© DEC 2022 | IRE Journals | Volume 6 Issue 6 | ISSN: 2456-8880

Simulation of Storage Potentials and Trend Analysis of Water Level in Shallow Unconfined Aquifer System of Benin-City and Environ, Southern Nigeria

JOSHUA OLUWASANMI OWOSENI
Department of Applied Geology, Federal University of Technology, Akure, Nigeria

Abstract- Evaluation of aquifer storage potentials and groundwater level fluxes require analysis of groundwater recharge and discharge rates. Volumetric groundwater budget of the recharge and discharge of the shallow unconfined aquifer system of Benin-City and environ have been simulated using a three-dimensional groundwater flow and a particle-tracking model. This is with a view to elucidating groundwater storage potential and water level fluctuations in the area. Nine burrow pit exposures and thirty borehole logs were also studied. Well correlation and geologic cross-sections of the subsurface geology culminated in hydrostratigraphic model, and determination of saturated thickness and lateral extent of aquiferous units. Burrow pit exposures revealed occurrence of surficial reddish lateritic cover underlain by laminated loose sands varying in colour with clay and clayey-sand intercalations. Annual groundwater level fluctuations were 0.85 - 1.25 and 0.82 to 1.60 meters at Ikpoba and Ogba respectively. Thirty-year period groundwater recharge rates from precipitation and river leakage were 0 to 1.075×10^5 m^3/day and 02.737 x 10^5 to 1.114×10^6 m^3/day respectively. Groundwater discharge rates through baseflow and evapotranspiration rates were 1.165×10^4 to 4.219×10^6 m^3/day and 7.486×10^5 to 3.715×10^7 m^3/day respectively. The cumulative groundwater recharge rates (2.73×10^8 m^3/day) exceeded the discharge rates (5.07×10^7 m^3/day). Hence, the aquifer has very high storage potentials.

Indexed Terms- Borehole data, groundwater modelling, groundwater recharge,Niger Delta, trend analysis

I. INTRODUCTION

Proper analysis of groundwater recharge and discharge rates is necessary in order to estimate the storage potentials of any aquifer and the groundwater level fluxes in it. This will go a long way assisting in sustainable groundwater resources development in a rapidly growing urban area like Benin-City and environ. The phenomenal rise in population coupled with urbanization, increasing industrialization and competition for economic development has increased water demands in the area. Besides, population growth had put more pressure on the available groundwater resources on which the dwellers depend for domestic, industrial and agricultural water in the region (Nwankwoala, 2014). Idiata*et al*. (2010) anticipated a staggering demographic and water demand statistics of Benin-City for years 2010, 2015, 2020 and 2025 at growth rates of 3.3 and 1.4 % (Table 1). Conservatively, a projected population of two million and per capita demand of 120 l/day have been estimated for Benin-City with the domestic water demand put at about 240,000m^3/day (Oteze, 2011). The current study aimed at simulating volumetric groundwater budget of the recharge and discharge of the shallow unconfined aquifer system of Benin-City and environ with a view to enhancing present understanding of aquifer storage potentials and groundwater level fluxes, for sustainable groundwater development in the study area.

- *Description of the Study Area*

Benin-City and environ situate within longitude E005^o 30' and E005^o 45' and latitudes N06^o 15' and N06^o 30' in western Niger Delta, southern Nigeria (Figure 1). Average altitude in the area was about 110 m and 70 m above mean sea level towards the north and south respectively. The weather condition of the area was transitional between the equatorial and tropical types of climates with mean annual precipitation, evapotranspiration, infiltration and surface runoff of about 2280 mm, 1320.6 mm, 592.8 mm and 364.8 mm respectively (Ezeigbo& Aneke, 1993). The vegetation was generally dense with closed canopy and the rural dwellers cultivate both arable and cash crops. The drainage system was dendritic and byIkpoba River, Ogba River, Rivers Aruvbi and Okhuiahe, and their tributaries.

Table 1: Population growth rate and water demand in Benin-City and environ(Idiata*et al.*, 2010)

Year	Population (3.3% rate)	Water demand (l/day)	Population (1.14%rate)	Water demand (l/day)
2010	1,440,900	171,627,122	1,296,435	154,418,404
2015	1,694,866	201,875,527	1,372,036	163,423,203
2020	1,993,595	237,457,122	1,452,046	172,953,151
2025	2,344,977	279,310,182	1,536,721	183,038,878

- *Geological Setting*

The study area was underlain by the Benin Formation, also called Coastal Plain Sands, which is made up of predominantly freshwater continental friable sands and gravels that are of excellent aquifer properties, with intermittent intercalation of clays. The Ogwashi-Asaba Formation underlies and grades upwards into the Benin Formation and is Oligocene to Miocene in age (Doust &Omatsola, 1990).

The Ogwashi-Asaba Formation consists of sands and grits as well as lignite alternating with gritty clays. It outcrops along stream channels east of Ekiadolor and north of Uzalla localities in the north eastern part of the study area. Besides, there are recent deposits of alluvium consisting of gravels, sands, silts and clayey sands washed down the river valley and occurring along Ikpoba and Ovia flood plains (Figure 2).

II. METHODOLOGY

Subsurface geological studies were restricted to excavated pit exposures (because of largely poor accessibility to outcrops), and borehole lithologic logging.

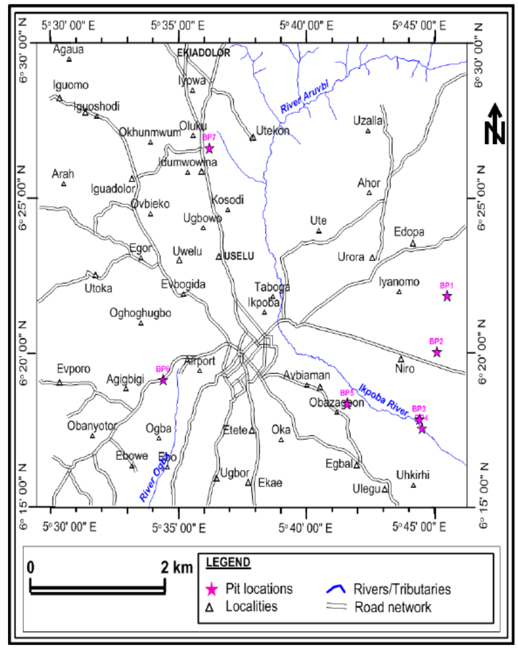

Fig. 1 Location map of Benin City and environ

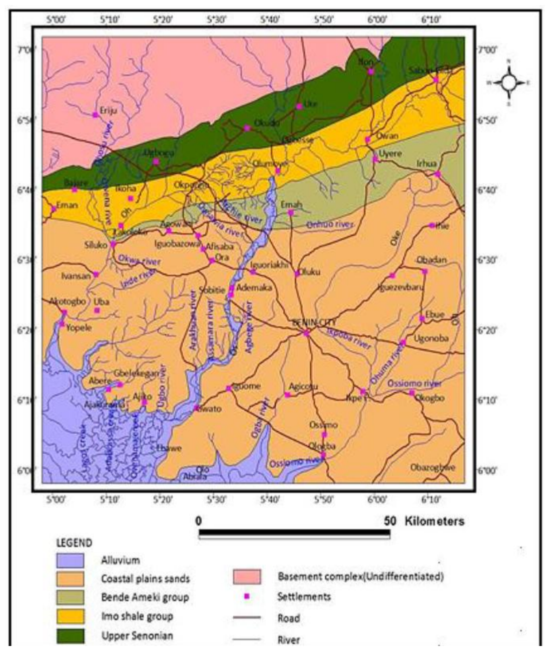

Fig. 2 Geological map of Benin-City and environ (Modified after Olatunji *et al.*, 2014)

- *Subsurface Geological Mapping*

Sub-surface geological field mapping, through litho-stratigraphic study, was carried out by visiting six (6) excavated pit locations (Figure 3) in the metropolis and one (1) borehole drilling site at Ologbo. Twentyone (21) representative soil samples were taken from various lithologic horizons encountered in two (2) active excavated pit locations (at Okhuaiha and Niro) and the aforementioned borehole drilling site at Ologbo. Ditch cuttings were sampled at depth intervals, examined and described in terms of colour, texture, lithology and depth of occurrence. The lithology at the seven burrow pit exposures were logged. Aquifer horizons were correlated from fifty borehole lithologic logs along six traverse lines using RockWorks version 15 software package.

- *Particle-size Analysis and Permeability Tests of Soil Samples*

Bulk representative soil samples were taken at depth intervals, studied and described on colour, texture, lithology and depth of occurrence. The soil samples were preserved in air-tight polythene bags for further engineering laboratory determination of their grading and permeability characteristics. The particle size analysis is significant in textural soil identification and classification. The mechanical sieving method was adopted and carried out in accordance with British standard BS 1377of 1990. It was conducted on the bulk representative soil samples in the Engineering Geology laboratory of the Department of Applied Geology, Federal University of Technology, Akure. About 500 g of air-dried soil sample was deflocculated with sodium hexametaphosphate solution for a period of about 24 hours. The samples were shaken and squeezed at intervals for proper desegregation of any iron sesquioxide and effective separation of particles to their actual sizes. Soil fractions retained on sieve No. 200 (0.063 mm) was oven-dried and subjected to sieving using mechanical sieve shaker.Permeability test was conducted to determine the hydraulic conductivities of the sampled aquifer horizons using constant head permeameter apparatus. It was conducted on the six (6) burrow pit and fifteen (15) borehole samples. The coefficients of permeability were empirically calculated using equation (1) or (2). The hydraulic conductivity values for the aquifer materials were also estimated from laboratory grain-size analysis results using equation 3 (Hazen, 1911). Typical of many natural soils, especially lacustrine and alluvial soils, is the fact that groundwater flow is much easier in the horizontal direction than vertical direction.

$$K = \frac{al}{A}\frac{(\log_e h_1 - \log_e h_2)}{t_2 - t_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$= \frac{al}{A}\frac{(\log_e h_1/h_2)}{\Delta t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Hazen's (1911) Correlation

$$K_{Hazen} = C(D_{10})^2 \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where K = hydraulic conductivity (cm/s);
C = Hazen's coefficient (Sorting and grain-size coefficient); D_{10} = effective grain size
(0.01cm< D_{10}< 0.3 cm).

III. RESULTS

- *Hydrogeologic Framework*

Lithologic logs representing Stratigraphic Sections at Burrow pit Outcrops

Figure 3 shows Lithologic logs representing Stratigraphic Sections at Burrow pit Outcrops. At Okhuaihe, three stratigraphic units were present below the top soil. The first was a yellowish-brown sand unit about 4 meters in thickness. This was underlain by a whitish loose sand horizon which extended to a depth of about 27 meters (being about 13 meters in thickness). The bottommost unit was brownish-yellow pebbly loose sand characterized by cross-bedding structural features. Around Bye-pass area, two distinct stratigraphic units were identified beneath the top soil, viz: reddish lateritic sand and whitish loose sands units which were roughly 2.5 meters and over 10 meters in thickness respectively.

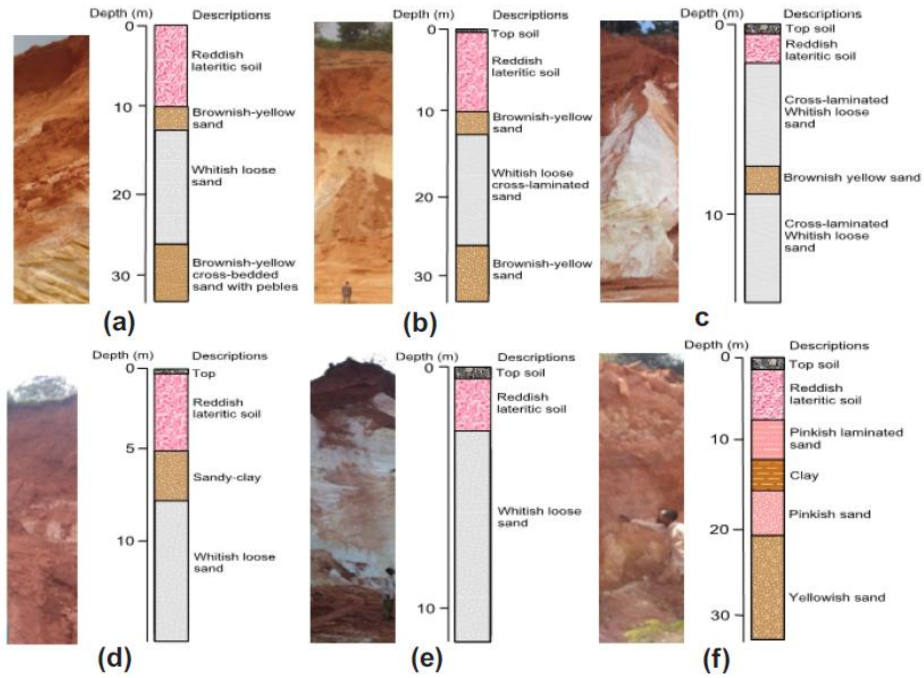

Fig. 3 Lithologic logs representing burrow pit exposures at (a) Okhuaihe (b) Bye-pass (c) Sapele Bye-pass (d) Asoro Hill (e) Bye-pass (f) Iguosa

- *Lithologic Correlation of Aquifer Horizons and Stratigraphic Cross-sections*

Aquifers were identified and correlated along some traverse lines, A - A', B - B', C - C', D - D', E - E' and F - F' (Figure 4). The results were presented in forms of stratigraphic cross-sections. Lithologic logs revealed three layers of fairly well-graded, unconsolidated, fining upward aquiferous sand deposits which were intercalated by discontinuous clays.Figures 5 and 6 show the results of lithologic correlation and stratigraphic cross-section of aquifer horizons along A – A' and B – B' traverse lines which pass through Iguadolor – Iguoshodi - Ekiadolor and Egor – Iguosa – Igbimogba respectively. Figures 7 and 8 represent the lithologic correlation and stratigraphic cross-section of aquifer horizons along C – C' and D – D' traverse lines which pass through Ogba – Igbiogboko – Ring Road – Uselu – Urora and Iguoshodi – Egor – Ogba respectively.Figures 9 and 10 represent the results of lithologic correlation of aquifer horizons along E – E' and F – F' traverse lines which pass through Igbinmogba – Urora – Ironegbo-Ogbesan – Ugbeku and Ekiadolor – Oluku– Iguosa – Ugbowo – Airport Road respectively. Generally, two main aquiferous units were recognizable in the study area. The upper water table aquifer was finer in texture than the lower confined sand aquifer.The first (uppermost) and second (middle) aquifer units constitute the model layers for groundwater flow and contaminant transport simulations.

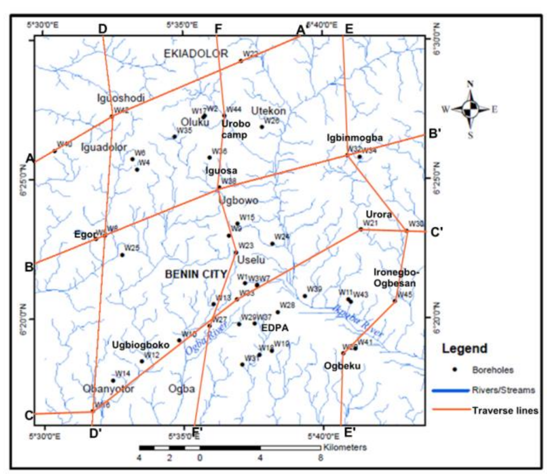

Fig. 4 Traverse lines for stratigraphic cross-sections

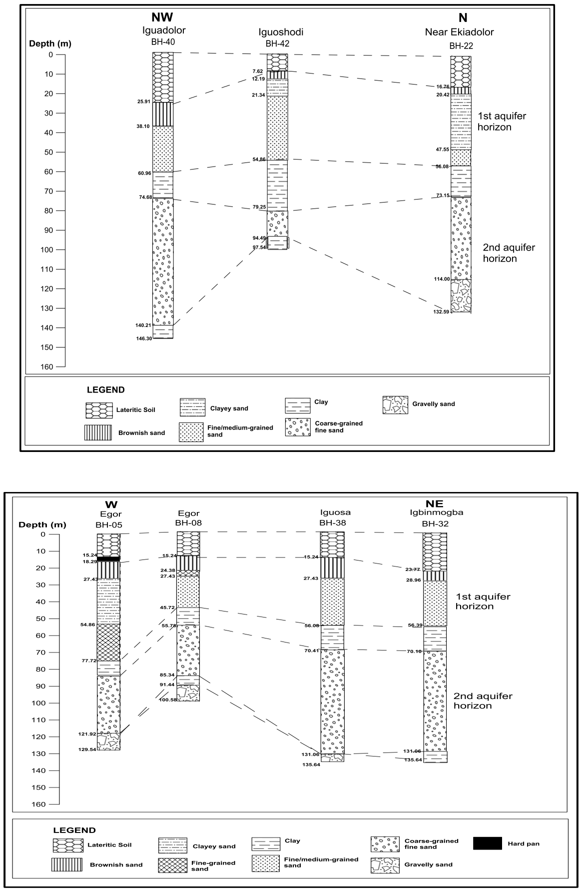

Fig. 5 Lithologic correlation of aquifer horizons along (a) A – A' traverse line (b) B – B' traverse line

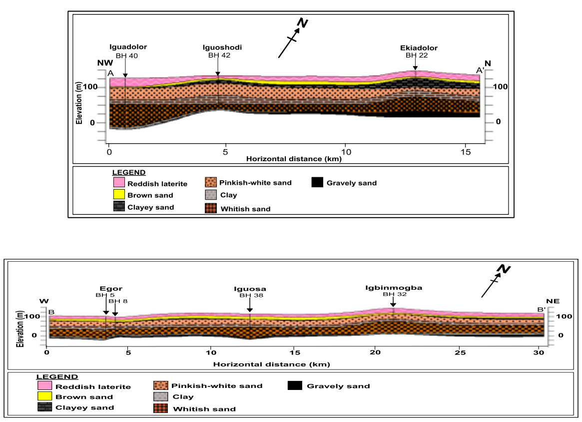

Fig. 6 Stratigraphic cross-section along (a) A – A' traverse line (b) B – B' traverse line

They were presented in the forms of stratigraphic panel (fence diagram) of Benin-City andenviron (Figures 11).The conceptualized hydrostratigraphic units, problem domain boundaries and fluxes adopted is presented in Figure 12. The geometry of upper aquifer is presented in Table 2 with indications of depth to upper and lower boundaries and thicknesses in each borehole.

IV. DISCUSSION

- Hydrogeology

From the foregoing, two main lithologies represent the subsurface geology in the study area. These are upper and lower sand deposits separated by clay intercalations. At shallow depths, there is occurrence of sandy clay or clayey sand inter-bed too. The aquiferous sand units vary in texture from fine through medium to coarse grains. Pebbly or gravely sands also occurred at depth in some of the localities. Meanwhile, there is also lignite in handful localities in places such as Urora and Oregbeni-Ogbesan. Occurrence of laterite concretions (<5 meters thick) at shallow depth (about 15 meters) was also observed in few boreholes from Okoro Egor and Urora localities respectively.

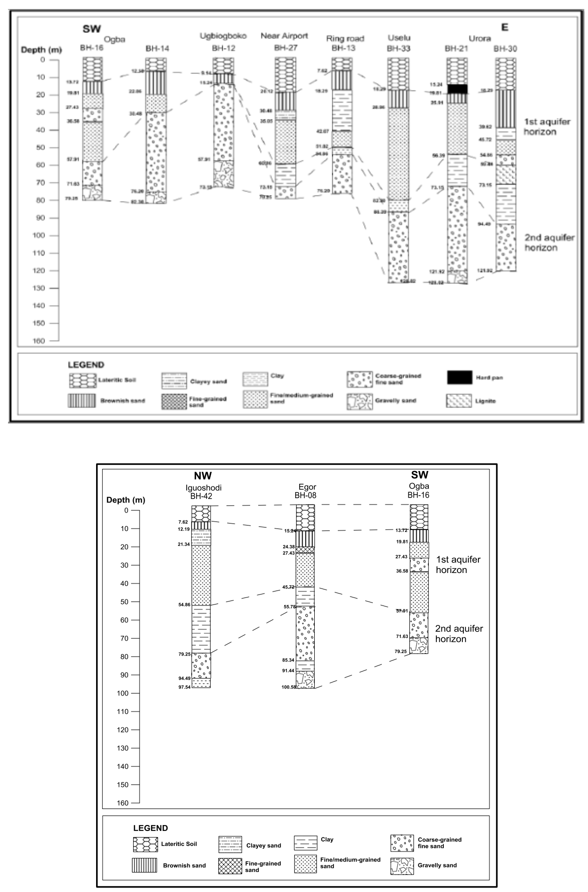

Fig. 7 Lithologic correlation of aquifer horizons along (a) C – C' traverse line (b) D – D' traverse line

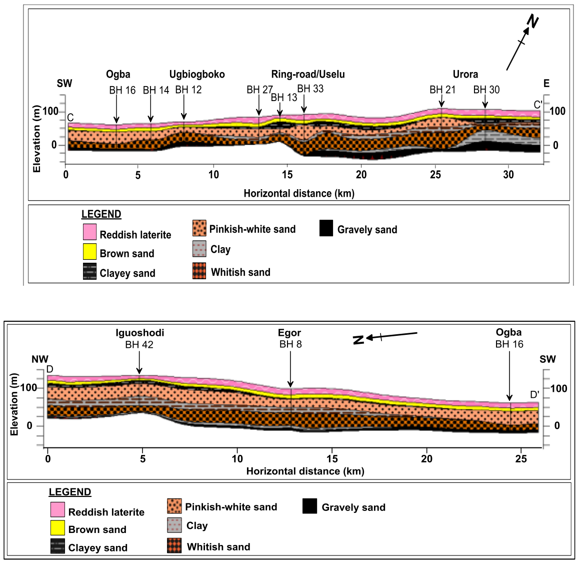

Fig. 8 Stratigraphic cross-section along (a) C – C' traverse line (b) D – D' traverse line

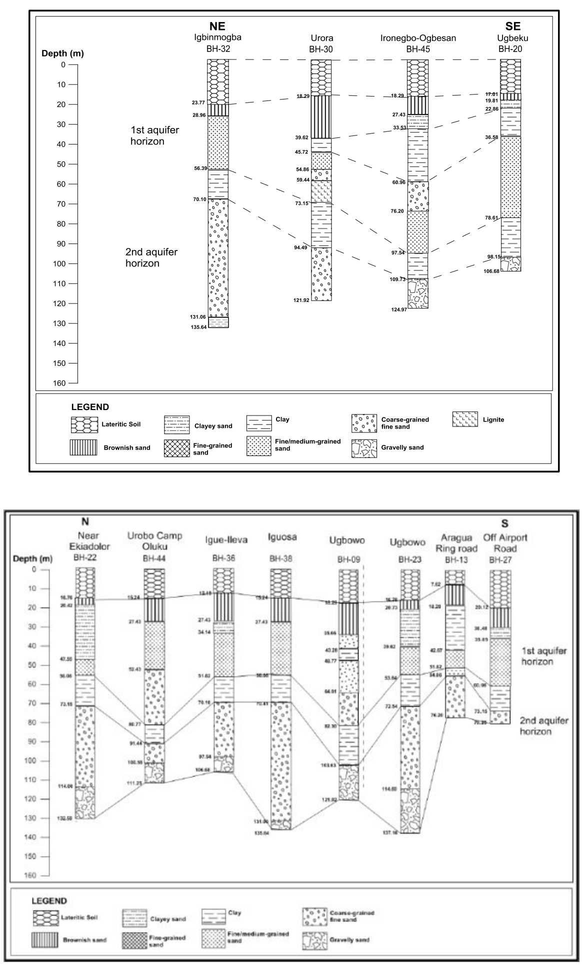

Fig. 9 Lithologic correlation of aquifer horizons along (a) E – E' traverse line (b) F – F' traverse line

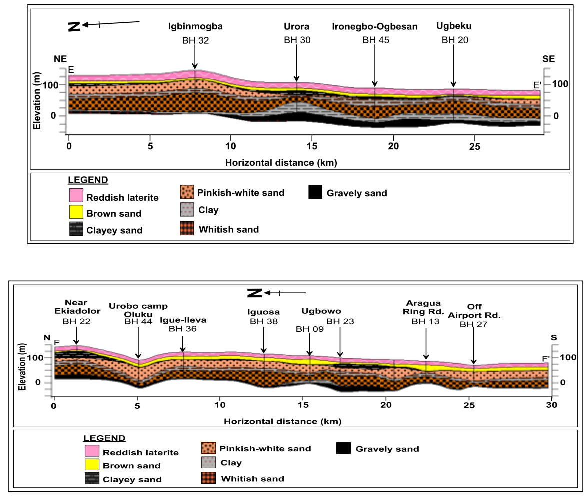

Fig. 10 Stratigraphic cross-section along (a) E – E' traverse line (b) F – F' traverse line

The sedimentary sequence penetrated by the studied boreholes had been grouped into three main aquifer systems separated by discontinuous clay layers in most parts except in some places towards the south-western part of the study area.

- *First Aquifer System*

This uppermost aquifer system was encountered at shallow depth of about 7.62 meters above mean sea level in Ring Road and at deeper depth of 60.96 meters in Iguadolor. Its average thickness was about 50 meters. It was penetrated by all the boreholes studied. The water bearing horizon consists of fairly well graded unconsolidated fine -medium grained brownish to pinkish-white sands. It is a fining upward sequence of sands whose vertical continuity is disrupted by clayey-sand (near Ekiadolor, Egor, Airport area, Iguoshodi, Ugbowo) and lignite lens (at Urora). This first aquifer horizon is separated from the lower (second) aquifer horizon by a clay unit of variable thickness (average of 16 meters) in most places except Ogba and Igbiogboko areas towards south-western part where the clay unit is missing.

- *Second Aquifer System*

This aquifer horizon occurs between 73.15 meters above the sea level around Ekiadolor and 140.21 meters below the sea level in Iguadolor. It has a thickness of about 55 to over 68 meters. The aquifer horizon consists of poorly sorted fine-medium-coarse grained pinkish- white loose sands. The grainsize increases with depth and grades into gravelly sand in some places (like Ekiadolor, Egor, Iguosa,Urobo Camp, Ugbowo, Ugbiogboko and Urora) while clay lenses underlay in other places (like Iguadolor, Iguoshodi and Igbinmogba).

Table 2 Summary of upper aquifer geometry

Borehole ID	Longitude (°)	Latitude (°)	Upper Aquifer (Depth) Upper boundary (m)	Lower boundary (m)	Thickness (m)
BH01	5.6201	6.3545	12.19	51.82	39.63
BH02	5.5965	6.4548	10.67	54.86	44.19
BH03	5.6273	6.3532	18.59	60.96	42.37
BH04	5.5558	6.4228	18.29	76.2	57.91
BH05	5.5311	6.3813	18.29	54.86	36.57
BH06	5.5532	6.4288	15.24	71.63	56.39
BH07	5.6273	6.3533	15.24	35.97	20.73
BH08	5.5365	6.3833	15.24	45.72	30.48
BH09	5.6105	6.3830	18.29	43.24	24.95
BH13	5.6012	6.3419	7.62	51.82	44.2
BH14	5.5410	6.2968	12.19	48.77	36.58
BH15	5.6157	6.3900	12.19	70.1	57.91
BH16	5.5287	6.2783	13.72	57.91	44.19
BH17	5.5957	6.4536	19.81	67.06	47.25
BH18	5.6284	6.3117	21.34	57.91	36.57
BH19	5.6359	6.3141	23.77	63.09	39.32
BH21	5.6894	6.3863	19.81	56.39	36.58
BH23	5.6149	6.3730	12.19	53.64	41.45
BH24	5.6365	6.3781	13.72	73.15	59.43
BH26	5.6306	6.4477	15.24	54.86	39.62
BH27	5.5988	6.3290	20.12	60.96	40.84
BH28	5.6395	6.3373	18.29	82.3	64.01
BH29	5.6164	6.3300	9.14	48.77	39.63
BH30	5.7167	6.3853	18.29	59.44	41.15
BH31	5.6182	6.3057	12.19	60.96	48.77
BH33	5.6153	6.3446	18.29	82.3	64.01
BH36	5.5993	6.4296	12.19	56.39	44.2
BH37	5.6256	6.3301	15.24	79.25	64.01
BH38	5.6049	6.4117	15.24	56.08	40.84
BH40	5.5068	6.4341	25.91	60.96	35.05
BH44	5.6081	6.4546	15.24	80.77	65.53
BH45	5.7095	6.3432	18.29	97.64	79.35

- *Third Aquifer System*
  The third aquifer unit was encountered at depths of 91.44, 128.22, 105.07 and 106.23 meters above mean sea level in Egor, Iguadolor, Ugbowo and Ironegbo-Ogbesan respectively. Its thickness could not be ascertained due to depth limitation of the boreholes used. The water bearing horizon consists of gravelly sands.

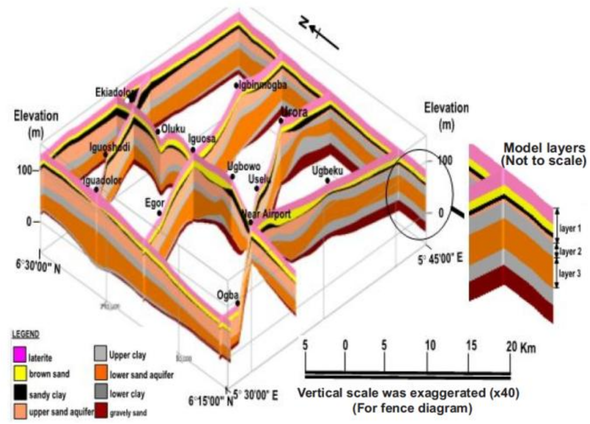

Fig. 11 Stratigraphic panel (fence diagram) of Benin-City and its environs

- *Grading and Hydraulic Characteristics of Aquifer Horizons*

The permeability coefficients of the first two aquifers from the top, varied from 4.1774 x 10^{-4} cm/s to 1.2844 x 10^{-2} and 1.0492 x 10^{-3} to 1.4346 x 10^{-2} cm/s respectively. The lithologic log of aquifer horizons in Ologbo area, near Benin-City is presented in Figure 12. The Ologbo aquifer materials are generally fairly well graded. There are indications of cycles of fining upwards sequences of deposition consistent with Akpoborie (2011) on the Neogene deposits of the Ndokwa area. Their permeability coefficients ranged from 0.00041 cm/s to 0.01435 cm/s with an average value of 0.006119 cm/s. For Okhuaihe and Bye-pass aquifer materials, the permeability coefficients varied from 0.00065 to 0.01284 cm/s and 0.000928 to 0.01101 cm/s respectively (Table 2).Fig. 13Shows the conceptualized hydrostratigraphic units, problemdomain boundaries and fluxes adopted.

- *Flow System Analysis*

The vector diagrams showing the direction of flow of water in the zone of saturation and the three-dimensional representations of the flows are represented in Figures 14 and 15 respectively. The regional flow direction is generally North-South (NE-SW-SE). However, there are intermediate and local variations which may indicate some structural controls. This is evident in the pattern of flow of the two major rivers in the area, Ikpoba and Ossiomo Rivers.

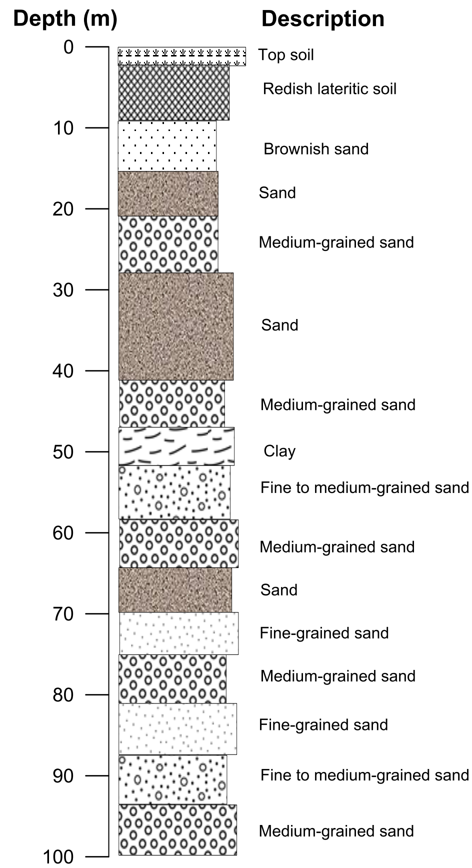

Fig. 12 Ologbo lithologic log

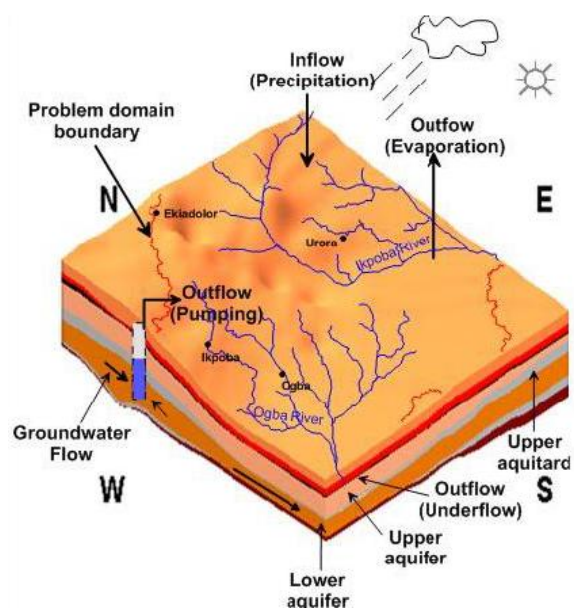

Fig. 13 Conceptualized hydrostratigraphic units, problemdomain boundaries and fluxes adopted

Table 3 Permeability characteristics of lithologic units of burrow pit exposures

Location	Longitude	Latitude	Approx. Depth (m)	Coefficient of permeability, *k* (cm/s)
RCC New pit, Okhuaihe area, Benin-Agbor Rd.	E005° 46' 1.56"	N06° 21' 47.16"	12.0	0.000652
			20.0	0.006702
			30.0	0.012844
Burrow pit along Bye-pass	E005° 45' 2.16"	N06° 17' 30.48"	10.0	0.000928
			20.0	0.008383
			30.0	0.011006

- *Model calibration*

The calibrated hydraulic head ranged between 10 and 440 m with reference to the mean sea level. The simulated hydraulic heads for peak dry seasons of the years 1981 and 2007 are presented in Figures 16 and 17 respectively. The scatter plot for model calibration of the simulated heads for December 2007 (Table 4) indicated strong positive correlation between observed and simulated heads (r = 0.9888) as shown in Figure 18.

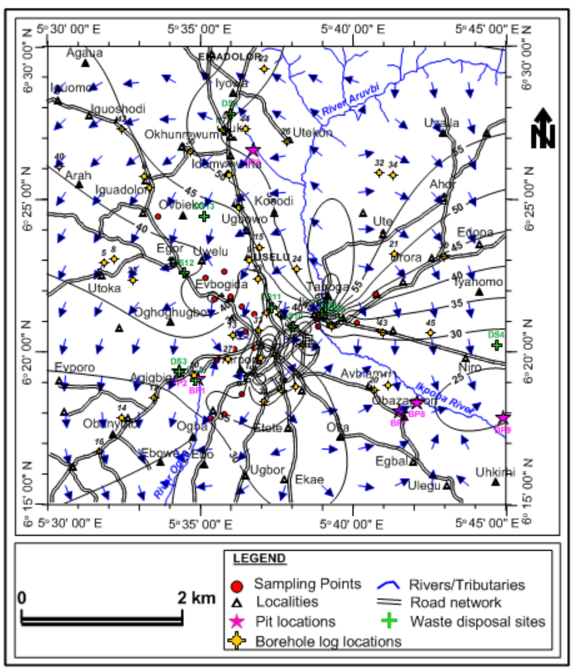

Fig. 14 Map of water table elevation and flow vectors

- *Transient groundwater levels in Upper aquifer*

Figures 19 and 20 show the time series of groundwater levels in the first (upper) aquifer at Ikpoba and Ogba respectively.

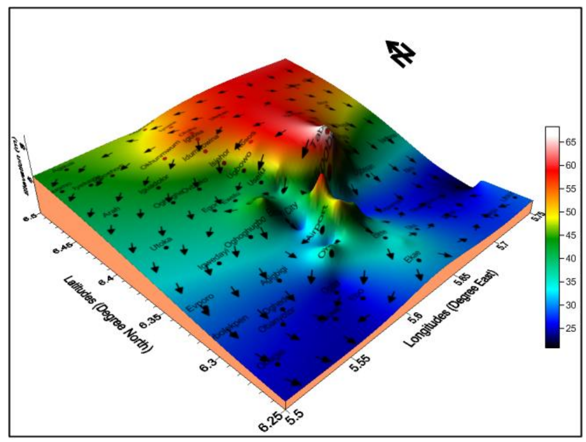

Fig. 15 3D view of flow direction

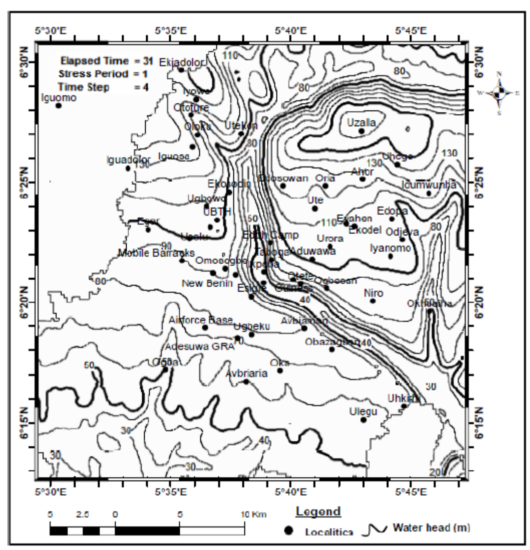

Fig. 16 Simulated hydraulic head for peak dry season, January 1981

Annual groundwater level fluctuation varied from 0.85 to 1.25 and 0.82 to 1.60 meters at Ikpoba and Ogba respectively. The least groundwater head (about 10 m) was registered south-east of Uleguwhile the highest (about 165 m) was recorded near Uzalla in the north-eastern part of the problem domain. There is no particular general groundwater flow direction but some local variations.

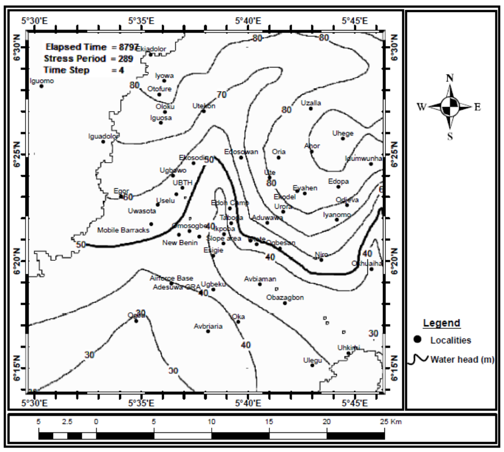

Fig. 17 Simulated hydraulic heads in peakdry Season, December, 2007.

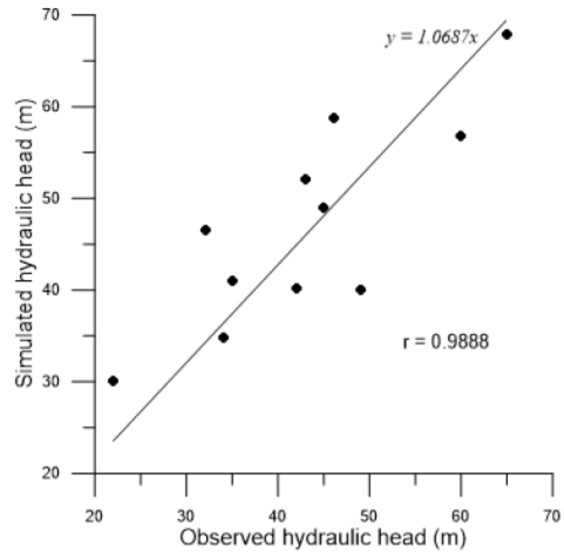

Fig. 18: Scatter plot comparing observed with simulated heads for December 2007

Table 4 Comparison of observed with simulated hydraulic heads in December 2007

Observation Name	Longitude (X)	Latitude (Y)	Observed Head	Simulated Head
Obs55	005° 37' 40.00" E	06° 20' 24.00" N	31	41
Obs56	005° 38' 3.00" E	06° 20' 21.99" N	42	40.2
Obs57	005° 36' 20.99" E	06° 23' 30.00" N	60	56.8
Obs58	005° 40' 30.00" E	06° 20' 43.00" N	27	46.5
Obs59	005° 35' 56.00" E	06° 25' 30.00" N	65	67.8
Obs60	005° 35' 40.99" E	06° 23' 35.00" N	42	58.7
Obs61	005° 35' 49.99" E	06° 22' 21.00" N	39	53.4
Obs62	005° 35' 56.00" E	06° 21' 43.99" N	36	50.7
Obs63	005° 36' 30.99" E	06° 17' 3.99" N	34	34.8
Obs64	005° 37' 53.00" E	06° 18' 3.99" N	49	38.7
Obs65	005° 39' 14.00" E	06° 15' 30.99" N	12	37.9

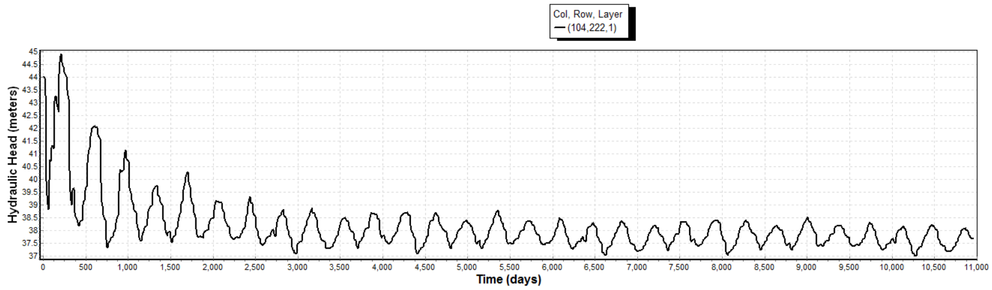

Fig. 19 Time series of changes in groundwater level (head-time curve) in model layer 1 at Ikpoba.

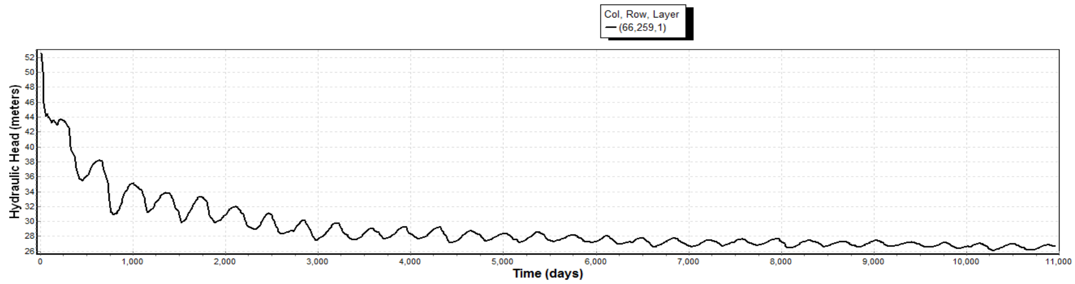

Fig. 20 Time series of changes in groundwater level (head-time curve) in model layer 1 at Ogba.

- *Volumetric Groundwater Budget*

Discharge from the aquifer system is accounted for by evaporation/evapotranspiration, leakage (baseflow) to rivers and streams, and groundwater withdrawal through pumping wells. Figures 21 and 22 show the computed seasonal variations of groundwater recharge rates from mean monthly rainfall (1981 – 2010) and seasonal variations of mean monthly evaporation/evapotranspiration (1981 - 1990) at Benin-City airport. The mass balance indicated that the rivers and their tributaries experienced both effluent and influent conditions. However, the rate at which the rivers gain water from the aquifer was lower than the rate of losing water to the aquifer. This may explain why some rivers or their tributaries are perennial.

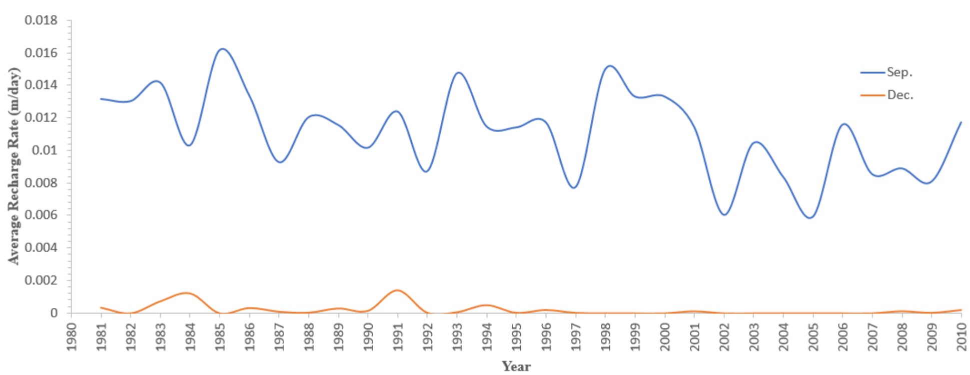

Fig. 21 Calculated seasonal variations of groundwater recharge rates from mean monthly rainfall at Benin-City airport (1981 – 2010)

The groundwater volumetric budget for entire model domain in July 2005 (Peak wet period) is presented in Table 5. Figures 23 and 24 represent the time series for rates of groundwater recharge and discharge for 10,957 days (January 1981 to December 2010). The thirty-year period groundwater recharge rates from precipitation and river leakage were 0 to 1.075×10^5 m^3/day and 2.737×10^5 to 1.114×10^6 m^3/day respectively. Groundwater discharge rates through baseflow and evapotranspiration were 1.165×10^4 to 4.219×10^6 m^3/day and 7.486×10^5 to 3.715×10^7 m^3/day respectively. The cumulative groundwater recharge rates which were 2.73 x 10^8 m^3/day and exceeded the discharge rates which was 5.07 x 10^7

m^3/day). Hence, there are indications that the aquifer has very high storage potentials.

CONCLUSION

River catchment water resource is capable of enhancing sustainable national development with complementary socio-economic, ecological, environmental and health benefits if properly harnessed and adequately managed. However, unplanned urbanization and industrialization, unregulated land-use activities and unchecked population growth can erode the gains. Hence, integrated field-scale outcrop study, borehole data analysis and applied groundwater modelling had enhanced the understanding of the hydrogeologic framework, transient water levels, recharge and discharge rates in Benin-City and environs, southwestern Nigeria. Such catchment-based study to simulate activities and interactions between the available water resources was necessary as a tool and a guide for groundwater exploration and exploitation, and to protect municipal potable water sources.

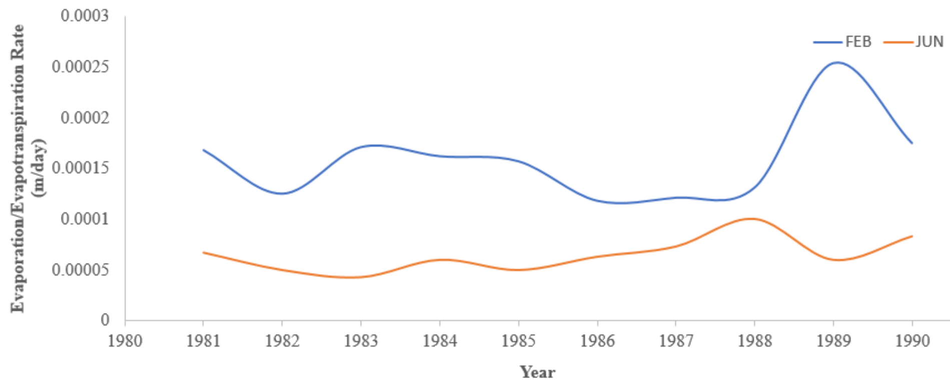

Fig. 22 Calculated seasonal variations of mean monthly evaporation/evapotranspiration at Benin-City airport (1981 - 1990)

Table 5 Groundwater volumetric budget for entire model domain in July 2005 (Peak wet period)

	Cumulative Volumes (m^3)		Rates (m^3/day)	
Flow Term	Inflow	Outflow	Inflow	Outflow
Storage	8.7105 x 10^{10}	1.0319 x 10^{10}	1.0820 x 10^6	1.8199 x 10^6
Recharge	1.7866 x 10^9	-	4.8746 x 10^5	-
River leakage	5.6111 x 10^{10}	2.2785 x 10^{10}	6.3568 x 10^6	1.1831 x 10^6
Evapotranspiration	-	1.1021 x 10^{11}	-	4.7366 x 10^6
Wells (Abstraction)	-	1.6894 x 10^9	-	1.8670 x 10^5
Total	1.4500 x 10^{11}	1.4500 x 10^{11}	7.9262 x 10^6	7.9262 x 10^6

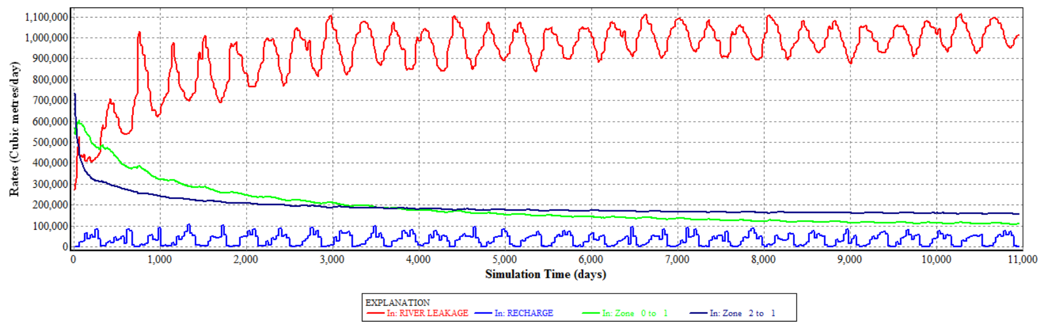

Fig. 23 Time series for rates of groundwater recharge for 10,957days (Jan. 1981 to Dec. 2010).

Outcrop studies and lithologic correlations of the sub-surface earth materials revealed a sedimentary sequence with reddish lateritic sandy soil cover which underlain by three groups of water bearing sand horizons. The first aquifer horizon is separated from the second by a clay unit of variable thickness (average of 16 meters) in most places except Ogba and Igbiogboko areas towards south-western part where the clay unit is missing. The second aquifer horizon consists of poorly sorted fine-medium-coarse grained pinkish- white loose sands. The grain size increases with depth and grades into gravelly sand in some places (like Ekiadolor, Egor, Iguosa, Urobo camp, Ugbowo, Ugbiogboko and Urora). The study had revealed that the thirty-year period cumulative groundwater recharge rates (2.73 x 10^8 m^3/day) exceeded the discharge rates (5.07 x 10^7 m^3/day), an indication that the aquifer has very high storage

potentials. Besides, the annual groundwater level fluctuation had been estimated at 0.85 - 1.25 and 0.82- 1.60 meters at Ikpoba and Ogba respectively.

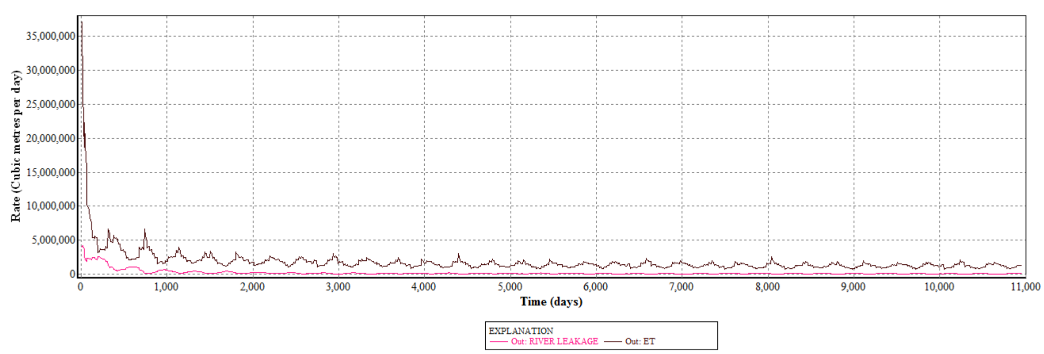

Fig. 24 Time series for rate of groundwater discharge for 10,957days (Jan. 1981 to Dec. 2010).

REFERENCES

[1] H. O. Nwankwoala, Problems and options of Integrated water resources management in Nigeria: Administrative constraints and policy strategies. International Letters of Natural Sciences, 2014, Vol. 9, pp. 12 - 25.

[2] D. J. Idiata, F. O. Omoruyi, and A.Iguisi, Water supply and population projections: Case of Benin City. Journal of Sciences and Multidisciplinary Research, 2010, Vol. 2. pp. 81-86.

[3] G. E. Oteze, Water supply, groundwater and flood control in Benin City, Presented at the NMGS, Benin Chapter sensitization workshop on water resources management and its implications in Benin City,22nd March, 2011.

[4] H. I. Ezeigbo, and B. C. Aneke, Water resources development plan for Benin-City and environs. Journal of Mining and Geology, 1993, Vol. 29. No. 2, pp. 147-158.Hazen, 1911

[5] Doust, H., and Omatsola, E. (1990) Niger Delta, In Edwards, J. D., and Santogrossi, P. A., eds.,

Divergent/passive Margin Basins, AAPG Memoir 48: Tulsa, American Association of Petroleum Geologists, pp. 239-248.

[6] Olatunji, A. S., Asowata, T. I. and Abimbola, A. F. (2014). Geochemical evaluation of metal content of soils and dusts of Benin City

[7] metropolis, Southern Nigeria. J. Geol. Geosci 3(4): 1 - 16.

[8] BS1377 Method of Testing soil for Civil Engineering purposes. British Standard Institute, London, 1990.

[9] A. Hazen, Discussion: Dams on sand foundations. Transaction. AmericanSociety of Civil Engineers, 73,1911, pp. 199.

[10] I. A. Akpoborie, Aspects of the hydrology of the western Niger Delta wetlands: groundwater conditions in the Neogene (Recent) deposits of the Ndokwa area. Afr. Geosci. Rev., 2011, 18(3), pp. 25-36.