also applicable in the development of strategic frameworks on crop management, design and construction of various surface and underground irrigation systems, hydrological water balance, and water resources management have become necessary in Sub-Saharan Africa. However, different methods exist for estimating ET, which include remote sensing, ground-based techniques, and also process modelling (Sorensson and Ruscica, 2018). Studies on ET estimations at different agricultural sites are important due to its wide range of applications in crop production and hydrological studies. Potential ET can be estimated with models such as Thornthwaite, Priestley-Taylor, Jensen and Haise, Blaney-Criddle, and Blaney-Morin-Nigeria (Idike and Anekwe, 2002; Idike, 2005; Ehumadu et al., 2024) which require different meteorological variables. Also models such as Hargreaves-Samani, Penman, Ritchies, and Makkink, require aerodynamic and energy balance principles to determine ET (Wang et al., 2017). The use of Penman-

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Monteith method also referred to as PM-56 method is the most accurate, reliable and recommended FAO ET estimation method (Awari et al, 2018; Ehumadu et al., 2024). This estimation method is regarded as the best with crucial parameters driving energy and aerodynamic exchanges (Obioma et al., 2015). Ilesanmi et al., (2014) also postulated that calculations using Penman-Monteith method generates a more reliable ETo values when compared to other methods. The dearth of available ETo data at various geopolitical zone is a serious challenge for crop production and water management in Nigeria. Addressing this challenge becomes difficult because crucial energy and aerodynamic parameters such as solar radiation, air temperature, wind, and relative humidity generated from meteorological stations are difficult to obtain. Potential evapotranspiration (ETo) estimates generated using Penman Monteith method is FAO approved and considered as a reliable and standardized method. According to Łabędzki, et al., (2011), reference evapotranspiration can be calculated from meteorological data using approved FAO Penman-Monteith Method. This timely study was designed to estimate ETo of states in each geopolitical zone of Nigeria using Penman-Monteith method. This study will help in mitigating challenges on crop growth and water management. It is also necessary in addressing difficulties experienced sourcing of climatological data in different geopolitical zones of Nigeria. This study is limited to comparative analysis of potential evapotranspiration estimates in states such as South-east (Enugu State), South-south (Cross River State), South-west (Ogun State), North-central (Kogi State), North-east (Adamawa State) and North-west (Jigawa State). The outcome of this study will be beneficial to farmers and researchers, scientists and government agencies. This study differs from Ehumadu et al (2024), which focused on ascertaining the suitability and reliability of different ETo estimation models compared to the approved FAO model.

2 MATERIALS AND METHODS

2.1 Elucidation of the Study Area

2.1.1 Enugu city

Enugu city is the capital of Enugu state located in the Southeastern geo-political zone of Nigeria. Enugu State is situated at the lower part of the Udi Plateau bordering Abia State, 25km to the south, to the east it borders Ebonyi State, 84km to the northeast it borders Benue State, 112km to the northwest it borders Kogi State and 139km to the west it borders Anambra State. Enugu city sits at about 223m above sea level. The mean temperatures of 30.64°C and 15.86°C occur in the hottest and coldest months of February and November respectively. The average yearly temperature of the area is 28.27°C which is less than Nigeria's average by -1.19%. Enugu city experiences a rainfall of about 158.57 millimeters annually.

2.1.2 Calabar City

Calabar, a city found in Nigeria's South-south geo-political zone, is Cross River State's capital. The city is located at a latitude of **4.982873**, and a longitude of **8.334503. Calabar has** a lengthy ten-months wet season and two months dry season. Throughout the year, the temperature is almost constant, with its average highest ranging from 25 to 28°C. Calabar experiences an average rainfall of 3,000mm annually. The city has an average land area of 406km².

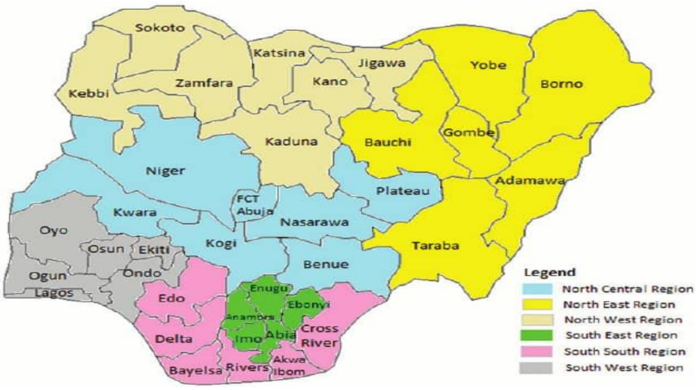

Figure 1: Geopolitical zones of Nigeria

2.1.3 Abeokuta City

Abeokuta is the capital city of Ogun State in the southwestern part of Nigeria. It is located at the eastern bank of the Ogun River, which is 77km north of Lagos State using railway, and 130 km by water. The city has a total area of 879 km² (339 sq mi). It has a latitude of **7.145244 North**, and a longitude is **3.327695 with** a daily temperature average above 91°F. March, is the hottest month with a temperature of 93°F and 76°F, its lowest.

Figure 2: Aerial view of Nigeria showing data collection points. **Source:** Google map

2.1.4 Ilorin City

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Ilorin which is Kwara State capital city, is situated within the North Central geopolitical zone, with 8° 30' 0.0000'' N and 4° 32' 60.0000'' E as coordinates, has an annual rainfall ranging from 990.3 to 1318 mm. The maximum temperatures of the city range from 33 91.4 and 98.6 °F.

2.1.5 Yola City

Yola is the capital city of Adamawa State, Nigeria. It has a global positioning system (GPS) coordinates of 9° 12' 12.5856'' N and 12° 29' 43.4040'' E. It is located on the Benue River with dry and wet seasons, with tropical climates bordering a semi-arid climate. The city has a warm temperature year-round, with the lowest at 31.3 °C (88.3 °F) in August and September while the highest of 42.8 °C (109.0 °F) is observed in March. The city receives a precipitation of 872.4 mm annually, during where wet season (May to October) and dry season (February to April). Diurnal temperature variations are higher during the dry season. August which is observed as the wet month, receives 196.1mm rainfall.

2.1.6 Duste City

Duste is the capital of Jigawa State, Nigeria having a Latitude of 11° 45' 22.25" N and Longitude: 9° 20' 20.26" E, 151.9km near the Niger border. The city is 30 Km ENE to Kiyawa, Jigawa, 54.9 Km W to Wudil, Kano and 76.2 Km SE to Gwaram, Jigawa.

2.2 Data Collection

Meteorological data such as minimum and maximum temperature, relative humidity, sun hours, and wind were sourced from Climate-Data.org over an average of 20years. Location data was also sourced using OpenStreetMap licensed with the Open Database License. The estimated potential evapotranspiration was obtained using the Penman-Monteith method with the aid of an FAO-recommended model called CROPWAT model. The results were obtained as means of three replications using the analysis of variance (ANOVA) technique.

3.0 RESULTS AND DISCUSSIONS

1) Table 1 and Table 2 show results on the average daily, weekly, and monthly potential evapotranspiration in mm, and comparative analysis of average daily and cumulative potential evapotranspiration in mm, respectively. The mean values obtained using the FAO-recommended Penman Monteith method for different geopolitical zones in Nigeria were compared to help mitigate challenges on crop growth and agricultural water management. Figures 3 and 4 present a comparative analysis of average daily, weekly, and monthly cumulative potential evapotranspiration in mm, and average monthly and cumulative yearly potential evapotranspiration in mm, respectively.

3.1 Discussions

The daily and monthly cumulative estimated potential evapotranspiration were calculated using the FAO-approved cropWAT model for the different geo-political regions of Nigeria. The estimated ETo were presented as average daily, weekly, and monthly basis as shown in Figure 3. Estimated daily ETo values were obtained using weekly mean estimates throughout study as presented in Table 1. Data shown in Table 1 indicates that Enugu City experienced the highest ETo in April (4.03mm) and the lowest in August (3.01mm) with an average daily ETo of 3.47mm. The months of January, July, September, and December recorded very low ETo ranging from 3.11-3.24mm. The maximum weekly and monthly ETo were 24.21 and 121.52mm respectively. The minimum weekly and monthly ETo were 21.07 and 93.31mm respectively. The results obtained for Enugu City were close to what Ezenne and Obiajuibe, 2021 recorded using meteorological data from NASA. Abeokuta city recorded the highest daily ETo in April (4.01mm) similar to Enugu city. The lowest ETo was observed in July (2.85mm) with an average daily ETo of 3.38mm. According to Fadipe *et al* (2023), the maximum and minimum ETo values per day obtained from Abeokuta are 2.83 mm/day to 6.37 mm, respectively. The months recording lower ETo were January, June, July, August, and September with values ranging from 2.85-3.16mm. 28.07 and 124mm were recorded as the maximum ETo observed in April and March respectively. 19.95 and 88.35mm were observed as the minimum daily and monthly ETo recorded in April. High values of ETo were recorded from October to December ranging from 101.4-105.3mm. Table 1 shows that Calabar City recorded 3.67mm as the highest daily ETo which was observed in February and March. 2.60mm was observed as the lowest daily ETo value recorded in August. The months of July, August, and September recorded very low daily ETo ranging from 2.60-2.90mm. 3.63-3.67mm daily ETo were recorded for months February, March, and April which were the months with the highest ETo. The maximum weekly and monthly ETo were 25.69mm and 113.77mm, respectively, both observed in March. The minimum weekly and monthly ETo was 18.20mm and 80.60mm respectively. Dutse city

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experienced the highest daily ETo in June (4.75mm) and the lowest ETo in January (2.63mm) with an average daily ETo of 3.73mm. The result is different from Abdulsalam *et al*., 2023, which recorded 5.4805 mm/day and 4.51mm as the lowest using the Abstew model for Kano, a state in the northwest geopolitical zone. The months of January, February, March and December recorded low daily ETo ranging from 2.63-3.24mm. The maximum weekly and monthly ETo recorded in June were 33.25 and 142.50mm, respectively. The minimum weekly and monthly ETo was 18.41 and 81.53mm respectively. Ilorin City recorded the highest daily ETo in March (4.05mm) and the lowest daily ETo was observed in January (2.95mm) similar to Dutse City as shown in Table 1. The average daily ETo for the city was 3.45mm. January, July, August, September, and December were months recording low daily ETo ranging from 2.95-3.20mm. The maximum weekly and monthly ETo were 28.35 and 125.55mm, respectively as shown in Figure 3. The minimum weekly and monthly ETo were 20.65 and 91.45mm respectively. Yola City recorded 4.47mm as the highest daily ETo which was observed in May. 2.84mm was observed as the lowest daily ETo value recorded in the month of January. The months of January, February, November and December recorded low daily ETo ranging from 2.84-3.38mm. 4.06-4.47mm daily ETo were recorded for months April, May, June, and October which were the months with the highest ETo. The maximum weekly and monthly ETo were 31.29 and 138.57mm, respectively, both observed in May. The minimum weekly and monthly ETo were 19.88 and 88.04mm, respectively.

Table 2 and Figure 4, show the average daily and cumulative monthly potential evapotranspiration. The table was achieved considering the number of days in each month of the year. This gives an idea of the crop water requirement considering the climate characteristics of the area. Enugu City recorded 1266mm as the average cumulative daily ETo for the year. 1231.26mm was observed as the cumulative daily ETo of the year for Abeokuta City. Cumulative daily ETo of 1173.87mm, 1360.79mm, 1260.38mm, and 1332.35mm were recorded for Calabar, Dutse, Ilorin, and Yola, respectively. The highest cumulative ETo was observed in Duste City, Northwestern geo-political zone of Nigeria. Calarbar City recorded the highest cumulative daily ETo in January while Yola city had the highest cumulative daily ETo of 672.39mm in June. In July, Dutse City took over having the highest cumulative ETo of 800.95mm. The lowest cumulative daily ETo was observed in Calabar City. Abeokuta City recorded the highest daily cumulative ETo of 203.24mm in February and Dutse City had the lowest value of 164.13mm. Enugu City recorded the highest daily cumulative ETo of 562.65.24mm in May while Duste City experienced the least value of 520.50mm.

4.0 CONCLUSION

The inferences drawn from the data studied are as follows;

The variations observed in the estimated values of the potential evapotranspiration show that higher values of ETo were experienced in the northern part of Nigeria compared to what was recorded in the southern part of the country. This implies that the crop water consumptive use of crops will be higher in the northwest and the northeast compared to other parts of the country. The variations in the estimated ETo showed the north-central region of the country experience similar ETo values compared to the southern part of the country, implying that water requirements of crops cultivated in the southern part of the country could be used in the cultivation of the crop in the north-central part of the country. The months of February, March April, and May which can be regarded as the months experiencing dry season recorded very high ETo compared to other months of the year. This implies that the crop water requirements of different crops will be higher these months compared to other months of the year. In the southern part of the country, July and August experienced the lowest ETo values compared to other months of the year compared to January and December in the Northeastern and Northwestern parts of the country. Crop water requirement considering the climatic characteristics of the area was highest in the Northwestern geo-political zone of the country compared to the south-south geo-political zone which had the lowest crop water requirement.

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Table 1: Average daily, weekly, and monthly potential evapotranspiration (mm)
Legend; A-Average daily potential evapotranspiration (mm), B- Average weekly potential evapotranspiration (mm), C- Average monthly potential evapotranspiration (mm)

	ENUGU			ABEOKUTA			CALABAR			DUSTE			ILORIN			YOLA		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
January	3.12	21.84	96.72	3.16	22.12	97.96	3.20	22.4o	99.20	2.63	18.41	81.53	2.95	20.65	91.45	2.84	19.88	88.04
February	3.72	26.04	104.16	3.76	26.32	105.28	3.67	25.69	102.76	2.95	20.65	82.60	3.51	24.57	98.28	3.17	22.19	88.76
March	3.92	27.44	121.52	4.00	28.00	124.00	3.67	25.69	113.77	3.24	22.68	100.44	4.05	28.35	125.55	3.62	25.34	112.22
April	4.03	28.21	120.9	4.01	28.07	120.30	3.63	25.41	108.90	3.85	26.95	115.50	4.04	28.28	121.20	4.10	28.70	123.00
May	3.85	26.95	119.35	3.63	25.41	112.53	3.47	24.29	107.57	4.53	31.71	140.43	3.93	27.51	121.83	4.47	31.29	138.57
June	3.41	23.87	102.30	3.11	21.77	93.30	3.06	21.42	91.80	4.75	33.25	142.50	3.69	25.83	110.70	4.06	28.42	121.80
July	3.11	21.77	96.41	2.85	19.95	88.35	2.63	18.41	81.53	4.45	31.15	137.95	3.15	22.05	97.65	3.75	26.25	116.25
August	3.01	21.07	93.31	2.89	20.23	89.59	2.60	18.20	80.60	4.15	29.05	128.65	3.00	21.00	93.00	3.57	24.99	110.67
September	3.21	22.47	96.30	2.95	20.65	88.50	2.91	20.37	87.30	4.36	30.52	130.80	3.20	22.40	96.00	3.78	26.46	113.40
October	3.48	24.36	107.88	3.34	23.38	103.54	3.13	21.91	97.03	4.05	28.35	125.55	3.55	24.85	110.05	4.11	28.77	127.41
November	3.56	24.92	106.80	3.51	24.57	105.30	3.36	23.52	100.80	3.10	21.7	93.00	3.42	23.94	102.60	3.38	23.66	101.40
December	3.24	22.68	100.44	3.31	23.17	102.61	3.31	23.17	102.61	2.64	18.48	81.84	2.97	20.79	92.07	2.93	20.51	90.83
Average	3.47	24.30	105.51	3.38	23.63	102.61	3.22	22.54	97.82	3.73	26.08	113.40	3.46	24.19	105.03	3.65	25.54	111.03

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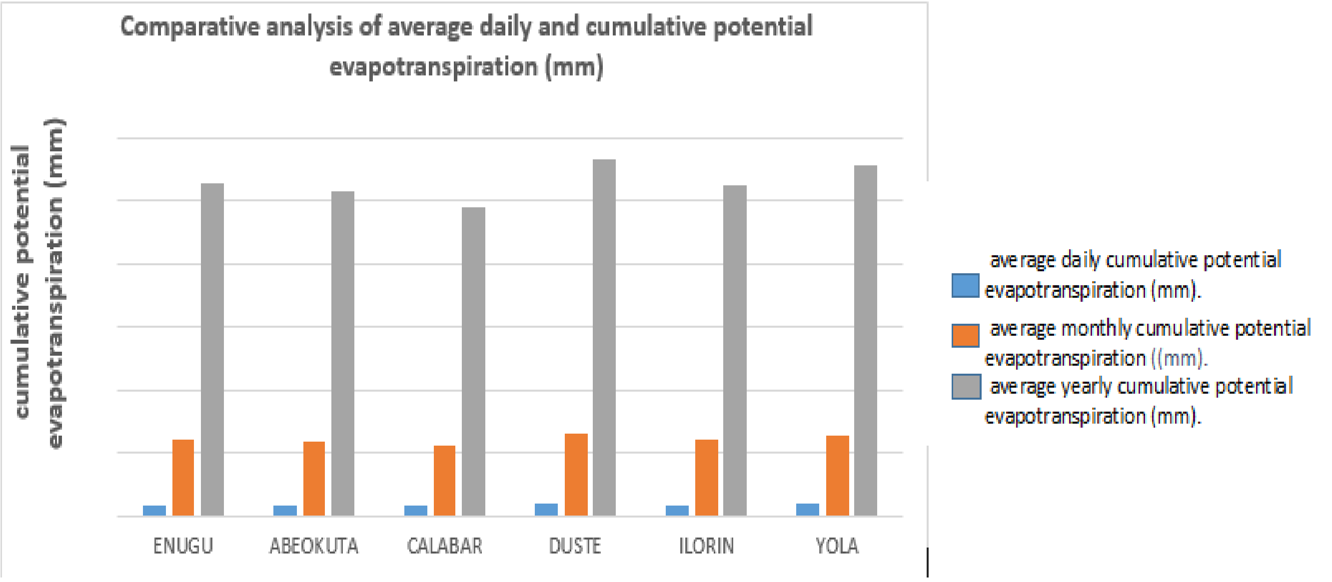

Figure 3. Comparative analysis of average daily, weekly, and monthly cumulative potential evapotranspiration (mm).

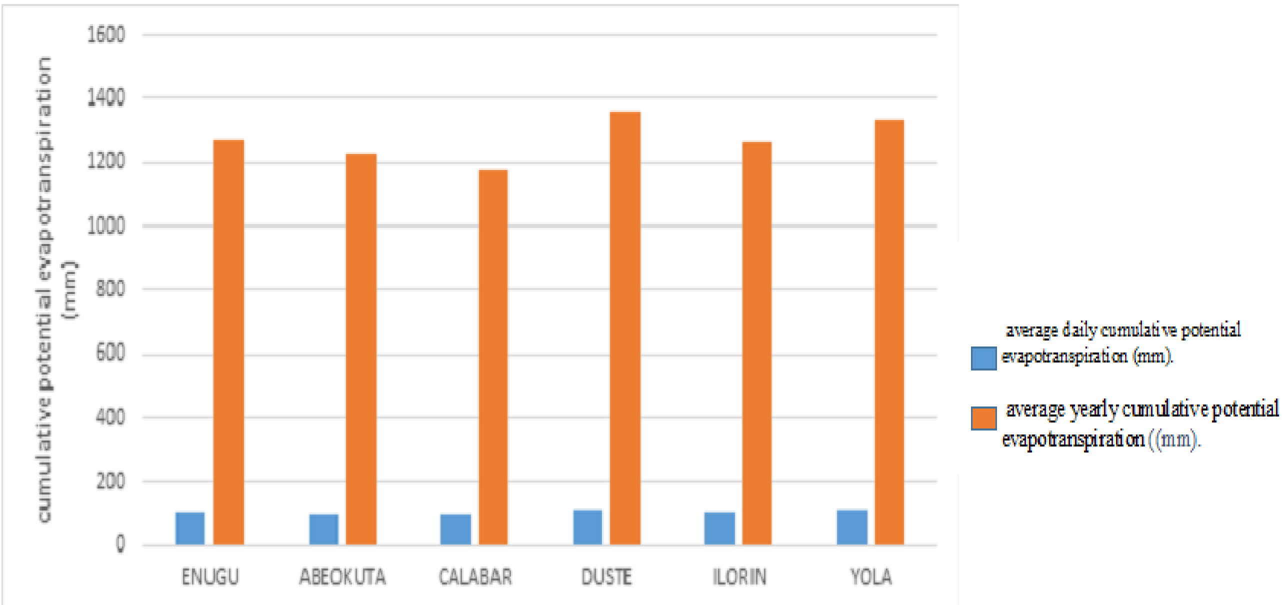

Figure 4. Average monthly and cumulative yearly potential evapotranspiration

Table 2: Comparative analysis of average daily and cumulative potential evapotranspiration (mm)

	ENUGU		ABEOKUTA		CALABAR		DUSTE		ILORIN		YOLA	
	A	B	A	B	A	B	A	B	A	B	A	B
January	3.12	96.72	3.16	97.96	3.20	99.20	2.63	81.53	2.95	91.45	2.84	88.04
February	3.72	200.88	3.76	203.24	3.67	201.96	2.95	164.13	3.51	189.73	3.17	176.80
March	3.92	322.40	4.00	327.24	3.67	315.73	3.24	264.57	4.05	315.28	3.62	289.02
April	4.03	443.30	4.01	447.54	3.63	424.63	3.85	380.07	4.04	436.48	4.10	412.02
May	3.85	562.65	3.63	560.07	3.47	532.20	4.53	520.50	3.93	558.31	4.47	550.59
June	3.41	664.95	3.11	653.37	3.06	624.00	4.75	663.00	3.69	669.01	4.06	672.39
July	3.11	761.36	2.85	741.72	2.63	705.53	4.45	800.95	3.15	766.66	3.75	788.64
August	3.01	854.67	2.89	831.31	2.60	786.13	4.15	929.60	3.00	859.66	3.57	899.31
September	3.21	950.97	2.95	919.81	2.91	873.43	4.36	1060.4	3.20	955.66	3.78	1012.71
October	3.48	1058.85	3.34	1023.35	3.13	970.46	4.05	1185.95	3.55	1065.71	4.11	1140.12
November	3.56	1165.65	3.51	1128.65	3.36	1071.26	3.10	1278.95	3.42	1168.31	3.38	1241.52
December	3.24	1266.09	3.31	1231.26	3.31	1173.87	2.64	1360.79	2.97	1260.38	2.93	1332.35

Legend; A-Average daily potential evapotranspiration (mm), B- Average monthly cumulative potential evapotranspiration (mm)

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