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Monitoring of Groundwater Recharge for Flood Management

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Abstract

This paper proposes regular groundwater recharge estimation as a viable process capable of revealing possible occurrences of flooding in drainage basins for emergency actions and future water planning. Flooding is often monitored by considering the surface water flow/stream flow level. However, changes in groundwater levels can be a source of flood forecasting information. We inferred from results obtained from hydrograph separation and water table fluctuations methods carried out from stream flow and twenty (20) groundwater level monitoring in Ogun River basin that regular estimation of groundwater recharges in the basin area can assist in establishing the peaks of fluctuations, which can be a vital flood prevention mechanism.

Key words: groundwater recharge, flood management, hydrograph separation, water table fluctuations, Ogun River basin

Introduction

No doubt groundwater remains an important water supply source worldwide. It is the source of about one third of global water withdrawals and provides drinking water for a large portion of the global population (Parker, 2000). However, the spatial irregularities in the occurrence of groundwater and the extraction pattern with associated environmental and ecological problems is a task many groundwater resource managers in many countries are facing, despite the fact that the world's aggregate groundwater appears abundant (Macdonald *et.al*, 2012). The Ogun River and its tributaries are major source of recharge to groundwater in the underlying aquifers, and both the river and groundwater are vital sources of water to the city of Abeokuta and adjoining communities. The impacts of climate change are being witnessed, in form of high intensity of rain leading to flooding on one part and drought in the other, all revealing groundwater level fluctuations. Drought and flooding affect groundwater recharge. Recharge here refers to long-term average renewable groundwater resources, via increases in mean temperature, precipitation and sea level variability (Zbigniew, 2009). According to Zbigniew (2009), groundwater recharge is projected to increase in the warming world, but many semi-arid areas that suffer from water stress already may face decreased groundwater recharge. However, in areas with a land surface elevation of a few metres or more, groundwater availability is more strongly impacted by changes in groundwater recharge.

Floods, as a form of disaster, occur when soil and vegetation cannot absorb all the water; water then runs off the land in quantities that cannot be carried in stream channels or retained in natural ponds and constructed reservoirs. Periodic floods occur naturally on many rivers, often as a result of heavy rain causing rivers to overflow their banks.

Ogun River flood plains have been attractive locations for urban development for reasons such as sources of water and food, its potential for cultivation (Montz, 2000), and to satisfy status taste (Isheri Housing Estate etc), with settlements locating close to river valleys or spread onto the flood plains (Lafenwa, Ita eko, Adigbe). The topographical changes to flood plains resulting from urbanization can have influence on the location, timing and extent of flooding (Montz, 2000). Series of flooding witnessed in the southwestern cities of Nigeria are related to unmanaged drainage based flooding and lack of understanding of the impact groundwater level plays in this. Flooding has been a great challenge in Nigeria as it has contributed immensely to the loss of human and property and little effort has been spent to solve it hydrologically. This paper intends to infer from groundwater recharge estimation results, obtained using hydrograph separation methods and water level fluctuations in Ogun River basin, to argue for the regular monitoring of groundwater levels, which can alert managers and citizen on possible occurrence of flooding, with the aim of achieving a considerable reduction in the havoc that could be done in Ogun River Basin.

Study Area

The Ogun River basin is located in southwestern Nigeria, bordered geographically by latitudes 6^{o} 26' N and 9^{o} 10'N and longitudes 2^{o} 28'E and 4^{o} 8 'E (Figure 1). The land area is about 23,000km^{2}. The relief is generally low, with the gradient in the north-south direction. The Ogun River takes its source from the Iganran hills at an elevation of about 530 m above mean sea level and flows directly southwards over a distance of about 480 km, before it discharges into the Lagos lagoon (Martins, 1987). The major tributaries of the Ogun River are the Ofiki and Opeki Rivers. Two seasons are distinguishable in the Ogun river basin; a dry season from November to March and a wet season between April and October. Mean annual rainfall ranges from 900 mm in the north to 2000 mm towards the south. The total annual potential evapotranspiration is estimated at between 1600 mm and 1900 mm (Martins, 1987).

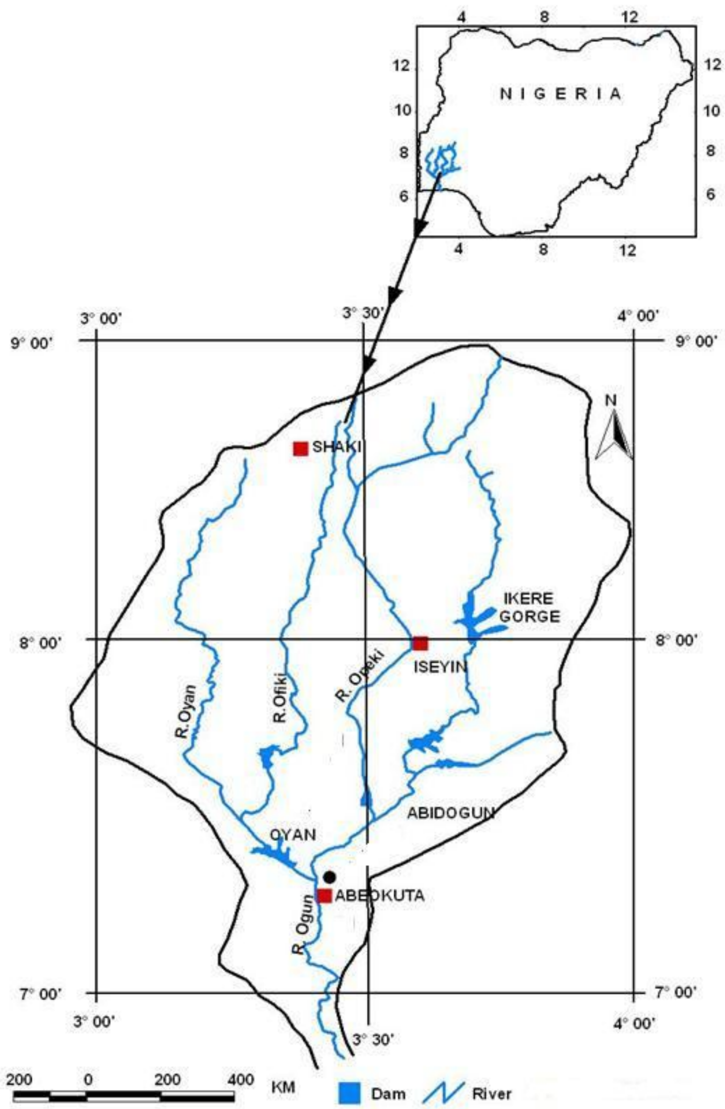

Figure 1: Map showing Ogun drainage basin

The two major vegetation zones that can be identified in the basin are the high forest vegetation in the north and central parts, and the swamp/mangrove forests that cover the southern coastal and floodplains, next to the lagoon. The geology of the study area is described as a rock sequence that comprises of the Precambrian Basement (Jones and Hockey, 1964) and which consists of quartzites and biotite schist, hornblende-biotite, granite and gneisses. The foliation and joints on these rocks control the course of the rivers, causing them to form a trellis drainage pattern, particularly to the north of the study area. The sedimentary rock sequences are from Cretaceous to Recent; the oldest of them, the Abeokuta formation, consists of grey sand intercalated with brown to dark grey clay. It is overlain by Ewekoro formation, which typically contains thick limestone layers at its base. About 9 km upstream of Abeokuta town, there is a sharp change in land gradient, changing the river morphology from fast flowing to slow moving and leading to the formation of alluvial deposits overlying the sedimentary formation of Ewekoro, Ilaro and Coastal plain sands, in sequence towards the Lagos lagoon.

Material and Method

Hydrograph separation technique and groundwater level fluctuation were employed in quantifying the recharge, while the variation shows the effect, which if properly understood, can help in preventing flooding in the drainage basin.

Rainfall data were obtained from the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos State data base. Stream level data of River Opeki were obtained from Ogun-Osun River Basin Development Authority (OORBDA). Groundwater level fluctuation of twenty monitoring wells scattered within Abeokuta were used.

Baseline data

Topographical map, digital elevation map showing the contour of the basins and land uses map of the basins showing build-up on the flood plain and its impact on flood pathways, and the potential for groundwater flooding.

Hydrograph Analysis

Stream level data were obtained from OORBDA for the hydrological year 1988 -2009. Discharge was estimated using rating equation. Some of the data were given in both height and discharge, constant a and b were calculated as 6.65 and 1.9 respectively. Average monthly discharge was estimated. Discharge coefficient estimation was calculated using Equation 1.

$$(\log Q_0 - \log Q^t)/0.434t \qquad (1)$$

where Q_0 was selected on the recession limb of each hydrographs, the log scaled hydrograph was used to detect the point where the recession starts. Q_t is the end of each recession, t the days between these points. Hydrograph separation analysis was carried out where; Q_0 and Q_m represent the beginning and end of the dynamic reserve in March. The V_o and V_m values was derived from the equation Q86400/a, where a, is the average discharge coefficient. The groundwater recharge was the addition of base flow and the dynamic reserve change.

Water level fluctuations

Twenty (20) groundwater monitoring wells were picked in Ogun floodplain. Monitoring of water levels was undertaken on a weekly basis for a year at starting from January, 2011 to December, 2011 using water level indicator. The average of the monthly groundwater levels fluctuation was obtained from the weekly readings taken. As well as water levels, river flows are routinely measured within the study area by OORBDA on the River Ogun and its tributaries. Long rainfall record from the Nigeria Meteorological Station in Lagos was also used.

Results and Discussion

Baseline Data Analysis

Analysis of the topographic data for the flood plain (Figure 2), revealed the downward flow of the flood towards the Atlantic lagoon. Locations of monitored well were shown, which revealed more locations are within floodplain of Abeokuta city. The floodplain had been impacted upon by various land uses in the study area between built-up residential in the major town, natural water bodies, wetlands, and floodplain agricultural activities, among others. Water level data show that the flow of groundwater within the flood plain sediments is complex. Numerous zones of recharge from, and discharge to, the river network are observed. Groundwater levels generally fluctuate within the upper few metres of the flood plain sediments with a greater range of fluctuation occurring at the flood plain margins. In the vicinity of rivers and streams, groundwater levels generally correlate well with surface water levels, indicating good hydraulic connection.

Water Level Fluctuations, Recharge and Flood Control

For flood control and prevention, in addition to relevant engineering and policy-making improvements, non-engineering measures must be taken to reduce flood damage. It becomes important to establish an integrated flood forecasting system able to provide real-time hydrological and meteorological forecast data (NCHC, 2012).

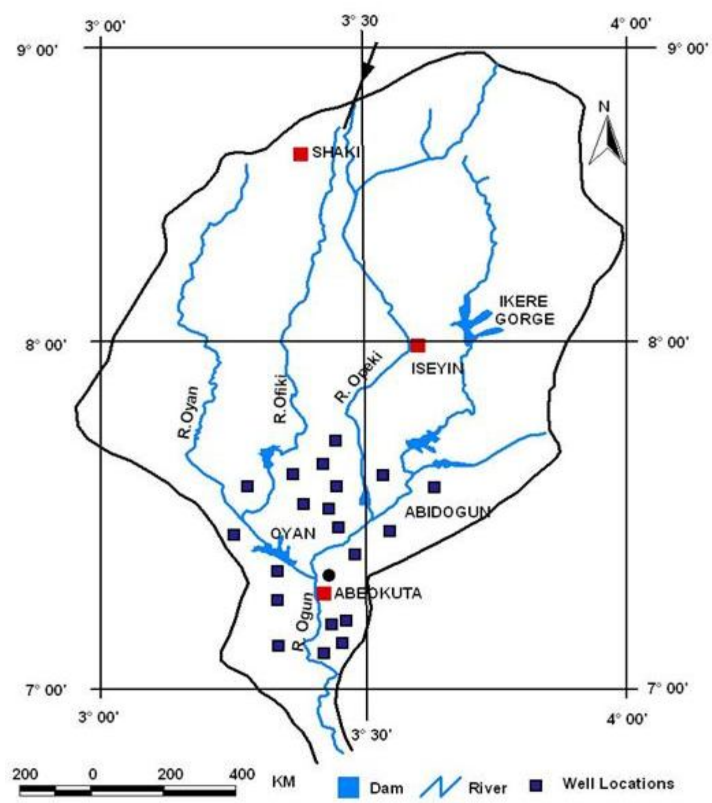

Figure 2: Map of Ogun River basin showing monitored wells location

Regarding hydrological monitoring, accurate judgments and interpretations of water level changes at various water level stations require the use of "water level identification" technology for effective result (NCHC, 2012). We used water level indicator to monitor changes in water levels in this study area. Change in height ΔH (tj) was estimated as the difference between the peak of a water-level rise and the value of the extrapolated antecedent recession curves at the time of the peak. This recession curve is the trace that the well hydrograph would have followed had there been any precipitation. The mean water table rise is 5.6. A typical example of the graph of water fluctuation against month is given below.

The result revealed that different monitoring points behave differently in terms of recharges. For example sites Well 1, Well 2 and Well 3 water level fall within number 2-4 even during dry seasons with little fluctuations. It was observed that sites were in the city of Abeokuta where most of the land has been covered by impermeable materials. This is different from sites Well 4-Well15 that are within the Lafenwa , Sabo, Adigbe- Alowonle in Abeokuta floodplain. Wells around villages close to Oyan, Well 19 and Well 20 also behave similar to Well15 maybe because of closeness to the alluvial soil of the river.

Table 1: showing monitoring wells against the months (2011)

Months	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10	Well 11	Well 12	Well 13	Well 14	Well 15	Well 16	Well 17	Well 18	Well 19	Well 20
Jan	3.3	3	3.6	5	7	8	8.3	9	8	8	8.2	7	7.5	8.7	8.9	5	4.5	5	8	8.2
Feb	3.3	3.1	3.7	5.2	7.3	8.2	8.7	9.1	8.3	8.4	8.9	7.3	7.9	9	9.2	5.3	4.9	5.1	8.2	8.3
Mar	2.4	2.2	2.9	4.5	6.5	7.4	8	8.2	7.5	7.7	8.2	7.5	6	8.1	8.2	4	4.2	4.6	6.4	6.7
Apr	2.9	2	2.7	5.3	6.4	8.3	8	8	7.4	7.6	7.1	6.4	7.6	7.05	7.1	4.4	4	4	6.3	6.6
May	2.7	2.9	2.5	4.4	6.4	7.5	7.7	7.8	7.35	7.2	7.9	7	7.05	7.7	6.7	4	3.7	3.8	5.9	5.1
Jun	2.5	2.7	2.5	4.9	6	6	7.5	8.4	6	6.1	5	4.9	6	5.9	4.3	3	3.2	3.4	5.2	4.5
Jul	2	2.3	2.3	3.9	5.7	5.3	7	7.2	6.2	5	5.1	4.6	5	4.3	4	3.2	3	3	5.4	4.7
Aug	2.2	2.4	2.5	4	5.5	5.4	6.9	7	6.5	5.3	5.5	3.9	4.2	4.5	4.2	3.5	3.1	3	5.5	5.1
Sep	1.9	2	1.9	3.2	4.8	4	5	5	5.2	4	5.4	3.8	3.9	3.3	3.6	3.6	2.5	2.6	4.2	4
Oct	2.2	2.1	2.1	3.4	4.75	4	4.9	4.8	4.1	3.9	6	5	4.1	5.3	3.9	3.9	3	2.9	4.5	4.7
Nov	3	3.2	3.5	3.3	5.6	6.5	6.8	5.9	5.8	4.2	6.3	4.9	6	6.9	5.2	4	3.5	4	6	5
Dec	3.2	3.4	3.6	4.2	6.5	7	7	7.9	6.9	6.5	7.2	6	6.3	7.2	7.1	4.6	4	4.9	7.2	7

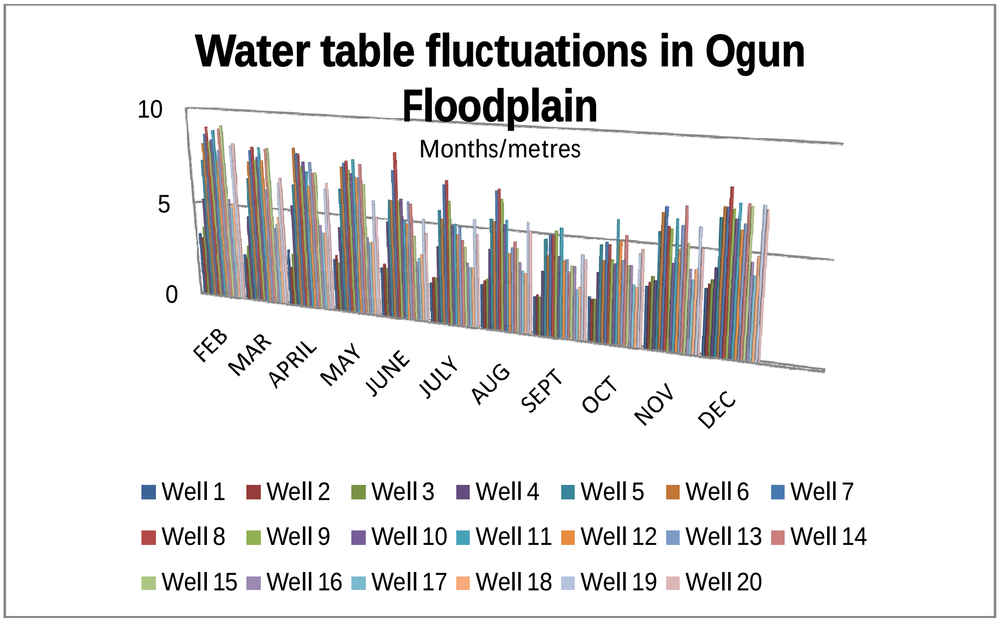

Figure 3: Water table fluctuations obtained from Twenty (20) monitoring wells in Ogun floodplain (January, 2011- December 2011)

Changes in Monthly Discharge from Ogun River tributary

Changes occurring in stream flow discharge shows variation in amount of water discharge at Opeki river of Ogun drainage basin. For example, in the water year 1988/89 varies from 0.01 in april, 1988 to 9.79 in 1989; with the highest peak in August, 1988 at July, 1988 with value of 63.55. Whereas, water year 2008/2009 gave different discharge rate and time. April 2008 had a value of 5.55 to 10.64 in March, 2009 and highest peak in September, 2009. Figure 5 below shows the variation.

The highest discharge was obtained in the year 1998/1999 and 2000/2001 water years, with values ranges between 106.84 to 99.30, with the highest being 189.36 in September 1998. Same highest discharge was also recorded in the 2007 and 2008.

The implication of this is that information gathered from stream flow data and subsequent estimation of recharge by year will reveal water behavior which can be used to predict future occurrences.

Table 2: Water year and the corresponding groundwater recharges

WATER YEAR	MARCH DISCHARGES (M3/S) Qo	Qm	DYNAMIC RESERVE (86400Q/a) (X1o**6 M**3) Vo	Vm	DYNAMIC RESERVE CHANGE (x10**6 M**3)	BASEFLOW (x10**6 M**3)	RECHARGE (x10**6 M**3)
88/89	0.02	9.79	0.070073	34.30544	34.23537	104.51	138.7454
89/90	9.79	10.75	34.30544	37.66436	3.358918	197.54	200.8989
90/91	10.75	7.66	37.66436	26.82406	-10.8403	281.69	270.8497
91/92	7.66	0.43	26.82406	1.508275	-25.3158	80.93	55.61421
92/93	0.43	3.01	1.508275	10.54293	9.034658	61.31	70.34466
93/94	3.01	2.58	10.54293	9.032494	-1.51044	72.88	71.36956
94/95	2.58	5.74	9.032494	20.09857	11.06608	160.47	171.5361
95/96	5.74	6.96	20.09857	24.3698	4.27123	160.99	165.2612
96/97	6.96	0.99	24.3698	3.46873	-20.9011	148.66	127.7589
97/98	0.99	1.91	3.46873	6.694345	3.225615	50.1	53.32561
98/99	1.91	6.93	6.694345	24.2765	17.58216	101.61	119.1922
99/00	6.93	1.91	24.2765	6.694345	-17.5822	186.64	169.0578
00/01	1.91	6.88	6.694345	24.10698	17.41263	120.88	138.2926
01/02	6.88	0.02	24.10698	0.06003	-24.0469	117.72	93.67305
02/03	0.02	2.23	0.06003	7.803696	7.743666	53.01	60.75367
03/04	2.23	0.44	7.803696	1.539894	-6.2638	56.83	50.5662
04/05	0.44	7.16	1.539894	25.10185	23.56195	63.07	86.63195
05/06	7.16	8.00	25.10185	28.02204	2.920196	122.28	125.2002
06/07	8.00	7.58	28.02204	26.56766	-1.45439	34.09	32.63561
07/08	7.58	9.09	26.56766	31.83707	5.269416	121.58	126.8494
08/09	9.09	10.64	31.83707	37.27406	5.436985	205.98	211.417

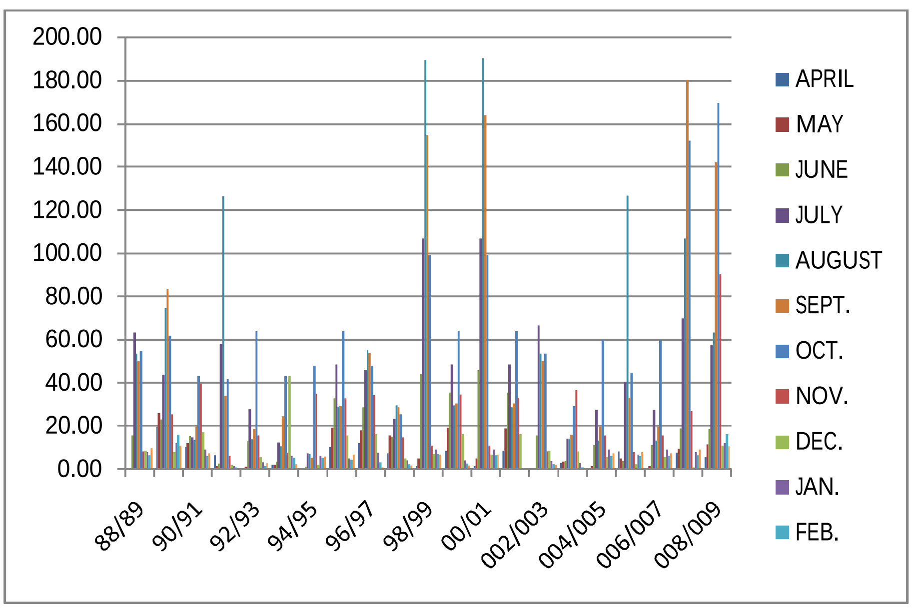

Figure 4: Graph showing average monthly discharge of Opeki river (m3/s)

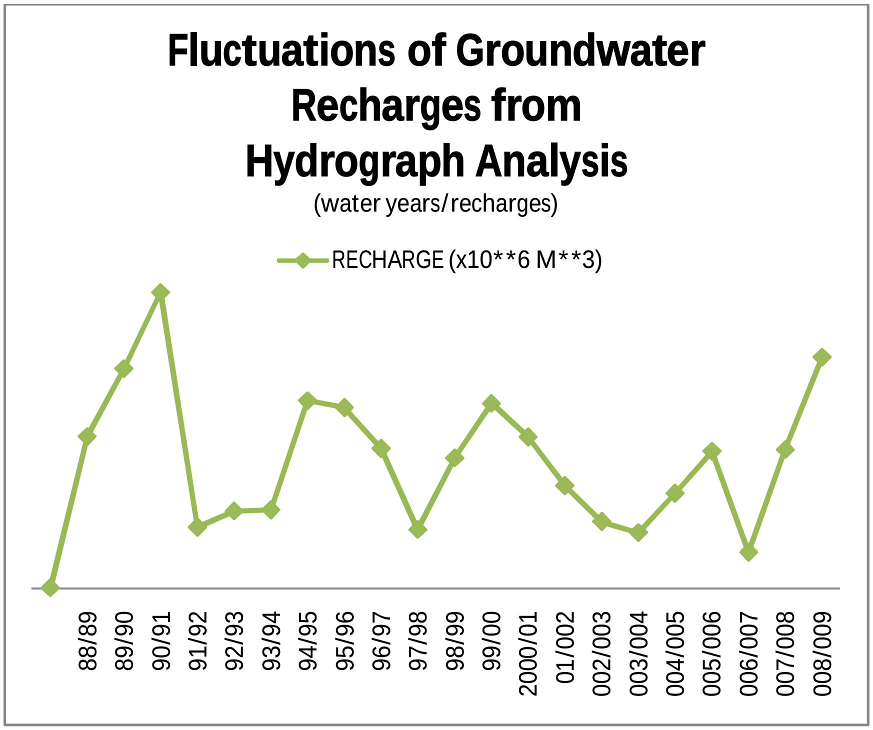

Figure 5 Fluctuations in Groundwater Recharges between 88/89 to 2008/2009 Water Years

Conclusion

Groundwater recharge had been monitored for the study area. Analysis of the topographic data for the flood plain revealed the downward flow of the flood towards the Atlantic lagoon. Various land uses had impacted on the floodplain caused by human activities such built-up residential area, hotels activities and urban agriculture, among others. Water tables generally fluctuate within the upper few metres of the flood plain sediments while groundwater levels in the river or stream area generally correlate well with surface water levels, indicating good hydraulic connection. Different monitoring points equally behave differently in terms of recharges in these floodplains. Well levels in the city of Abeokuta fall within 2-4metres even during dry seasons with little fluctuations and it is been adduced that this could have been caused by covering of the city by impermeable materials. This is different from sites that are within the Lafenwa , Sabo, Adigbe- Alowonle in Abeokuta floodplain, while wells around villages close to Oyan floodplain area behave similar because of the closeness to the alluvial soil of the river.

It is been concluded that for effective flood control and prevention, groundwater level monitoring could be a vital processes that if taken could reduce flood damage. Alongside with this, information gathered from stream flow data and subsequent estimation of recharge by year will reveal water behavior which can be used to predict future occurrences. In line with the recommendation of NCHC, (2012) regarding the use of an integrated flood forecasting to provide real time hydrological forecast data, this paper posits that accurate judgments and interpretations of water level changes at various water level stations, with the use of water level identification technology will provide an effective flood forecasting result (NCHC, 2012).

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