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Determination of rainfall-recharge relationship in River Ona basin using soil moisture balance and water fluctuation methods

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A quantitative evaluation of spatial and temporal distribution of groundwater recharge is a pre-requisite for the management of ground water resources system in an optimal manner. The amount of groundwater recharge depends upon the rate and duration of rainfall, as rainfall is the principal means for replenishment of moisture in the soil water system and recharge to ground water. This paper investigated the relationship between rainfalls and groundwater recharge within Ona River basin, southwest Nigeria, using soil moisture balance and water table fluctuation. Analysis of rainfall trends within the Ona River basin suggests that there is considerable high annual rainfall occurrence, with a mean of 1623.48. It must be noted that the mean annual lost due to evapotranspiration of 1361.68 mm is very high when compared to the rainfall (83.9%). The results obtained from the soil moisture balance when considering the three dominant soil types within the basin, that is, sandy loam, clay and find sand, having water capacity of root zone value of 70, 70, and 50 respectively, suggests that groundwater recharge follows a positive trend as the corresponding rainfalls. However, empirical relationships of: y = 0.540x – 606.2, with a coefficient of determination (r^2) value of 0.719, for sandy loam and clay; and y = 0.552x – 621, with a coefficient of determination (r^2) value of 0.726 for fine sand was established for the basin area. On the other hand, recharge ranging from 220.25 to 40.50 mm was computed from the water table fluctuation method.

Key words: Rainfall–recharge relationship, soil types, soil moisture balance, Ona River basin, water table fluctuation.

INTRODUCTION

The need to determine local rainfall recharge relationship through the use of locally determined empirical formula as a viable option for prediction of groundwater recharge is the main focus of this paper. Groundwater recharge is understood as the downward flow of water recharging the water table, forming an addition to the groundwater reservoir (Backundukize et al., 2011). But Kumar (1973) asserted that the quantification of the rate of natural groundwater recharge is a basic pre-requisite for efficient groundwater resource management. The case study happens to be in the humid region where the amount of recharge in wet season is usually high because such region receive large amount of rainfall and the relative proportion of these components fluctuate according to the

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climatic conditions, geology, and geomorphology. Although in the humid tropics region, the most important mechanisms of ground recharge are considered to be indirect recharge by infiltration from floods through the beds of ephemeral streams (Marechal et al., 2008), there are several methods for estimating groundwater recharge, which are being used until date. The use of methods depends on the temporal and spatial resolutions of required estimates. Estimation of groundwater recharge is normally with errors and uncertainties (Dages et al., 2009; Sophocleous, 2004; Fitzsimons and Misstear, 2006). The best way to minimize these uncertainties is to use a combination of several methods (Scanlon et al., 2002). However, the Food and Agricultural Organization of the United Nation (FAO) recommends the use of Penman-Monteith equation as the standard for estimating reference evapotranspiration because it approximates better with lysimeters (Jabloun and Sahli; 2008; Trajkovic, 2001). Thus, in this paper, reference evapotranspiration was calculated using Penman-Monteith equation. This is useful for estimation of recharge using the soil moisture balance. A water table fluctuation method was also used to estimate groundwater recharge in the Ona River basin.

The aim of this paper is to estimate groundwater recharge within Ona River basin using both soil moisture balance and the water table fluctuation methods; and to establish an empirical relationship between recharge and rainfall. In other to carry out the main objective, the following sub-objective is considered: estimation of monthly and annual evapotranspiration using Penman-Monteith equation; estimation of annual groundwater recharge using soil moisture balance, and water table function methods; and establishment of empirical relationship between the groundwater recharge and rainfall.

Justification

Two major cities in Nigeria are located within Ona River Basins with other smaller urban settlements. They are Ibadan and Ijebu Ode. These cities are with considerable high population. For example, the population of Ibadan city is hovering around 6 million people and Ijebu Ode around 1 million. Equally, major industries are located within the drainage basin in question. However, there exist challenges in water sourcing in these cities. Although the cities are blessed with various rivers, streams and rivulet, they are often polluted and the State Government is finding it difficult in satisfying the water provision using surface water. Also, lots of buildings, both surface and underground were observed in these cities; so also asphalt overlay and pavement construction capable of preventing recharge into the water table is eminent in the study area. Whereas the majority of the people rely on groundwater for domestic, industrial and irrigational purposes, the activities in the cities is preventing recharge into the groundwater. But natural recharge by downward flows of water through the unsaturated zone is generally the most important mode of groundwater recharge. It is therefore crucial to estimate groundwater recharge for safe and efficient management of groundwater resource (Fitzsmons and Misstera, 2006).

As a result of possible excess withdrawals from groundwater reservoirs against natural replenishment which lead to regular lowering of water table, detailed study of groundwater recharge within Ona basin is essential.

Study area

River Ona is located in Southwestern part of Nigeria, an area whose boundaries are approximately latitudes 6° 34' N and 7° 38' N, and longitudes 3° 26' E and 3° 59' E (Figure 1). The basin occupies an area of 6,800 km^2 with its greater part in Ogun State before it terminates in the Lagos lagoon. The Ona basin is located west of the Oshun River basin as well as the Owa, Ibu and Omi rivers.

The climate of the Ona basin is similar to what obtained in the southwestern Nigeria. It is influenced by the movement of the inter-tropical convergence zone (the ITCZ), a quasi-stationary boundary zone which separates the sub-tropical continental air mass over the Sahara and the equatorial maritime air mass over the Atlantic Ocean. The former air mass is characterized by the dry northeasterly winds known as Harmatan, the latter by the rain-bearing southwesterly winds from the gulf of Guinea.

The ITCZ moves northwards beyond the basin at the peak of the raining season in June and July, and southward to the coast in the middle of the dry season in December and January. The change from the raining season to the dry season is rather abrupt while the onset of the rains after the dry season is gradual. Data obtained from the basin shows that February and March are the hottest months of the year. During these months, temperatures are high over the entire area. The mean daily maximum temperature for February is 31.4°C in the south and as high as 34.6°C in the north. The lowest mean minimum temperature in the north are recorded in December (17°C), that is, during the harmatan; in the southern part, the lowest mean temperature of 22.8°C was recorded in July during the raining season. In general humidity decreases northward in the basin. The lowest mean monthly humidity at 12.00 GMT is 62% in the south and 50% in the north, while the mean annual humidity varies from 75% in the south to 55% in the north. The raining season begins early in the south, which occurs in March and continues until the end of October or early November giving at least seven month of rainfall. In late July and early August, the mean wet season rainfall varies from 1020 to 1520 mm in the south

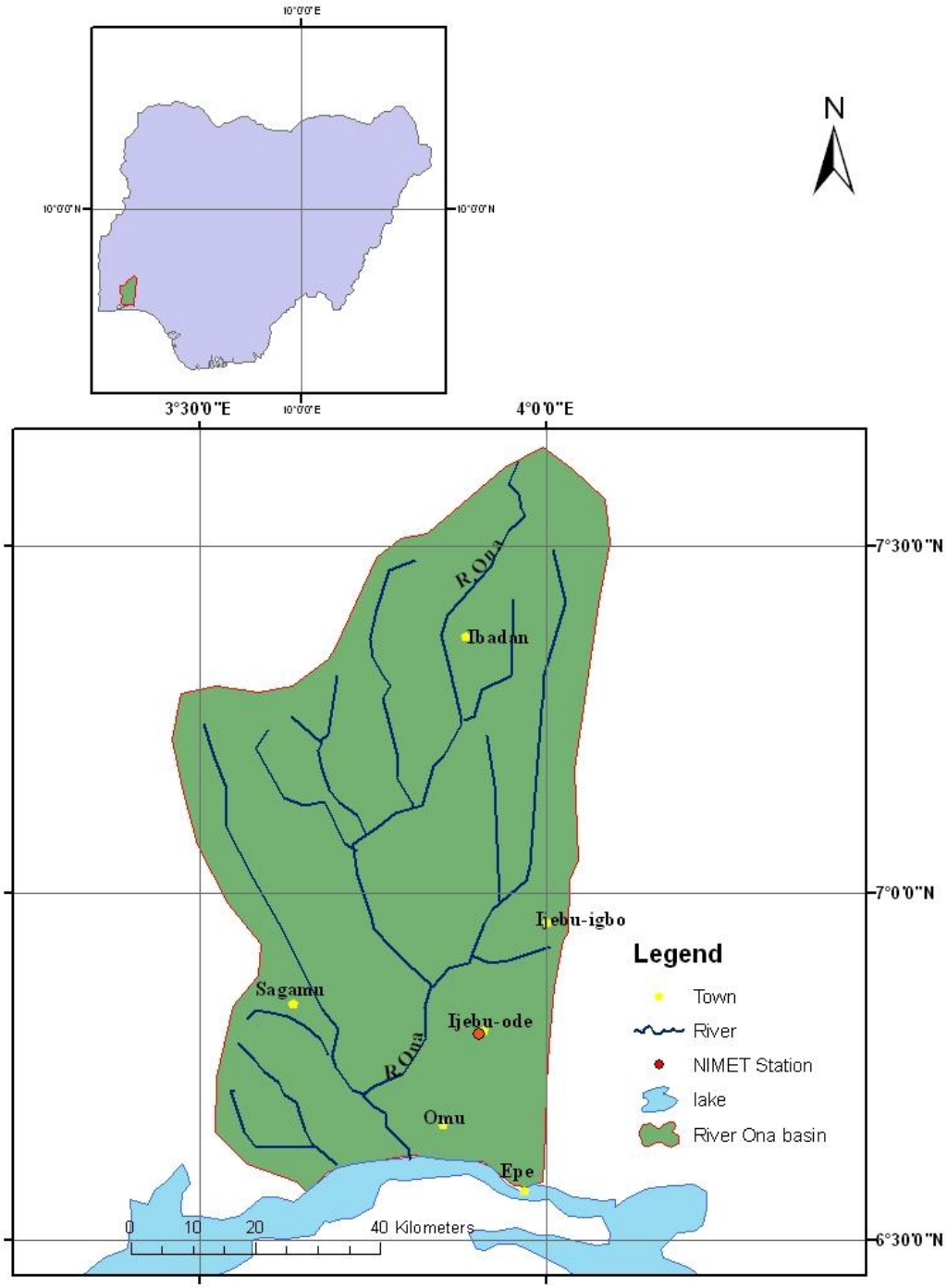

Figure 1. Map of Ona River basin.

of the basin and it is less than 1020 mm in the north. The mean dry season rainfall, on the other hand varies from 127 to 178 mm in the north and from 178 to 254 mm in the south.

Geologically, sedimentary rocks of cretaceous and latter deposit are found in the southern section of Ona River basin; the remaining section are composed of crystalline rock of the basement complex consisting folded gnesis, schist, and quartzite complexes which belong to the older intrusive series.

METHODOLOGY

The main data employed in this project are rainfall data and water

Table 1. Annual soil water budget calculation (Thornthwaite and Matter, 1957) after Backundukize et al. (2011).

	S_B = CAP	Wet season [SUR = (P-Ro) – PET > 0]		Dry season [SUR = (P-Ro) – PET < 0]
		S_B < CAP		
		(P-Ro) – PET ≤ CAP - S_B	(P-Ro) – PET > CAP - S_B	
S_B	CAP	S_B + (P-Ro) – PET	CAP	CAP*$e^{-APWL/CAP}$
R_N	(P-Ro) - PET	0	(P-Ro) – PET – (CAP - S_B)	0
AET	PET	PET	PET	(P-Ro) + ΔS_B
DEF	0	0	0	PET - AET

P = Precipitation (mm); Ro = runoff (mm); PET = potential evapotranspiration (mm); APWL = accumulated potential water loss (mm) [PET - (P-Ro)] accumulated for subsequent dry months; AET = actual evapotranspiration (mm); S_B = water stored in soil: S_B = CAP*$e^{-APWL/CAP}$; CAP = soil capacity (mm): maximum water content of soil, without gravitational water (= average rooting depth (mm) * water content at field capacity (in volume %); ΔS_B = Change in S_B; DEF = deficit (PET - AET) (mm); SUR = surplus [(P-Ro) – AET] (mm); R_N = natural groundwater recharge (SUR - ΔS_B) (mm).

levels data from wells within the river basins.

Rainfall data

Rainfall data were obtained from the Nigeria Meteorological Agency (NIMET) Ijebu-Ode, Ogun State station. The meteorological parameter obtained at this station include precipitation, maximum and minimum temperature, relative humidity, sunshine duration and cup counter anemometer. The time series of meteorological data covering 22 calendar years, that is, 1990-2012 was obtained. Time series of relative humidity, wind speed and solar radiation are only available for a period of 10 years (2000 to 2010). Missing data in time series were filled using arithmetic mean of adjacent month (Backundukize et al., 2011). Larger gaps were filled using arithmetic mean of the previous to the recent data for the period of 2000 to 2010. Time series data including solar radiation, precipitation, maximum and minimum temperature, and relative humidity are available and this enable us to compute the potential evapotranspiration using the standard Penman Monteith equation.

Water level from wells

Water level indicator was used to measure the water level daily between the hours of 4 pm for a year. The total number of wells monitored was twenty (20) scattered within the river basin.

Penman-Monteith equation

The standard Penman-Monteith method for estimating evapotranspiration can be mathematically expressed as follows (Allen et al., 1998):

$E_0 = (\Delta/\gamma H + E_a)/ \Delta/\gamma$

Where Δ/γ is an empirical parameter depending on temperature. H is calculated as

$H = (1-r)\ Rin – Ro$

where Rin (incoming radiation) is given by:

$(1-r)\ Rin = 0.95*Ra\ (0.18 + 0.55\ n/N)$

Where Ra is the solar radiation, Ro is the outgoing radiation, r is the albedo (0.05 for water), and n/N is the ration between actual sunshine hours and possible sunshine hours. The term n/N can also be estimated using the cloudiness, e.g., a cloudiness of 60% gives an *n/N* of 40% (=100 - 60). R_0 is calculated by:

$R_0 = \sigma\ T_a 4\ (0.56 – 0.09\sqrt{ed})(0.10+0.90\ n/N)$

Where ed is the actual vapor pressure and σT_a^4 is the theoretical black body radiation.

Ea is calculated by:

$Ea = 0.35(0.5 + u^2/100)\ (ea – ed)$

Where u^2 is the wind speed in m/s and ea is the saturation vapor pressure. Remember that the relative humidity RH = ed/ea.

Soil moisture balance method

Each parameter of soil moisture balance are computed separately in an excel sheet (Table 1). In these method the concepts of water balance of the unsaturated zone (Thornwaite and Matter, 1957) is applied. It consists of keeping track of the accumulated potential water loss (APWL) and the amount of water in the soil (Sb). Calculation to determine Sb and APWL are performed for each month using monthly precipitation (p) and potential evapotranspiration (PET) (Table 3).

The monthly climatic data available were first rearranged into hydrologic years, a hydrologic year in south-west Nigeria starts with April, which is the beginning of the rainy season, and terminates at the end of March, that is, the end of the dry season.

Actual evapotranspiration (AET): (1) In wet months, when there is enough rain, that is, when P-Ro > PET, the AET is at its maximum value, which is equal to the PET (PET = AET).

(2) In dry months, when there is not enough rain, that is, when P-Ro < PET,

AET = PET + P-Ro

Soil capacity (CAP): The soil water-holding capacity of the root zone is typically expressed in mm and can be obtained by multiplying the water content at field capacity by the effective depth of the root-zone. Hence assuming a uniform water-holding capacity of 30% over the entire the root-zone and a rooting depth of 0.25 m for shallow rooted crops, the water capacity of the root zone becomes 75 mm (Table 2).

Table 2. Showing groundwater recharges estimation using soil moisture balance method.

Year	Month	P	Ro	P-Ro	PET	(P-Ro) - PET	PET - (P-Ro)	APWL	S_B	ΔS_B	AET	DEF	SUR	R_N	Annual R_N
1996	April	183.1	43.28	139.82	115.95	23.87	-23.87	0	75	-75	115.95	0.00	23.87	-51.13	
	May	87	20.57	66.43	122.02	-55.59	55.59	55.59	35.74	39.259	105.69	16.33	-39.26	0.00	
	June	360.4	85.20	275.20	127.14	148.06	-148.06	0	75	-39.26	127.14	0.00	148.06	108.80	
	July	391	92.43	298.57	125.75	172.82	-172.82	0	75	0	125.75	0.00	172.82	172.82	
	August	204.2	48.27	155.93	132.92	23.01	-23.01	0	75	0	132.92	0.00	23.01	23.01	
	September	119.5	28.25	91.25	129.4	-38.15	38.15	38.15	45.1	29.903	121.15	8.25	-29.90	0.00	
	October	338	79.90	258.10	105.44	152.66	-152.66	0	75	-29.9	105.44	0.00	152.66	122.75	
	November	1.4	0.33	1.07	86.2	-85.13	85.13	85.13	24.11	50.895	51.96	34.24	-50.89	0.00	
	December	11.6	2.74	8.86	104.5	-95.64	95.64	180.77	6.734	17.371	26.23	78.27	-17.37	0.00	
1997	January	0	0.00	0.00	131.92	-131.92	131.92	227.56	3.609	3.1254	3.13	128.79	-3.13	0.00	
	February	0	0.00	0.00	76.16	-76.16	76.16	208.08	4.679	-1.07	-1.07	77.23	1.07	0.00	
	March	272.4	64.40	208.00	109.94	98.06	-98.06	0	75	-70.32	109.94	0.00	98.06	27.74	
Total		1968.6													403.99

Table 3. Annual rainfall of the 22 years (1990 to 2012).

Year	Annual rainfall
1990/1991	1767.40
1991/1992	1601.80
1992/1993	1686.60
1993/1994	1526.30
1994/1995	1414.90
1995/1996	1908.50
1996/1997	1968.60
1997/1998	1510.08
1998/1999	1337.38
1999/2000	1756.90
2000/2001	1774.55
2001/2002	1349.90
2002/2003	1449.84
2003/2004	1616.70
2004/2005	1865.60
2005/2006	1610.90
2006/2007	1585.25
2007/2008	1572.57
2008/2009	1576.69
2009/2010	1650.50
2010/2011	1599.18
2011/2012	1586.32

Runoff (R_0): The value of runoff is precipitation multiplied by runoff coefficient (R_c), where (R_c) is equal 0.2364 (Ayoade, 1975).

$R_0 = P * R_c$

Change in soil moisture storage (ΔS_b): This is the difference between the current soil moisture and the previous one.

Deficit (D): The deficit is the difference between the actual evpotranspiration and potential evapotranspiration.

D = PET - AET

Surplus (S): Surplus (SUR) is computed as the difference between P-Ro and the actual evapotranspiration (AET).

Groundwater recharge (RN): Groundwater recharge occurs when there is a surplus and the soil moisture is at its field capacity. It is calculated as the remaining surplus after the soil moisture has been brought to field capacity.

Rn = Δs + SUR

Water-table fluctuation method

Recharge is calculated as:

R(tj) = Sy*ΔH(tj)

Where R(tj) (cm) is recharge occurring between times t_0 and tj, Sy is specific yield (dimensionless), and ΔH(tj) is the peak water-table rise attributed to the recharge period (cm).

Key assumption and critical issues inherent in water table fluctuation that have greatly being on its successful application are: the observed well hydrograph depicts only natural water-table fluctuations caused by ground-water recharge and discharge; Sy is assumed in relation to the geologic properties of the area, and that is constant over the interval of the water-table fluctuation. For this study Sy was assumed to be 1.5%, that is for gneiss the pre-recharge water-level can be extrapolated to determine ΔH (tj) Rasmussen and Andreasen, 1959; while ΔH was computed with the graphical approach as the difference between the peak water level during a recharge even and the predicted level to which water levels would have declined to recharge event had not occurred. ΔH (tj) is estimated as the difference between the peak of a water-level rise and the value of the extrapolated antecedent recession curve at the time of the peak. This recession curve is the trace that the well hydrograph would have followed had there been any precipitation (Figure 2).

Figure 2. Depth to water surface chart.

Table 4. Descriptive statistics of the annual rainfall.

Years	Range	Minimum	Maximum	Mean	Standard deviation
22	631.22	1337.38	1968.6	1623.48	167.13

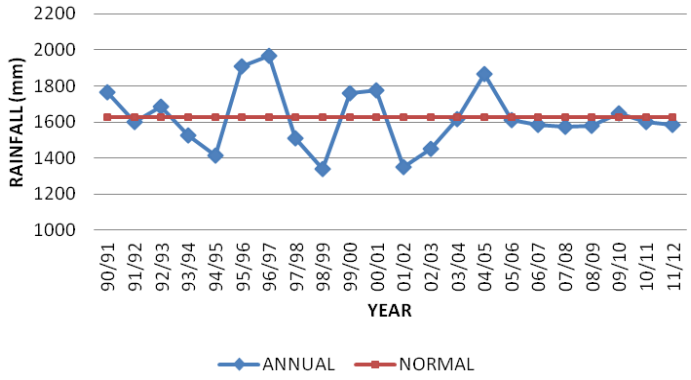

Figure 3. Trend of variation of annual rainfall for 22 years (90/91-11/12).

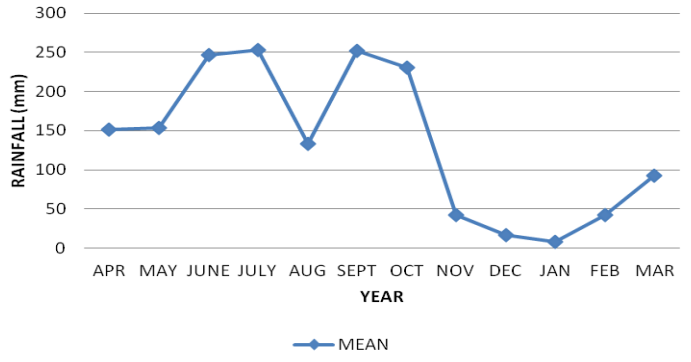

Figure 4. Trend of variation in mean monthly rainfall within the 22 years of study.

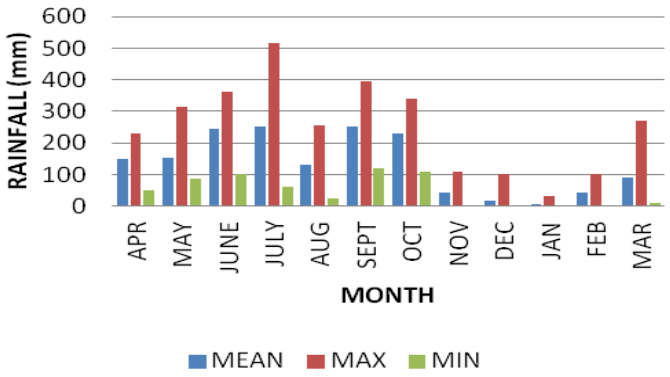

Figure 5. The mean, maximum and minimum monthly rainfall.

RESULTS AND DISCUSSION

This part encompasses the descriptive analysis of rainfall data obtained from Nigeria Meteorological Station (NIMET), the computed potential evapotranspiration and the analysis of the ground water recharge results obtained from the two methods, that is, soil moisture results balance for the duration of 22 years of the study and water table fluctuation analysis of 20 wells for the 2011.

Descriptive analysis of rainfall

Annual rainfall

The annual rainfall occurrence of the Ona River basin for the years of study (1990 to 2012) is presented in Tables 3 and 4. It can be observed that a maximum annual rainfall of 1968.6 mm was recorded for the hydrologic year 1996/1997, a minimum value of 1337.38 mm for 1998/1999. Also, a mean value of 1625.9 mm was observed for the 22 years of study according to Table 3 while a standard deviation of 167.12 mm shows that there is high variability in rainfall within the 22 years of study; this also indicate that the rainfall data deviate largely from their average value of 1625.9 mm.

The trend of variation of annual rainfall can also be observed from the line graph in Figure 3, however, there are 14 dry years (that is, years below normal rainfall of 1625.93 mm), while the remaining 8 were wet years.

Monthly rainfall

In Figure 4, the average monthly variation of rainfall was analyzed. The monthly rainfall for the Ona River basin can therefore be categorized into three seasons; which includes: two wet seasons, ranging from April to October; and a dry season from November to March; the mid break, that is, August break can also be observed.

However, it can be observed from the column chat in Figure 5 that the maximum rainfall ranges from 517.6 to

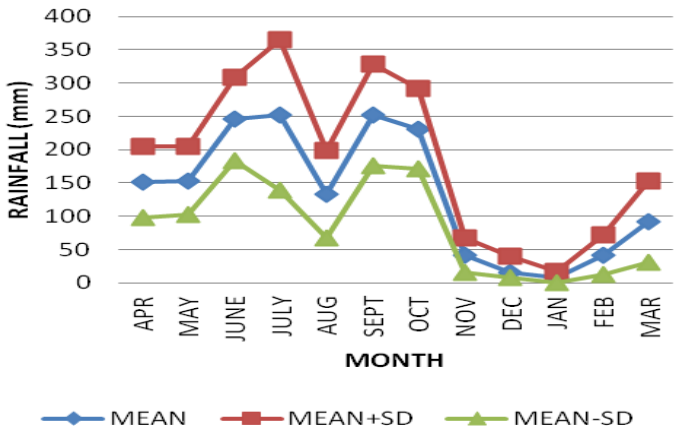

Figure 6. Variations in monthly rainfall pattern.

Table 5. Annual potential evapotranspiration computed from Penman equation.

Year	PET
1990/1991	1379.45
1991/1992	1390.44
1992/1993	1335.51
1993/1994	1353.5
1994/1995	1312.65
1995/1996	1393.01
1996/1997	1367.34
1997/1998	1376.76
1998/1999	1363.42
1999/2000	1332.19
2000/2001	1327.44
2001/2002	1334.61
2002/2003	1315.03
2003/2004	1353.09
2004/2005	1364.66
2005/2006	1434.12
2006/2007	1306.76
2007/2008	1331.8
2008/2009	1410.78
2009/2010	1415.68
2010/2011	1363.72
2011/2012	1395.04

Table 6. Descriptive statistics of annual PET.

Years	Range	Minimum	Maximum	Mean	Standard deviation
22	127.36	1306.76	1434.12	1361.68	35.31

31.8 mm, occurring in the month of July and January respectively. It can also be seen that the mean or normal monthly rainfall ranges from 252.61 mm in the month of July to 8.06 mm occurring in January. While the minimum

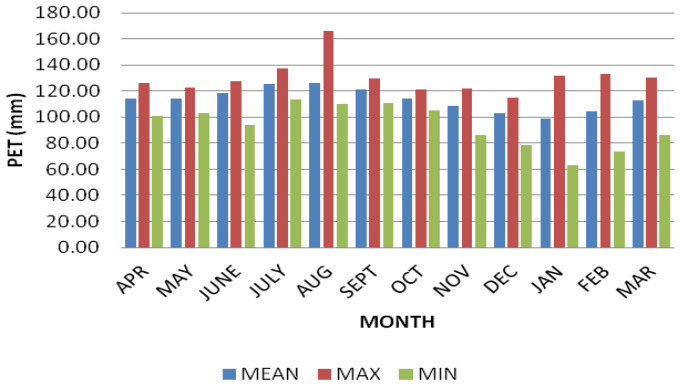

Figure 7. Monthly pattern of PET for the 22 years of study.

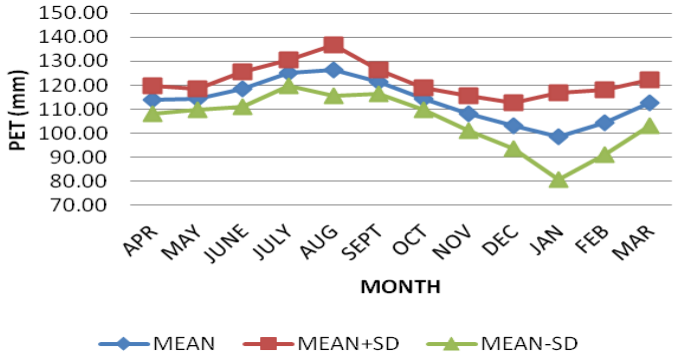

Figure 8. Seasonal PET patterns.

monthly rainfall range from 119.5 mm in September to 0 mm occurring from November to March within the 22 years of study.

It can be observed in the Figure 6 below that rainfall variation from normal occurring within each month for the 22 years of study reduces as we move into the dry season.

Potential evapotranspiration

It can be observed from Tables 5 and 6 that the maximum annual potential evapotranspiration falls in the hydrologic year 2005/2006 and with the value of 1434.12 mm, while minimum value of 1306.76 mm was observed in the hydrologic year 2006/2007; the standard deviation of 35.31 mm indicates a little deviation of annual PET from the mean value of 1361.68 mm per year. However, the mean of 1361.68 mm compared to the mean annual rainfall of 1623.48 mm shows that about 83.9% of the annual rainfall is lost to both evaporation and transpiration from plants.

It can be observed in the column chat in Figure 7 that August has the highest maximum PET with a value of 166.42 mm, while January records the lowest minimum PET with a value of 63.25 mm. In addition, it can be observed in the Figure 8 that there are high variations in

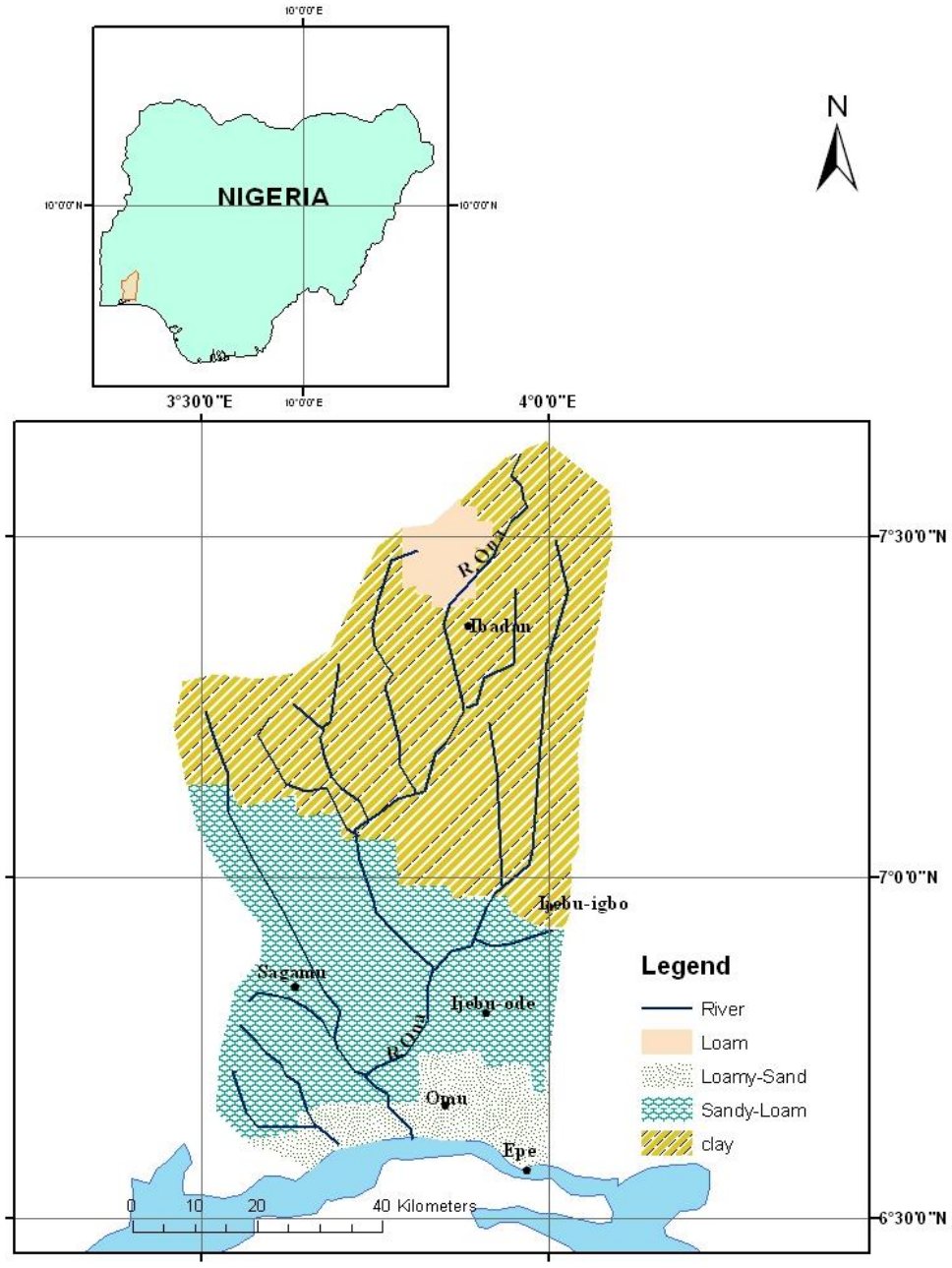

Figure 9. Soil map of the Ona River basin.

the dry months as compared to the wet months. The months with high deviation include August, along with November to March.

Analysis of groundwater recharge results obtained from soil moisture balance method

The soil dominant soil types within the Ona basin was considered for the estimation of groundwater recharge. The soils considered are clay, sandy load and fine sand (Figure 9).

From the Table 7, it can be seen that there are slight variation between recharge obtained for clay and sandy loam soils, and that obtained for fine sand.

For clay and sandy loam, the ground water recharge ranges from 509.01 to 140.82 mm, with a percentage recharge which also ranges from 24.33 to 9.20% of rainfall within the years of study.

On the other hand, the ground recharge obtained for fine sand ranges from 478.99 to 133.35 mm, with a percentage recharge, that ranges from 25.86 to 9.71% of rainfall.

From Table 8, the mean annual recharge of 273.75 mm

Table 7. Result obtained for different soils.

Year	Rainfall	Recharge			
		CAP=75		CAP=50	
		Clay and Sandy loam	%	Fine sand	%
1990/1991	1767.40	426.20	24.11	410.32	23.22
1991/1992	1601.80	229.42	14.32	229.86	14.35
1992/1993	1686.60	267.26	15.85	280.24	16.62
1993/1994	1526.30	195.22	12.79	207.70	13.61
1994/1995	1414.90	271.49	19.19	277.07	19.58
1995/1996	1908.50	338.28	17.72	341.75	17.91
1996/1997	1968.60	478.99	24.33	509.01	25.86
1997/1998	1510.08	213.53	14.14	213.53	14.14
1998/1999	1337.38	140.87	10.53	153.10	11.45
1999/2000	1756.90	422.81	24.07	426.75	24.29
2000/2001	1774.55	431.61	24.32	431.61	24.32
2001/2002	1349.90	156.84	11.62	156.84	11.62
2002/2003	1449.84	133.35	9.20	140.82	9.71
2003/2004	1616.70	266.43	16.48	280.33	17.34
2004/2005	1865.60	443.20	23.76	460.69	24.69
2005/2006	1610.90	245.13	15.22	252.06	15.65
2006/2007	1585.25	274.07	17.29	275.06	17.35
2007/2008	1572.57	213.53	13.58	213.53	13.58
2008/2009	1576.69	155.08	9.84	155.12	9.84
2009/2010	1650.50	227.83	13.80	230.48	13.96
2010/2011	1599.18	183.22	11.46	183.22	11.46
2011/2012	1586.32	243.41	15.34	245.50	15.48

CAP= (water capacity of root zone), % = (recharge/rainfall)*100.

Table 8. Descriptive statistics of the recharge results obtained.

Years	Soil type	SB	Maximum	Minimum	Mean	SD
22	Clay	75	478.99	133.35	273.75	111.78
22	Sandy loam	75	478.99	133.35	273.75	111.78
22	Fine sand	50	509.01	140.82	280.18	115.27

is computed for clay and sandy soil samples; while a mean of 280.18 mm is computed for fine sand soil sample, this shows a slight variation in results obtained (Figure 10). Consequently, the standard variation of 111.78 and 115.27 mm proves that the ground water recharge obtained for the 22 years of study deviate largely from their means.

Rainfalls-recharge relationships

Figure 11 show that the annual ground water recharge computed follows the same trend with the corresponding rainfall. It can be observed from Table 9 that the computed ground water recharge for the three types of soil has high positive correlations of 0.848 and 0.852 with the rainfall, the value 0.00 shows that these correlations

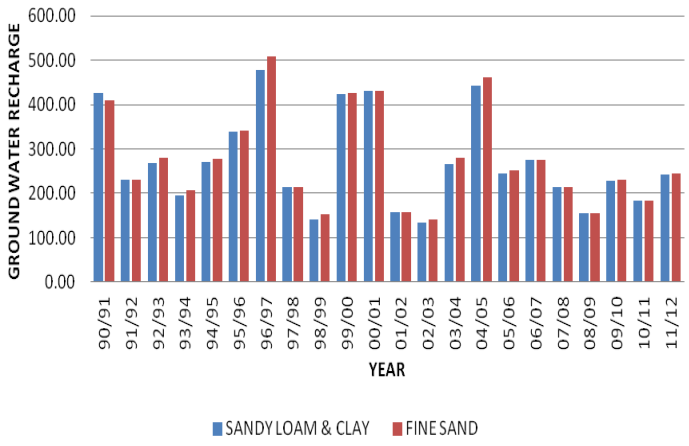

Figure 10. Column chat showing trend of variations in the computed recharge.

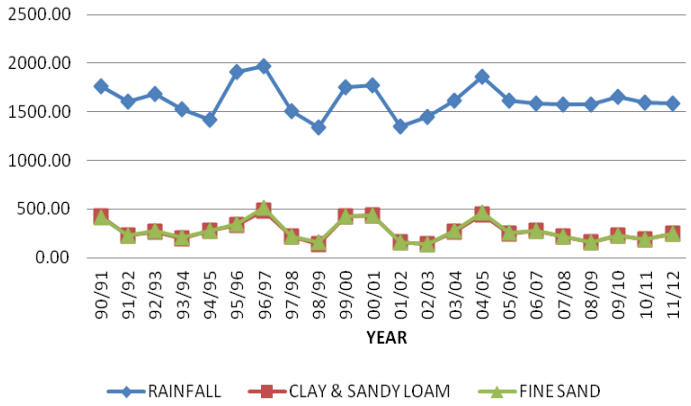

Figure 11. Trend of variation of annual rainfall and recharge.

Table 9. Correlations between recharge and rainfall.

Recharge correlation		Rainfall
Recharge clay and sandy loam	Pearson correlation	0.848**
	Sig. (2-tailed)	0.000
	N	22
Recharge fine sand	Pearson correlation	0.852**
	Sig. (2-tailed)	0.000
	N	22

**: Correlation is significant at the 0.01 level (2-tailed).

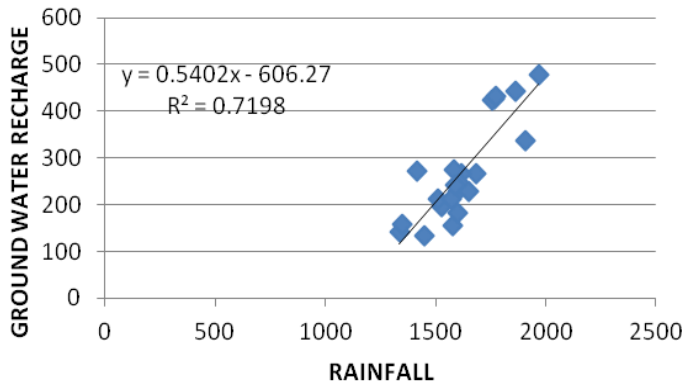

Figure 12. Regression analysis of recharge in clay and sandy loam and rainfall.

are significant at a level of p = 0.01; hence this relationship is not by chance.

The Figure 12 shows the regression analysis between ground water recharge in clay and sandy loam, and rainfall. The relationship shows a positive relationship as confirmed in the correlation analysis: y = 0.540, x – 606.2, and a coefficient of determination (r^2) value of 0.719. However, the regression analysis between recharge computed for fine sand soil and rainfall also shows a

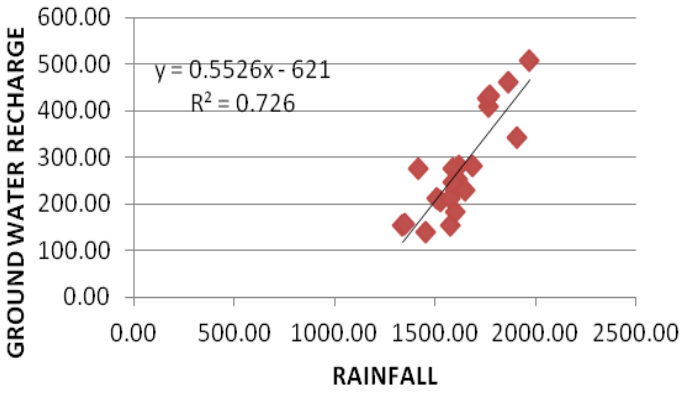

Figure 13. Regression analysis of recharge in sandy loam and rainfall.

Table 10. Ground water recharge computed.

Rainfall (mm)	SY	Range of ΔH (M)	Rn (cm)	%
1579.1	0.015	3.0	4.5	2.8
	0.015	13.5	20.25	12.8

Sy= specific yield, ΔH=peak water table rise, Rn= recharge, %= (Rn/Rainfall)*100.

positive relationship, that is, y = 0.552 x – 621, and a coefficient of determination (r^2) value of 0.726.

The r^2 values of 0.719 and 0.726 shows that there is a high relationship between observed values of rainfall and predicted values of groundwater recharge when the two equations are used (Figure 13).

Analysis of groundwater recharge result obtained from water table functuation method

It was assumed that the geologic material for the area is gneiss with specific yield (sy) of 1.5%. By multiplying the specific yield with the change in peak water rise, a recharge ranging from 4.5 to 20.25 cm (Table 10) was computed. In addition, the recharge percentage of rainfall was found to be between 2.8 and 12.8%.

Comparison of the two results

The percentage of rainfall that eventually becomes groundwater recharge in the Ona River basin ranges from 24.44 to 9.20% for the soil moisture balance method, and 19.4 to 1.9% for the water table fluctuation method. This shows that it can be concluded that the total percentage of rainfall that becomes groundwater recharge in the Ona River basin ranges from 2.8 to 24.44% (Table 11).

Table 11. Annual groundwater recharge computed from the two methods.

Method	No. of years	Range RN (mm)	Range %Rn
SMBM	22	478.99 - 133.35	24.44 - 9.20
WTFM	1	220.25 - 40.5	12.8 - 2.8

SMBM = Soil moisture balance method, WTFM =Water table fluctuation method, Rn = Recharge.

Conclusion

A quantitative evaluation of spatial and temporal distribution of groundwater recharge is a pre-requisite for the management of ground water resources system in an optimal manner. The amount of groundwater recharge depends upon the rate and duration of rainfall, as rainfall is the principal means for replenishment of moisture in the soil water system and recharge to ground water. This paper has investigated the relationship between rainfalls and groundwater recharge within Ona River basin southwest Nigeria, using two methods. The soil moisture balance and the water table fluctuation.

Analysis of rainfall trends within the Ona River basin suggests that there is considerable high annual rainfall occurrence, with a mean of 1623.48. Only eight years of the 22 years of study can be considered wet years, as the rainfall values of the eight years exceed the mean. It must be noted that the mean annual loss due to evapotranspiration of 1361.68 mm is very high when compared to the rainfall (83.9%).

The results obtained from the soil moisture balance when considering the three dominant soil types within the basin, that is, sandy loam, clay and find sand, having water capacity of root zone value of 70, 70, and 50 respectively, suggests that groundwater recharge follows a positive trend as the corresponding rainfalls. However, empirical relationships of: $y = 0.540x – 606.2$, with a coefficient of determination (r^2) value of 0.719, for sandy loam and clay; and $y = 0.552x – 621$, with a coefficient of determination (r^2) value of 0.726 for fine sand was established for the basin area. On the other hand, recharge ranging from 220.25 to 40.5 mm was computed from the water table fluctuation method.

The general conclusions drawn from this study are groundwater recharge within the Ona River basin follows a positive trend as rainfall, and that this recharge ranges from 2.8 to 24.44% of rainfall.

RECOMMENDATIONS

In other to carry out this study successfully, data from NIMET synoptic stations were obtained. As a result, the study was limited to little data recorded at this station only; therefore, it is recommended that more synoptic stations should be installed across the basin area in other to have a consistent data which would result in a more accurate study of groundwater recharge.

River basin development authorities such as the Ogun-Oshun River Basin Development Authority (OORBDA) should carry out comprehensive studies concerning the groundwater resources of the Ona River basin, as well as provision of sophisticated equipments that will aid groundwater studies. However, to improve the reliability of ground water recharge estimates, the authority must monitor aquifer behavior on a continuous or periodic basis to ensure that adequate data are available.

A 1998 international recharge estimation workshop concluded that no single comprehensive estimation technique can yet be identified from the spectrum of method available; all are reported to give suspect result. Hence, groundwater recharge estimation must be treated as an iterative process that allows progressive collection of aquifer-response data and resources evaluation. This can only be achieved by professionals in the field of ground water hydrology; therefore, the employment of professionals must be addressed.

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