GROUNDWATER RECHARGE USING BASEFLOW RECESSION ANALYSIS IN SOUTHWESTERN NIGERIA

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ABSTRACT

Baseflow recession analyses of Yewa and Ona rivers were carried out with a view to determining and comparing groundwater recharge in parts of the sedimentary and Basement Complex terrains of Southwestern Nigeria. Daily discharges of the rivers for ten years (1988 – 1997) were analysed. Groundwater recharge in Yewa Basin, located in a sedimentary area was 27.3 mm while that in Ona Basin, which is mostly urban and located within the Basement Complex, was 63.6 mm, representing 2.3% and 5.3% of the annual precipitation of the study area respectively. Baseflow were 21.5 mm and 65.3 mm, representing 34% and 8% of the average annual total runoff of Yewa and Ona rivers respectively. Ona Basin had a comparatively lower groundwater recharge than Opeki Basin (with 137.4 mm), which is in a similar terrain but in a rural environment of Southwestern Nigeria, indicating the negative effects of vegetation clearing and developmental activities, typical in urban environments, on infiltration and consequent increase in direct runoff and reduction in groundwater recharge. Identification and preservation of groundwater recharge areas, especially in urban environments, is therefore imperative in the sustainable management of groundwater in the study area.

Keywords: Groundwater Recharge, Baseflow Recession Analysis, Yewa Basin, Ona Basin, Opeki Basin, Southwestern Nigeria

INTRODUCTION

Groundwater recharge can be defined as an addition of water to a groundwater reservoir (Beekman and Xu, 2003). It normally takes place though infiltration of precipitation, but it can also occur as seepages from surface water bodies (like lakes, rivers and canals) and lateral or vertical inter-aquifer flow (MacDonald *et al.*, 2005). Typically, it travels vertically downwards through the unsaturated zone to the water table, from where it flows according to the hydraulic gradient, until it reaches an area of discharge where it occurs as springs or seepages, providing part of the dry season flow and constituting part of the streamflow hydrograph. Streamflow hydrographs are usually considered as consisting of two components; baseflow and direct runoff (Hammond and Han, 2006). The baseflow is regarded as the underlying dry season runoff and derives from delayed interflow and groundwater flow, while the direct runoff is the part that derives from surface or near-surface flow (Mazvimavi, 2004). A number of techniques for separating baseflow from direct runoff can be found in the literature (UNESCO, 1972; Tallaksen, 1995; Chapman, 1999; Eckhardt, 2005; Hammond and Han, 2006). Separation of the stream hydrograph into the two components is necessary in investigations concerning water balance of catchments and the relationship between surface water and groundwater. Such investigations enable the determination, not only of the groundwater contribution to the total stream flow, but are also useful for adequate water resources management and modelling (Carter and Driscoll, 2006), estimation of sustainable yield from aquifers and prediction of the impacts of underground construction (Rodhe and Bockgård, 2006).

Determination of the available groundwater resources and estimation of sustainable yields from aquifers have become essential in Nigeria considering the prevalent exploitation of groundwater in the country, which has raised concerns about its sustainability and the need for reliable estimates of groundwater recharge (Goni *et al.*, 2005; Goni, 2006). Groundwater development in Nigeria has increased tremendously over the last decade and many governmental and non-governmental organizations seek to improve the critically limited access to potable water, especially in the rural areas, through the construction of water wells. The importance of groundwater, therefore, in the overall development of Nigeria's economy cannot be over-emphasised (Goni, 2008) It has been estimated that over 75% of the population rely on groundwater for domestic consumption only (Goni, 2006) and that over 50 percent of the accessible and renewable fresh water resources in the country has been committed already (Musa, 1997). This means that even in Nigeria, where the available groundwater and surface water resources have been estimated to be 50 million trillion ℓ/year (Akujieze *et al.*, 2002) and 224 trillion ℓ/year (Hanidu, 1990) respectively, competition for water may soon become as serious as it is in some other parts of the world that are less endowed.

The evaluation of groundwater recharge is commonly done by the consideration of the difference between rainfall and evapotranspiration estimates, taking into account any surface – runoff (Ogunkoya, 2000; Sjodin *et al.*, 2001). In this study, however, the evaluation of groundwater recharge is done by analysing the stream hydrographs and recession equations of the two major rivers in Yewa and Ona drainage basins. The method has been used for the evaluation of Opeki drainage Basin, also in southwestern Nigeria, by Idowu and Martins (2007), and the results obtained were compared with the results of this study in order to provide a broad view of southwestern Nigeria. While the Yewa is located within the sedimentary terrain, the area where this study covers in Ona Basin, Figure 1 (i.e. upstream of Fidiwo, where the gauging station was located), is located entirely within the Basement Complex, where crystalline rocks occur, thereby making a comparison of groundwater recharge between the sedimentary rock and Basement Complex terrains of Southwestern Nigeria possible. The characteristics of the two drainage basins are presented in Table 1, while the average monthly discharges of the Yewa and Ona rivers are presented in Figure 2.

The Ona Basin falls within the Pre-Cambrian rocks of southwestern Nigeria, which is part of the Nigerian Basement Complex. The major rock types are schist-quartzites, granite-gneiss, banded gneiss, augen-gneiss, and migmatites (Jones and Hockey 1964; Olayinka *et al.,* 1999), with minor intrusions of pegmatite, aplites, quartz veins and dolerite dykes. Gneisses are migmatized in places, and characterized by predominantly medium-sized grains while schist-quartzites occur as elongated ridges striking NW-SE (Olayinka *et al.*, 1999). The sedimentary rocks of Yewa Basin are part of the layered sequence of rocks comprising five sedimentary formations – Abeokuta (Cretaceous), Ewekoro (Paleocene), Ilaro (Eocene), Coastal Plains Sands (Pleistocene-oligocene) and the Alluvial deposits (Recent). The formations are essentially a succession of sands, clays, shales and gravels with limestone occurring in the paleocene Ewekoro Formation (Jones and Hockey 1964).

METHODOLOGY

The daily discharge records of Yewa and Ona rivers for ten years, between 1988 and 1997, formed the data base for this study. The records were collected from the Ogun-Oshun River Basin Development Authority, the Federal Government Agency responsible for the water resources development of parts of southwestern Nigeria in which the drainage basins of the study area are located. The daily discharge values were obtained from daily stage measurements by using the respective rating curves for the rivers. The rating curves were calibrated using the Valeport Baystroke BFM002 current flow meter with standard system comprising both wading and suspension sets. The data analysed cover the years in which continuous records, appropriate for this kind of study, were available. The reliability of this analysis is naturally dependent on the accuracy of the data used. The data were consequently subjected to reliability analysis by determining coefficient alpha (using SPSS 11.0 for Windows), which is a measure of the internal consistency of the data, based on the average inter-item correlation. The values obtained were 0.83 and 0.9 for Ona and Yewa rivers respectively, both of which indicates high data consistency.

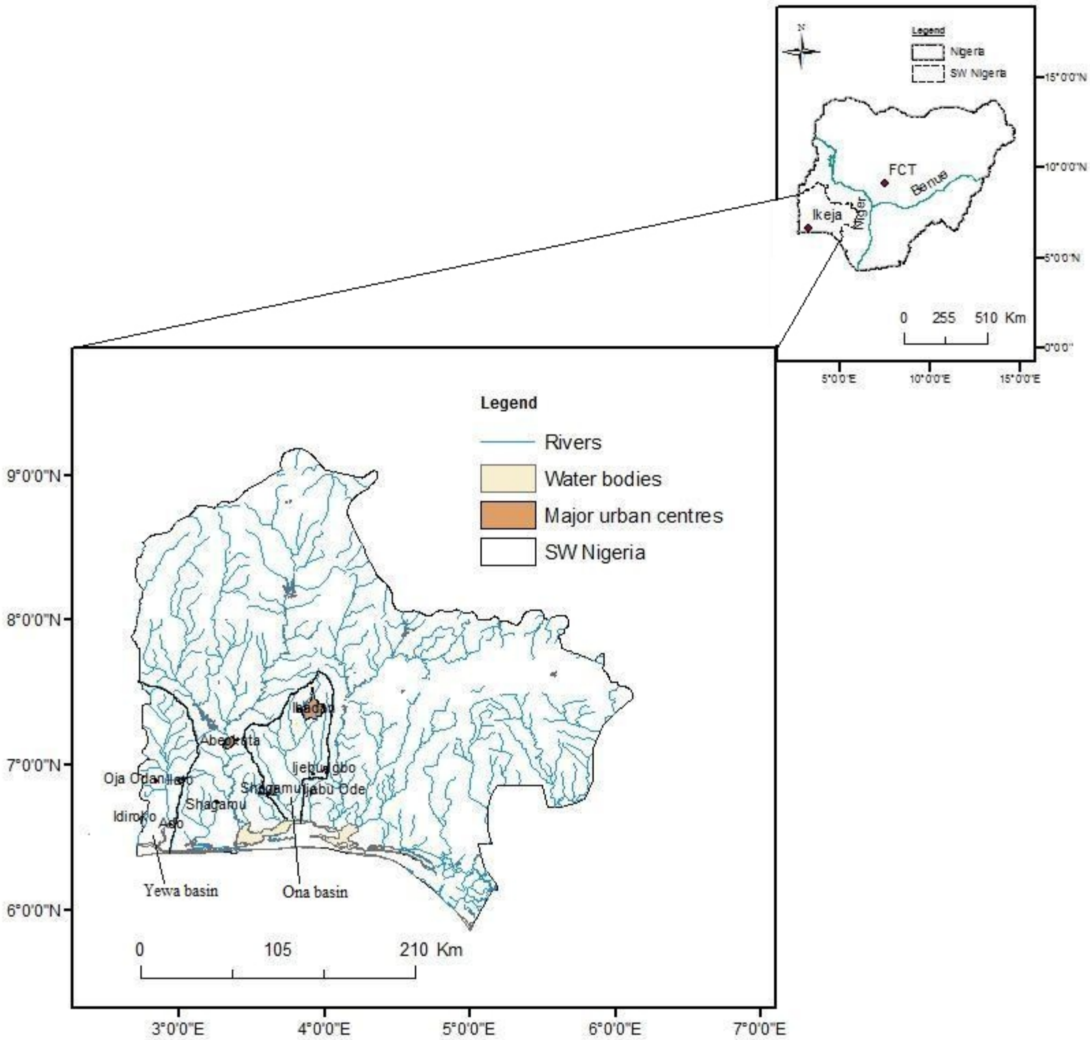

Figure 1: Map Showing the Study Area

Table 1: Characteristics of Yewa and Ona Drainage Basins

Parameters	Yewa	Ona
Location (latitude and longitude)	6^0 34' – 7^0 30'N 2^0 54' – 3^0 05'E	6^0 30' – 8^0 20'N 3^0 23' – 4^0 00'E
Geology	Sedimentary	Basement
Area (km^2)	4 700	6 483
Axial length (km)	130	170
Form factor	0.3	0.2
Basin circularity ratio	0.5	0.5
Elongation ratio	0.7	0.5
Discharge measurement location	Ajilete	Fidiwo
Average annual discharge (x10^8 m^3)	1.62	26.70

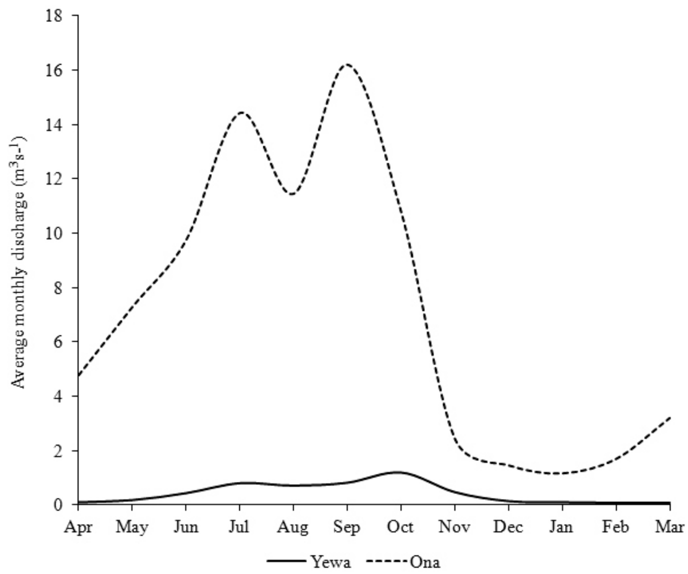

Fig. 2: Mean Monthly Flow of Ona and Yewa Rivers from 1988 – 1997

The hydrograph of baseflow may be represented as (WMO, 1974; Korkmaz, 1990):

$$Q_t = Q_o e^{-\alpha t} \qquad (1)$$

where Q_o and Q_t are the discharges at the beginning of the measurement period and at time t respectively, and α is the coefficient of recession or discharge coefficient.

In logarithmic form to base 10, the exponential formula (Eq. 1) was transformed into:

$$\log Q_t = \log Q_o - 0.4343\alpha t \qquad (2)$$

The discharge coefficient was obtained directly from Eq. (2) via

$$\alpha = \frac{(\log Q_0 - \log Q_t)}{0.434t} \qquad (3)$$

Q_o and Q_t were obtained from the recession limb of the hydrograph for each hydrologic year from 1988 to 1997, while t is the time interval between the two. Q_o was chosen to correspond with the beginning of recession when the falloff in stream flow was consistent while Q_t corresponded to the end of the recession. This ensured that the analyses covered the periods when the streams flows were sustained predominantly by baseflow.

If the discharge is from a linear reservoir as assumed in this study, then

$$Q = \alpha V \qquad (4)$$

where V = storage capacity or dynamic reserve (m^3)

Q = groundwater discharge ($m^3 day^{-1}$)

α = coefficient of recession or discharge coefficient (day^{-1})

On converting the measurements in seconds to days

$$V = \frac{86400Q}{\alpha} \qquad (5)$$

Eq. (5) applies at each instant so that if Q in Eq. (5) was taken as Q_t of Eq. (1), then

$$V = (86400\ Q_o/\alpha) \exp(-\alpha t) \qquad (6)$$

For a given time period, $\Delta t = (t_o - t_m)$, quantitative data about the dynamic reserve at the end of the period (t_m) may be calculated from the following equation (Korkmaz, 1990):

$$V_m = V_o + R - Q \qquad (7)$$

where V_m = dynamic reserve at the end of the period, t_m (m^3)

V_o = dynamic reserve at the beginning of the period, t_o (m^3)

R = groundwater recharge volume during the time period Δt (m^3)

Q = groundwater discharge volume during the time period Δt (m^3)

The difference between the dynamic reserve (V_m) at the end of a chosen water year (t_m) and the dynamic reserve at the beginning of the water year (t_o) is the dynamic reserve change (ΔV). The volume of groundwater recharge during the water year was determined from

$$R = Q \pm \Delta V \quad (8)$$

where R = groundwater recharge volume during the water year (m^3);
Q = groundwater discharge volume during the water year (m^3);
ΔV= dynamic reserve change during the water year (m^3)

In this analysis, the water year was taken as beginning in March when the rainy season usually starts as observed from the precipitation data. The groundwater discharge (baseflow) volume during the water year for each of the two rivers was obtained by separating the hydrograph of the total monthly flow of the rivers into surface (direct runoff) and subsurface (baseflow) components using the simplest and most common method of hydrograph separation (WMO, 1974; Linsley *et al*, 1982; Bras, 1990; Watson and Burnett, 1995). This was done by extending the baseflow recession curve that existed prior to the influence of the storm to a point directly under the storm peak (Figure 3). A straight line was then drawn to join that point to the point of greatest curvature on the recession limb of the hydrograph. The area under the curve above the line represented the surface component while the area below the line represented the subsurface component.

The precipitation data employed in this study were those obtained from the Ogun-Oshun River Basin Development Authority Headquarters in Abeokuta, which is central to the location of the two drainage areas under study. In order to appreciate the estimated amounts of baseflow, direct runoff and groundwater recharge, these values were compared with the average annual

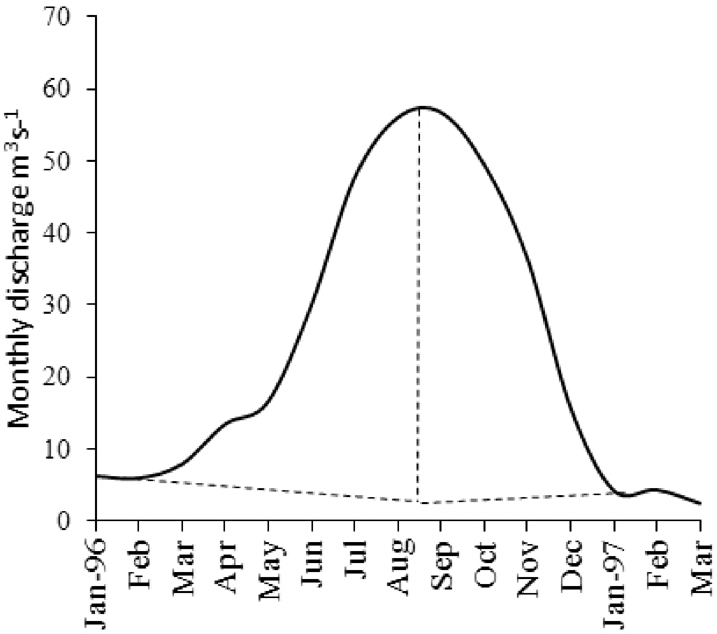

Figure 3: Hydrograph Separation Technique (Watson and Burnett, 1995)

RESULTS AND DISCUSSION

The summary of the results are presented in Table 2.

Table 2: Summary of Results

Water Year	Annual Rainfall (mm)	Discharge Coefficient, □ (day^{-1})			Dynamic Reserve Change (mm)			Baseflow (mm)			Recharge (mm)		
		Yewa	Ona	Opeki	Yewa	Ona	Opeki	Yewa	Ona	Opeki	Yewa	Ona	Opeki
88/89	1576	0.056	0.022	0.018	12	-33	29	26	45	188	38	12	217
89/90	1223	0.039	0.016	0.02	-40	3	6	18	64	128	-22	67	134
90/91	1336	0.032	0.019	0.015	32	-1	-12	14	51	277	46	51	265
91/92	1165	0.029	0.017	0.035	-40	6	-22	30	60	71	-10	65	49
92/93	1145	0.031	0.052	0.037	12	4	5	23	45	51	35	49	56
93/94	941	0.016	0.022	0.034	12	-12	-1	11	22	30	23	10	30
94/95	1030	0.005	0.028	0.013	12	33	11	20	90	113	32	123	124
95/96	1244	0.04	0.044	0.027	12	5	4	24	125	203	36	130	207
96/97	1058	0.014	0.025	0.02	40	-20	-19	27	86	174	67	66	155
Average	1191	0.03	0.03	0.02	5.78	-1.73	0.01	21.5	65.3	137.2	27.3	63.6	137.4
% of Average Annual Total Runoff								34	8	20			
% of Average Annual Rainfall											2.3	5.3	11.5

The results from Opeki Basin, obtained by Idowu and Martins (2007), were also included for comparison. The calculated average annual groundwater recharge in Yewa and Ona Basins were 27.3 mm and 63.6 mm respectively. These values represented 2.3% and 5.3% of the average annual rainfall of 1190 mm in Abeokuta for the period of study. Baseflow were 21.5 mm and 65.3 mm, representing 34% and 8% of the average annual total runoff of Yewa and Ona rivers respectively. The recharge, as well the baseflow of Ona Basin, were higher than those for Yewa, although the baseflow of Yewa represented a higher percentage of the total runoff. That may be a reflection of the geology of the respective basins, as Yewa is located within a sedimentary terrain, while Ona is located within the Basement Complex. The floodplains, as well as the aquifers, in sedimentary terrains are usually extensive (Idowu and Ajayi, 1998) and therefore provide a greater storage of water (during the raining season when flooding is common in the study area) from where discharge, in the form of baseflow, occurs during the dry season. In comparison, the floodplain and aquifers in Basement Complex terrains are usually restricted and storage within them, therefore, may not be as high as in sedimentary terrains. Within the sedimentary terrain of Sokoto Basin, groundwater recharge, determined from the analysis of streamflow hydrographs of Sokoto river at Wamako in northwestern Nigeria, was 29 mm, representing 4% of the annual rainfall (Adelana *et al*, 2006).

The groundwater recharge and baseflow in Opeki Basin, which is also located within the Basement Complex of southwestern Nigeria like Ona Basin, were 137.4 mm and 137.2 mm respectively. In comparison, however, the groundwater recharge and baseflow in Ona Basin are lower. Ona drains most parts of Ibadan city, the biggest city in Nigeria, as well as parts of Ijebu-Ode and Sagamu towns, whereas Opeki Basin is rural. In urban centres, unlike in rural areas, clearing of vegetation for development, driven by population growth and economic activities, results in the loss of vegetation cover and groundwater recharge areas, consequent less infiltration of rainfall, increased direct runoff and reduction in groundwater recharge (Alayande and Chukwuemeka, 2010).

CONCLUSION

Baseflow recession analyses of Yewa and Ona rivers have not only permitted the estimation of groundwater recharge in Yewa and Ona Basins, but have also enabled the comparison of the estimates in the sedimentary and Basement Complex terrains of southwestern Nigeria in which the basins are located. Groundwater recharge in Yewa Basin, located in a sedimentary terrain, was 27.3 mm while that in Ona Basin, located in the Basement Complex, was 63.6 mm representing 2.3% and 5.3% of the annual precipitation respectively. Although the recharge in Ona Basin was higher, the baseflow of Yewa Basin represents a higher percentage of the total runoff, indicating the probable control of geology in which the floodplains, as well as the aquifers, in the sedimentary terrains are typically extensive, and therefore, provide a greater storage of water (during the raining season when flooding is common in the study area) from where discharge, in the form of baseflow, occurs during the dry season. Being mostly urban, Ona Basin has a comparatively lower groundwater recharge than in similar terrains in rural environments in southwestern Nigeria, probably because clearing of vegetation and developmental activities, typical in urban environmental, result in less infiltration of rainfall, consequent increased direct runoff and reduction in groundwater recharge. Identification and preservation of groundwater recharge areas, especially in urban environments, is therefore imperative in sustainable management of groundwater in Nigeria.

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