Relationship between Evapo-transpiration and water availability in the tropical regions: A case study of a south western city in Nigeria

Abstract

The understanding of the impacts of evapotranspiration on water supply in time and space is critical to a purposeful water management effort. A study was conducted to examine annual water balance situation in the humid tropical city of Ogbomoso, Oyo State, Nigeria. A thirty-year rainfall and temperature data (1977-2006) were collected from NIMET Office for this purpose. Annual evapotranspiration values were empirically determined using temperature data and Thornthwaite's model. The study revealed that the major determinant of water balance is the availability of water at the surface which is majorly supplied by green surface and rainfall. Evapotranspiration rate was found to be relatively constant and high above 1000mm annually ranging from 1249.7mm in 1980 to1112.87mm in 2004 while annual rainfall total varies over the study period of 30 years ranging from 697.1mm in 2002 to 1595.5mm in 1999. It was noted that effort should be directed towards reforestation and or aforestation, planting of shade trees and other related measures that will encourage water availability for the process of evapotranspiration for improvement on water balance in the study area.

Key words: Evapotranspiration; tropical region; water management; Ogbomoso; temperature; rainfall.

INTRODUCTION

The understanding of the impacts of evapotranspiration on water supply in time and space is critical to a result-oriented water management effort. The determination of what volume of water to supply for use, when and where to ration water supply and so on require the knowledge of what is available of water resource both spatially and temporally. Jackson (1989) noted that potential evaporation in the tropics is much more constant from year to year, [variation coefficient of only 5% (Norman et al, 1984)] than is rainfall because of the small variation in key factors such as solar radiation. Apart from this, Jackson (1989) highlighted the essence of studying evapotransipration-water supply relationships. These include: (i) to provide a general overview of the water condition in an area, (ii) to form part of a model for investigating rainfall-runoff relationships and stream flow prediction from climatic data, (iii) to assess the suitability of an area for a particular crop (iv) to assess irrigation requirement, (v) to assess water use by a particular vegetation or crop type and (vi) to assess human impact on the system. According to Ufuogbunem (2011), water balance involves the calculation of what volume of water is left after subtracting the volume of water lost *(l)* from the volume of water supplied *(s)* usually from rainfall.Thus,

$$P – ET – Q – I = 0$$-----------------------------------(eq. 1)where

ET is Evapotranspiration, I is Infiltration, P is precipitation, and Q is River discharge

The equation was applied by Ufuogbune et al., (2011) on the basis of the following assumptions on which basis its application is equally based in this study:

a. since the computations are made on annual basis, net change of soil moisture and groundwater storage is assumed to be zero;
b. subsurface water exchange with neighbouring basins is assumed to be zero;
c. assuming no artificial diversion from elsewhere and that there is no water loss via runoff; and
d. that the total rainfall in the study area is available for man's access.

Thus,$P - ET_t, = 0$ ---(eq. 2)

Where the volume of *l* exceeds *s*, the water situation results in deficit supply while where *s* is greater than *l,* water balance becomes surplus. Thus, it is imperative that water management effort is geared towards ensuring that surplus water balance is realized to enable adequate water supply for a particular need such as agricultural, domestic or industrial needs in space and time. The major source of water is rainfall which forms the major source of replenishment to both surface and sub-surface sources. The rainwater is constantly lost through evapotranspiration, surface runoff, percolation and infiltration while rainfall is seasonal in the tropics. Another variant in water resource management is that water is constantly required for different purposes such as domestic, agriculture, industrial among others. Thus, it has become significant for water managers to work towards ensuring that surplus water balance (if possible), the situation which can only guarantee prompt and regular supply of this resource for any given use.

Evapotranspiration in the tropical regions is constantly high, the observation is attributed to the characterized high incidence of temperature. (Ufuogbunem, 2011; Ogunbode, 2015). Ayoade (1988) and Jackson (1989) further enumerated factors which influence evapotranspiration. These factors were categorized into two by Ayoade (1988), namely, climatological and non-climatological factors. It was stressed that non-climatological factors are only important in respect of actual evapotranspiration and include factors relating to the characteristics of the surface such as whether the surface is water or soil, and if soil whether vegetated or not, the type of soil and land management, the moisture condition of the soil profile, and the degree of plant cover and type. These will determine the availability of moisture at the evaporating surface and the ease with which the moisture is released into the atmosphere as well as the albedo of the surface. Potential evapotranspiration is independent of all surface control except for differences in albedo (radiation reflection due to colour) and is determined solely by climatic factors. Three major climatic factors influence the rate of evapotranspiration whether actual or potential. These are (i) the amount of energy available, atmospheric humidity and wind speed. About 590 calories of energy is required to vaporize a gram of water. The amount of energy available is indicated by air temperature in the absence of radiation data.

Humid regions, according to Brutsaert (1982), is seen from the perspective of "if a wet period is defined as any period when rainfall exceeds potential evapotranspiration (PET), the climate in the humid tropics can usually be characterized by the existence of a wet and dry season". In the wet season, water supply is plentiful, so that ET is approximately PET. In furtherance, PET is understood to refer to the maximum rate of ET, under the given weather conditions, from a large area covered completely and uniformly by an actively growing vegetation with adequate moisture supply at all times. Bruin (1983) found that for rainfall in the four driest months, AET depends to a great extent on the duration of that dry season. According to Stephenson (1990), a better understanding of the mechanisms controlling the distribution of vegetation might arise from considering water balance dynamics over a shorter period than the 30-year average discussed in that study. Similarly, it should prove useful to consider the seasonal magnitudes of water balance parameters rather than just their annual means. The water balance is useful in explaining patterns in vegetation not only on a continental scale but also on local scales affected by variations in soils and topography (Stephenson, 1988).

The de-facto standard method for estimating potential evapotranspiration, the Penman-Monteith equation, is relatively high data demanding and sensitive to data whose measurements are often error-prone. Therefore, due to the dearth of adequate data in the study area for the application of Penman-Monteith equation, especially in the developing world, the empirical model developed by Thornthwaite was adopted following Papadopoulou, et al., (2003) to generate Annual Potential Evapotranspiration (PE) data for the three locations. The Thornthwaite's method calculates potential evapotranspiration using observed air temperature and duration of sunlight data. The rationale, according to Papadopoulou, et al., (2003) is that air temperature, to a considerable extent, serves as a parameter of the net radiation. According to Huang, et al., (1996) this model is a shortcut of replacing a comprehensive atmospheric model, as well as some interactions by prescribing observed temperature and precipitation.

Kumagai et al. (2005) noted that tropical rainforests are among the most important biomes because of their vast amounts of primary productivity, and water and energy exchange with the atmosphere. Although, these forests now cover only 12% of the global total land surface (FAO, 1993), they contain about 40% of the carbon in the terrestrial biosphere (Skole and Tucker, 1993) and are responsible for 50% of terrestrial gross primary productivity (Grace et al., 2001). Also, according to Choudhury et al. (1998), tropical rainforests are also a major source of global land surface evapotranspiration and have profound influences on global and regional climates and hydrological cycling (e.g. Lean and Warrilow, 1989; Nobre et al., 1991). These large latent energy fluxes from tropical rainforests are known to influence global atmospheric circulation patterns (Paegle, 1987). In the observation of Bruijnzeel (1996) climate change in the humid tropics, might drastically alter hydrological regimes, because of altered rainfall patterns and land cover transformation mainly as a result of forest conversion. Such alterations may consequently accelerate further global climate change (Kumagai et al., 2005).

Evapotranspiration process, being an important medium through which water is lost into the atmosphere, especially in the humid regions, this study has been conducted to examine the magnitude of its influence on water balance. The study further revealed some measures which could be taken to improve on water balance for better access to water in the tropics.

Evapotranspiration studies by Bruijnzeel (1990), in humid tropical forests suggest that (i) the average annual transpiration was 1045 mm (range between 885-1285 mm), (ii) the average interception was 13% of the incident precipitation (range 4.5-22%), and (iii) the annual evapotranspiration ranged from 1310 to 1500 mm.

Methodology

Study Area

Ogbomoso is located within the tropical region (longitude $4^o11'$E and latitude $8^o01'$N) with distinctive wet (April –October) and dry seasons (November-March). According to (Adeboyejo and Abolade, 2009) Ogbomoso is a pre-colonial urban center and the second largest city, both in terms of population and spatial extent, in Oyo State Nigeria (Fig. 1). Ogbomoso, formerly the seat of Ogbomoso Local Government Area, is currently made up of five LGAs namely Ogbomoso North, Ogbomoso South, Orire, OgoOluwa and Surulere LGAs with their headquarters in Kinira-Ogbomoso, Arowomole, Ikoyi, Ajaawa and Iresaadu respectively. The city is located approximately 100 km north of Ibadan, the Oyo State capital, and roughly 80 km from both Kwara and Osun State capitals, Ilorin and Osogbo, respectively (Adeboyejo and Abolade, 2009). It is one of the main gateways to the northern regions of Nigeria from the Yoruba land, and is bounded by the river Ora to the east; there are no major physical barriers to the north, west and south. Ogbomoso develops laterally towards the north and south along the Ibadan-Ilorin road. The city is surrounded by a number of villages and medium sized towns such as Ikoyi, Odo-Oba and IressaApa, which all have organic connections with it, but at distances considered far enough to be beyond the influence of the expansion of Ogbomoso. The city of Ogbomoso is one of the many Yoruba settlements situated to the south-west of Nigeria, where urbanism as a way of life predates the European colonization of the country. Like the origin and development of most Yoruba settlements in the early 18th century, the city emerged from the activities of five different waves of migrants, who settled in different areas of the present city. It was the last wave of migrants, led by Soun Ogunlola, who as a result of their warring prowess, subjugated and pacified the separately developing villages and hamlets in the surrounding areas to form a large settlement known today as Ogbomoso. The initial impetus behind the growth of the city was provided by a substantial influx of refugees from the internecine wars in Yoruba land in the early 19th century, and of refugees fleeing the Fulani Jihadists who overran most of the northern towns, including Ilorin, situated approximately 80 km from Ogbomoso.

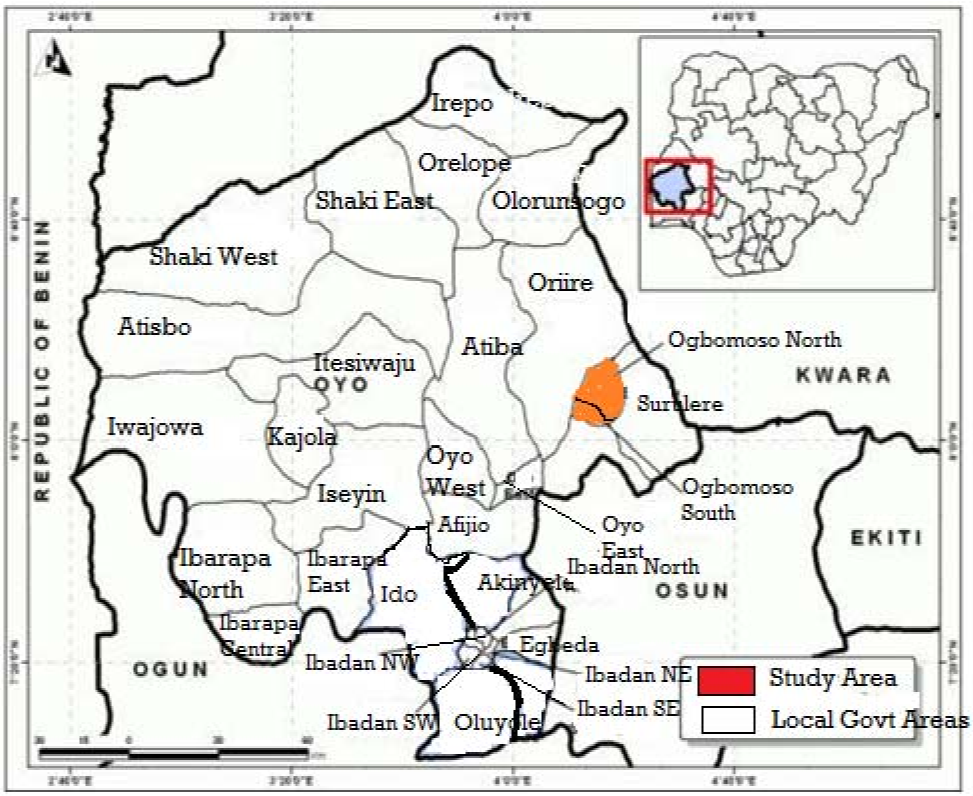


Fig. 1: Oyo State Map showing the study area
(Inset: Map of Nigeria showing the location of Oyo State)

Ogbomoso, in the last few decades has witnessed a tremendous expansion, the process which has led to the removal of natural vegetation for other infrastructural development like roads, schools, residential buildings among others. Thus urbanisation process has inflicted much on the environment that urban heat has increased abruptly. Even though, Ogbomoso is found in the tropics where the temperature is perpetually high all the year round, the urban heat island could have aggravated the rate at which water is vapourised.

Data Collection and Analysis

A 30-year rainfall and temperature data (from 1977-2006) collected from the Office of Nigeria Meteorological Agency in Ilorin. Rainfall data that was collected formed the main water input in the study area while temperature data was used to generate water loss via evapotranspiration empirically over the period on annual basis. Monthly rainfall totals were summed up to give annual rainfall total for each of the years studied. Evapotranspiration data for the study area was generated empirically using the empirical model as developed by Thornthwaite (1943) and also adopted by Papadopoulou, et al. (2003). Thus:

$E= 16* (10T/I)^a * \mu N/360$……………………………………..(eq. 1)

where E is monthly potential Evapotransipration (mm/month), T is mean monthly temperature (^{0}C), I is an Empirical Annual Heat Index, the sum of 12 monthly index values i

$I_j= 0.09* (Tj)^{1.5}$…………………………………………..(eq. 2)

where, j is the specific (month)

N = the mean number of daylight hours in a month

μ = the number of days in the month

a = an empirically derived exponent which is function of I, and is given by the formula:

$a= 0.016*(I+0.5)$………………………………………….(eq. 3)

Mean number of daylight hours in a month is taken to be 12 hours being a tropical region based on the adoption of Jalanpalmer's (2010) hours of daylight versus latitude versus day of the year.

Water balance equation was derived after Ufogbune et al., (2011) in a study of water balance of Oyan Lake. The equation is expressed as in eq. 4:

$P – ET – Q –I = 0$ where--(eq. 4)

ET is Evapotranspiration, I is Infiltration, P is Presipitation, and Q is River discharge.

The equation was applied by Ufuogbune et al., (2011) on the basis of the following assumptions on which basis its application is equally based in this study:

a. since the computations are made on annual basis, net change of soil moisture and groundwater storage is assumed to be zero;

b. subsurface water exchange with neighbouring basins is assumed to be zero;

c. assuming no artificial diversion from elsewhere and that there is no water loss via runoff; and

d. that the total rainfall in the study area is available for man's access.

Thus,

$P - ET_t, = 0$ ---(eq. 5)

Results and Discussion

I. Pattern of annual rainfall in Ogbomoso

The results in Table 1 and depicted in Figure 1 showed that annual rainfall in area varies from year to year and also ranges from 697.1mm in 2002 to 1595.5mm in 1999. Also, the results revealed that seven years (about 23.33 percent) of the period of study have annual rainfall less than 1000mm. These include 1989 (898.9mm), 1990 (794mm), 1993 (931.6mm), 1997 (945.3mm), 2001 (990.3mm), 2002 (697.1mm) and 2003 (903.3mm). These observations corroborated the findings of Mandeep, Nalinggam & Ismai (2011) which reported that annual rainfall in the tropical areas including Nigeria are exceeding 1000mm. This enormous rainfall which often spans through about eight months (April to October) also encourages luxurious vegetation implies availability of water for potential evapotranspiration in the area both from soil surface and vegetation surfaces.

Table 1: Annual Rainfall Total, Temperature, Potential Evapotranspiration and the Annual Water Balance in Ogbomoso, Oyo State (1970-2006).

S/N	Year	Annual Total Rainfall(mm)	Mean annual Temperature	PET (mm)	Water Balance (mm)
1.	1977	928.9	32.9	1172.72	-243.82
2.	1978	1209.4	32.2	1165.12	44.28
3.	1979	1193.1	31.9	1156.26	36.84
4.	1980	1237.1	31.7	1249.73	-12.63
5.	1981	1286.9	32.0	1159.86	127.04
6.	1982	1215.1	31.4	1158.63	56.47
7.	1983	1157.2	32.2	1147.89	9.31
8.	1984	1310.5	32.4	1163.52	146.98
9.	1985	1133.3	32.5	1165.54	-32.24
10.	1986	1328.4	31.9	1169.54	158.86
11.	1987	1213.7	33.1	1168.37	45.33
12.	1988	898.9	32.2	1156.10	-257.2
13.	1989	794	32.2	1177.80	-383.8
14.	1990	1020.1	32.4	1162.80	-142.7
15.	1991	1468.4	31.8	1161.77	306.63
16.	1992	931.6	32.0	1167.42	-235.82
17.	1993	1157.9	31.7	1154.48	3.42
18.	1994	1242.0	31.9	1158.35	83.65
19.	1995	1409.2	32.1	1152.45	256.75
20.	1996	945.3	32.4	1158.90	-213.6
21.	1997	1334.4	31.9	1159.20	175.2
22.	1998	1595.5	32.4	1164.47	431.03
23.	1999	1539.3	31.9	1169.54	369.76
24.	2000	990.3	32.7	1165.50	-17.52
25.	2001	697.1	33.2	1158.94	-461.84
26.	2002	902.3	32.7	1170.10	-267.8
27.	2003	1033.5	32.4	1176.61	-143.11
28.	2004	1294.0	32.3	1112.87	181.13
29.	2005	1305.9	32.4	1163.08	142.82
30.	2006	1303.8	32.2	1161.66	142.14

(Source: Author's fieldwork, 2012)

II. Evapotranspiration in the Study area

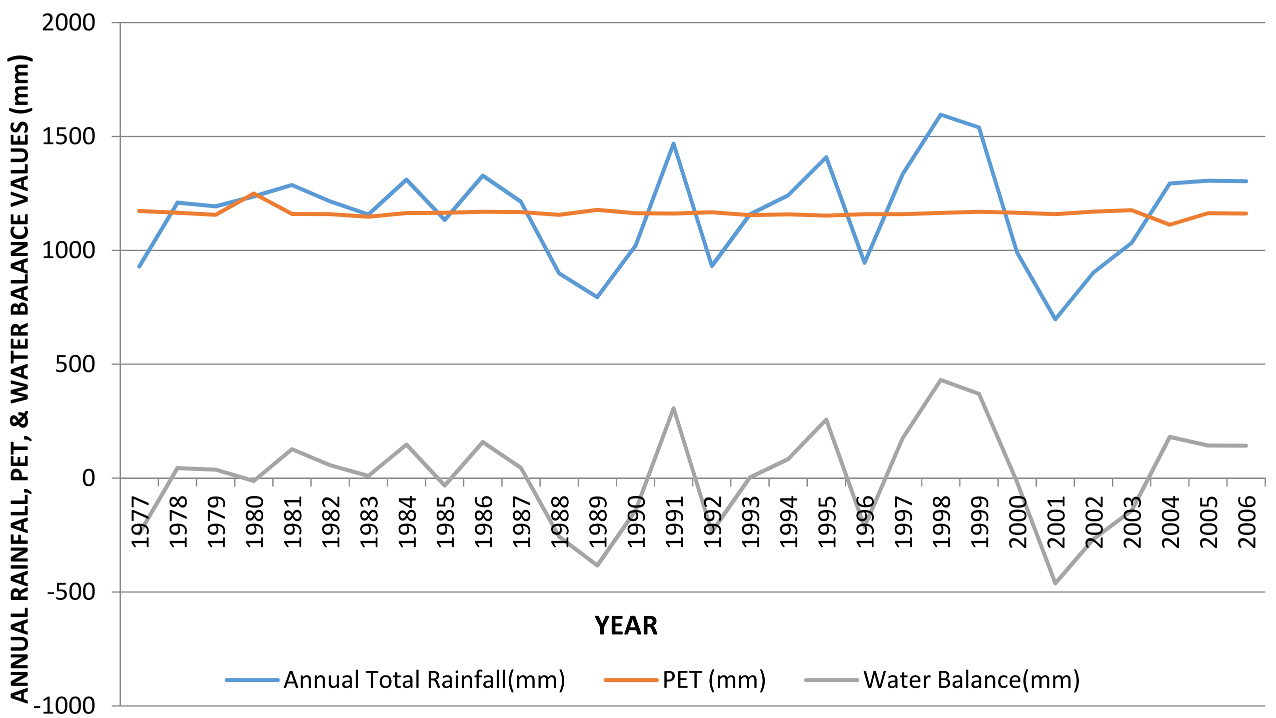
The results as shown in Table 1 revealed that evapotranspiration is high throughout the year ranging from 1249.7mm in 1980 to 1112.87mm in 2004. One of the determinants of evapotranspiration status is the availability of energy which is generated by temperature.

Tropical regions are endowed with high temperature as the sun is always overhead at the region. Table 1 shows that the temperature over the period being investigated ranges between 31.4°C in 1982 and 33.2°C in 2001. Thus there is always energy for evaporation and transpiration processes throughout the year as long as water is made available on the surface. Rainforests, like all forms of vegetation, affect the surface albedo or reflectivity of a surface by absorbing more heat than bare soil. In turn, this warmth carries moisture from forest trees into atmosphere where it condenses as rain (Butler (2012).

III. Relationship between rainfall, evapotranspiration and water balance

Table 1 which is depicted in Figure 2 showed the values of annual rainfall, potential evapotranspiration and water balance in the study area over the period of 30 years. The figure revealed that while rainfall totals vary from year to year, the values of potential evapotranspiration remain almost constant throughout the year. This scenario, however has affected the water balance over the studied period to the extent that there were years of negative water balance record. For instance, the respective water balance for 1977, 1980, 1985,1988, 1989, 1991, 1993, 1997, 2002, 2003 and 2004 were respectively -243.82mm, -12.63mm, -32.24mm, 383.8mm, -42.7mm, -235.82mm, -213.6mm, -17.52mm, -461.84mm, -267.8mm and -143.11mm. This forms 36.7 percent of the entire period of study. A critical look at this finding sends a signal to water resources manager in this location to work hard in order to avert acute shortage of water for human use. The persistent high potential evapotranspiration ranging between 1249.73mm and 1112.87mm recorded in the study area only affirms the established findings in the humid tropical regions (Ojo, 1990). Thus, it could be established that the main determinant of water availability in the study area is dependent on how much of rainfall is recorded at any point in time. For instance, in 1989, 898.9mm of rainfall was recorded while evapotranspiration in the same year was 1156.1mm which resulted in water balance deficit of -383.8mm. Similarly, in 2001, annual rainfall was 697.1mm while 1158.94mm of evapotranspiration was recorded, giving rise to an enormous deficit water balance of -461.84mm. On the contrary, some years had water surplus over the period of study. These include 1981 (127.04mm), 1984 (146.98mm), 1986 (158.86mm), 1998 (431.03mm) among others. These years of water surplus recorded enormous rainfall which enhanced the excess rainfall recorded over evapotranspiration values in the period. The implication of these findings is that years of water balance deficit were supplemented with the antecedent rainfall to ensure water availability. Thus, water availability in the deficit years have dependent on the reserved water over the years of water surplus which, however, needs to be improved on to enhance water balance. This is to ensure prompt water supply for human utilization in the study area.

Fig. 2: **Relationship between annual rainfall, Potential evapotranspiration and water balance in Ogbomoso (1977-2006)**



IV. Resuscitating Green Vegetation: A Strategy for improving water balance situation in the study area

The characterized persistent high temperature in the tropics which influences high evapotranspiration in the study area has engendered the need to mitigate the former so as to improve on annual water balance in the study area. One important strategy of improving water balance in a given area is through aforestation and/or reforestation. According to Bruijnzeel (2004), deforestation disrupts the global water cycle because the removal of forest leads to reduction in water-holding capacity of the soil in an area which, however is crucial in the determination of water balance (also in Stephenson, 1990). According to Anon (1994) and Brijnzeel, et al. (2005), water resources often affected by forest removal include drinking water, fisheries and aquatic habitats among others.

Chomitz et al (2007) also affirmed that urban water protection is potentially one of the most important services that forest provides. Even though the evapotranspiration rate is high throughout the year, any avenue to reduce water contents could aggravate the evapotranspiration leading to dryness or water supply deficit situation. Thus, tree planting should be encouraged to increase water availability in the study area. Sheil and Murdiyarso (2013) and Kumaga et al (2013) noted in their studies that forest vegetation influences rainfall in their different areas of study. Sheil and Murdiyarso (2013) reported that under the new hypothesis, high rainfall occurs in continental interiors such as the Amazon and Congo River basins only because of near-continuous forest cover from interior to coast. In addition, Jauregui (1990), Taha (1997) Kumagai et al. (2005), Peel et al., (2010) and Nuruzzaman (2015) all noted the relevance of green vegetation, shade trees and existence of water bodies among others in mitigating urban heat island which Taha (1997) noted could reverse and offset their impacts on energy use. Taha further stated that increase in vegetation in urban areas can result in some 2^{o}C decrease in air temperature and even, under some circumstances like soil-vegetation systems and favourable meteorological conditions, the localized decrease in air temperature can reach 4^{o}C. From the ongoing, if there will be any remarkable improvement on the water balance in the study area, effort will be made to embark on reforestation and or aforestation. In the past three decades, Ogbomoso has witnessed expansion round its circumference which, invariably has imparted on the natural forest endowed. Most of the vegetation in different locations of the city have been cleared for this development purposes while buildings were erected without the provision of shade trees.

V. Conclusion

The characterized high evapotranspiration discovered in the study area in view of its tropical climate endowment is noted to be partly due to its high temperature. It is also observed that annual rainfall is high, generally above 1000mm. This is not without its peculiarity as it fluctuates from year to year. It is therefore found that water balance status in the area is mostly dependent on rainfall amount as annual evapotranspiration is generally high and almost constant throughout the year. Thus, if there will be any result-oriented effort towards improving on water balance, effort should be geared towards mitigating high evapotranspiration in the area. Such effort which is more of checkmating urban heat island (UHI) include reforestation and/or forestation, provision of shade trees and also existence of water bodies in the area. All these measures can minimize albedo in the urban centre and invariably influence the rate of evapotranspiration.

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