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Original Research Article

Groundwater Flow Modelling of Two Wetlands in Northern Bida-Basin Nigeria

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ABSTRACT

Two wetlands in northern Bida-Basin were studied for their groundwater flow. The wetlands are important agricultural zones on which shallow aquifers have been exploited. Water level measurements were carried out with the aid of a dip-meter in seventy-seven (77) wells, including forty-three (43) from parts of Bida and thirty-three (33) from parts of Egbako sheets respectively. The collected elevation data and coordinates of each well were used to derive the hydraulic heads in the wells for the regional modelling of groundwater flow at both locations. Low hydraulic head values of 77.5 m at Emi-Yagi and environs and 24.9 m at Gogata and environ and high hydraulic head values of 138.5 m at Zanagi and environ and at Pati-Gbadafu respectively for parts of Bida and Egbako were recorded. They are the recharge and discharge zones expected to indicate the areas of contaminant greatest impact and contaminant less impact within the two wetlands respectively. Groundwater flow direction seems to be from both the east and west with a convergence in the SW area in Egbako sheet. In the part of Bida sheet, the main flow direction appears to be from the NW and NE with a groundwater gradient observed along the flow path.

1. INTRODUCTION

The high complexity of the hydrological process for floodplain wetlands is mainly due to complicated and heterogeneous hydraulic connectivity with adjacent water bodies such as rivers and underlying aquifers (Winter 1999; Wolski and Savenije 2006). Resolving the complexity of flow in a groundwater reservoir is a challenging but important task for securing water supply around the world (Dah et al., 2023).

Groundwater level or water table depth is a significant variable related to groundwater and can vary between 0 m in wetland areas to depth of hundreds of meters from the land surface in arid regions (Li et al., 2023). Hydrological connectivity in wetland ecosystems comprises a combination of hydrodynamic, hydrochemical, and biological characteristics and the hydrodynamic characteristics of wetlands are the temporal and spatial changes in the water level, flow direction, quantity, recharge, and discharge conditions of surface water and groundwater (Liu et al., 2022). The hydrodynamics of the wetlands at Wuya and Kakakpagi on the river Kaduna and Chanchaga floodplains within the central Bida basin is not clearly studied. It is difficult to predict water flow and contaminant transport on a field-scale based on the current monitoring and modelling techniques (Kumar, 2018). The water movements in the unsaturated zone, together with the water holding capacity of this zone are very important for the recharge of the groundwater storage.

In order to define groundwater flow directions and rates through aquifers, individual measurements of hydraulic head are combined to generate contour maps of water level or potential energy. These maps define the potentiometric surface, which is much like a topographic contour map but defines the distribution of potential energy in the groundwater system. Each contour or equipotential represents a line of equal hydraulic head. These flow systems can also be evaluated quantitatively and in a distributed manner allowing a site-specific search for geofluid-related resources (Czauner et al., 2022). In addition, interactions of superimposed flow systems with different driving forces can result in specific situations, such as regional fluid-potential, minimum zones of converging flows, which can serve as hydraulic traps for matter and heat (Czauner et al., 2013). In the wetland ecosystem, contaminants can move along groundwater flow paths and contaminate shallow aquifers. Therefore, the need to study the groundwater flow and relates to contaminant transportation.

2. MATERIALS AND METHODS

2.1. Hydrogeology of the Area

The study area is part of the Bida Basin in central Nigeria. The basin extent has been estimated to be approximately 350 km long and varies in width from 75 to 150 km (Rahaman et al., 2019). Adelana et al. (2008) in an extensive report show that the area of the Middle Niger Basin extends north-westwards along the river Niger from the confluence with the River Benue in Lokoja. Olabode et al. (2012) reported sedimentary rocks with varying thickness of 40 m to 300 m and their studies shows that the formation material consists mainly of very fine to coarse grain pebbly sandstone. Crystalline basement rocks adjoin the area on all sides except to the southeast where it has a common boundary with the Cretaceous sediments of the Lower Benue Basin (Du Preez and Barber, 1965). Two major aquifer types have been identified in the study area i.e., confined and unconfined aquifer which ranges between 3 and 34 meters thick and is composed of fine to medium grained, poorly sorted sandstones (Olabode et al., 2012). Large quantities of groundwater occur in the sediments of the basin especially in the alluvium areas of Shonga, Baddegi and Lafiagi. The Basin area is drained by minor rivers flowing SW-NE, and N-S from the Kabba and Jos highlands, in the south and the north respectively (Adelana et al., 2008). Sidi (2019) reported from field hydrogeological mapping of parts of the central Bida Basin around Baddegi that the average water level in wells is 6.1 m below ground surface, average wells depth is 8.8 m and average water column in the wells is 2.7 m.

2.2. Hydrogeological Mapping

A total of seventy-seven (77) hand dug water wells were mapped. Thirty-three (33) of the water wells were within the Egbako sheet while forty-four (44) were within the Bida Sheet. In situ measurement of hydraulic head was accomplished by measuring the water level elevations in wells and then the depth to groundwater is measured with the aid of an electric sounding instrument (dip meter) and water level elevations were obtained by subtracting the measured depth to water from the land surface elevation. The water column in the water wells was calculated from the Equation 1.

$$\text{Water Column} = \text{Well depth} - \text{Dynamic Water level} \tag{1}$$

The hydraulic head data obtained from Equation 2 was used to modelled the regional groundwater flow in the two wetlands. Amah and Agbebia (2015) explain the procedure for the use of hydraulic head data to show the regional groundwater flow direction.

$$\text{Hydraulic Head (m)} = \text{Elevation (m)} - \text{Static water level (m)} \quad (2)$$

The distribution of head at various locations were contoured for the entire study area using Arc GIS software.

3. RESULTS AND DISCUSSION

3.1. Ground Water Flow Modelling

The generated field data from the hydrogeological mapping conducted in parts of Egbako and Bida sheets 183 and 184 respectively are presented in tables 1 and 2. The hydraulic head data obtained were used to model the regional groundwater flow in the two wetlands. The groundwater flow maps are presented in Figures 1, 2, and 3 for the parts of Egbako and Figures 4, 5 and 6 for parts of Bida sheet respectively.

The regional groundwater flow directions of the two studied areas are controlled by the hydrodynamics. Lowest hydraulic head values of 77.5 m at Emi-Yagi and environs and 24.9 m at Gogata and environ and highest hydraulic head values of 138.5 m at Zanagi and environ and at Pati-Gbadafu respectively for parts of Bida and Egbako sheets were recorded reflecting the regional groundwater discharge and recharge zones. In Egbako sheet, the hydraulic head appears to be lowest in the southwestern corner, around L12 (water table elevation drops from 125 m to less than 50 m amsl near L12) Figure 1, the respective groundwater flow directions in both surfer and ArcGIS are presented in Figures 2 and 3. Therefore, groundwater seems to flow from both the east and west, creating a kind of convergence in the southwest area.

The flow of groundwater in these two wetlands is also influenced by the rivers flowing through in the catchments. Medium to coarse grain sandstones intermixed with silt and clay give a permeability of 4.3 m/day within the shallow alluvial aquifers (Sidi 2019). The intermediate to deeper aquifers occurs at 50 to 70 meters and are mostly confined to semi-confine (Olabode et al., 2012). Groundwater flow in these two wetlands is expected to be controlled by the porosity of the sediments within the shallow aquifers as well as the hydraulic gradient at depth beyond the shallow levels. The lithology in the two wetlands underlain by the alluvial deposits is sandstone which is consistent mainly of fine to coarse grained sandstones well sorted to poorly sorted (Olabode et al., 2012).

In part of Bida sheet, a complex groundwater flow system was established with four divides (Figures 4, 5 and 6). The main flow direction appears to be from the NW and NE, i.e., from L26 towards L18, because the water level elevation changes from 130 m amsl to less than 90 m, creating a gradient (figure 4). A similar, though less prominent component is observable in the southern half of the area, moving towards L43. A south-westerly flow pattern exists at the northeast corner, from L9 to L18. There are expected fluctuations in the hydraulic head within the wetlands due to the regime of the two major rivers that drained the plains.

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Table 1: Wells and their hydraulic heads obtained in parts of Egbako Sheet

Location	North	Eastern	Elevation (m)	Water Level (m)	Hydraulic head (m)
L1 (Gbamache)	09°10'04.2''	005°45'51.7''	134	14.5	119.5
L2 (Gbangban)	09°09'40.0''	006°45'26.5''	141	15.5	129.5
L3 (Yagbenti)	09°07'33.0''	005° 45'25.6''	129	6.5	122.5
L4 (Pati-Kasangi)	09°06'58.0''	005°45'28.4''	157	23.5	133.5
L5 (Emi-Manzhi)	09°08'24.0''	005°45'57.8''	135	13.1	121.9
L6 (Emi-Worogi-Tasha)	09°04'47.4''	005°46'02.5''	136	10.1	125.9
L7 (Mastwagi)	09°04'41.3''	005°45'56.8''	131	10.1	120.9
L8 (Etsu-Tasha)	09°04'13.7''	005°46'09.9''	114	10.1	103.9
L9 (Emi-Dogbezhi/Sakiwa	09°03'52.2''	005°47'03.1''	101	9.5	91.5
L10 (Emi-Mafin)	09°03'39.0''	005°47'33.4''	109	12.1	96.9
L11 (Emi-Shaba Ndako)	09°03'35.6''	005°47'31.9''	107	11.5	95.5
L12 (Gogata)	09°06'33.8''	005°47'11.7''	140	115.1	24.9
L13 (Wuya-Kede)	09°08'16.1''	005°49'19.7''	97	9.5	87.5
L14 (Lukoro)	09°10'10.7''	005°46'05.8''	136	12.5	123.5
L15 (Satifu)	09°13'06.6''	005°45'35.6''	130	18.5	111.5
L16 (Sabafu)	09°13'38.6''	005°46'07.9''	117	8.1	108.9
L17 (Gbarigi)	09°13'38.2''	005°45'08.0''	116	7.1	108.9
L18 (Sonfada Gabi)	09°11'51.5''	005°48'47.0''	113	11.1	101.9
L19 (Ekoko)	09°11'35.7''	005°47'36.1''	148	11.6	136.4
L20 (Ekoko 2)	09°11'30.3''	005°47'37.0''	135	14.1	120.9
L21 (Wuyako)	09°08'39.2''	005°49'17.5''	89	6.5	82.5
L22 (Edobagi)	09°06'51.1''	005°51'20.8''	98	6.1	91.9
L23 (Patigi)	09°06'30.2''	005°51'07.2''	92	4.5	87.5
L24 (Edozhigi)	09°05'56.2''	005°51'11.6''	104	10.1	93.9
L25 (Gbadafu)	09°10'48.6''	005°52'46.4''	134	9.1	124.9
L26 (Patita-Gbadafu)	09°11'29.3''	005°53'16.7''	149	10.5	138.5
L27 (Kusolukpa)	09°13'05.0''	005°53'15.3''	116	8.5	107.5
L28 (Sharubutu)	09°13'16.4''	005°52'42.6''	101	8.1	92.9
L29 (Yenifu)	09°13'18.6''	005°52'32.9''	104	7.1	96.9
L30 (Dingi)	09°10'56.5''	005°51'42.6''	110	9.1	100.9
L31 (Dari)	09°11'12.6''	005°51'45.5''	108	11.5	96.5
L32 (Bramafu)	09°09'39.4''	005°51'43.1''	100	7.5	92.5
L33 (Evungi)	09°11'26.6''	005°51'06.7''	92	8.5	83.5

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Table 2: Wells and their hydraulic heads obtained in parts of Bida Sheet

Location	North	Eastern	Elevation (m)	Water Level (m)	Hydraulic head (m)
L1 (Mantuntu)	09°19'10.8''	006°13'06.6''	131	14.3	116.7
L2 (Mantuntu)	09°19'14.3''	006°13'12.0''	145	16.7	128.3
L3 (Mantuntu)	09°19'15.3''	006°13'05.7''	137	16.1	120.9
L4 (Bisanti)	09°19'39.0''	006°12'39.5''	120	10.1	109.9
L5 (Kagowgi)	09°19'16.9''	006°11'56.0''	113	9.5	103.5
L6 (Godna)	09°20'22.0''	006°11'05.8''	110	9.1	100.9
L7 (Godna 2)	09°20'17.9''	006°11'05.3''	115	9.5	105.5
L8 (Kparaka)	09°19'56.9''	006°14'04.0''	145	12.5	132.7
L9 (Maraya)	09°18'05.4''	006°12'26.9''	138	12.5	125.5
L10 (Wasagi)	09°17'05.5''	006°12'49.7''	116	3.1	112.9
L11 (Wasagi 2)	09°17'03.4''	006°12'56.1''	108	6.1	101.9
L12 (Ewun)	09°16'04.7''	006°13'20.7''	98	6.8	91.2
L13 (Egbanasara)	09°15'26.5''	006°12'01.3''	101	13.5	87.5
L14(Kusogi Kakakpagi)	09°16'15.2''	006°11'43.7''	100	8.1	91.9
L15 (Kakapkangi)	09°16'37.6''	006°11'28.6''	103	2.5	100.5
L16 (Emi-yagi)	09°16'21.6''	006°10'55.9''	94	10.1	83.9
L17 (Emi-Yagi 2)	09°16'26.7''	006°10'57.9''	88	10.5	77.5
L18 (Emi-Natsu)	09°16'43.3''	006°10'36.0''	93	12.2	80.8
L19 (Emi-Sheshi)	09°16'37.4''	006°11'00.6''	92	3.5	88.5
L20 (Kyawogi)	09°15'47.5''	006°10'50.6''	98	15.1	82.9
L21 (Sabongida)	09°14'29.6''	006°09'03.5''	116	9.1	106.9
L22 (Kuhizi)	09°15'22.7''	006°04'26.0''	134	3.6	130.4
L23 (Batako)	09°16'48.1''	006°05'03.2''	136	7.5	128.5
L24 (Batako 2)	09°16'48.1''	006°05'00.4''	133	7.1	125.9
L25 (Batako 3)	09°16'52.2''	006°05'01.7''	133	8.7	124.3
L26 (Zanagi)	09°17'54.0''	006°04'59.1''	147	8.5	138.5
L27 (Ladigi)	09°17'50.7''	006°06'58.1''	132	11.5	120.5
L 28 (Ladigi 2)	09°17'54.3''	006°06'58.6''	124	14.1	109.9
L29 (Sagi)	09°18'20.1''	006°06'48.6''	130	17.1	112.9
L30 (Sagi 2)	09°14'09.3''	006°08'43.3''	121	5.5	115.5
L31 (Store/Danko)	09°13'59.3''	006°08'18.0''	118	9.5	108.5
L32 (Danudu)	09°13'16.9''	006°08'54.6''	109	7.1	101.9
L33 (Barje)	09°10'43.9''	006°05'58.9''	127	8.5	118.5
L34 (Chekpa)	09°10'55.1''	006°05'50.8''	133	11.5	121.5
L35 (Masalaci)	09°10'14.7''	006°05'08.7''	145	18.1	126.9
L36 (Gogata)	09°09'08.0''	006°06'53.8''	127	8.9	118.1
L37 (Anfani)	09°09'12.0''	006°05'40.7''	118	8.9	109.1
L38 (Komu)	09°09'35.6''	006°06'46.2''	133	10.5	122.5
L39 (Mundi)	09°09'47.3''	006°05'43.5''	139	11.5	127.5
L40 (Emagiti)	09°11'11.9''	006°04'16.3''	129	8.1	120.9
L41 (Emi-Ndayagi)	09°11'03.0''	006°04'30.8''	135	10.5	124.5
L42 (Kuchita)	09°10'47.2''	006°05'05.0''	134	12.1	121.9
L43 (Kalachi)	09°12'18.1''	006°05'42.91	102	5.1	96.9
L44 (Ndaji)	09°13'55.5''	006°05'12.6''	119	3.9	115.1

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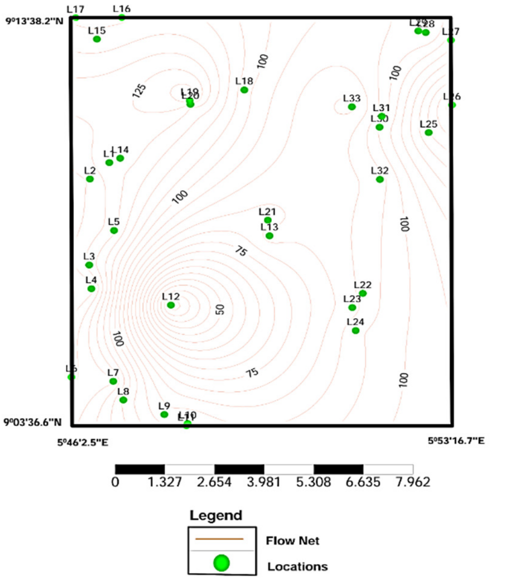

Figure 1: Groundwater flow net for parts of Egabko sheet

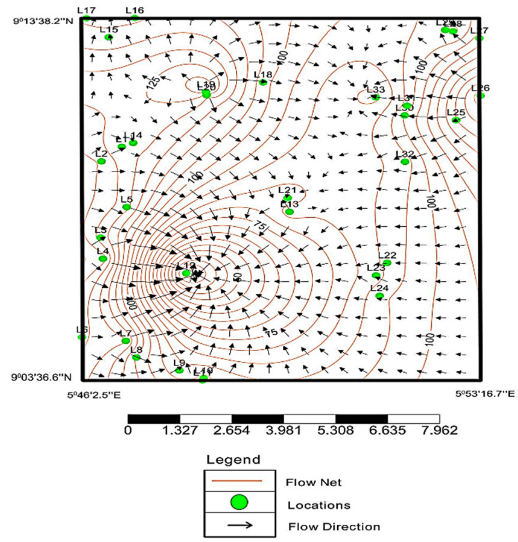

Figure 2: Groundwater flow direction on surfer for the parts of Egbako sheet

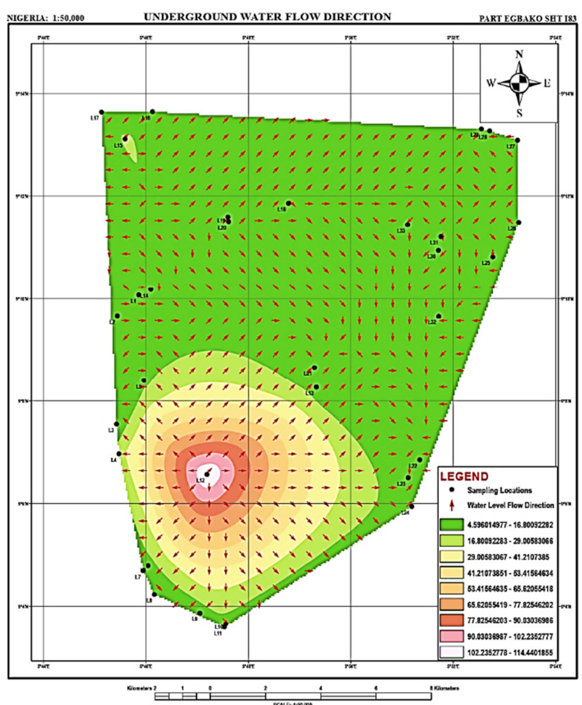

Figure 3: The groundwater flow model of part of Egbako Sheet on ArcGIS

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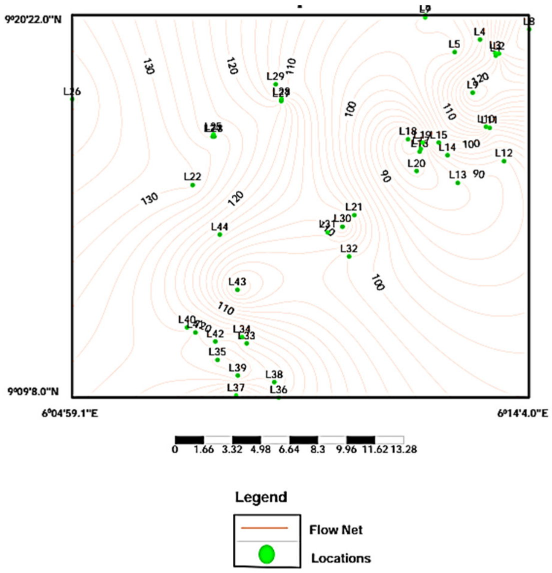

Figure 4: Groundwater flow net for parts of Bida sheet

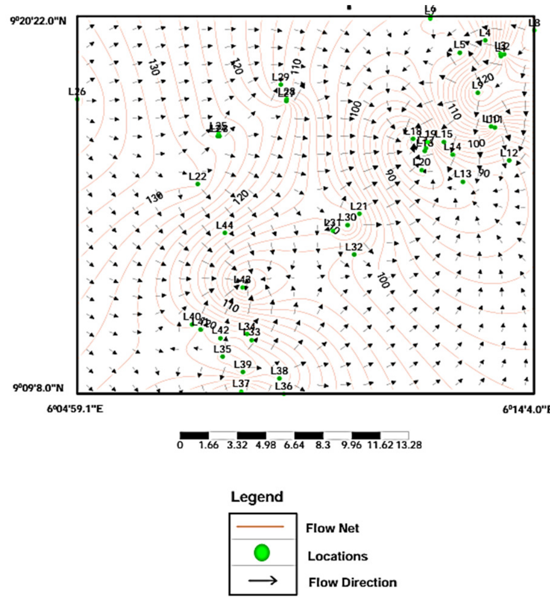

Figure 5: Groundwater flow direction on surfer for the parts of Bida sheet

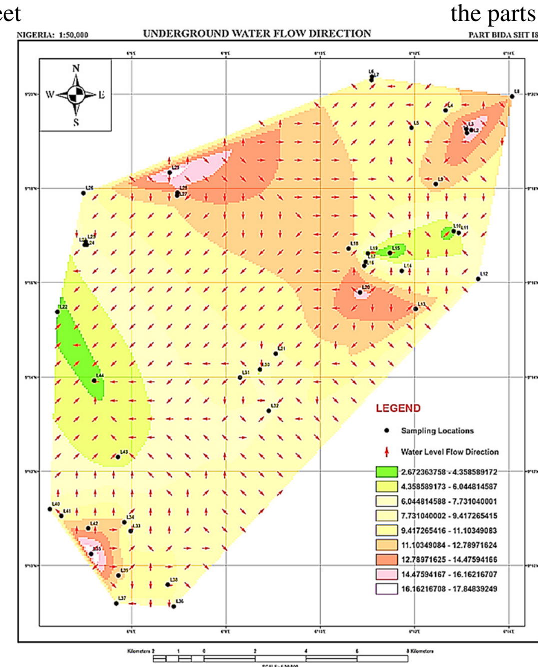

Figure 6: The groundwater flow model of part of Bida sheet on ArcGIS

4. CONCLUSION

The regional groundwater flow directions from the two wetlands located in the northern Bida Basin of Egbako (sheet 183) and Bida (sheet 184) from hydraulic head of water wells has been established. The lowest hydraulic zones in the two locations are at the villages of Emi-Yagi and Gogata in Bida and Egbako sheets respectively and represent the groundwater recharge areas. The highest hydraulic heads were obtained at Zanagi and Pati-Gbadafu in Bida and Egbako sheets respectively and represent the groundwater discharge zones within the two locations. These recharge and discharge zones are expected to indicate the areas of contaminant greatest impact and contaminant less impact within the two wetlands respectively. It is expected that the contaminant transportation in the two wetlands may adopt the same transportation pattern as the groundwater flow patterns within the wetlands. The chemical analysis of groundwater in these two wetlands is necessary to determine the spatial distribution of solutes in groundwater and to document changes in solute concentrations in the direction of flow which may reflect hydrochemical processes. The use of environmental and radioactive tracers is also suggested to monitor possible changes in the groundwater flow and also contaminant transport.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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