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Application of Thornthwaite's model of annual water balance for stream flow estimation in Ikpa River, Uyo – Akwa Ibom State, Nigeria

E. C. Ukpong[1]

ABSTRACT

The study was conducted in order to estimate the amount of groundwater contribution to streamflow in Ikpa River. The estimation was carried out using Thornthwaite's scheme for determining annual water balance and the input data comprised the precipitation and evaporation records for 10 years, from 2000 to 2009 meteorological centre, Uyo. The average baseflow estimated for Ikpa River for the period was $3.3x10m^3$ while the average ground water discharge represented approximately 37% of the total annual streamflow.

INTRODUCTION

Baseflow is described as a long term discharge into natural storages and is a significant component of streamflow, which also includes direct run-off, and storm run-off that results from rainfall excess. Baseflow is the water discharged from ground water aquifers, which accounts for up to 40% of the average annual streamflow (Ayoade, 1976). It plays an important part in sustaining flow between rainfall events. Thus, the determination of groundwater discharge into the stream is crucial for proper and efficient water management as well as water resources development at the watershed scale (Hewlet and Nuter, 1970). This research study is intended to estimate the amount of groundwater contribution to the streamflow at Ikpa River, which will be useful in the aspect of managing groundwater withdrawals, depletion and pollution as well as water budget implementation. It will be accomplished by determining the major component of stream flow, the natural groundwater which is the rainfall that infiltrates the soil and penetrates to the underlying strata.

The quantity of water that can be accommodated under the surface depends on the porosity of the sub-surface strata. For the porous rock its capacity to hold water and act as aquifers implies that it is constantly recharged such that the regional natural groundwater resources are also considered as the natural productivity of regional aquifer (White and Sloto, 1990), that will be replenished within the process of a successive hydrological cycle. The sustainable yield or safe yield of natural groundwater resources for a region indicates the maximum limit of regional groundwater exploitation for a long term period of time without diminishing the features and functions of the groundwater flow regime. The expression for the sustainable yield of groundwater is as followed:

$$Qs = Qn + \frac{W}{\Delta t} - \Delta Q \qquad (1)$$

where Qs represents the sustainable yield of groundwater,

Qn is the regional natural groundwater resources (groundwater recharge)

W is gives the aquifer groundwater storage

Δt indicates the time of groundwater withdrawal and ΔQ is the additional groundwater resource

For a long period, if $\Delta t \to \infty$ (i.e. if Δt tends to infinity), with ΔQ absent, then the sustainable yield of groundwater regime is determined only by the regional natural groundwater resource (Qn).

In this study, the regional natural groundwater resources are quantified based on the hydrogeological conditions of the region and the interactive relationship between surface water and groundwater within the hydrological cycle (Wolman and Riggs, 1990; Barnard, 1932). In all cases baseflow is a reasonable approximation of groundwater discharge to the streamflow(Hwang, 1994).

[1] Department of Civil Engineering Faculty of Engineering University of Uyo, Uyo Akwa Ibom State, Nigeria ; cletoec@yahoo.com

A study such as this, which attempts to estimate the amount of groundwater contribution to the streamflow, requires information on rainfall data (precipitation), potential evaporation, and soil moisture holding capacity (Wolman and Riggs, 1990). The use of Thornthwaite’s climatic water balance model in analyzing the groundwater and its contribution to streamflow in the study area (Ikpa river) is to obtain reasonable estimates of other streamflow components required in Uyo and of the actual amount of water that infiltrates into the ground which is the amount that contributes to the streamflow (Kirk and Charles, 1990; Metarland and Morgan,1996). Therefore, information derived from precipitation and potential evaporation help in estimating the water surplus, water deficits and surface run-off each year from which baseflow is determined

The study area

Ikpa River is situated 2km from Uyo, the capital city of Akwa Ibom State (Fig.1) in southeastern Nigeria. It is one of the major tributaries of Ntak Inyang River and is flowing continuously throughout the year because of the high baseflow contribution. The entire basin is underlain by one main geological formation, the Coastal Plain Sands comprising largely of poorly consolidated sands and sandstones, as exposed especially in the upper course of the basin between Osuk and Afaha Ise. The sands, which make up by far the greater part of the deposit, possess several characteristics which are especially in deep gully channels. The coarse sand fractions contain rounded grits and pebbles around Ikot Edung. In the more northerly parts of the study area, the beds are stained deep brown to reddish brown by iron oxides. However sands are more abundant.

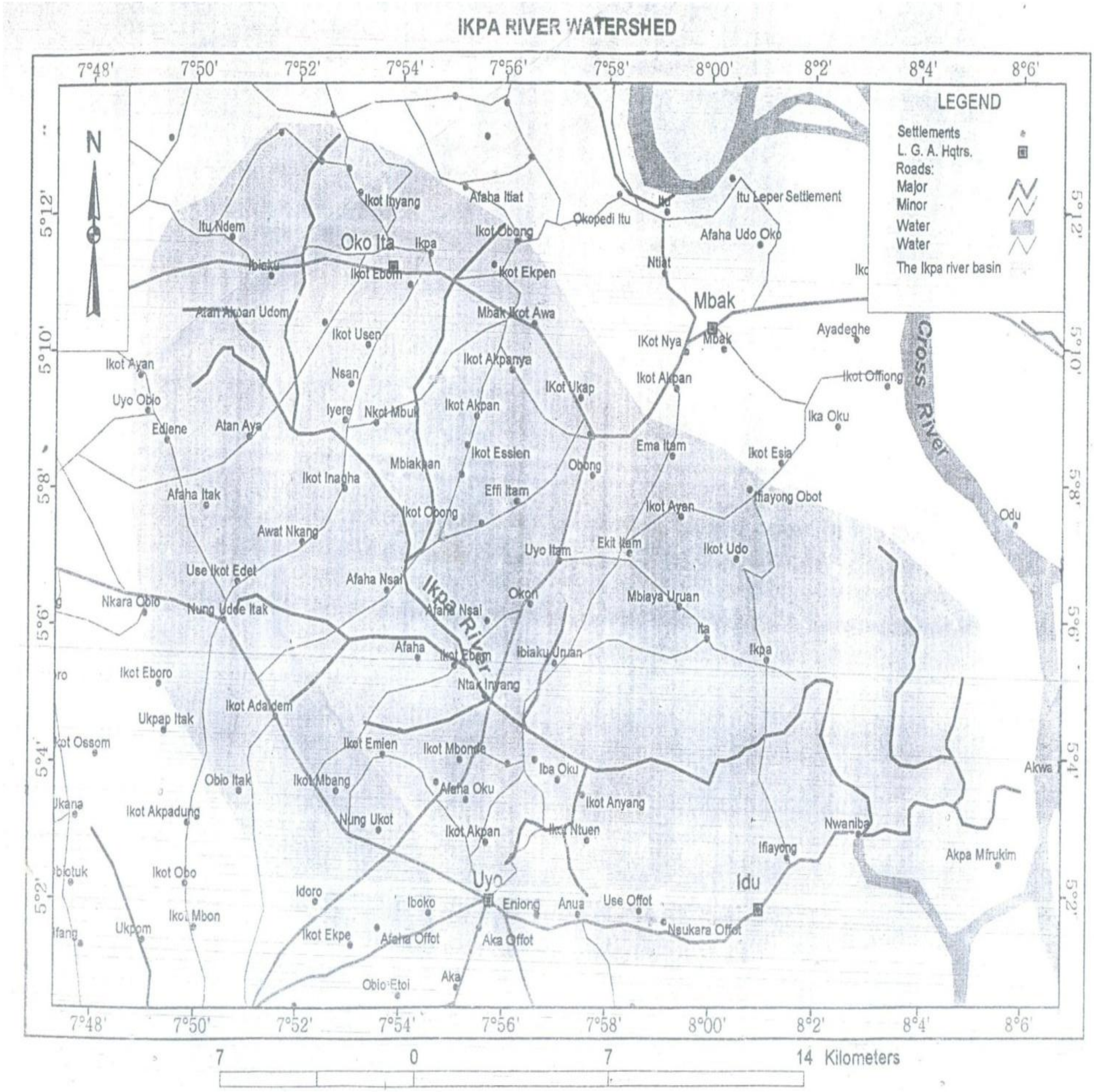

Fig. 1**.** Map showing Ikpa River watershed

MATERIAL AND METHODS

Data required/collection

The data required for this research study included, rainfall and evaporation record and map of the study area. These were obtained from the Department of Geography, University of Uyo and from the Department of Meteorological Services which is an agency of the Federal Government of Nigeria.

Method of data analysis

Thornthwaite's climatic water balance was used in analyzing the groundwater and its contribution to streamflow in the study area. The method requires data on precipitation, potential evaporation and soil moisture holding capacity for estimating the amount of water that infiltrates into the ground which is the amount that contributes to the stream flow.

Analysis of data

Table 1 illustrates the water balance computation procedure for Uyo, using the Thornthwaite's model. In line one (1) are recorded values of mean monthly potential evaporation(PE) collected from the Meteorological Centre. Mean monthly precipitation (P) values were collected from the same station and are recorded in line two (2) while the difference (P-PE) are recorded in line three (3). If (P-PE) is negative, it indicates the amount by which precipitation fails to satisfy the water needs of vegetation, while a positive value indicates the potential amount of excess water available for soil and groundwater recharge or streamflow. The sum of the monthly values of positive (P-PE) gives the amount of annual potential water surplus.

Similarly the annual potential water deficit is the sum of the monthly values of negative (P-PE). The water deficiency at the end of the wet season will be zero and this value is used to start accumulation of the negative values of (P-PE) during the following dry season. Otherwise, it is imperative to use the successive approximation method to obtain the value with which to start accumulating the negative value of (P-PE) in line four (4). For a given amount of accumulated potential water deficit, there is a storage amount depending on the water holding capacity of the soil which was assumed to be 250mm. This was read from the appropriate tables.

The positive (P-PE) values represent additions to the moisture already in the soil. When the soil is fully saturated with moisture, subsequent positive (P-PE) values are recorded as water surplus available for run-off or groundwater recharge. To estimate actual evapo-transpiration (AE) itself, we need to know the change in soil moisture storage from one month to another. This is calculated from an equation of the form $\Delta STN = STN - STN\text{-}1$, where ΔSTN = change in storage for month N, STN = moisture storage for month N and STN-1 = moisture storage in the preceding month. AE is estimated as follows: when the precipitation is greater or equal to the potential evapotranspiration, the soil remains fully charged with water and

AE = PE. However, when the precipitation is less than PE, the soil begins to dry out so that AE < PE. In such situations, the actual evapotranspiration (AE) is equal to the precipitation (P) plus the water withdrawn from the soil i.e. $AE = P + \Delta ST$.

The water surplus (S) is derived as S = (P- PE) when the soil is at filled capacity. Water deficit (D) is just the difference between PE and AE. In computing the monthly run-off in line (10), it is assumed, following Thornthwaite and Matter (1957) that only about 50% of the surplus water available for run-off in a given month actually run-off. The other 50% is detained in the catchment and made available for run-off during the following month.

RESULT AND DISCUSSION

The values of precipitation, potential evapotranspiration and actual evapotranspiration are included in Tables 1 – 10 and in the graphs of Figs. 2-11. The Tables and figures also contain information on annual statistics of computed water deficit, surplus water and runoff. Comparison between total annual precipitation, potential evaporation, water deficit and surplus water (2000 – 2009) is shown in Table 11 while baseflow estimates are presented in Table 12 with an average of about 3.3 x $10^9 m^3$. The water balance in 2000-2009 shows that between November and March, the monthly value of potential evaporation is greater than precipitation (Tables 1-10), which indicates a period of water deficit. Initially, plants make use of the excess soil moisture from the previous rainy season – soil moisture utilization.

Groundwater recharge begins from March/April to May. This marks the beginning of the planting season, while the months of May/June to October depict the period of water surplus. Baseflow was computed by assuming half of the surplus water to be run-off while the remaining half represents the amount of water that found its way through the soil to the stream (Udosen2008,2006 and 2000).
Thus the important variables to compare are actual evapotranspiration (AE), the water surplus (S) and the water deficit (D).

Values of water surplus (S) increase at the expense of values of actual evapotranspiration. The values of water deficit are correspondingly decreased since water deficit (D) is the difference between PE and AE. This has implications for climatic classification based on a moisture index.

Although the rainy season lasted for about 8 to 9 months, more than 80% of the total annual rainfall recorded at Uyo fell in 6 months, that is from May to October, and about 60 percent of the annual total rainfall appears on the surface as run-off. The highest meanly monthly rainfall of 552.0mm was recorded in July 2005 which coincided with the highest number of rain days (19). On the other hand, rain days were fewer in the months of December to February. Consequently, the antecedent soil moisture condition (API) was correspondingly low. The number of rain days per month during the wet season, ranged from 13 to 19 rain days/months between May and October. Similarly, the value of API ranges from 190.90 to over 300 in months of May to October. In 2002, 2003, 2007 and 2009 the surplus water dropped in June as depicted in the graphs (see Figs. 4, 5, 9 and 11).

Another striking feature in the water balance is that in 2007, the value of the water deficit or water depletion was enormous as depicted in Figure (7). The water deficit in the month was as high as 160mm. This means that the surface of the soil may dry (with minor desiccation cracks).

Another notable feature of water balance in 2000 and 2005 was the remarkable fluctuation in the water surplus level as shown in Figs.3 and 7. The computed water balance in 2000, 2002 and 2008 indicates that there was no August break during this period. In 2008 for instance, the highest monthly precipitation was recorded in August and was about 485.1mm. On the other hand, the monthly precipitation in August of most of the other years was quite low.

In conclution, there is a close link between groundwater contribution to streamflow and rainfall in the Ikpa River watershed. The estimated baseflow contribution (mean monthly) to streamflow for the years 2000 to 2009 ranged between 32 and 44% with an average of 37%. Thesebare how ever useful for basin scale comparison being largely dependent on the assumed value of soil moisture holding capacity.

Table 1. Estimated annual water balance for Ikpa River basin at Uyo (2000) for soil moisture holding capacity of 250mm

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	92.9	150.6	120.2	73.5	56.3	40.6	38.8	32.8	31.7	44.6	48.6	86.8	817.4
P	9.5	1.2	118.2	101.7	326.9	302.1	330.5	313.2	276.3	189.4	132.1	38.7	21440.4
P-PE	-83.4	-149.4	-2	28.2	270.6	261.5	291.7	280.4	244.6	144.8	-	-47.1	-
APWD	130.5	-279.9	-281.9	-	-	-	-	-	-	-	-	-47.1	-
ST	160.2	90.1	88.3	47.0	250	250	250	250	250	250	250	203.4	-
ΔSTN	-43	-70.1	-1.8	-41.3	203	0	0	0	0	0	0	0	-46.6
AE	52.5	41.3	120	73.5	56.3	40.6	38.8	38.8	32.8	31.7	44.6	48.6	86.3
D	40.4	79.3	0.2	0	0	0	0	0	0	0	0	0.5	120.4
S	0	0	0	0	67	216.5	291.7	280.4	244.6	144.8	83.5	0	1373.5
R	41.4	20.7	10.3	5.2	33.5	147.5	219.6	250	247.3	196.1	165.5	82.7	1373.5

PE = potential evaporation; P = precipitation; APWD = accumulated potential water deficit; ST = moisture storage; ΔST = water withdrawn from the soil; AE = actual evapo- transpiration ; D = water deficit (PE- AE); S = water surplus; R = run-off

Table 2. Estimated annual water balance for Ikpa River basin at Uyo (2001)for soil moisture holding capacity of 250mm . See Table 1 for details of parameters

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	103.4	134.1	74.0	65.1	58.5	43.4	38.9	31.0	34.4	41.8	51.6	78.3	1280.6
P	0	5.2	201.0	234.4	329.6	556.3	203.4	96.1	248.3	248.6	94.6	3.7	2207.0
P-PE	-103.4	-128.9	127	169.3	271.1	512.9	164.5	65.1	214.3	192.8	43	-746	-
APWD	-178.1	-306.9	-	-	-	-	-	-	-	-	-	-74.6	-
ST	80.1	50.2	74.4	250	250	250	250	250	250	250	250	193.5	-
ΔSTN	-113.4	-29.9	24.2	175.6	0	0	0	0	0	0	0	-56.5	-
AE	113.4	35.1	74.0	65.1	58.5	43.4	38.9	31.0	34.0	41.8	51.6	60.2	-
D	10	99	0	0	0	0	0	0	0	0	0	18	127
S	0	0	0	0	271.1	512.9	164.5	65.1	214.3	192.8	43	0	1463.7
R	29	14.5	7.2	3.6	135.6	324.3	244.4	154.8	184.6	188.7	115.9	58	1463.7

Table 3. Estimated annual water balance for Ikpa River basin at Uyo (2002) for soil moisture holding of 250mm. See Table 1 for details of parameters

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	156.7	120.2	70.4	59.3	58.3	48.0	43.2	33.1	41.8	36.4	54.9	91.3	813.7
P	0.0	24.2	125.1	257.9	302.1	285.1	174.8	388.8	266.7	398.8	****	6.3	2315.7
P-PE	-156.7	-96	54.7	198.6	243.8	237.1	131.6	355.7	224.8	362.4	31.4	-85	-
APWD	-241.7	-337.7	-	-	-	-	-	-	-	-	-	-85	-
ST	98.9	67.0	84.8	250	250	250	250	250	250	250	250	179.4	-
∆STN	-80.5	-31.9	17.8	165.2	0	0	0	0	0	0	0	-706	-
AE	50.5	56.1	70.4	59.3	58.3	48.0	43.2	33.1	41.9	36.4	54.9	76.9	-
D	76.2	64.1	0	0	0	0	0	0	0	0	0	14.4	154.7
S	0	0	0	0	243.8	237.1	131.6	355.7	244.8	362.4	31.4	0	1606.8
R	42.2	21.1	10.6	5.3	121.9	179.5	155.6	255.7	255.7	250.2	306.3	168.9	1606.8

Table 4. Estimated annual water balance for Ikpa River basin at Uyo (2003) for soil moisture holding of 250mm. See Table 1 for details of parameters.

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	88.4	85.8	92.3	57.0	48.7	42.1	42.4	34.3	36.6	45.1	50.1	84.0	706.6
P	23.4	121.0	112	250.5	207.7	149.3	475.0	274.3	388.8	191.3	101.3	4.5	2298.5
P-PE	-65	35.2	18.8	193.5	159	107.2	432.8	240	352.2	146.2	51.2	-79.5	-
APWD	-144.5	-	-	-	-	-	-	-	-	-	-	-795	
ST	154.3	79.3	250	250	250	250	250	250	250	250	250	184	-
∆STN	-29.7	-75	170.7	0	0	0	0	0	0	0	0	66	-
AE	53.1	85.8	92.3	57.0	48.7	42.1	42.4	34.3	36.6	45.1	50.1	70.5	-
D	35.3	0	0	0	0	0	0	0	0	0	0	14	49.3
S	0	0	0	0	159	107.2	432.8	240	352.2	146.2	51.2	0	1488.6
R	34.4	17.2	8.6	4.3	79.5	93.4	263.1	251.6	301.9	224.1	137.7	68.9	1488.6

Table 5. Estimated annual water balance for Ikpa River basin at Uyo (2004) for soil moisture holding of 250mm. See Table 1 for details of parameters.

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	90.3	122.5	119.9	66.8	56.5	42.6	38.9	36.4	38.9	45.9	51.6	71.8	787.1
P	4.3	56.0	27.4	177.7	164.0	379.0	380.0	240.6	355.8	284.1	93.4	1.5	2163.8
P-PE	-86	-66.5	-92.5	110.9	107.5	336.4	341.1	204.2	316.9	238.2	41.0	-70.3	-
APWD	-156.3	-152.5	159	-	-	-	-	-	-	-	-	-70.3	-
ST	139	142.3	133.4	70.1	250	250	250	250	250	250	250	199.4	-
∆STN	-60.4	3.3	-89	-63.3	179.9	0	0	0	0	0	0	-50.6	-
AE	64.7	59.3	36.3	66.8	56.5	42.6	38.9	36.4	38.9	45.9	1.6	52.1	-
D	25.6	63.2	83.6	0	0	0	0	0	0	0	0	19.7	192.1
S	0	0	0	0	0	336.4	341.1	204.2	316.9	238.2	41.8	0	1478.6
R	37.2	9.3	9.3	4.6	2.3	168.2	255.2	229.7	273.3	255.7	148.8	74.4	1478.6

Table 6. Estimated annual water balance for Ikpa River basin at Uyo (2005) for soil moisture holding of 250mm. See Table 1 for details of parameters.

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	140.5	83.3	62.1	49.5	46.4	33.8	27.9	31.6	34.6	42.3	60.7	64.0	677.0
P	30.7	83.0	170.4	314.1	229.6	319.0	552.0	295.0	280.6	381.8	154.4	2.6	2813.2
P-PE	-109.8	-0.3	108.3	264.5	183.2	285.2	529.1	263.4	245.7	339.5	93.7	-61.4	-
APWD	-171.2	-171.5	-	-	-	-	-	-	-	-	-	-61.4	-
ST	87.1	89.3	61.2	250	250	250	250	250	250	250	250	206.4	-
∆STN	-119.3	2.2	-28.1	188.8	0	0	0	0	0	0	0	-43.8	-
AE	150	80.8	62.1	49.5	46.4	33.8	27.9	31.6	34.9	42.3	60.7	-43.6	-
D	9.5	2.5	0	0	0	0	0	0	0	0	0	17.8	29.8
S	0	0	0	0	183.2	285.2	524.1	263.4	295.7	33905	93.7	0	1934.8
R	50.3	25.1	12.6	6.3	91.6	188.4	356.3	309.8	277.8	308.6	201.2	100.6	1934.8

Table 7. Estimated annual water balance for Ikpa River basin at Uyo (2006) for soil moisture holding of 250mm. See Table 1 for details of parameters.

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	71.0	69.7	68.4	63.9	44.5	46.7	32.5	39.8	31.0	46.7	67.4	98.4	680.0
P	5.4	62.1	192.7	216.7	292.9	486.1	269.0	277.9	414.8	299.0	37.6	0.0	2554.2
P-PE	-65.6	-7.6	124.3	152.8	248.4	39.4	236.5	238.1	383.8	252.3	-29.8	-98.4	-
APWD	-164	-171.6	-	-	-	-	-	-	-	-	-	-98.4	-
ST	102.4	89.3	98.2	250	250	250	250	250	250	250	250	164	-
ΔSTN	-61.6	-13.1	8.9	151.8	0	0	0	0	0	0	0	86	-
AE	67	75.2	68.4	63.9	44.5	46.7	32.5	39.8	31.0	46.7	37.6	86	-
D	4	5.5	0	0	0	0	0	0	0	0	29.8	12.4	51.7
S	0	0	0	0	248.4	439.4	236.5	288.1	383.8	252.3	0	0	1798.5
R	35.5	17.8	8.9	4.4	124.2	281.8	259.2	248.6	316.2	284.3	142.1	71.1	1798.5

Table 8. Estimated annual water balance for Ikpa river basin at Uyo (2007) for soil moisture holding of 250mm. See Table 1 for details of parameters

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	160.6	94.4	98.0	51.2	51.	41.1	36.8	33.7	36.9	45.3	27.3	75.9	755.3
P	0.0	17.3	121.1	290.8	345.5	313.3	267.0	261.6	394.4	237.7	277.6	62.9	2587.2
P-PE	-160.6	-77.1	23.1	239.6	292.4	272.2	230.2	227.9	357.5	192.4	250.3	-13	-
APWD	-173.6	-250.7	-	-	-	-	-	-	-	-	-	-13	-
ST	85.3	63.9	12.8	250	250	250	250	250	250	250	250	348.2	-
ΔSTN	-262.9	-21.4	-51.1	237.2	0	0	0	0	0	0	0	98.2	-
AE	262.9	38.7	98.0	51.2	51.1	41.1	36.8	33.7	36.9	45.3	27.3	35.3	-
D	102.3	55.7	0	0	0	0	0	0	0	0	0	40.6	189.2
S	0	0	0	0	292.4	272.2	230.2	227.9	257.5	192.4	250.3	0	1822.9
R	61.5	30.7	15.4	7.7	146.2	209.2	219.7	223.8	290.7	241.5	245.9	123.0	1822.9

Table 9. Estimated annual water balance for Ikpa River basin at Uyo (2008) for soil moisture holding of 250mm. See Table 1 for details of parameters.

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	111.1	133.7	75.1	67.1	55.9	39.4	36.0	32.0	43.8	48.0	60.5	73.3	775.9
P	37.3	0	134.9	218.1	375.4	329.9	275.7	485.1	145.2	192.1	49.8	49.8	2293.3
P-PE	-73.8	-133.7	59.8	151.0	319.5	290.5	239.7	453.1	101.4	144.1	-10.7	-23.5	-
APWD	-97.3	-231	-	-	-	-	-	-	-	-	-	-23.5	-
ST	165	99.7	23.2	250	250	250	250	250	250	250	250	208.7	-
ΔSTN	-43.7	-65.3	-76.4	226.7	0	0	0	0	0	0	0	14.3	-
AE	81	65.3	75.1	67.1	55.9	39.4	36.0	32.0	43.8	48.0	49.8	91.1	-
D	30.1	68.4	0	0	0	0	0	0	0	0	10.7	17.8	127
S	0	0	0	0	319.5	290.5	239.7	454.1	101.4	144.1	0	0	1549.3
R	22.9	11.5	5.7	2.7	159.8	22.1	232.4	343.3	222.4	183.4	91.7	45.8	1549.3

Table 10. Estimated annual water balance for Ikpa river basin at Uyo (2009) for soil moisture holding of 250mm. See Table 1 for details of parameters.

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL (mm)
PE	72.7	69.9	69.7	63.1	52.6	38.8	31.4	31.6	32.1	44.4	68.6	94.5	669.4
P	46.9	58.0	63.5	165.4	224.5	368.5	187.3	276.5	319.9	210.0	40.5	0.0	196.1
P-PE	-25.8	-11.9	-6.2	102.3	171.9	329.7	155.9	244.9	287.8	165.6	-28.1	-94.5	-
APWD	-120.3	-132.2	-138.4	-	-	-	-	-	-	-	-	-94.5	-
ST	97.8	65.4	14.5	250	250	250	250	250	250	250	250	159	-
∆STN	-61.2	-32.4	-50.9	-235.5	0	0	0	0	0	0	0	9	-
AE	108.1	90.4	114.4	63.1	52.6	38.8	31.4	31.6	32.1	44.4	40.5	103.5	-
D	35.4	20.5	44.7	0	0	0	0	0	0	0	28.1	9	137.7
S	0	0	0	0	171.9	329.7	155.9	244.9	287.8	165.6	28.1	85.5	1469.4
R	50.9	25.5	12.73	6.4	85.9	207.8	181.9	213.4	250.6	208.1	118.1	101.8	1469.4

Table 11. Summary of total precipitation, potential evaporation, water deficit and surplus water (2000-2009).

YEAR	PRECIPITATION (mm)	POTENTIAL EVAPORATION (mm)	WATER DEFICIT (mm)	SURPLUS WATER (mm)
2000	2140.4	817.4	120.4	1373.5
2001	2207.2	1280.6	127.0	1463.7
2002	2315.7	813.7	154.7	1606.8
2003	2298.5	706.6	49.0	1488.6
2004	2163.8	782.1	192.1	1478.6
2005	2813.2	677	29.8	1934.8
2006	25542.2	680	51.7	1798.5
2007	2587.2	755.3	199.2	1822.9
2008	2293.3	775.9	127.0	1549.3
2009	1961.0	669.4	137	1469.4

Table 12. Estimated baseflow (2000-2009) for a bzsin area of $4.135x10^8m^2$

YEAR	**BASEFLOW ESTIMATE (mm)**	**YIELD(m^3)**
2000	687	284074500
2001	732	302682000
2002	803	332040500
2003	744	307644000
2004	739	305576500
2005	967	399854500
2006	899	371736500
2007	912	377112000
2008	775	320462500
2009	735	303922500
Average		**3305105500**

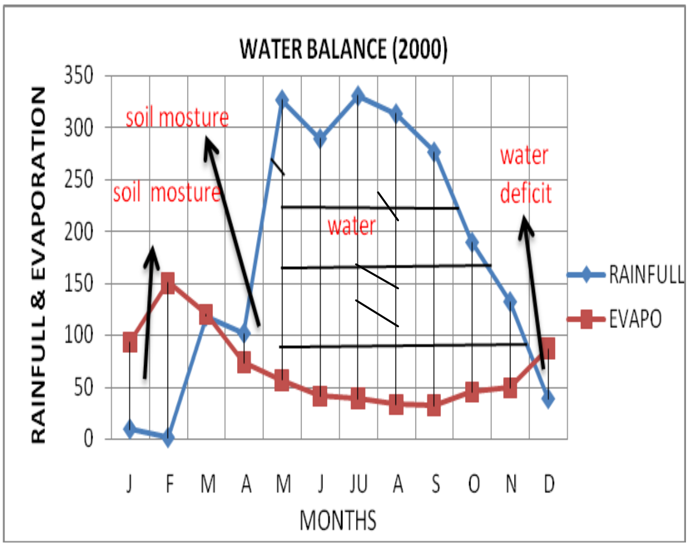

Fig. 2. Evaluation of baseflow in Ikpa River for the year, 2000

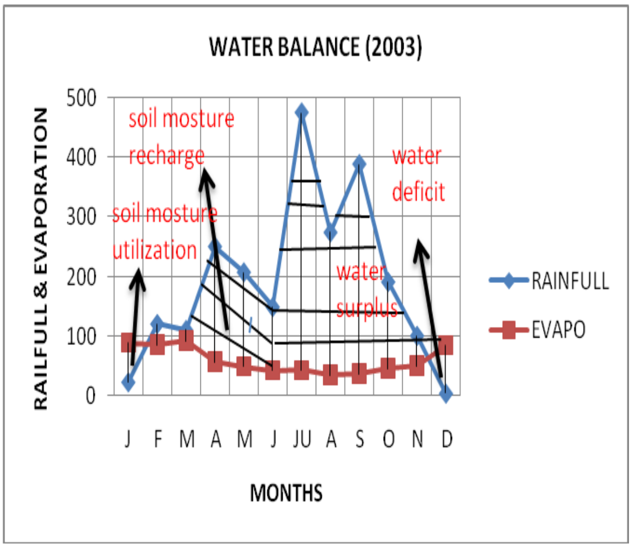

Fig. 5. Evaluation of baseflow in Ikpa River for the year, 2003

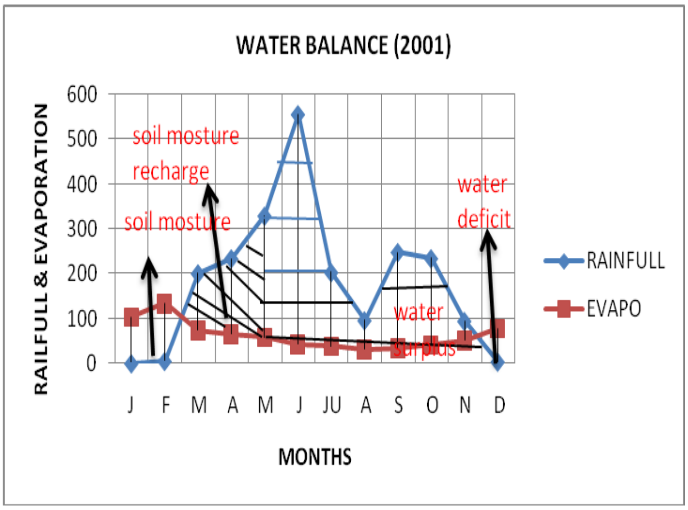

Fig. 3. Evaluation of baseflow in Ikpa River for the year, 2001

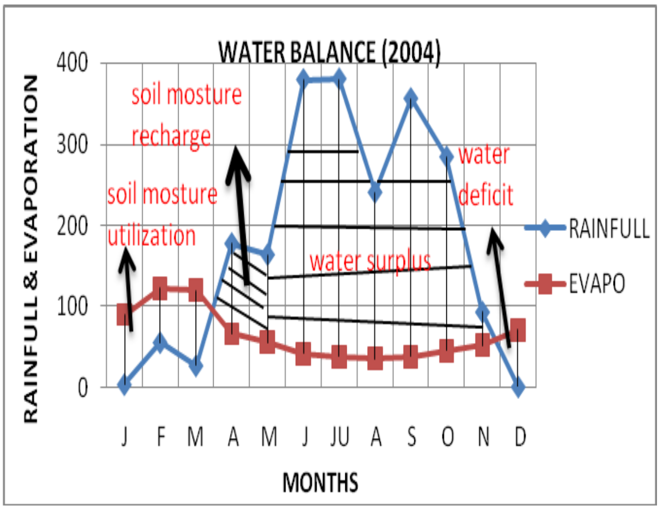

Fig. 6. Evaluation of baseflow in Ikpa River for the year, 2004

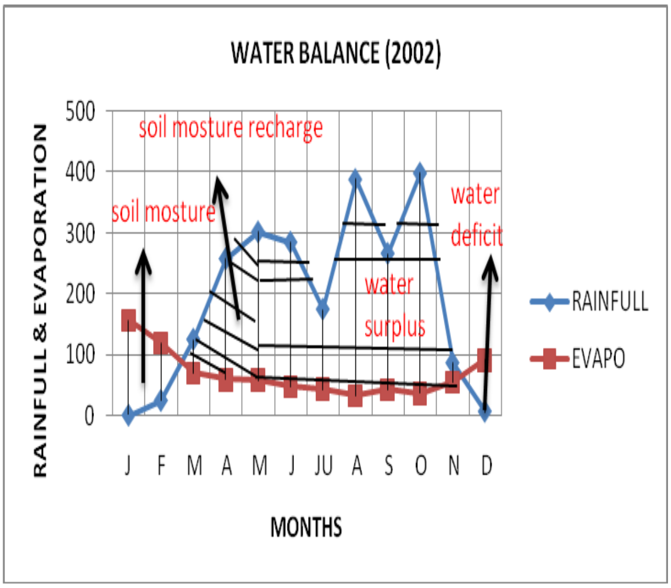

Fig. 4. Evaluation of baseflow in Ikpa River for the year, 2002

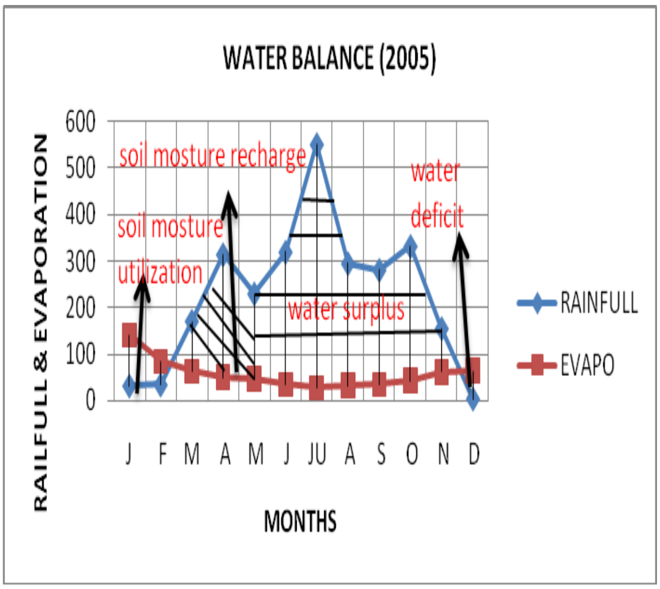

Fig. 7. Evaluation of baseflow in Ikpa River for the year, 2005

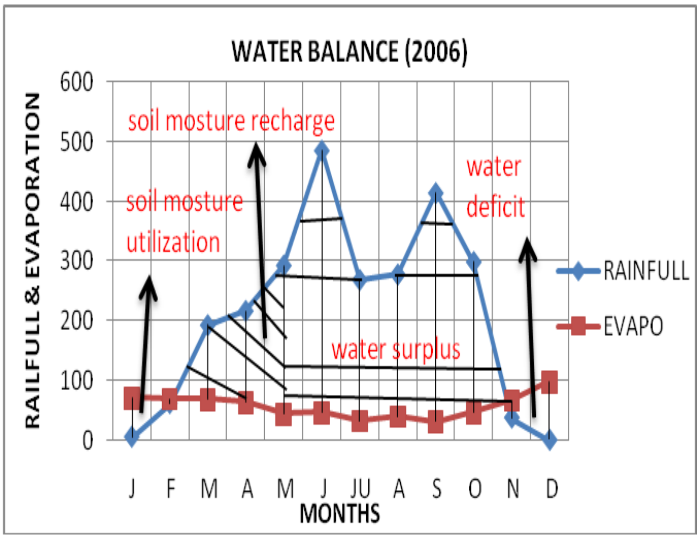

Fig. 8. Evaluation of baseflow in Ikpa River for the year, 2006

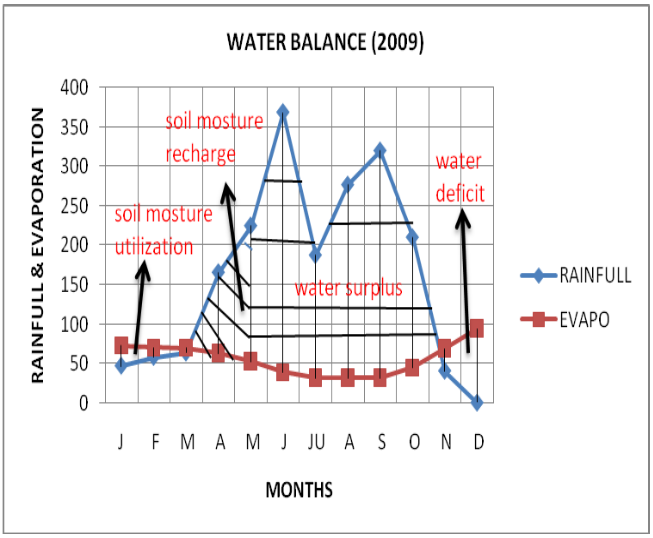

Fig. 11. Evaluation of baseflow in Ikpa River for the year, 2009

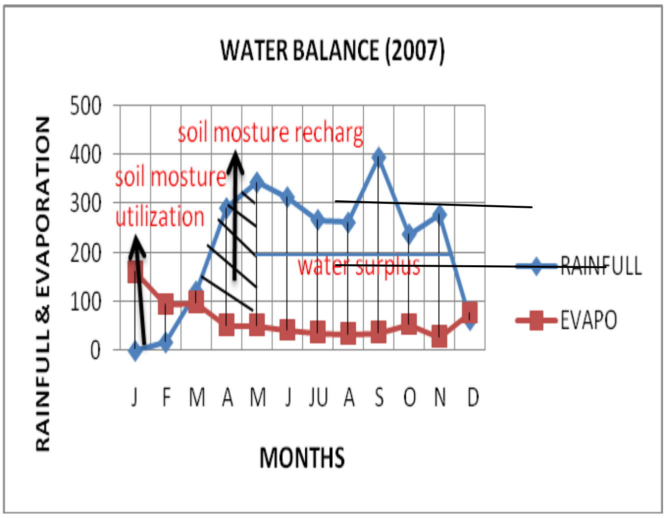

Fig. 9. Evaluation of baseflow in Ikpa River for the year, 2007

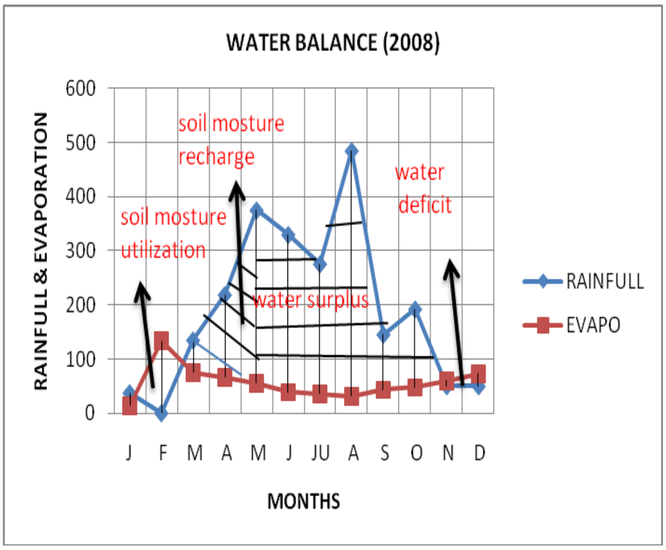

Fig. 10. Evaluation of baseflow in Ikpa River for the year, 2008

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