International Journal of Rural Development, Environment and Health Research
[Vol-7, Issue-2, Mar-Apr, 2023]
Issue DOI: https://dx.doi.org/10.22161/ijreh.7.2
Article DOI: https://dx.doi.org/10.22161/ijreh.7.2.2
ISSN: 2456-8678 ©2023 IJREH Journal

Investigation of groundwater flow direction using Geospatial technology: A case study in part of Port Harcourt, Rivers State, Nigeria

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Received: 05 Mar 2023; Received in revised form: 08 Apr 2023; Accepted: 15 Apr 2023; Available online: 25 Apr 2023

Abstract— *A geospatial technique was used in some parts of the Port Harcourt metropolis to establish the direction of groundwater movement. This method included the use of twelve carefully selected boreholes and a variety of cutting-edge tools, such as depth meters, handheld GPS, and measuring tape. The static water level in the boreholes and the ground surface elevation in relation to the average sea level of the region were two of the variables that were gathered. High-end software was used to analyze the data in order to create groundwater flow direction maps and 3D visualizations for displaying the whole research region based on the fluctuation in static water levels. This software included Microsoft Excel, ArcGIS 10.4, and ArcScene 10.4. Afterward, the main and minor flow directions were identified. The results showed that groundwater in the area moves from the north to the south, with group 4 having the largest hydraulic gradient and group 1 coming in second. On the other hand, groups 3 and 2 had the lowest hydraulic gradient. The main factors influencing groundwater flow were determined to be gravity and external pressure brought on by pumping. The research region's southern regions are more vulnerable to groundwater pollution, which may result from zones with higher hydraulic heads, according to the flow pattern in the aquifer system. As a result, it is advised that residential boreholes and municipal water wells be located on the study area's northern sides, whereas sanitary landfills and garbage sites should only be located in the southwest.*

Keywords— *Flow direction; Hydraulic gradient; deep meter; groundwater; Geospatial technology*

I. INTRODUCTION

Groundwater flow direction is the way in which groundwater flows within an aquifer. The path of groundwater flow is affected by several variables, including the elevation of the water table, the hydraulic conductivity of the soil or rock through which the groundwater flows, and the position of replenishment and release regions. Groundwater is defined as water that is present beneath the Earth's surface in geologic materials such as rocks, soil, and sediment; an aquifer is a geologic material that is saturated with water and can create or transfer useful quantities of water; and the clay, silt, sand, and gravel that rivers and marine processes have accumulated in the research region are a multi-aquifer system. According to different authors, these sediments are found within the Benin Formation and are distinguished by their geologic features and ages. (Etu-Efeotor and Akpokodje, 1991; Oborie et al., 2014). Groundwater is not static, but rather moves or travels beneath in reaction to different factors, claims Todd (1980). The two main factors affecting the flow of groundwater are gravity and external pressure. Gravity is associated with the naturally occurring slope of the rocks in the shallow aquifer beneath the region, whereas external pressure is associated with the pressure changes brought on by drilling wells, which can shift the natural flow direction of groundwater. Buddemeier and Schloss (2000) recommend taking numerous readings of groundwater elevation throughout the length of the aquifer and mapping the data to identify the direction of groundwater movement. Equipotential lines, which link points with the same elevation, allow one to depict the same pressure between adjoined locations. (Fetter, 1990). Delleur (1999) asserts that groundwater travels perpendicular to equipotential lines, moving from higher value lines to lower value lines, which are associated with higher and lower elevations or pressures, respectively. A popular way to represent groundwater flow patterns on equipotential surface maps is with arrows that point in the direction the groundwater is moving (Oborie et al., 2017). It ultimately flows into streams, lakes, rivers, oceans, ponds, and boreholes. In contrast to surface water, groundwater flow does not always coincide with surface water flow. Water always moves from an area of greater head to a region of lower head, according to Wehrmann's explanation in 2007. As a result, the quality of the water accessible to people who live in areas with lower water levels is immediately impacted by the use of groundwater in areas with higher water levels. Due to the presence of colleges and other government institutions, the study area is quickly expanding and has a rising population. The water corporation's supply is restricted, so residents must depend on tainted public water and groundwater that is drawn from hand-dug wells. Groundwater developments are a feasible choice for the supply of potable water in order to satisfy the demand for high-quality groundwater sources and understanding and controlling groundwater resources can benefit from using geospatial technology to investigate the path of groundwater movement. The term "geospatial technology" applies to a wide range of methods and devices that make use of spatial data and research to reveal information about natural systems. Therefore, this research area's groundwater flow pattern needs to be examined, though, due to worries about the amount and purity of the groundwater. In order to anticipate the most probable pattern of contaminant movement and make sound suggestions, it is essential to understand the pattern of groundwater flow using geospatial technology.

II. STUDY AREA

The study area of investigation is located in Rivers State communities (Figure 1.1) in Port Harcourt, Obio/Apor, and Eleme Local Government Areas in Rivers State. The area lies within Latitude 4°48'0"N – 4°51'0"N and Longitude 7°0'0"E – 7°1'0"E. The area has a good road network that links to other parts of the state that is situated in southern Nigeria and has an abundance of aquatic resources, including rivers, creeks, and wetlands. The state's hydrogeology is distinguished by a complicated network of river systems and alluvial deposits. The state's aquifer system is primarily made up of unconsolidated sand and gravel layers, which serve as the major supply of groundwater. The Niger Delta sedimentary basin, which consists of overlapping layers of sandstones, shales, and claystones, dominates the hydrogeology of Rivers State, according to Abam and Nwankwoala (2020). The basin's aquifers are usually unconfined or semi-confined and are enriched by rainwater and surface water. The area's groundwater flow is usually toward the sea, which is consistent with the regional groundwater flow trend. Furthermore, anthropogenic activities such as oil and gas development, saltwater incursion, and pollution from household and commercial waste have an impact on groundwater in Rivers State. The impacts of these actions on the groundwater system, according to Nwankwoala et al. (2021), have resulted in a deterioration in water quality, posing a major danger to public health. To summarize, Rivers State's hydrogeology is complicated and affected by a variety of variables, including geology, climate, and human actions. More study is required to comprehend how these factors interact and how they affect the groundwater system.

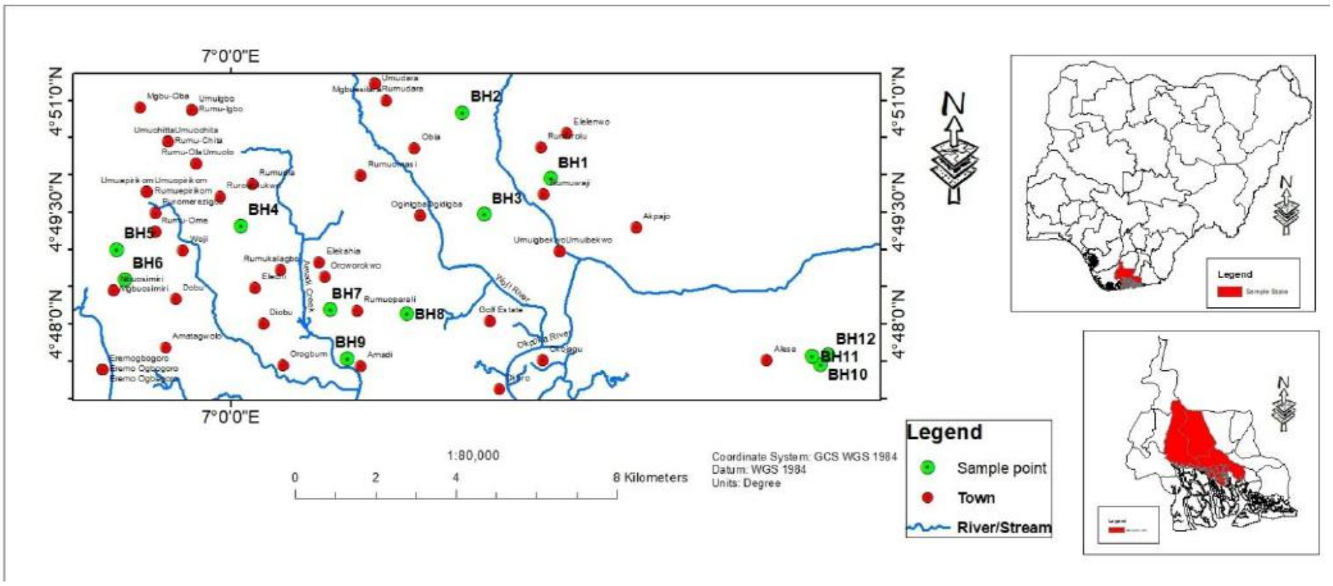

Fig.1: Map of the Study Areas

III. MATERIALS AND METHOD

Data collection

A field survey was conducted using a Garmin 76csx global positioning system (GPS) to record the longitude, latitude, and surface elevations with respect to mean sea level at various borehole locations throughout the study area. This information was used to determine the direction of groundwater flow. A deep meter and measuring tape were used to measure the static water level (SWL) in the boreholes, and a coaxial water level meter was used to measure the SWL in the wells. Prior to taking measurements, the well pump was shut off for at least two hours to verify that the environment remained static (non-pumping). The height to which water naturally rises in a well is known as the hydraulic head (HH), and this was later discovered. This result was obtained by deducting the borehole water table depth from the ground elevation relative to the mean sea level. In conclusion, the acronyms SWL for static water level, GSE for ground surface elevation with respect to mean sea level, and HH for hydraulic head—which is determined by subtracting GSE from SWL—were all utilized.

Data processing

Microsoft Excel was used to evaluate the field survey data and categorize the information into categories based on the triangulation of three wells. Straight lines were used to link the hydraulic heads at each point, and the distances between them were then computed. The contours of the water table were then shown by connecting the equal increments of elevation difference with lines that had the same values. The direction of the greatest elevation change, which is shown by the line perpendicular to the straight lines joining the height increments, is where groundwater flows from higher altitudes to lower elevations.

Arc GIS 10.4 and Arc Scene 10.4 are two examples of applications that were used to create the contour map. The data must be structured as XYZ files, where X and Y represent the coordinates of the measurement locations and Z represents the height of the water table or piezometric surface above a selected reference level. The generated map displays several patterns in the research area's groundwater flow direction. This kind of digital map is helpful for creating a numerical groundwater flow model for a project or for aquifer management in a geographic information system.

IV. RESULTS AND DISCUSSION

BH1 is located at longitude 7.071666667 and latitude 4.8325 in Figures 1, 2, and Table 1. BH2 is located at longitude 7.071666667 and latitude 4.847338, and BH3 is located at longitude 7.056723 and latitude 4.824588.

The results show that the hydraulic head for BH1 is 36.5 m, BH2 is 40.1 m, and BH3 is 11.45 m, indicating that the hydraulic gradient is 0.01 m and that the groundwater flow direction in the area is flow from north to south-west, implying that contaminants in the area will move from north to south-west.

Table 1: Parameter for determination of flow direction of study area.

SAMPLE CODE	Lat	Long	location	GSE	SWL	Hydraulic Head	Group
BH1	4.8325	7.071667	Oil mill 1/ Elelenwo	41.7	5.2	36.5	G1
BH2	4.847338	7.0519	Oil Mill 2/ Rumuokurusi	44.9	4.8	40.1	
BH3	4.824588	7.056723	Woji	16.25	4.8	11.45	
BH4	4.821944	7.002222	GRA/Polo Club	18	4.4	13.6	G2
BH5	4.816667	6.974444	Agip Estate 1	13.4	4.8	8.6	
BH6	4.81	6.976389	Agip Estate 2	12.96	4.4	8.56	
BH7	4.803236	7.022366	Trans Amadi 1	15.7	4.8	10.9	G3
BH8	4.802222	7.039444	Trans Amadi 2	14.82	5.1	9.72	
BH9	4.792243	7.026175	Trans Amadi 3	13.4	5.8	7.6	
BH10	4.790913	7.132038	E leme 4	26.1	4.6	21.5	G4
BH11	4.792722	7.130128	Eleme 5	32.2	5.8	26.4	
BH12	4.793058	7.133656	Eleme 6	26.4	3.2	23.2	

Group 1

BH 2 Hydraulic head (H)= 40.10 m

BH3 Hydraulic head (L) = 11.45 m

Distance between BH 2 to BH3 = 2570 m

Hydraulic Gradient = BH2 (H) – BH3(L)
Length between BH2 – BH3

= 40.10 m – 11.45 m = 0.01 m
2570 m

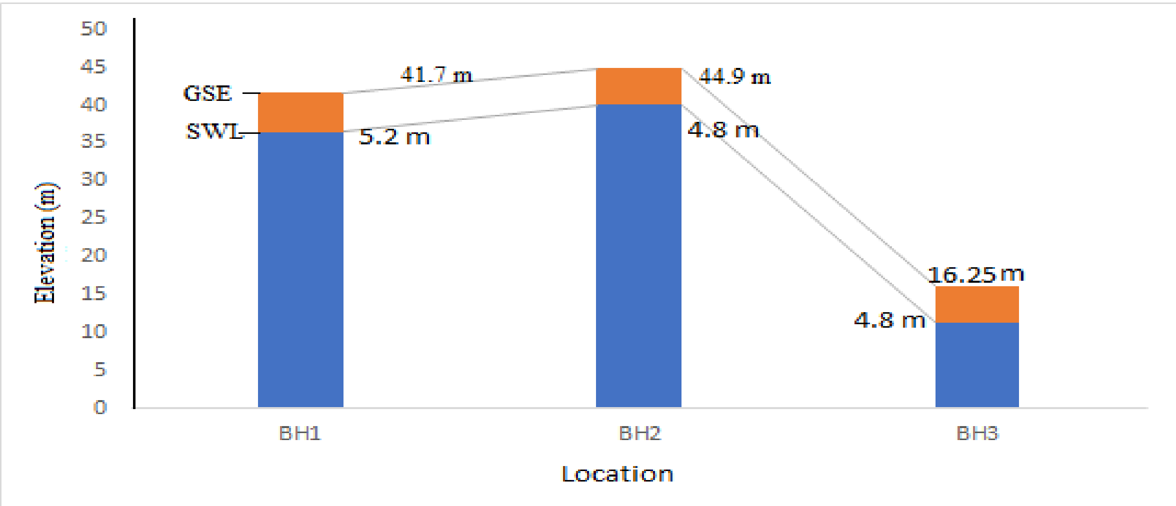

Fig.2: Graphical presentation of Ground surface elevation and Static water level in the boreholes Group 1.

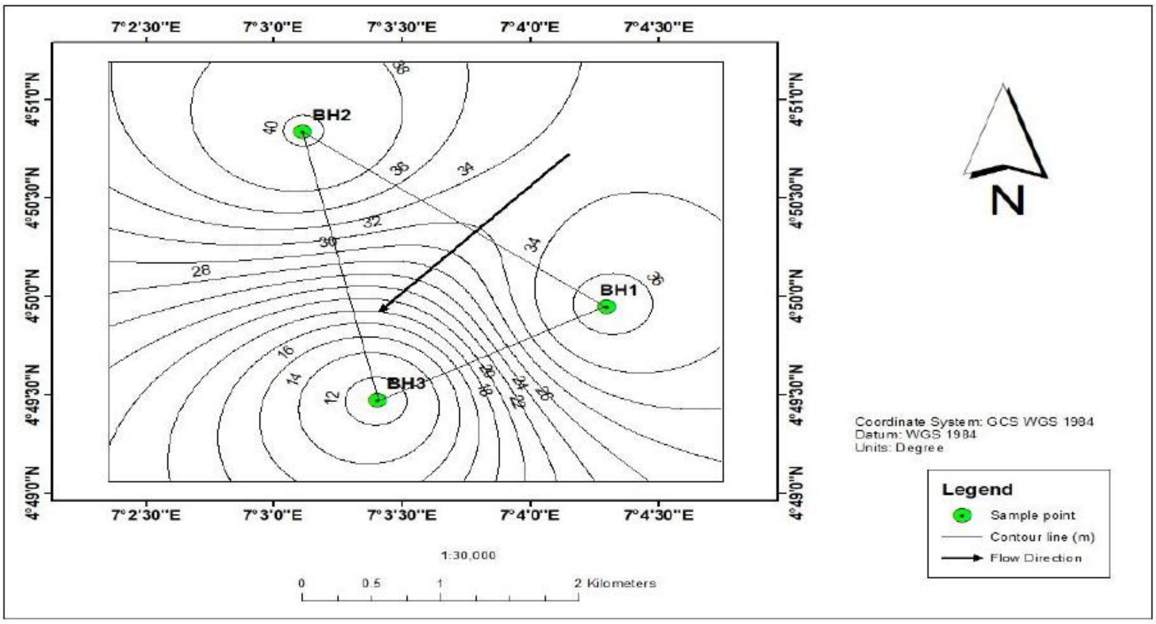

Fig.3: Groundwater flow direction map in Group 1

Group 2

BH 4 Hydraulic head (H)= 13.60 m

BH 6 Hydraulic head (L) = 8.56 m

Distance between BH 4 to BH 6 = 3150m

$$\text{Hydraulic Gradient} = \frac{\text{BH4 (H)} - \text{BH6(L)}}{\text{Length between BH4} - \text{BH6}}$$

$$= \frac{13.60\text{ m} - 8.56\text{ m}}{3150\text{ m}} = 0.002\text{ m}$$

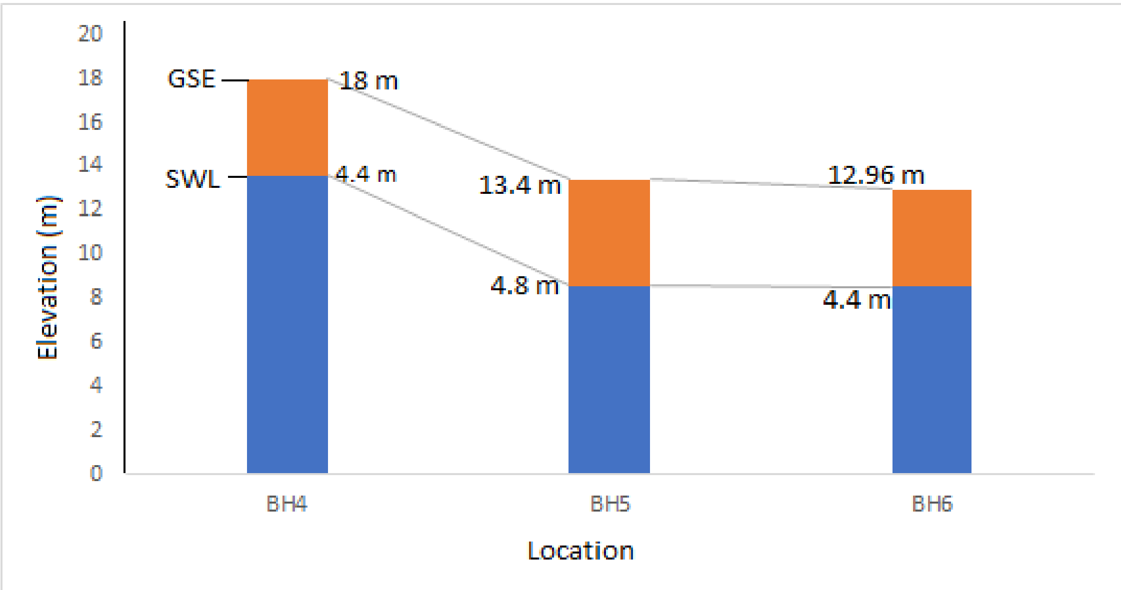

Fig.4: Graphical presentation of Ground surface elevation and Static water level in the boreholes Group 2.

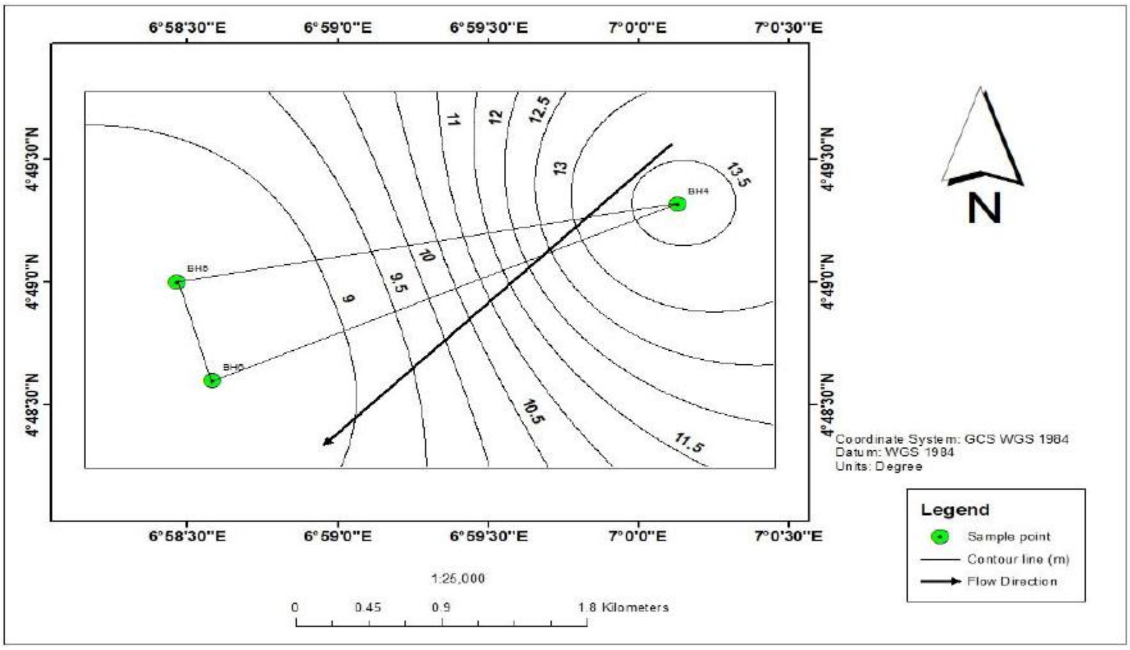

Fig.5: Groundwater flow direction map in Group 2.

Figures 4, 5, and Table 4.1 contain BH4 with longitude 7.002222 and latitude 4.821944, BH5 with longitude 6.974444 and latitude 4.816667, and BH6 is located at longitude 6.976389 and latitude 4.81. The results show that the hydraulic head for BH4 is 13.6 m, BH5 is 8.6 m and BH6 is 8.56 m. Therefore, the hydraulic gradient indicates 0.002 m and it reveals that the groundwater flow direction in the area flows from north towards south-west, which implies that contaminants in the area will move from north toward the south-west direction.

Group 3

BH 7 Hydraulic head (H)= 10.90 m

BH 9 Hydraulic head (L) = 7.60 m

Distance between BH 7 to BH 9 = 1290m

$$\text{Hydraulic Gradient} = \frac{\text{BH4 (H)} - \text{BH6(L)}}{\text{Length between BH4} - \text{BH6}}$$

$$= \frac{10.90\text{ m} - 7.60\text{ m}}{1290\text{ m}} = 0.003\text{ m}$$

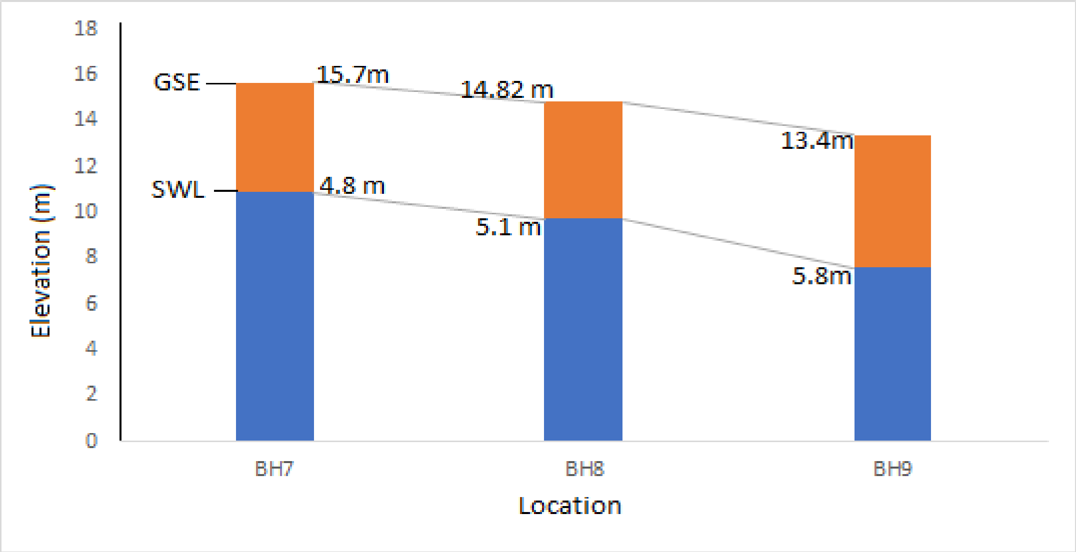

Fig.6: Graphical presentation of Ground surface elevation and Static water level in the boreholes Group 3.

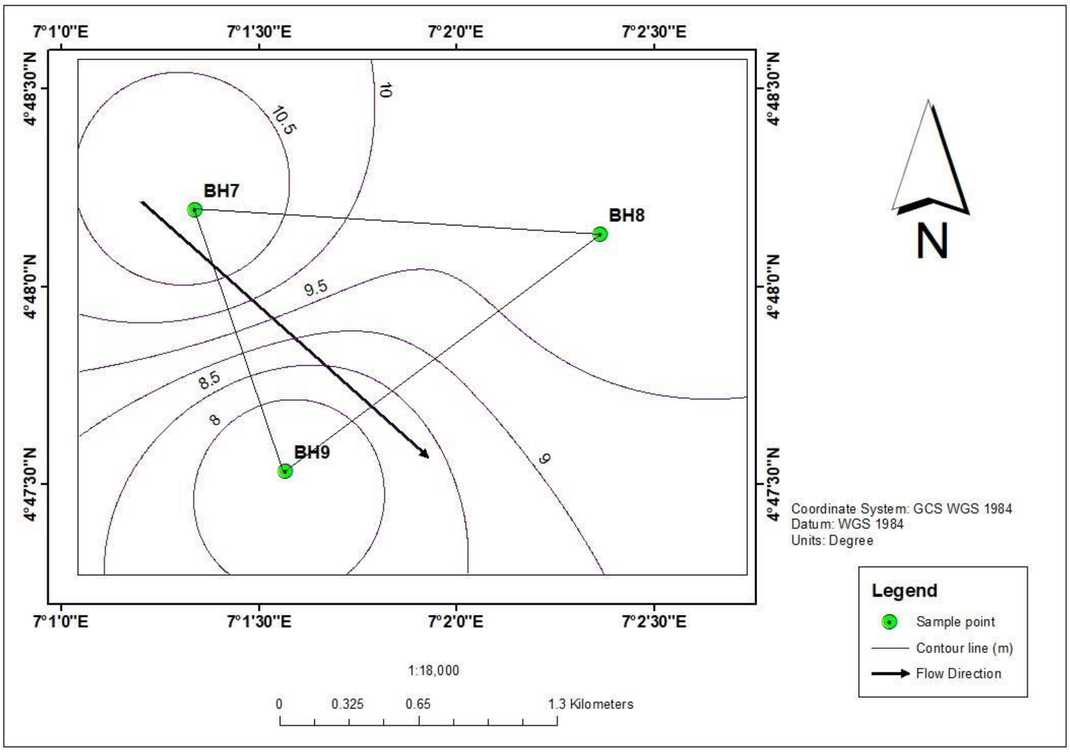

Fig.7: Groundwater flow direction map in Group 3

Figures 6 and 7 as well as Table 1 include BH7, BH8, and BH9. BH7, BH8, and BH9 are found at longitude 7.022366 and latitude 4.803236, 7.039444 and latitude 4.802222, and 7.026175 and latitude 4.792243, respectively. The results show that BH7, BH8, and BH9 each have hydraulic heads of 10.90, 9.72, and 7.60 meters, respectively. This results in a hydraulic gradient of 0.003 m, which shows that the area's groundwater flows in a north to southeast path. As a result, it is anticipated that any pollutants in the area will move southeastward, following the movement of groundwater.

Group 4

BH 11 Hydraulic head (H)= 26.40 m

BH 10 Hydraulic head (L) = 21.50 m

Distance between BH 11 to BH 10= 290m

$$\text{Hydraulic Gradient} = \frac{\text{BH11 (H)} - \text{BH10(L)}}{\text{Length between BH4} - \text{BH6}}$$

$$= \frac{26.40\text{ m} - 21.50\text{ m}}{290\text{ m}} = 0.02\text{ m}$$

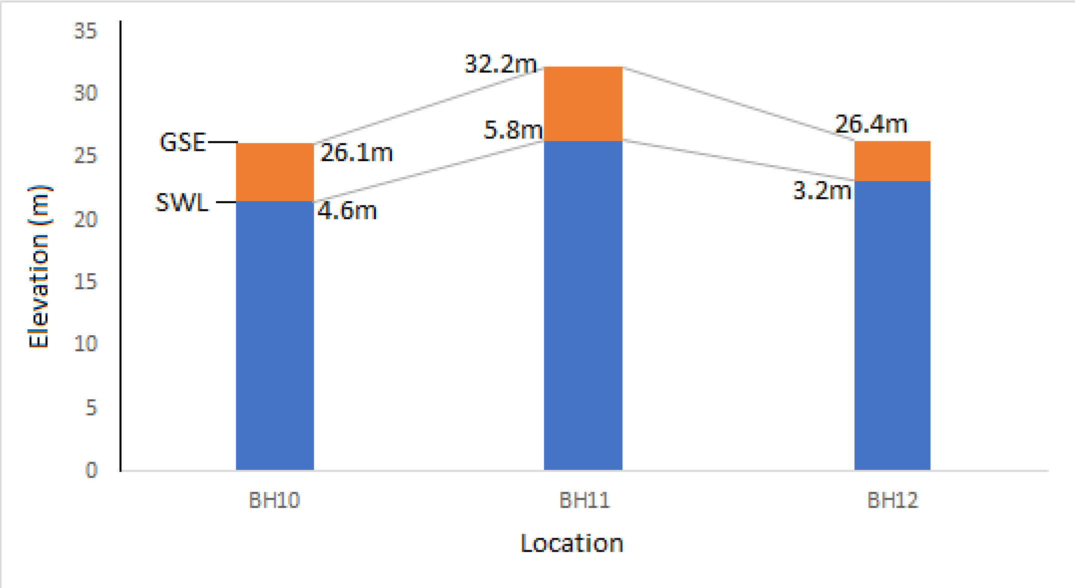

Fig.8: Graphical presentation of Ground surface elevation and Static water level in the boreholes Group 4.

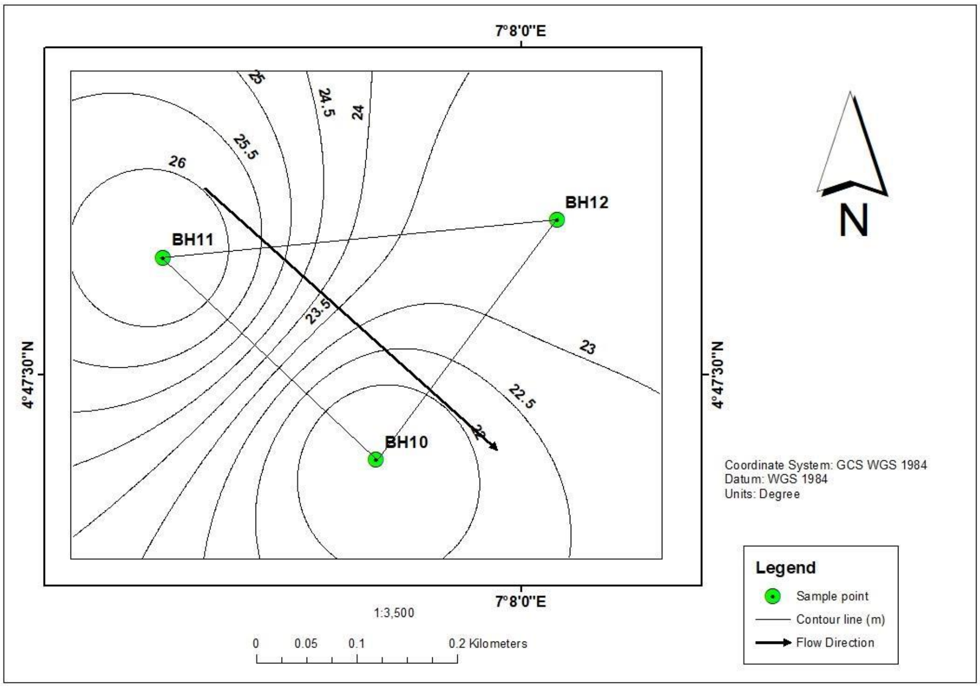

Fig.9: Groundwater flow direction map in Group 4

Figures 8, 9, and Table 1 show BH10, BH11, and BH12, correspondingly. BH10 is positioned at 4.790913 latitude and 7.132038 longitude, BH11 at 4.792722 latitude and 7.130128 longitude, and BH12 at 4.793058 latitude and 7.133656 longitude. BH10 has a hydraulic head of 21.50 meters, BH11 has a hydraulic head of 26.40 meters, and BH12 has a hydraulic head of 23.20 meters, according to the results. The hydraulic gradient, which is the water table's steepest incline, is the greatest gradient measured at 0.02 m. This suggests that the groundwater in this group moves more quickly than it does in the others and that the groundwater in the region moves from the north to the southeast. Consequently, any contaminants

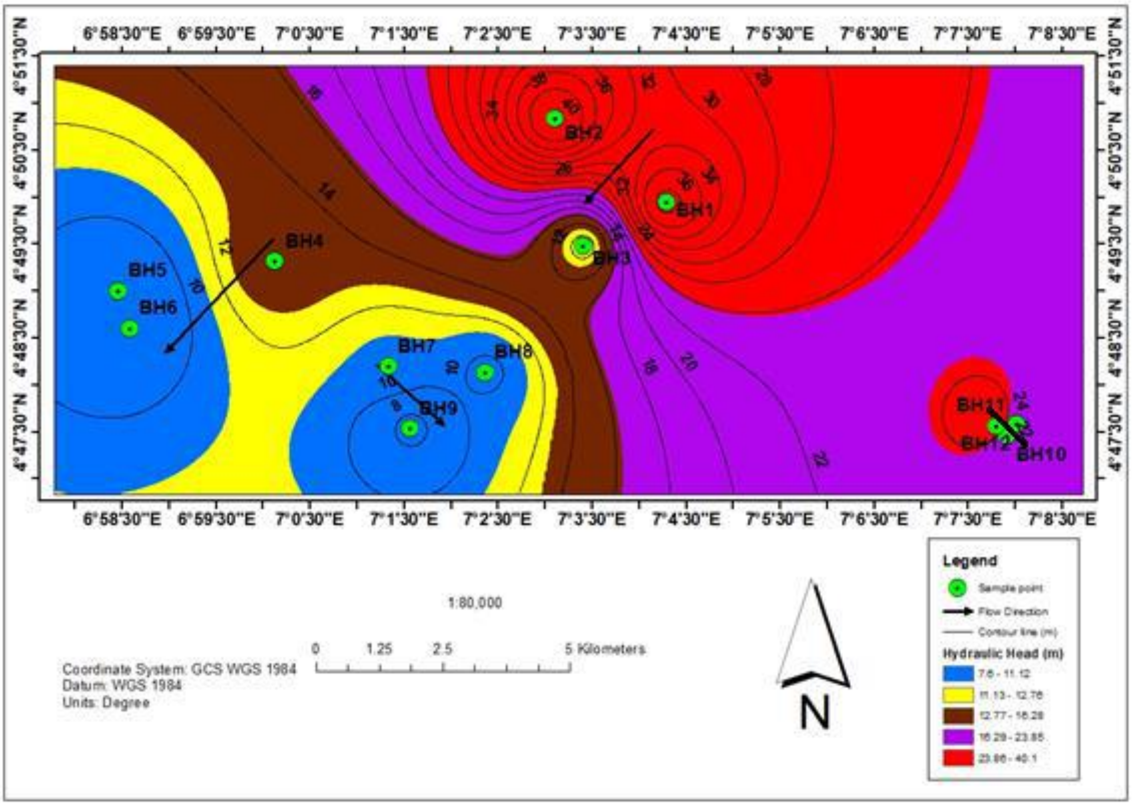

Fig.10: Groundwater flow direction map of part in Port Harcourt, Rivers State

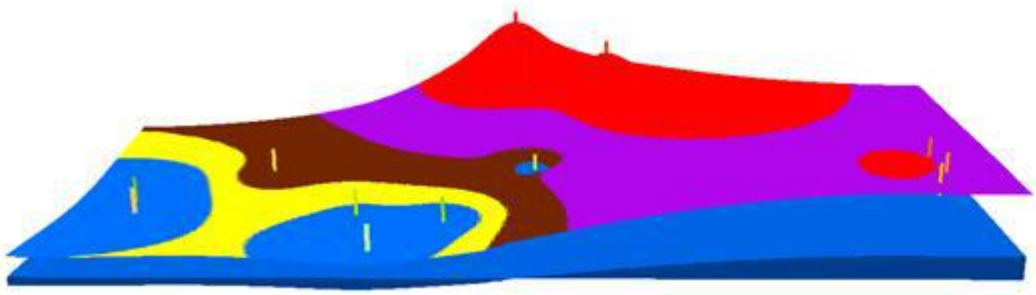

Fig.11: 3D Groundwater flow direction map in part of Port Harcourt, Rivers State

From the findings of the computer-aided contouring of the aquifer system in Figures 10 and 11, groundwater moves from the north towards the southeast region and southwest of the study area. As a result, contaminants that enter the groundwater system in the study area's northern regions are likely to move toward the southeast and southwest. According to the statement, communities in the southern zones of the research area may be more significantly impacted by excessive land use activities in the area, such as indiscriminate solid refuse dumping, underground sewer leaks, and petroleum storage facilities. This is due to the likelihood that contaminants flowing from the north towards the southeast corner and southwest will have an impact on the groundwater in these regions.

To reduce the negative effects on the groundwater system in the southern zones, it is crucial to take action to manage and regulate land use activities in the northern sections of the study region. This might entail putting in place tighter rules for disposing of solid refuse, making sure that subterranean sewer systems are managed properly, and controlling the building and upkeep of petroleum storage facilities to stop leaks and spills. To detect any possible contamination and take the necessary action to resolve it, frequent monitoring of the groundwater quality in the research area's southern zones is also required.

V. CONCLUSION

The map of Port Harcourt revealed that groundwater flows from the north toward the southern part of the region, with group 4 having the highest hydraulic gradient, followed by group 1, while the lowest hydraulic gradient is in group 3, followed by group 2. The implication of this with respect to vulnerability to groundwater pollution is that the southern section of the aquifer is more susceptible to receiving transported contaminants from the northern part of the study area. It is therefore advisable to site municipal boreholes in the north, while the location of landfills and solid waste dumpsites should be restricted to the southern region of the study area.

VI. RECOMMENDATION

It is recommended that the Rivers State government and other stakeholders in the area ensure that residents in the area are educated on the importance of ensuring clean/environmentally sustainable practices and are encouraged to do so in order to avoid contamination of the groundwater resources available within the study area, particularly in the northern sections, which could easily spread throughout the aquifer system.

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