Full Paper

NUMERICAL GROUNDWATER MODELLING OF NANKA AQUIFER FLOW SYSTEM IN ANAMBRA STATE

A.A. Adegbola
Department of Civil Engineering
Ladoke Akintola University of Technology
Ogbomoso
dayomos2002@yahoo.com

O. A. Agbede
Department of Civil Engineering
University of Ibadan
Ibadan

ABSTRACT

Numerical groundwater flow models of the Nanka aquifer domain within the Anambra State part of the Anambra Basin were developed to better understand the aquifer system and to determine the long term availability of groundwater by simulating groundwater conditions resulting from historical pumpage for the period 1979–1999 and simulating possible future conditions resulting from ground-water pumpage.

The models were developed using assumptions and approximations to simplify the actual aquifer system. The model idealized the complex hydrogeologic relations of the actual system based upon the data and the assumptions used to develop it. The Nanka ground-water flow system was numerically defined by discretizing the aquifer system into finite difference grids, determining the boundary conditions for the aquifer, estimating the rate and distribution of recharge and discharge, and estimating the aquifer properties within the model. To simulate historical conditions, steady-state (predevelopment) and transient-state (postdevelopment) models were formulated and calibrated. Results of the steady-state simulation were used as initial conditions for the transient-state model.

The simulated hydraulic heads for steady state conditions generally were within 0.94 to 25.42m of the measured water levels for 1979-83, of nine observation wells. The Root Mean Square Error (RMSE) for steady state calibration was 15.53m. The Mean Error (ME) was 3.62m, which indicated a model bias toward under-estimating head values. After calibration, for transient state conditions, the simulated heads were within about 4.90 to 26.21m of measured water levels for the entire domain. For the transient verification, the RMSE was 12.86m, and the ME was −7.07m.

The calibrated Nanka groundwater flow transient model could be used to simulate the potential effect of water-extraction plans on hydraulic heads and ground-water movement.

Keywords: *Groundwater flow, simulation, calibration, model-grid, calibration.*

1. INTRODUCTION

Provision of potable water to the generality of communities within the Nanka aquifer domain was grossly inadequate, based on reliable community population statistics ranging from 670 to 101,796 persons [1].

Apart from boreholes, the community members obtained their water from rain harvesting, streams, and from water vendors. A typical household of 10 spent about 45% of their monthly earnings on water vending. Hand dug wells were not feasible except in the riverine areas. Groundwater table lies between 60.0m and 450.0m below ground level. Existing deep boreholes have depths between 54.0m and 288.0m with yields varying from 2.2L/s to 6.4L/s. The shallow boreholes have depths 32.0m to 40.0m and yields 1.80L/s to 1.90L/s [1].

Conceptual, mathematical and numerical groundwater flow models of the Nanka aquifer within Anambra State were developed to better understand the aquifer system and to determine the long-term availability of ground water. These were carried out by simulating groundwater conditions resulting from historical pumpage for the period predating 2000, and simulating possible future conditions resulting from ground-water pumpage for the period 2000 – 2030. The models were developed using assumptions and approximations to simplify the actual aquifer system and by idealizing the complex hydrogeologic relations of the actual system based on data simplifications.

The United States Geological Survey (USGS) Modular Three-Dimensional Finite Difference Ground-Water Flow Model (MODFLOW) code developed by [2] and associated universal modified packages were assembled to simulate flow in the Nanka aquifer domain. In addition to approximating the actual groundwater flow system, the calibrated model was used to determine gaps and potential anomalies in data and in understanding the aquifer system.

The groundwater flow system in the problem domain was numerically defined viz: discretizing the aquifer system into a finite difference grid, determining the boundary conditions for the aquifer, estimating the rates and distribution of recharge and discharge, and estimating the aquifer properties within the model. The accuracy of these input data, in part, determined the degree of approximation to reality, of the model.

To simulate historical conditions, steady state (pre-development) and transient-state (post-development) models were formulated and calibrated. Results of the steady-state simulation were used as initial conditions for the transient-state model.

The purpose of this paper is to develop, with available data, a calibrated Nanka groundwater flow model, which could be used to simulate water extraction plans on hydraulic heads and groundwater movement.

2. HYDROGEOLOGY

Literatures [3,4] described the Nanka formation as the lateral equivalent of the Ameki Formation. Literature [5] reported that the Agulu, Nanka and Oko areas are underlain by the Nanka Sands. Literature [6] described Nanka Formation as being thinly overlain by the lignite-clay seams of the Oligocene Ogwashi-Abasa Formation and underlain by the Imo Formation. This description is confirmed by the cross-sectional lithological profile across the domain (Figure 1). The problem domain of Nanka Formation covers Nanka, Idemili, Oko, Agulu, Aguata and Nkpologwu areas of Anambra State. Literature [7] described the Nanka Sands as a prolific aquifer of high yield, while [3] concluded that in the Nanka Sands, around Nanka, Idemili and Oko, the water table is generally low, ranging from 30 to 300m. It was observed that the development of the Nanka Sands aquifer could be achieved by means of deep boreholes. The Nanka domain is idealized as a water table aquifer with lowest elevation of 50m below sea level.

3. METHODOLOGY

The Nanka aquifer problem domain was discretized into a finite difference grid of 25 rows and 15 columns, with the origin at the upper left corner.

The model grid of the Nanka aquifer domain was formed of 25 rows and 15 columns. The origin of the grid (that is, the upper left corner of the grid; row 1, column 1) is at a coordinate of $6^{0}50'$E and $6^{0}19'$N (Figure 2). The Nanka domain is idealized as a water table aquifer with an average bottom elevation of 50m below sea level.

All the model cells formed by the grid of the Nanka have dimensions of 26,000m by 26,000m along the x and y axes respectively.

The boundary of the aquifer is approximated in a stepwise fashion, making some of the nodes within the model grid to be outside the aquifer area. By assigning zero transmissivities to such nodes outside the boundaries, they are excluded from the calculations.

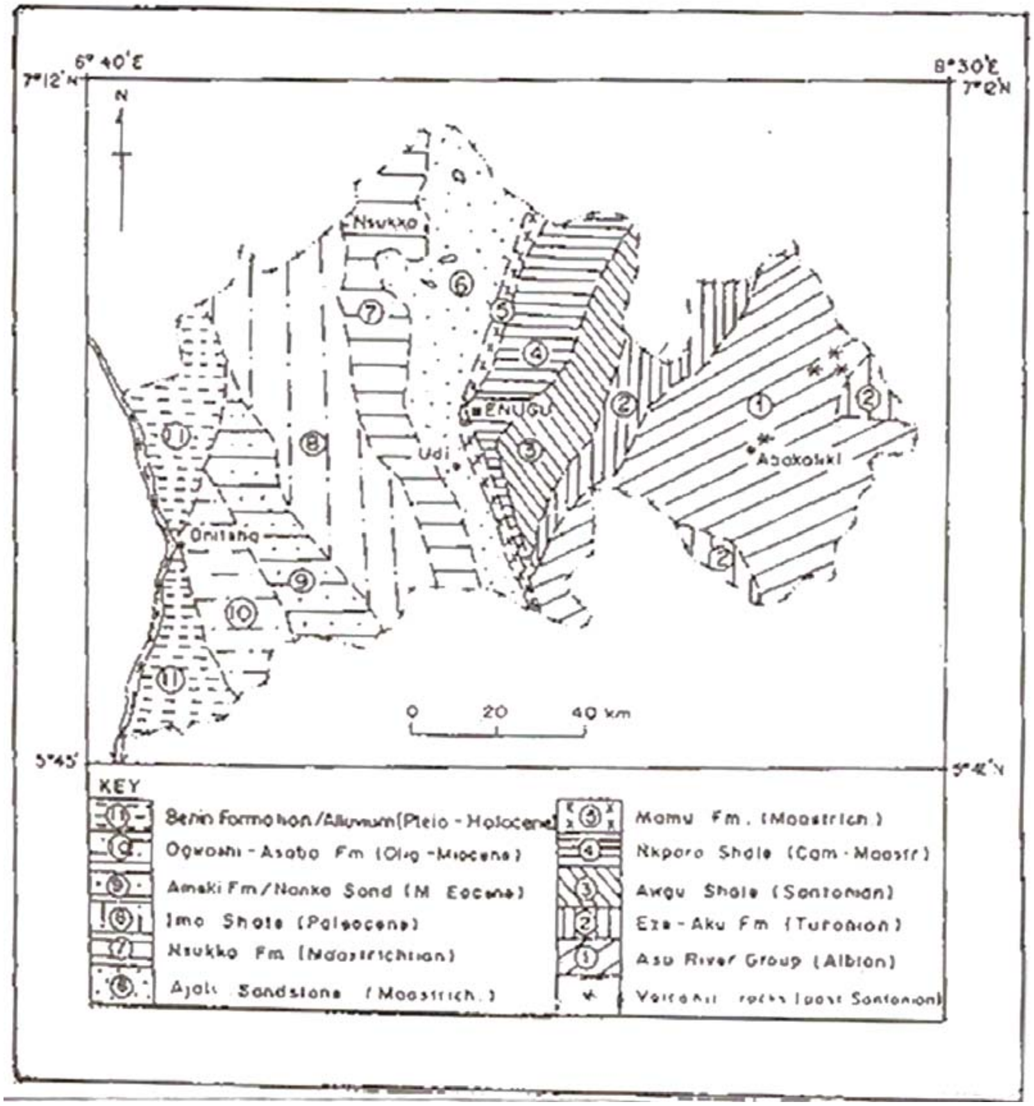

Fig 1: Hydrological map of old Anambra state

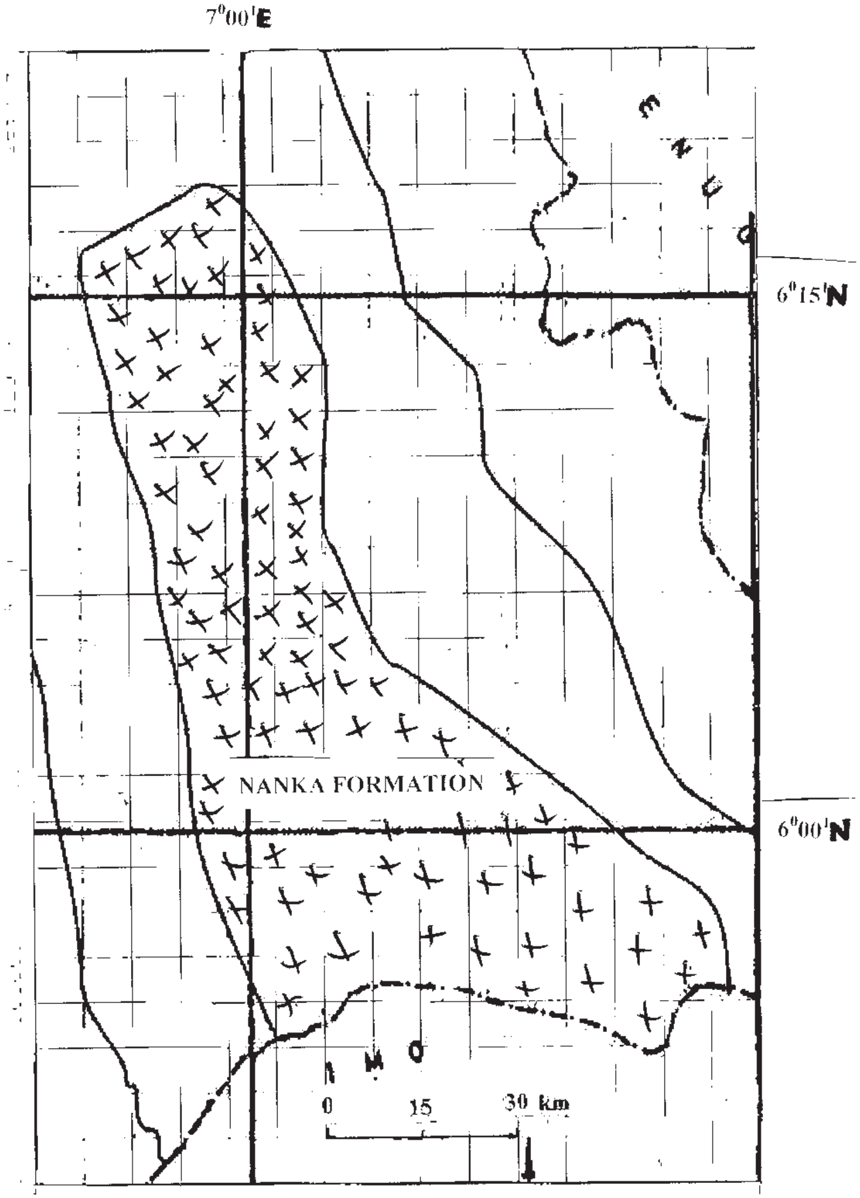

Fig 2: Model Grid of the Nnanka Aquifer Domain

The MODFLOW codes used included Basic (BAS), Block-Centered Flow (BCF), Well (WEL), River (RIV), Recharge (RCH), Discretization (DIS), and Strongly Implicit Procedure (SIP) [BAS, BCF, WEL, RIV, RCH, DIS and SIP [2]], MODPATH/MODPATH PLOT [8], GWM [9], SURFER [10] and VISUAL MODFLOW [11].

Aquifer properties, such as hydraulic conductivity, transmissivity, specific yield, and storage coefficient, control the rate at which water moves through the aquifer, the volume of water in storage, and the rate and areal extent of water-level declines caused by groundwater development.

The aquifer system properties across the study area were initially estimated from well logs, specific capacity tests and the published literature (Table 1). Final estimates of these properties were made using a trial-and-error approach during steady state and transient state model simulations. The aquifer property values varied considerably spatially because of the heterogeneity of the aquifer system material.

Spot heights derived from topographical maps on a scale of 1:50,000, were extrapolated to generate the topographical map for the entire Anambra State (Nanka study area inclusive) on a base map (Figure 3). A FORTRAN program source-code was developed for the preparation of input data for the Visual MODFLOW and SURFER contour plotting softwares. The topographical map was then superimposed on the Nanka problem domain.

The governing equation,as outlined by [2], for the three-dimensional movement of ground water of constant density through the Nanka study area was described by the partial-differential equation:

$$\frac{\partial}{\partial x}\left\{K_{xx}\frac{\partial h}{\partial x}\right\}+\frac{\partial}{\partial y}\left\{K_{yy}\frac{\partial h}{\partial y}\right\}+\frac{\partial}{\partial z}\left\{K_{zz}\frac{\partial h}{\partial z}\right\}-W=S_s\frac{\partial h}{\partial t} \qquad (1)$$

where:

Table 1: Aquifer System Properties across the Study Area [12]

Borehole Zone	Average Drawdown (m)	Average Yield (m)	Average Static Water Level (m)	Average Transmissivity (m2/day)	Average Specific Capacity (m3/day/m)	Average Storage Coefficient(x 10-2)
Nanka	10.78	13.14	38.07	38.16	208.55	0.12
Nanka	10.41	13.20	72.94	4.39	24.00	0.05
Nanka	5.26	7.63	76.13	10.54	57.60	0.10

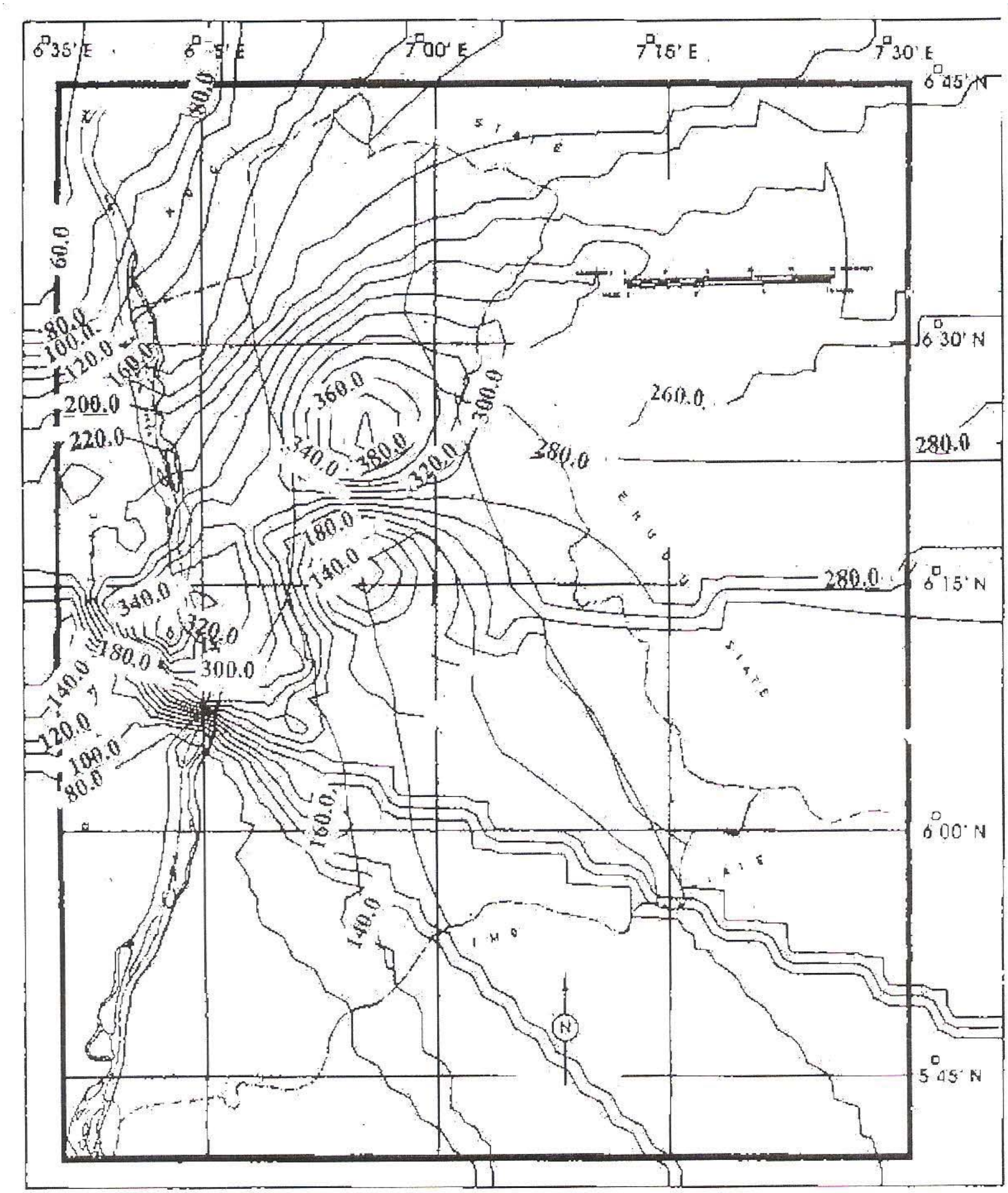

Fig 3: Topological Map of Anambra State on Base Map

K_{xx}, K_{yy} and K_{zz} are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (LT^{1});

h is the potentiometric head (L);

W is a volumetric flux per unit volume and represents sources and/or sinks of water (T^{-1});

S_s is the specific storage of the porous material (L^{-1}); and

t is time (T).

In general, S_s, K_{xx}, K_{yy} and K_{zz} are functions of space ($S_s = S_s(x,y,z)$, $K_{xx} = K_{xx}(x,y,z)$, $K_{yy} = K_{yy}(x,y,z)$ and $K_{zz} = K_{zz}(x,y,z)$) and W is a function of space and time ($W = W(x,y,z,t)$).

Equation (1) describes groundwater flow under non equilibrium conditions in a heterogeneous and anisotropic medium, provided the principal axes of hydraulic conductivity are aligned with the coordinate directions. Equation (1), together with specification of flow and/or head conditions at the boundaries of the aquifer system (problem domain), and specification of initial-head conditions, constituted a mathematical representation of the Nanka groundwater flow system.

Recharge to the aquifer domain included natural recharge by the infiltration of precipitation runoff directly and along the normally dry wash that traverses the basin and Anambra River which flows from the north eastern region of the study area and joining River Niger at Onitsha. The initial estimate of natural recharge from precipitation runoff used to calibrate the steady state model was 2005mm/yr [12].

Ground-water pumpage is the main discharge from the basin. Ground-water pumpage in the study area began during the colonial era, in the fifties. There was however, no record of daily, monthly or yearly groundwater pumpage for the entire study area. The distribution of pumpage for the simulation exercise was therefore estimated as a percentage of water based on well-capacity data from pumping tests.

Steady-state flow conditions exist when inflow is equal to outflow, and aquifer storage does not change with time. Transient conditions exist when inflow does not equal outflow, and hydraulic heads and volumes of water in storage change. Ground-water conditions prior to 1983 (assumed to represent pre-development conditions) were used to calibrate the steady-state model and groundwater conditions for the period 1979–99 were used to calibrate the transient-state model. These assumptions are similar to the ones obtained in published literatures viz: [13,14,15,16,17].

The calibration process involved iterative simulations. The steady-state model was calibrated by computer aided adjustments of key parameters until simulated heads matched measured heads in a number of observation wells measured during 1979–83, and until simulated water-budget components matched estimates. The steady state heads were used as initial heads in the transient state simulation. The set of raw data used for the transient verification exercise is presented in Table 2. The transient model was calibrated by computer aided trial-and-error adjustments of only the key parameters specific to the transient model until simulated heads matched measured heads during the period 1979–99 in observation wells. The simulated boundary fluxes were checked for reasonableness.

The Mean Error (ME),as outlined by [18], was computed as:

$$\text{ME} = \sum_{n=1}^{N} X_J \;/\text{N} \tag{2}$$

where $Xj = a_j - b_j$ (3)

X_j = residual head obtained after calibration.

a_j = observed head.

b_j = simulated head.

N = number of observation wells used for the calibration process.

The Root Mean Square Error (RMSE) for the calibration process was computed as:

$$\text{RMSE} = \left(\sum_{n=1}^{N} X_J^{\,2} \;/\text{N}\right)^{0.5} \tag{4}$$

Upon achieving a satisfactory steady-state calibration, transient ground-water conditions were modeled for the 22-year period between 1979 and 1999. The transient-state model consisted of 22 annual stress periods. Each stress period had 5 time steps. The time units were days. Transient conditions were the result of stresses applied to the aquifer domain, such as pumpage from production wells. For the transient-state calibration, the quantity and distribution of natural recharge was increased, and the boundary conditions were assumed to be the same as those calibrated for the steady-state simulation. Estimates of total ground-water pumpage from the aquifer domain were not modified for the model simulations because it was assumed that the estimates were fairly accurate. Because pumpage per unit time from individual wells generally was not available, the distribution of total pumpage from wells was based on well-capacity data.

To test the response of the calibrated models to a range of values for the initial hydraulic properties, a sensitivity analysis was carried out. This was done by varying the value of one input parameter while keeping all others constant. From this analysis, it was possible to observe the relative sensitivity of the model to various input properties. Thus, separate model simulations were made with varied input properties, and the changes in simulated hydraulic heads and in components of the water budgets were observed.

The Linear Regression Formula as outlined by [18] was used to compute the regression equation and the coefficient of correlation for each of the aquifer domains. The derived equations were used to plot the regression curves for all the domains.

The Regression Formula was expressed as:

$$Y = A + BX \tag{5}$$

where Y is the calculated or simulated head (m); X is the observed head (m); A is the constant term of regression and B is the regression coefficient. The letter N, in equations 6 to 8, is the number of records of data.

$$A = \frac{(\sum Y)(\sum X^2) - (\sum X)(\sum XY)}{N\sum X^2 - (\sum X)^2} \tag{6}$$

$$B = \frac{N(\sum XY) - (\sum Y)(\sum X)}{N\sum X^2 - (\sum X)^2} \tag{7}$$

The coefficient of correlation (r) was expressed as:

$$r = \frac{N(\sum XY) - (\sum Y)(\sum X)}{\sqrt{\{N\sum X^2 - (\sum X)^2\}\{N\sum Y^2 - (\sum Y)^2\}}} \tag{8}$$

Table 2: Set of Raw Data used for Transient Verification Exercise [12]

S/No	Location of Borehole	Year of completion of facility	Borehole distance coordinates from the origin of the base map		Yield of Borehole (m^3/hr)	Elevation of static water levels (SWL) above mean sea level (AMSL) (m)
			x (m)	y (m)		
A	Obiono	1999	250,000	350,000	8.82	20.10
B	Awa	1999	349,000	345,000	19.80	114.20
C	Ufuma	1998	550,000	325,000	16.81	100.70
D	Ihite	1999	567,272	285,000	12.60	62.60
E	Ezira	1999	500,000	290,000	13.61	10.00
F	Nteje	1999	278,636	570,000	9.18	60.90
G	Awkuzu	1999	283,636	525,000	1.26	53.50
H	Enugwu-Ukwu	1999	354,545	460,000	8.00	64.60
I	Abba	1999	198,000	355,000	14.40	5.70
J	Azia	1999	275,000	130,000	18.00	11.60
K	Orsumoghu	1999	279,000	137,000	17.75	9.40
L	Oraifite	1998	212,727	375,000	16.20	60.80
M	Ichi	1999	260,000	312,000	16.49	26.30
N	Nodun-Okpuno	1998	370,000	515,000	10.66	48.20
O	Umudioka	1999	278,000	620,000	10.80	14.00
P	Nzam	1999	135,818	690,000	6.48	23.90
Q	Umuemwelum	1999	141,818	600,000	6.48	11.40
R	Oroma-Etiti	1999	141,818	508,000	6.55	7.20
S	Igbedor	1999	100,818	750,000	6.84	22.20
T	Igbokenyi	1999	110,818	710,000	6.66	24.00
U	Obeledu	2000	425,454	350,000	9.61	147.50
V	Akwaeze	2000	375,545	340,000	10.8	22.00
W	Uke	1999	290,636	315,000	10.08	73.00

4. RESULTS AND DISCUSSION

The steady state calibration involved matching the simulated hydraulic heads to measured water levels from wells in the Nanka aquifer domain between 1979-83. The measured water levels for nine wells, ranging from 31.00m to 235.30m AMSL, were assumed representative of the hydraulic heads of the domain prior to groundwater development. The assumption is consistent with the works of previous modelers on various model domains as outlined among others by [19,20,21]. The works of [13], [22] and [23], were also based upon available historical and reliable sequence of data. The simulated hydraulic heads for steady state conditions generally were within 0.94 to 25.42m of the measured water levels for 1979-83, of nine observation wells. See Table 3 for details. Measured water levels and simulated hydraulic heads for 1979-83 were plotted along the 1 : 1 correlation line in Figure 4. The correlation graph is presented in Figure 5. The procedure for plotting is in agreement with that established by [20,21].

The RMSE for steady state calibration was 15.53m. The ME was 3.62m, which indicated a model bias toward under-estimating head values. The accuracy of the calibration is within ranges obtained from previous similar exercise elsewhere, as outlined by [24,20,21], with RMSE ranging from 6.25 to 28.95.

Upon achieving a satisfactory steady-state calibration, transient groundwater conditions were modeled for the 22-year period between 1979 and 1999. The transient-state model consisted of 22 annual stress periods. Each stress period had 5 time steps. The time units were days. For the transient-state calibration, the quantity and distribution of pumpage, storage coefficient, hydraulic conductivity and the boundary conditions were assumed to be the same as those calibrated for the steady-state simulation.

Estimates of ground-water pumpage from the Nanka aquifer formation were not modified for the model simulations because it was assumed that the estimates were fairly accurate.

The calibration procedure for transient conditions consisted of adjusting the natural recharge during 1979–99. Calibration was achieved when the adjustments resulted in simulated hydraulic heads that approximated measured water levels in five observation wells. After calibration, the simulated heads were within about 4.90 to 26.21m of measured water levels for the entire domain. See Table 4 for details. For the transient verification, the RMSE was 12.86m, and the ME was −7.07m. Measured water levels and simulated hydraulic heads for 1999 were plotted along a 1 : 1 correlation line as shown in Fig. 6. The correlation graph is presented in Figure 7. The equation of the straight line graph is $y = x$. The points located above the correlation line indicate an over-estimation of simulated water level heads at the corresponding observation wells, with discrepancies equal to the vertical difference between the coordinate and the correlation line, while points located below the correlation line indicate an under-estimation of simulated hydraulic heads at the corresponding observation wells. The vertical difference between the points and the 1:1 correlation line depicts the degree of underestimation. The procedure adopted is in line with similar numerical modeling analyses carried out by [14,25,26,27].

In general, the differences between simulated and measured values were perhaps due to: an inaccurate distribution of pumpage to the individual wells, an inaccurate estimation of the quantity and distribution of natural recharge, and/or inaccuracies in the reported water-level measurements. The steady state calibration contour for the water levels (1979-83) is presented in Figure 8. The positions of observation wells are plotted on the map. Also, the transient state calibration contour for the water levels (1979-99) is depicted in Figure 9. The positions of observation wells are also plotted on the map. The simulated water budgets at the end of the calibrated steady-state (1979) and the transient-state (1999) simulations were used to describe the flow characteristics in the domain. The water budgets of inflow (recharge to) and outflow (discharge from) in the Nanka model domain are presented in Table 5. The steady-state (pre-1979) water budget represents the state of the groundwater system prior to groundwater development.

Table 3: Selected Hydrogeological Data for the Nanka Domain Steady State Calibration Process

S/N	Observation Well (OBS)	Local Government Area	Community	Problem Domain/ Geological Formation	Borehole Coord. N	Borehole Coord. E	Spot Heights (m) Above Mean Sea Level	Static Water Level (SWL) Depth (m)	Observed Head (m) Above Mean Sea Level (AMSL)	Calculated Head (m) (b)	Residual Error X = (a-b)
1	OBS 1	Anaocha	Nri	NANKA	6°09’	7°04’	250	150.00	100.0	125.42	-25.42
	OBS 2		Agulu	NANKA	6°09’	7°10’	230	165.00	65.0	75.85	-10.85
	OBS 3		Adazi	NANKA	6°11’	7°00’	230	152.00	78.0	77.06	0.94
2		Orumba S.	Ugunamo	IMO SHALE	5°55’	7°14’	120	32.00	88.0		
			Isulo	IMO SHALE	6°52’	7°11’	150	38.00	112.0		
3	OBS 4	Aguata	Igbo Ukwu	NANKA	6°01’	7°07’	400	164.70	235.30	210. 65	24.65
	OBS 5		Igbo Ukwu	NANKA	6°02’	7°07’	400	243.30	156. 70	152.10	4.60
	OBS 6		Mpologwu	NANKA	5°57’	7°07’	200	169.00	31.0	46. 86	-15.86
4		Ayamelum	Omasi Uno	AJALLI	6°38’	7°04’	60	0.00	60.0		
			Umumbo	AJALLI	6°32’	7°02’	35	0.00	35.0		
5		Orumba N.	Enugu Nanka Omogbo Oko	IMO SHALE	6°05’	7°05’	60	13.00	47.0		
				IMO SHALE	6°05’	7°10’	180	110.50	69.50		
				IMO SHALE	6°04’	7°07’	200	125.10	74.0		
6		Ihiala	Okija Jun.	AMEKI	5°54’	6°49’	60	20.45	39.55	39.88	
7		Nnewi N.	Otolo	AMEKI	6°02’	6°47’	140	75.00	67.00	60.00	
			Uruagu	AMEKI	6°01’	6°54’	120	63.25	56.75	65.00	
8		Ogbaru	Atani Comp.	AMEKI	6°02’	6°45’	60	51.36	8.64	8.26	
			Ogbakuba	AMEKI	5°53’	6°41’	30	20.19	09.81	11.95	
9		Nnewi S.	Osumeyi	AMEKI	5°55’	6°58’	60	48.00	12.0	16.00	
10		Ekwusigo	Nza	AMEKI	5°52’	6°54’	60	31.00	29.0	19.34	
11		Anambra W.	Nzam	ALLUVIUM	6°25’	6°44’	60	50.00	10.0	21.00	
12		Anambra E.	Otuocha	ALLUVIUM	6°20’	6°50’	150	45.00	105.0	110.91	
13		Awka N.	Achalla	IMO CLAY SHALE	6°20’	6°57’	100	57.90	42.10		
14		Awka S.	Mbakwu	IMO CLAY SHALE	6°17’	7°05’	151	65.60	85.40		
15		Idemili N.	Ogidi	AMEKI	6°09’	6°51’	142	40.00	102.0	82.00	
16	OBS 7	Njikoka	Enugu Agidi	NANKA	6°10’	6°51’	195	40.00	155. 0	133.47	21.53
17		Anambra W.	Umueze Anom	ALLUVIUM	6°17’	6°48’	60	5.00	55.0	60.58	
18		Anambra E.	Nsugbe	ALLUVIUM	6°16’	6°46’	100	70.00	30.0	16.54	
19	OBS 8	Oyi	Ifite	NANKA	6°10’	6°55’	213	65.60	147.4	130.52	16.88
20		Idemili S.	Awka Etiti	AMEKI	6°03’	6°55’	220	151.00	96.0	71.00	
21	OBS 9	Dunukofia	Nangu	NANKA	6°11’	7°02’	180	15.50	164.5	148.41	16.09
22		Onitsha N.	Onitsha	ALLUVIUM	6°12’	6°46’	60	45.00	15.0	30.54	
23		Onitsha S.	Onitsha	AMEKI	6°05’	6°46’	100	89.00	11.0	12.83	

STATISTICS FOR HEAD RESIDUALS		
a. Maximum Residual Error	**-25.42**	
b. Minimum Residual Error	**+0.94**	
c. Mean Error (ME)		3
d. Root Mean Square Error (RMSE)		

Table 4: Selected Hydrogeological Data for the Nanka Domain Transient State Calibration Process

Observation Well (OBS)	S/N	Location of Borehole	Year of completion of facility	Aquifer Domain	Borehole distance coordinates from the origin of the base map		Observed Head in metres (a)	Calculated Head in metres (b)	Residual Error (X= a-b)	Mean Error (ΣX/obs)	Sq Er (X
					x (m)	y (m)					
OBS'A'	1	Obiono	1999	NANKA	250,000	350,000	20.10	25.00	-4.90		24
	2	Awa	1999		349,000	345,000	114.20				
	3	Ufuma	1998		550,000	325,000	100.70				
	4	Ihite	1999		567,272	285,000	62.60				
	5	Ezira	1999		500,000	290,000	16.00				
OBS'B'	6	Nteje	1999	NANKA	278,636	570,000	60.90	70.90	-10.00		100
OBS'C'	7	Awkuzu	1999	NANKA	283,636	525,000	53.50	65.25	-11.75		138
OBS'D'	8	Enugwu-Ukwu	1999	NANKA	354,545	460,000	64.60	51.82	12.78		163
OBS'E'	9	Abba	1999	NANKA	198,000	355,000	5.70	11.00	-5.30		28
	10	Azia	1999		275,000	130,000	11.60				
	11	Orsomoghu	1999		279,000	137,000	9.40				
	12	Oraifite	1998		212,727	375,000	60.80				
	13	Ichi	1999		260,000	312,000	26.30				
	14	Nodun-Okpuno	1998		370,000	515,000	48.20				
	15	Umodioka	1999		278,000	620,000	14.00				
	16	Nzam	1999		135,818	690,000	23.90				
	17	Umuemwelum	1999		141,818	600,000	11.40				
	18	Oroma-Etiti	1999		141,818	508,000	7.20				
	19	Igbedor	1999		100,818	750,000	22.20				
	20	Igbokenyi	1999		110,818	710,000	24.00				
OBS'F'	21	Obeledu	2000	NANKA	425,454	350,000	147.50	151.61	-4.11		16.
OBS'G'	22	Akwaeze	2000	NANKA	375,545	340,000	22.00	48.21	-26.21		68
	23	Uke	1999		290,636	315,000	73.00				
				STATISTICS FOR HEAD RESIDUAL							
				a. Maximum Residual Error					**-26.21**		
				b. Minimum Residual Error					**-4.90**		
				c. Mean Error (ME)						**-7.07**	
				d. Root Mean Square Error (RMSE)							

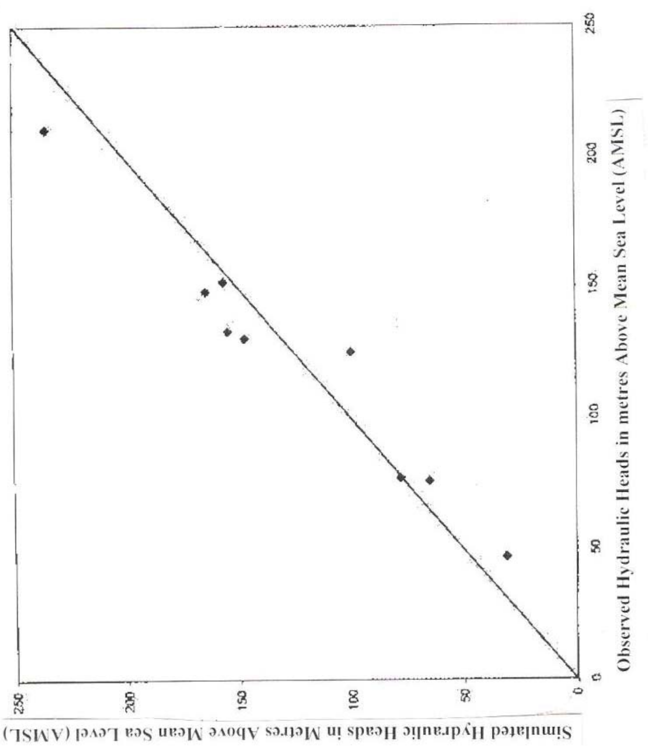

Fig 4: Ratio 1:1 Correlation Graph of Selected Simulated and Observed Hydraulic Heads in the Nanka Aquifer Domain for the Steady State Calibration Process

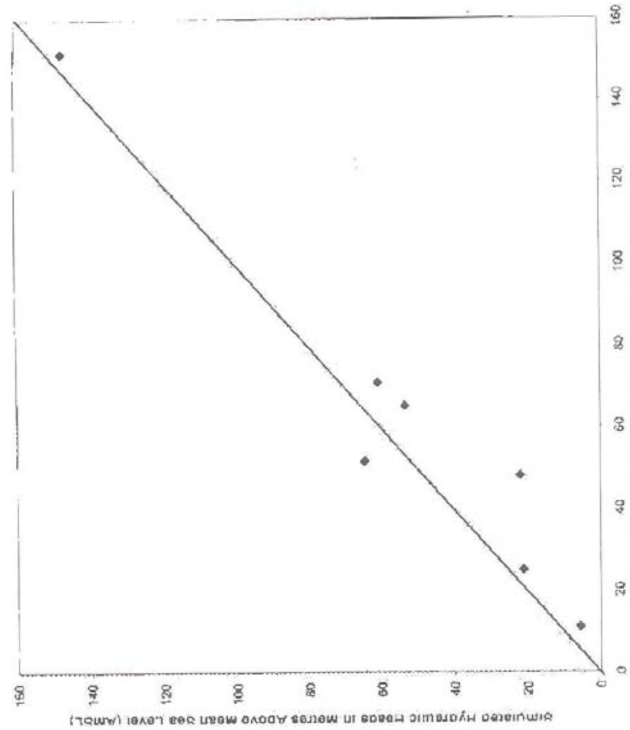

Figure 6: Ratio 1:1 Correlation grapg of selected simulated and observed hydraulic heads in the Nanka Aquifer Domain for the transient state calibration process

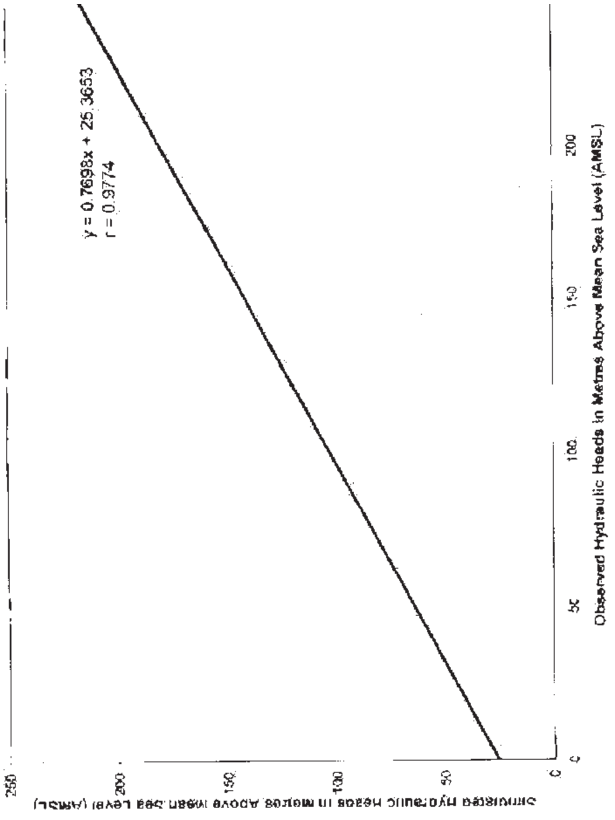

Figure 5: Correlation Graph of Selected Simulated and Observed Hydraulic Heads in the Nanka Aquifer Domain for the Steady Calibration Process

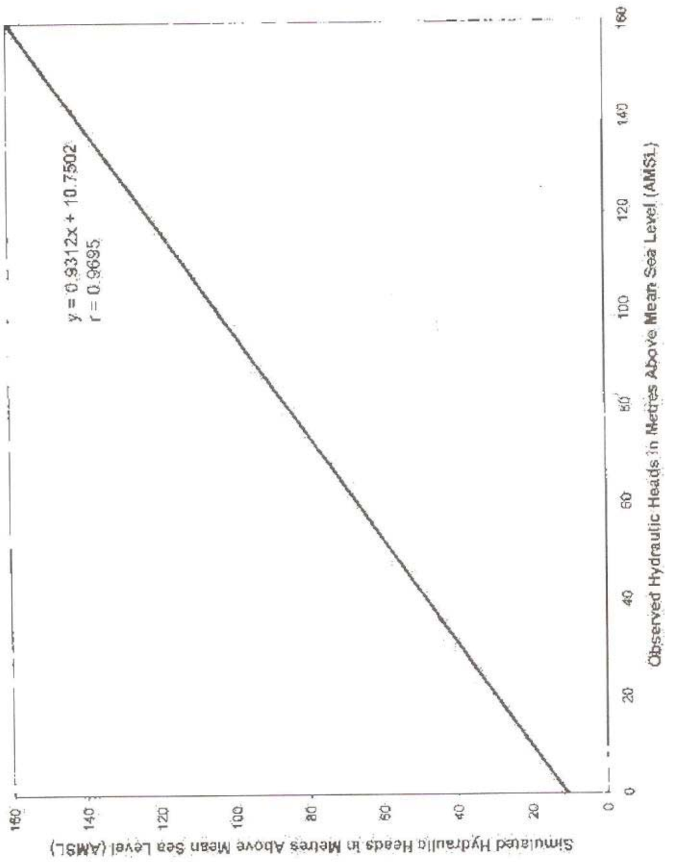

Figure 7: Correlation graph of selected simulated and observed hydraulic heads in the Nanka Aquifer Domain for the transient calibration process

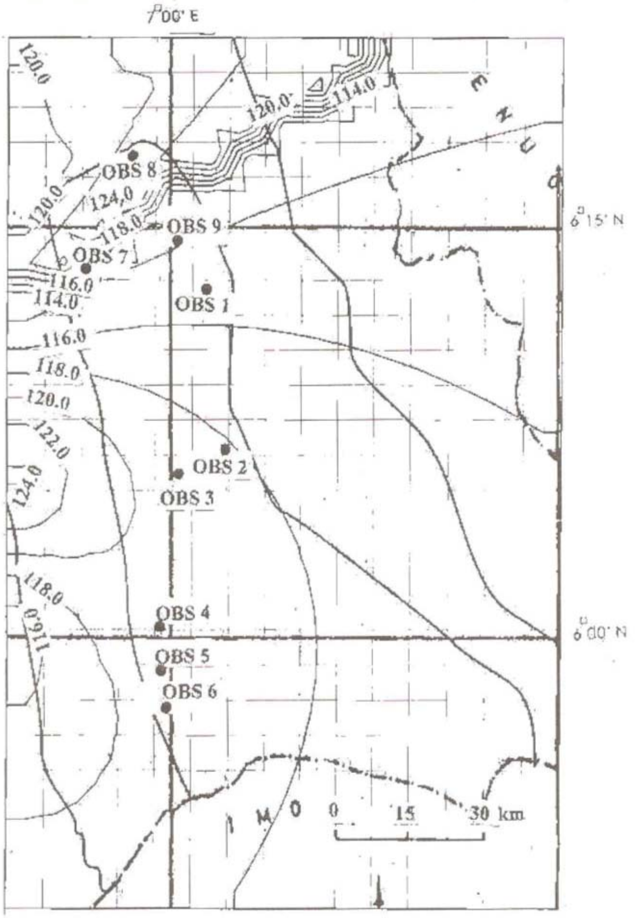

Figure 8: Steady state calibration contour for the water levels (1979-83) for the Nanka Aquifer Domain

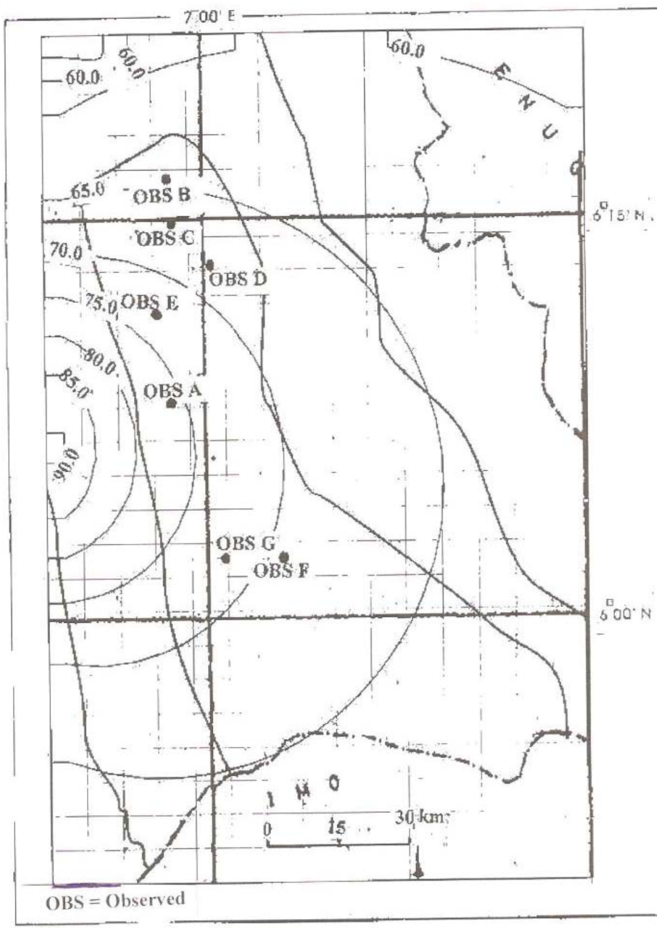

Figure 9: Transient state calibration contour for the water levels (1979-83) of the Nanka Aquifer Domain

Table 5: Water Budgets of Inflow and Outflow in the Nanka Model Domain

	Steady-state (Pre-1979) Conditions (m^3)	Transient (1999) Conditions (m^3)
Inflow:		
Natural recharge	130,702,560	316,468,560,000
River Leakage	0.00	0.00
Total in	130,702,560	316,468,560,000
Outflow:		
Pumpage	130,702,221	316,468,560,200
Constant Head	0.00	0.00
Total out	130,702,221	316,468,560,200
Inflow – outflow	339.00	-200

The transient (1999) budget represents the state of the groundwater system after 22 years of water-resources development in the Nanka aquifer domain. Results of the model simulations showed that in the steady-state simulation, the total recharge was about 130,702,560m^3. All the recharge during steady state conditions resulted from infiltration of precipitation runoff. The simulated water budget for the end of the transient-state simulation (1999) showed that, for 1999, about 316,468,560,000m^3 of water recharged the aquifer system and about 316,468,560,200m^3 discharged from the system.

5. CONCLUSIONS

The Nanka aquifer models (MODFLOW based) compiled using the Lahey FORTRAN 95, were used to simulate groundwater flow with appropriate initial and boundary conditions within the study area. After steady state calibration in the Nanka Aquifer Formation, the simulated hydraulic heads were within 0.94 to 25.42m of nine (9) observed water levels, with RMSE of about 15.53m. The Mean Error (ME) was 3.62m which indicated a model bias towards under-estimating head values. For the transient simulation, hydraulic heads matched observed values within 4.90 to 26.21m, using 1999 measured water levels in seven (7) observation wells. The RMSE was about 12.86m while the ME was -7.07m. The calibration procedure was through a trial-and-error approach.

The accuracy of the Nanka groundwater models is limited by the assumptions made in formulating the governing flow equations and in the assumptions made during model construction. The models were also limited by the availability of data and the interpolations and extrapolations of available data. Although the models were calibrated and verified, the calibrated parameter values might not be universally unique in satisfying a particular distribution of hydraulic heads.

The Nanka transient models are suitable for analyzing ground water flow on a regional scale. Site-specific analysis is limited by horizontal and vertical discretization of the model and the availability of site-specific data. The limitations mentioned above agree with previous works such as: [13,22,23]. In future, with additional data, further refinement of the model could be possible, which will improve the accuracy of model prediction of the effects of additional stresses on the aquifer system, such as increased withdrawals or drought.

REFERENCES

[1] A. Tokun, Planning and Performance Comparison of Rural and Urban Water Development in Nigeria. Osot Associates Consulting Engineers Bi-Monthly Seminar, Prost Building, Opposite The Polytechnic South Campus, Sango-Eleyele Road, Ibadan, 2003.

[2] M. G. McDonald and A. W. Harbaugh, A Modular Three-Dimensional Finite Difference Flow Model. V.S. Geological Survey Techniques of Water Resources Investigations, book 6, chap. A2, 2004, 286 pp.

[3] M. E. Offodile, An Approach to Groundwater Study and Development in Nigeria. MECON Services Limited, P. O. Box 6022, Jos, 1992.

[4] C. S. Nwajide, Eocene Tidal Sedimentation in Anambra Basin Southern Nigeria J. Sed. Geol. 25, 1980, pp. 180-200.

[5] E. S. Njumbe and K. M. Onuoha, Velocity Distribution Within the Anambra Basin, South Eastern Nigeria: Implications for Hydrocarbon Exploration. AAPG Annual Meeting, Houston, Texas, 2002.

[6] E. A. Emenike, Geophysical Exploration for Groundwater in a Sedimentary Environment: A Case Study from Nanka over Nanka Formation in Anambra Basin, South-eastern Nigeria. Global Journal of Pure and Applied Sciences, 7(1), 2001.

[7] T. Ezeigbo, Quality of Water Resources in Anambra State Nigeria, Nigeria Journal of Mining and Geology, 23(1 & 2), 1987.

[8] D. W. Pollock, User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model: U.S. Geological Survey Open-File Report, 1994, 94-464.

[9] D. A. Ahlfeld, P. M. Barlow and A. E. Mulligan, GWM – A ground-water Management Process for the U.S. Geological Survey, Modular ground water model (MODFLOW – 2000). Open file report, 2005 – 1072. 124p

[10] D. Smith, W. Wall, Z. Cheng R. Barnes, Surfer (Win 32) Surface Mapping System. Golden Software, Inc. Golden Colorado, 1996.

[11] N. Guiger and T. Franz, Visual Modflow. Waterloo, Hydrogeologic, Inc. Waterloo Ontario, 2003.

[12] OSOT Associates Consulting Engineers, National Rural Water Supply Project in Anambra State: Baseline Survey Report. The Petroleum Trust Fund (PTF) National Borehole Programme, Abuja, 1997.

[13] M. A. O. Busari, and O. A. Agbede, Modelling of Groundwater Flow and Pollution. A technical paper presented at the National workshop on Development of Groundwater Resources held at the Conference Centre, U.I., Ibadan between 24th and 31st July, 1992.

[14] S. M. Eberts and L. L. George, Regional ground-water flow and geochemistry in the Midwestern Basins and Arches Aquifer System in parts of Indiana, Ohio, Michigan and Illinois: U.S. Geological Survey Professional Paper 423-C, 2000, 103 p.

[15] O. A. Agbede and A. A. Adegbola, Application of the Numerical Modelling Techniques to the Simulation of Groundwater Flow in the Gwandu Sedimentary Formation of the North Western Nigeria. Journal of Applied Science and Technology. (JAST) Vol. 3, No. 1, 2003.

[16] L. M. Bexfield and D. P. McAda, Simulated Effects of Ground-Water Management Scenarios on the Santa Fe Group Aquifer System, Middle Rio Grande Basin, New Mexico, 2001-40, 2003.

[17] J. N. Densmore, Simulation of Ground-Water Flow in the Irwin Basin Aquifer System, Fort Irwin National Training Center, California, 2003.

[18] M. R. Spiegel and L. J. Stephens, Theory and Problems of Statistics. Third Edition, Tata McGraw-Hill Publishing Company Limited, New Delhi, 2000.

[19] J. Bear and A. Verruijt, Modelling Groundwater Flow and Pollution. D. Reidel Publishing Company. Dordrecht/Boston/Lancaster/Tokyo, 1992.

[20] H. Bouwer, H. T. Gro-Buxton and D. A. Smolensky, Simulation of the effects of development of the ground-water flow system of Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 98-4069, 1999, 57 p.

[21] O. A. Agbede and A. A. Adegbola, Modelling Groundwater Flow in the Sokoto Basin using the Finite Difference Technique. Journal of Research Information in Civil Engineering (RICE). 2(1), 2005, 26-33.

[22] Y. A. Asiwaju-Bello and O. S. Oladeji, Numerical Modelling of Groundwater Flow Patterns Within Lagos Metropolis, Nigeria. Journal of Mining and Geology. 37(2), 2001, 185-194.

[23] J. A. Olowofela, and O. D. Akinyemi, A Numerical Model for the Migration and Fate of Contaminants in Groundwater. Nigerian Journal of Science. 35(1), 2001, 87-93.

[24] O. A. Agbede, Model as a Management Tool in Water Resources. Modelling, Simulation and Control C, AMSE Press. 19(1), 1989, 1-10.

[25] D. M. Ely, M. C. Hill, C. R. Tiedeman, G. M. O'Brien, Evaluating observations in the context of predictions for the Death Valley regional groundwater system, in Proceedings of the 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management, July 30 to August 2, 2000, Minneapolis, MN, American Society of Civil Engineers, 10 p, 2000.

[26] J. F. Fish, and M. J. Stewart, Hydrogeology of the Surficial Aquifer Systems, Dade country, Florida. U.S. Geological Survey Water Resources Investigations Report 86-4126. Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Denver, Colorado, 50 pp, 1991.

[27] J. F. Harsh and R. J. Laczniak, Regional Aquifer-System Analysis-Northern Atlantic Coastal Plain Conceptualization and Analysis of Ground-Water Flow System in the Coastal Plain of Virginia and Adjacent Parts of Maryland and North Carolina, 1990.