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Modelling of Groundwater Flow in Ibeji Lekki Local Government Area of Lagos State Nigeria

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Abstract:- This study created a groundwater flow model using Groundwater Modeling System (GMS) software integrated with MODFLOW to create a steady-state groundwater flow model for the Ibeju Lekki Local Government Area of Lagos State. Aquifer parameters (hydraulic conductivity, transmissibility), groundwater recharge data (rainfall/climate, recharge rate), topography, and a hydrogeological map were acquired from both public and commercial organisations. The contour of the head solution demonstrates that the groundwater flow of the research region flows from the north-east, where the value of the head is high, to the south, where it also declines.The head expresses the potential energy of the groundwater per unit weight and thereby influences the direction of the groundwater flow.

Keywords: Groundwater flow model, MODFLOW, Steady-state model

I. INTRODUCTION

[1]Lagos' population has risen from ten to fifteen million in recent years as a result of a significant inflow of people from other regions of Nigeria, with an annual population increase of 3%. As a result, there is a rise in water demand, resulting in a concomitant acute water scarcity to fulfil the people's daily water consumption demands. The majority of the population has resorted to relying on borehole water for both household and industrial purposes, resulting in the over-exploitation of groundwater.

Groundwater quantity and quality have declined as a result of an ongoing reliance on it. [2]The quality of groundwater is harmed by salty water intrusion caused by over-exploitation of groundwater; hence, the drinkable water surface and the saline water surface must be balanced.

Excessive abstraction quantities or rates may harm the environment or other groundwater users. The main concerns associated with groundwater extraction and utilisation are a decline in groundwater levels; inflow of low-quality recharge water; and interference between neighbouring wells or boreholes.There is a need for proper management of the groundwater resources which can be achieved by groundwater models.

The goal of this research is to develop a groundwater flow model that is indicative of the groundwater flow in Lagos State's Ibeju Lekki Local Government Area. This research, which focuses on developing steady-state models, will aid in predicting long-term groundwater reactions. Steady-state models are frequently used in resource management to analyse the long-term implications of various expected amounts of extraction.

A. Groundwater Models

Any computer approach that offers an estimate of an underground water system is referred to as a groundwater model[3]. While groundwater models are, by definition, a simplification of a more complicated reality, they have shown to be valuable tools for addressing a variety of groundwater problems and assisting in decision-making over several decades.[12]Groundwater management and policy choices must be founded on knowledge of the groundwater system's historical and present behaviour, the predicted reaction to future changes, and an appreciation of the uncertainty in those responses. Groundwater flow models are used to estimate pumping drawdown and are frequently used in water resource evaluations to determine the aquifer's long-term productivity.This research work is of the utmost importance mainly to visualize groundwater flow through the aquifer system. This will also help in the proper management of the groundwater resources of the study area.

B. Location

[3]Ibeju Lekki is located between latitudes 4015 N and 4017 N and longitudes 13015 E and 13020 E. It is bordered to the north by Ogun State and to the west by Eti-Osa Local Government. It is flanked on the east by Epe Local Government and on the south by the Atlantic Ocean. It is approximately 75 kilometres long and 20 kilometres wide at its widest point. To summarise, the land area of Ibeju Lekki Local Government is around 646 km2, accounting for one-quarter of the entire landmass of Lagos State. The whole area lies below sea level, with just a few exceptions when the ground rises above sea level. Except in a few locations, the terrain is sandy along the shore, with some areas of mud.

C. Geology and Hydrogeology

[13]Lagos State is rich in agricultural land, and the area is also characterised by barrier beaches and sand deposits. Water is drawn from four aquiferous units in Lagos; the first, the alluvium formation, spans from the ground level to around 12m below the surface layer of clay and sand. Because of its shallow depth, this aquifer is prone to pollution. The second aquifer, coastal plain sand, is situated near the Igando axis and lies between 20 and 100 metres below sea level. The third aquifer (Ilaro formation) is located 130-160 metres below sea level. It is most common in Lagos's downtown business district.The fourth aquifer (the Ewekoro/Abeokuta formation) is located around 450 metres below sea level. A substantial layer of shale separates it from the third aquifer. This aquifer is only tapped by a few boreholes.The geographical map of the case study area is shown in figure 1.

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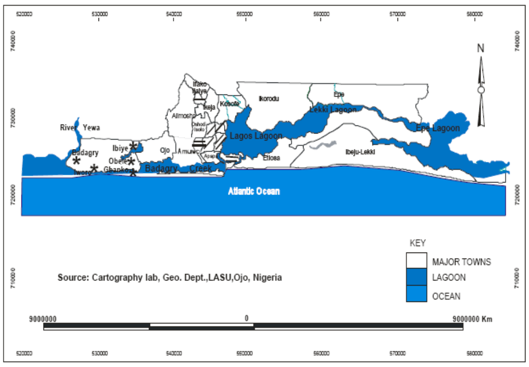

Fig. 1: Geographical map of the case study area

Source: Cartography Laboratory, Geology Department Lagos State University[6]

D. Climate

[13]In Ibeju Lekki, there are two primary climatic seasons: the dry season, which lasts from November to March, and the wet season, which begins in April and ends in October, with a little respite in mid-August. [1]The average annual precipitation exceeds 1700mm, which provides a significant source of groundwater replenishment. The temperatures range from 32ºC to 37ºC.

II. RESEARCH METHODOLOGY

A. Groundwater flow processes

[11]The governing flow equation for three-dimensional saturated flow in saturated porous media is:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-Q=S_z\frac{\partial h}{\partial t}$$

……………. 3.1

Where:

K_{xx}, K_{yy}, K_{zz} = hydraulic conductivity along the x,y,z axes which are assumed to be parallel to the major axes of hydraulic conductivity;

h = piezometric head;
Q = volumetric flux per unit volume representing source/sink terms;
S_s = specific storage coefficient defined as the volume of water released from storage per unit change in head per unit volume of porous material.

B. Data Collection

To carry out the modelling of groundwater for Ibeju Lekki Local Government Area of Lagos State. The following data were obtained;

- Geological map
- Groundwater recharge data (Rainfall/Climatic data, recharge data
- Borehole Data (which includes aquifer thickness, rate of recharge, Static water levels and hydraulic conductivity)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1948	0	140	34	278	342	305	20	46	65	82	20	0	1332
1949	0	3	100	57	294	401	148	105	217	159	114	0	1598
1950	0	26	28	227	245	434	195	18	91	124	64	1	1453
1951	97	0	151	55	265	355	384	125	172	368	111	0	2083
1952	59	65	178	170	299	251	149	8	396	167	88	60	1888
1953	0	132	65	90	360	536	247	23	171	208	128	3	1962
1954	51	145	126	88	256	618	40	39	81	290	43	17	1792
1955	80	10	139	144	175	629	200	105	140	355	22	18	2018
1956	0	72	118	144	252	322	230	9	96	158	75	87	1564
1957	7	13	113	115	351	405	613	195	269	198	79	39	2396
1958	51	47	151	83	513	818	3	12	171	108	120	35	2113
1959	63	28	105	168	423	330	409	100	125	191	45	0	1988
1960	69	77	39	293	183	490	67	105	182	199	69	0	1772
1961	3	0	153	220	231	673	319	2	131	91	39	49	1910
1962	23	13	143	158	180	834	274	157	38	167	120	21	2128
1963	2	18	47	118	301	304	493	370	296	124	87	2	2160
1964	3	20	104	157	218	686	48	58	77	178	40	5	1593
1965	4	56	101	216	260	435	648	139	300	134	25	1	2319
1966	13	20	70	199	195	272	448	50	134	219	80	12	1712
1967	52	19	107	115	129	405	441	5	133	221	66	10	1703
1968	13	53	21	182	172	597	927	527	535	190	31	18	3265
1969	31	2	217	163	369	527	283	134	68	221	52	4	2071
1970	127	8	35	102	302	587	477	35	328	306	68	0	2372
1971	8	95	26	58	214	357	356	27	220	59	48	18	1485
1972	85	26	24	157	197	468	91	9	117	74	20	16	1284
1973	36	37	109	90	221	271	78	273	239	194	41	69	1656
1974	79	26	112	84	324	394	359	58	279	79	16	0	1810
1975	0	79	14	211	159	298	647	185	62	110	41	110	1915
1976	0	140	224	206	146	589	120	22	55	120	42	15	1679
1977	104	0	28	108	223	418	211	23	87	147	7	9	1365
1978	18	61	101	298	294	189	269	24	84	275	101	27	1741
1979	3	19	60	136	378	364	468	269	239	161	120	4	2221
1980	133	47	52	74	267	342	142	400	201	122	171	0	1950
1981	7	3	52	169	256	449	96	84	241	115	22	1	1494
1982	0	17	25	215	288	666	280	5	64	109	32	0	1700
1983	0	0	30	67	433	604	69	14	175	35	48	0	1472
1984	15	25	70	127	235	274	94	95	267	194	35	0	1429
1985	56	25	35	98	398	155	125	79	207	191	9	0	1378
1986	12	41	89	89	128	450	41	6	170	337	16	0	1378
1987	4	87	114	51	235	524	142	402	333	150	13	2	2057
1988	77	33	30	140	248	548	659	119	322	161	54	42	2432
1989	0	0	6	65	236	251	328	270	111	434	15	0	1716
1990	0	3	14	205	91	555	611	9	316	169	22	36	2030
1991	16	33	108	241	233	448	325	40	365	121	0	0	1929
1992	0	0	10	43	244	339	221	21	292	133	45	9	1358
1993	0	8	105	153	381	352	208	42	-1	-1	-1	-1	-1
1994	7	46	148	93	197	278	86	20	340	339	15	0	1570
1995	13	74	76	169	195	461	-1	-1	-1	-1	-1	-1	-1
Mean	29	41	91	144	267	445	275	81	159	189	60	21	1801

Table 2.1: Rainfall data of the case study area

Source: Cartography Laboratory, Geology Department Lagos State University[6]

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Location	Northing	Easting	Depth (m)	Elevation (m)	Static Water Level (m)	Draw down (m)	Yield (m^3/day)	SC (m^3/day/m)	Aquifer thickness (m)
Oniru Estate, Lekki	711495	550756	236	9	10.16	31.05	1377.6	44.38	12
Rocky Sport Compound	710941	550539	251	3	15.17	37.18	1896	51.00	11
Lekki, Nepa Sub-station	711360	554528	220	6	10.74	2.65	1618	610.57	8
Seagate Estate, Ikate Elegushi	712256	554557	235	10	10.87	2.04	1425.6	698.53	15
Discovery Garden, Lekki	711305	557422	240	9	11.42	2.16	1406.4	651.11	7
Kusenla Street, Ikate Elegushi	712149	554174	20	14	2.5	3.40	114.912	33.80	12
Femi Okunnu, Lekki	712157	556115	40	15	0.35	2.85	114.912	40.32	9
Ascon Property, Lekki	712539	551102	10	10	0.55	2.66	114.912	43.20	15
Willow green, Lekki	712845	556474	20	12	0.95	2.10	114.912	54.72	15
Block 9, Plot 19, Palace Rd, Oniru Estate	710787	549608	70	3	1.82	4.58	114.912	25.09	16
BRIONI Court, Lekki	712765	553040	30	11	0.78	5.11	114.912	22.49	12
Clover Court, Lekki	710828	556811	50	2	2.41	2.70	114.912	42.56	13
James Pinnock Estate III	714454	556519	231	13	10.662	0.472	432	915.25	6
Maymount Sch. Lekki Phase I	714106	566529	213	1	11.243	2.290	679.104	296.55	18
Tender Tummies	718425	565497	210	18	10.483	1.563	991.872	634.60	18
Wisdom Plaza, KC Bus Stop	718339	566930	235	17	12.046	0.693	1350.43	1948.67	20
Lekki Gardens, Phase IV	714323	565969	195	14	13.397	0.989	1659.74	1678.20	23
Awoyaya, Ibeju Lekki	718033	565965	42	16	16.34	2.57	1490.4	579.92	21
Falling rain Estate, Lekki	713606	567015	35.5	19	14.10	0.47	1391.04	2959.6	13
Akodo, Ibeju Lekki	721060	566887	31.1	20	13.632	2.011	1330.56	661.64	25
Dolphine Estate	713852	545504	270	17	20.15	65.35	1771.2	27.10	23

Table 2: Static water level of the case study area

Source: Lagos Water Corporation, Ijora, Lagos State[14]

C. Developing a Conceptual Model

GIS tools in the map module would be used to develop a conceptual model of the study area. The location of the sources\sinks, layer parameters such as hydraulic conductivity, model boundaries, and all other data necessary for the simulation would be defined at the conceptual model level. Once this model is complete, the grid would be generated and the conceptual model would be converted to the grid model and all of the cells by cell assignment would be performed automatically. The steps in developing the conceptual model are illustrated in the flow chart below:

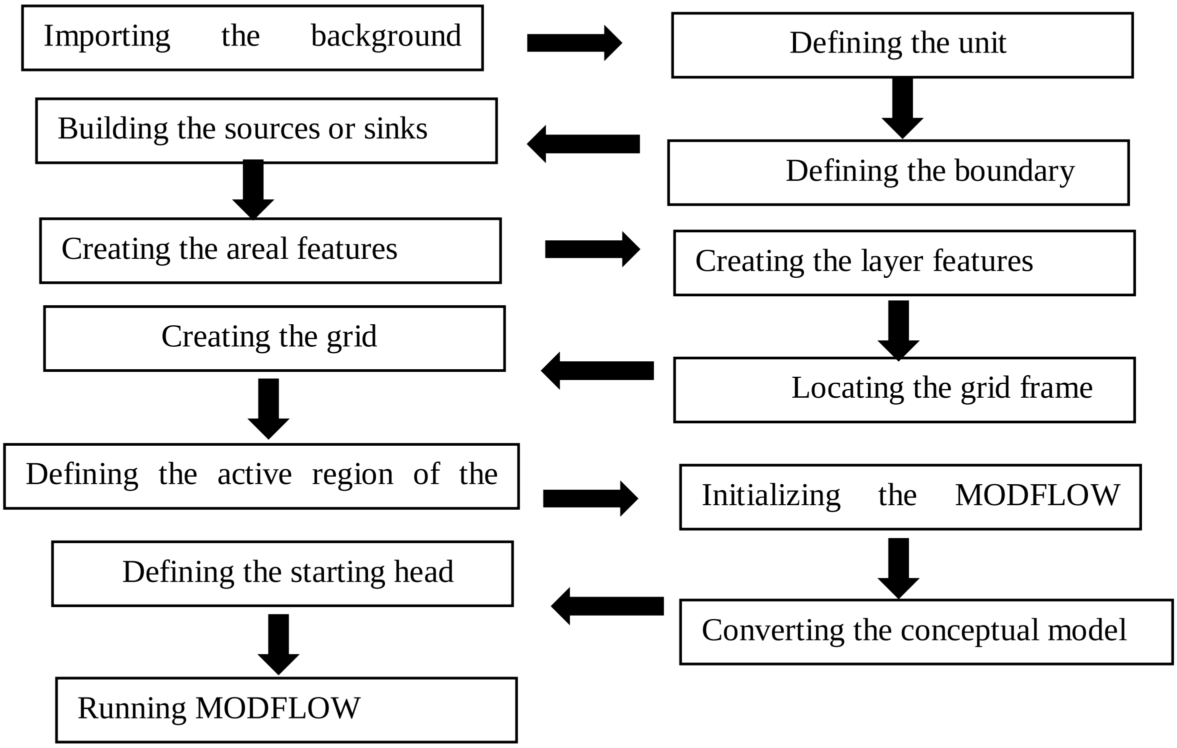

Fig. 2: The steps in developing the conceptual model

Source:Australian groundwater modelling guidelines.[5]

III. RESULTS AND DISCUSSION

A. Conceptual Model

A conceptual (hydrogeological) model is a descriptive depiction of a groundwater system that includes geology and hydrological interpretation. Figure 1 depicts the conceptual model of the Ibeju-Lekki Local Government Area, with the model elevation determined and top and bottom elevation values applied. The conceptual model serves as the foundation for the interactive, site-specific model. A conceptual model's components include identifying the aquifer system's extents and features, as well as establishing knowledge of groundwater flow directions, sources, and sinks.The conceptual model of the study area consists of some coverages, one coverage was typically used to define the sources and sinks such as wells, rivers and drains, other coverages were used to define the recharge and hydraulic conductivity zones

Fig. 1 : Conceptual Model for the Study Area

B. Model Grid

Figure 2 shows the active/inactive zones of the model. Each of the cells in the interior of any polygon in the local sources/sinks coverage is designated as active and each cell that is outside of all of the polygons is designated as inactive. Active zones groundwater flow paths are continuous, responsive to annual recharge and climatic variability. Inactive cells define inactive zones within the model domain. Inactive zone groundwater has extremely limited or no communication with annual recharge and has groundwater mean residence times that do not progressively lengthen along the flow path.

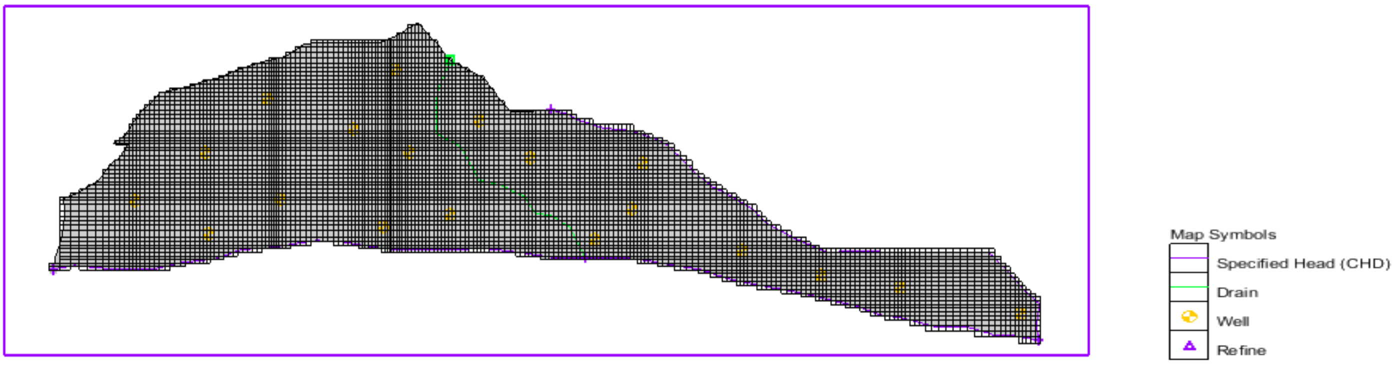

Fig. 2: Model Active/ Inactive Zones

C. Numerical Flow Model

Figure 3 shows the numerical model of the study area which is a result of the conversion of the conceptual model. In the numerical model the cells underlying the drains, wells, and specified head boundaries are visible.

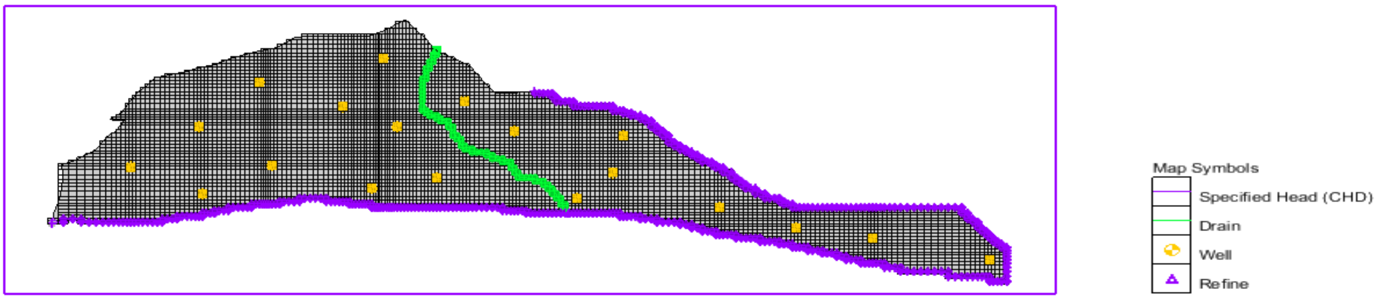

Fig. 3: Numerical Model of the Study Area

D. Model Output

Figure 4 shows the contour of the computed head solution which ranges between 5-15(m). The contour of the head solution shows that the groundwater flow of the study area moves from the North-East where the value of the head is high and decreases toward the South, it also decreases toward the North-West. The head expresses the potential energy of the groundwater per unit weight and thereby influences the direction of the groundwater flow.

Flow occurs from regions of high hydraulic head to areas of low hydraulic head. This concept applies in most (if not all) hydrogeologic situations, but the determination of flow direction becomes more complicated when there are significant spatial differences in groundwater density. Exploiting of groundwater resources has the potential to significantly alter groundwater levels. Flow occurs from regions of high hydraulic head to areas of low hydraulic head, but the determination of flow direction becomes more complicated when there are significant spatial differences in groundwater density. Exploiting of groundwater resources has the potential to significantly alter groundwater levels.

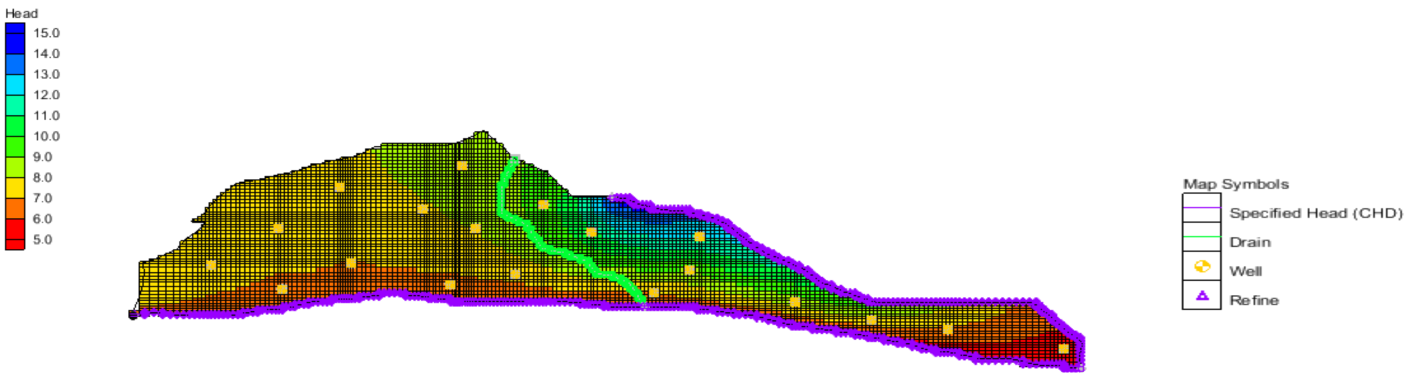

Fig. 4: Computed Head Solution

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IV. CONCLUSIONS

The conceptual model developed serves as a foundation upon which the interactive, site-specific model is built. The steady-state model was developed to represent the simplified version of the complex natural system of the study area which can serve as the basics to build a transient model which can be used to predict the response of groundwater to pumping. The groundwater flow of the study area moves from the North-East where the value of the head is high and decreases toward the South, it also decreases toward the North-West.

V. RECOMMENDATIONS

The State water agencies should create a platform whereby quality groundwater data can be easily accessible for the future development of this study. A transient state model should be developed for the study area to have a better understanding of hydraulic head distribution, recharge and discharge when the magnitude and direction of the flow change with time.

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