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Investigation of Groundwater Flow Direction in Port Harcourt, Nigeria

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K E Y W O R D S

Contour map, Groundwater, Hydraulic head, Port Harcourt.

A B S T R A C T

The lack of reliable municipal water supply in the city of Port Harcourt has led to indiscriminate drilling of boreholes by the residents however, the direction of groundwater flow within the entire city has not been established. Hence, the research investigated the flow direction of groundwater in the study area in order to understand the best location for siting septic tanks and dumpsites with respect to the position of the existing or proposed borehole. This was achieved by determining the hydraulic heads (Hh) of twenty boreholes evenly distributed within the city by subtracting the static water level (SWL) from the corresponding earth surface elevation (E) with the use of a GPS and dipmeter. Results revealed that the hydraulic heads ranged from 0.14 – 23.16m while the surface elevation and static water level lies between 1.93 – 39.33m and 1.79 – 17.27m respectively. The contour map of the hydraulic heads indicated that the groundwater flows towards the southern and south-western directions hence, the residents were advised to take into cognizance when sitting dumpsites, landfills, and septic tanks with respect to proposed or existing boreholes.

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1. Introduction

Port Harcourt is an urbanized and industrialized city in the coastal region (toward the Atlantic Ocean) of Nigeria. The water supply in Port Harcourt metropolis is largely relied on groundwater due to the deterioration of the surface waters within the city by the rapid urbanization and industrialization, coupled with the high rate of rural-urban migration.

Municipal water supplies in Port Harcourt represent less than 1% of the available water sources [1]. Hence, residents primarily rely on privately constructed and maintained boreholes for domestic purposes, which are supplemented with commercially packaged bottled and sachet water for drinking. The shallowness of the water table which reduced the cost of drilling further encouraged the residents to drill boreholes to the extent that virtually every building in Port Harcourt has a borehole. However, 85% of the residents used flush toilets connected to septic tanks while the rest relied on toilets and latrines that drain directly into surface waters [1]. This simply suggests that there will be a high possibility of contamination of boreholes by septic tanks since the boreholes and septic tanks are usually found within the same compound. This has earlier been identified by numerous literature that most borehole water in Port Harcourt and other Nigerian cities are polluted with contaminants that could be linked to septic tanks and landfills [2, 3].

Understanding the direction of groundwater flow in Port Harcourt will enable the residents to determine the best location for siting septic tanks, landfills, dumpsites, etc with respect to proposed or existing boreholes. Usually, septic tanks, landfills, and dumpsites are sited downslope while boreholes and hand-dug wells are sited upslope. However, the direction of groundwater flow in a given area may not be the same as that of surface water hence, the need for developing the true direction of groundwater flow in Port Harcourt cannot be overemphasized.

2. Description of Study Area

Port Harcourt is the capital of Rivers State of Nigeria and at the same time the largest city in the state, occupying an approximated area of 369 km^2 [4]. It is located between Latitude 4^0 42' 00" to 4^0 57' 03" North and Longitude 6^0 53' 11" to 7^0 8' 49" East. It is bordered by Ikwerre Local Government Area (LGA) at the North-West; Etche LGA and Oyigbo LGA at the North- East; Emuoha LGA at the West; Eleme LGA at the East; Degema LGA at the South-West and Okrika LGA at the South-East (Figure 1). As of the 2006 population census, Port Harcourt metropolis recorded a population of 1,005,904 [5]. There is rapid expansion of the city due to the amalgamation of nearby settlements. This could be attributed to the high invasion of individuals willing to reside in the city due to the employment opportunities available in the oil and gas industries thus, increasing the number of inhabitants.

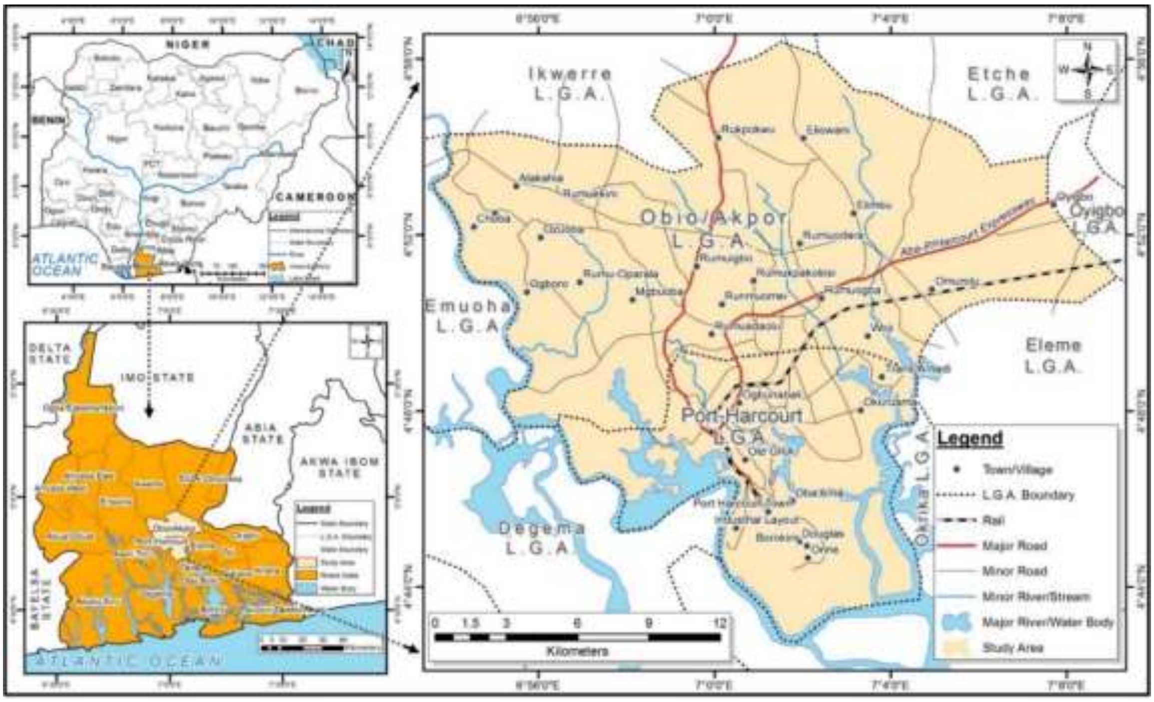

Figure 1: Map of Port Harcourt metropolis (Abio-Akpo and Port Harcourt LGAs)

The rainy season in Port Harcourt is very long compared to the dry season [6]. Harmattan season is known to be very severe in most West African countries but its effect is mild in Port Harcourt. The peak rainfall which is approximately 367 mm is usually experienced during September whereas the mean rainfall for the driest month is roughly 20 mm and mostly occurs during December. Also, the mean temperature of the area within a year normally ranges from 25 °C – 28 °C [7].

The high precipitation frequently recorded in the area easily percolates through the topsoil since it is mostly sandy, to recharge aquifers. Groundwater quality in some parts of the study area (especially the southern part) is salty due to seawater intrusion. Common vegetations that could be found within the area are mangrove forest, raffia palms as well as the tropical rain forest. The aquifers are mostly sandy layers ranging from fine to coarse as well as sub-angular to sub-rounded grain particles however, the transmissibility lies in between 1.05×10^{-2} and 11.3×10^{-2} m^2/sec while storage coefficient and specific capacity range from 1.07×10^{-4} to 3.53×10^{-4} and 19.01 to 139.8m^3/h/m drawdown respectively [8].

3. Materials and Method

The map of the study area was obtained through a global online portal and thereafter, 20 points were selected randomly within the study area map and presumed to represent the locations of boreholes. A preliminary visit (feasibility studies) to the presumed locations was made with the guide of the study area map. However, it was noted that the geographical coordinates of the presumed locations did not correspond to the exact position of the boreholes within the areas visited. Hence, the nearest boreholes to the presumed locations were considered. This was followed by negotiating with the owners of the boreholes to grant accessibility to them. A handheld Global Position System (GPS) with model number: Etrex 20x, made by Garmin, USA was used in recording the geographical coordinates of the considered boreholes, and the values were recorded as shown in Table I.

TABLE I: Description of boreholes

Site Code	Site Name	Geographical Coordinate	Description
B1	UPTH	N 04º 54' 05.5", E 006º 55' 37.2"	Uniport Teaching Hospital water scheme.
B2	Rumuodomaya	N 04º 53' 33.1", E 005º 59' 56.4"	Residential area at Akwaka phase 3, Rumuodomaya.
B3	Eligolo Road	N 04º 51' 58.7", E 007º 00' 48.3"	Residential/school area at Eligolo road.
B4	Abuloma	N 04º 46' 50.7", E 007º 02' 59.5"	Hotel/residential area at Abuloma.
B5	T/Amadi	N 04º 48' 10.6", E 007º 02' 52.2"	School premises (Tago Int'l Sch., off Odili Rd, T/Amadi).
B6	Elelenwo	N 04º 50' 07.3", E 007º 04' 16.3"	Church premises/residential area at Elelewon.
B7	Rumuokwurushi	N 04º 52' 05.1", E 007º 04' 24.6"	Residential area before Nzor hotel, Rumuokwurushi.
B8	Oroigwe	N 04º 52' 21.5", E 007º 02' 40.0"	Residential area at Oroigwe, Elimgbu.
B9	Eneka	N 04º 53' 40.0", E 007º 02' 28.7"	Model Health Centre, Eneka.
B10	Rukpoku	N 04º 55' 42.6", E 007º 00' 39.8"	Residential area at Egbelu new road, Rukpoku
B11	Rumuagholu	N 04º 53' 21.4", E 006º 58' 52.5"	Residential/school area, off SARS road, Rumuagholo
B12	Rumuepirikom	N 04º 50' 08.4", E 006º 58' 36.1"	Commercial area at Rumuepirikom by Ada George Road.
B13	Rumuigbo	N 04º 50' 25.5", E 007º 00' 16.3"	Residential area behind PHWC, Psychiatric Rd, Rumuigbo
B14	Iriebe	N 04º 52' 08.8", E 007º 06' 32.4"	Residential area at Iriebe, off Confidence School Junction.
B15	New Layout	N 04º 53' 11.7", E 007º 05' 46.7"	New layout (farming activities) along Interlocked Rd, Iriebe
B16	Rumuolumini	N 04º 48' 40.6", E 006º 57' 20.2"	Church Premises (St Mark's Ang. Church, Rumuolumini).
B17	Iwofe	N 04º 48' 47.8", E 006º 56' 18.4"	Newly residential area at Erico Street, Iwofe Road.
B18	Borokiri	N 04º 45' 01.5", E 007º 02' 23.7"	Commercial area at UPE, Borokiri.
B19	Town	N 04º 45' 52.9", E 007º 01' 09.5"	Residential area at 6, Hospital Road, PH Township.
B20	Rumuokokwa	N 04º 48' 22.8", E 006º 59' 02.3"	Commercial area at 4, Nnokam Street (close to RSU gate).

Past literature revealed that groundwater abstraction in the study area occurs mainly under water table conditions [9, 10]. Notwithstanding, confirmation of the assertion was carried out. This was done by obtaining the lithological profile up to a depth of 130ft of five sites at the northern (B10), southern (B19), eastern (B14), western (B1), and the central part (B3) of the study area as shown in Figure 2 using resistivity method of geophysical techniques.

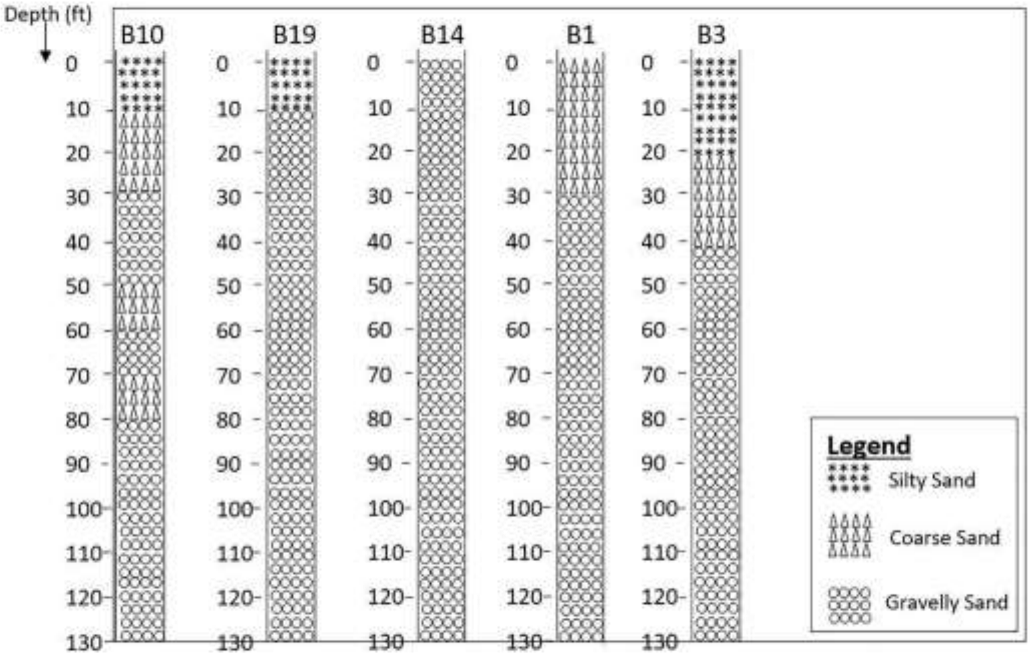

Figure 2: Lithological profile of some soils within the vicinity of the study area

The depth of boreholes in the study area are usually not deeper than 120ft therefore, it could be inferred from Figure 2 that the boreholes were tapping water from unconfined aquifers hence, the static water level in the wells were considered as the water table.

The earth surface elevations of the considered boreholes with respect to mean sea level (MSL) were recorded using a GPS and denoted as *E* while the static water levels (SWL) of the various boreholes were determined using a dipmeter (Plate 1). This was achieved by inserting the sensor probe of the dipmeter in the boreholes and gradual lowering of the graduated cable (tape) until the device beeps a sound (indicating that the sensor probe has touched water). The corresponding values on the tape were recorded as the SWL.

The hydraulic heads (H_h) of the various boreholes were determined by subtracting the static water level (SWL) from their corresponding earth surface elevations (*E*) as shown in both Figure 3 and Equation (1).

Plate 1: Dipmeter used for determining SWL

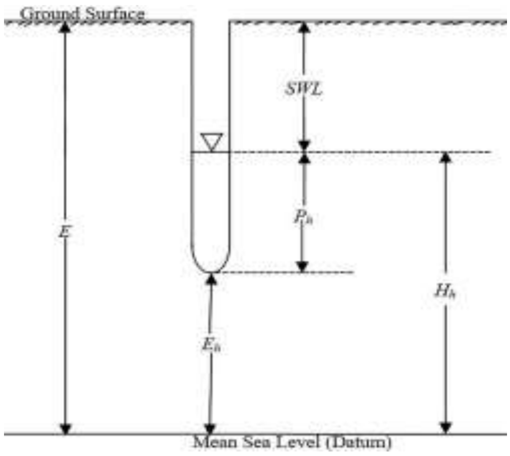

Figure 3: Distribution of heads in a borehole

$$H_h = E_h + P_h = E - SWL \quad (1)$$

In Equation (1), H_h is the hydraulic head, E_h is the elevation head, P_h is the pressure head, E is the earth surface elevation with respect to mean sea level while SWL is the static water level. Since the direction of groundwater flow is governed by hydraulic gradient as given by Darcy's law, it implies the water will flow from points of high hydraulic heads to points of low hydraulic heads.

The geographical coordinate of boreholes with a column for hydraulic head values were imputed on a Microsoft Excel sheet and imported into ArcGIS 10.7.1 software. Inverse Distance Weighted (IDW) interpolation method was used to convert the hydraulic head values to a continuous raster surface. The raster to contour tool in ArcGIS 10.7.1 was used to create a contour map of the hydraulic head while the flow direction tool was employed to calculate the flow direction using the converted hydraulic head raster as input. Thereafter, a 3D hydraulic head map was created in Surfer 13 software using the extracted contour from the raster tool while the flow direction arrows were imported from the direction created in ArcGIS 10.7.1 software.

4. RESULTS AND DISCUSSION

The computed hydraulic heads (H_h) of the various boreholes considered are given in Table II while the contour maps showing the direction of groundwater flow are presented in Figures 4 and 5. The contour maps revealed that the groundwater flows towards the southern and south-western directions of the study area.

TABLE II: Hydraulic heads of considered boreholes

Site code	Geographical coordinate	Earth surface elevation (m) E	Static water level (m) SWL	Hydraulic head (m) $H_h = E - SWL$
B1	N 04º 54' 05.5", E 006º 55' 37.2"	15.81	13.14	2.67
B2	N 04º 53' 33.1", E 005º 59' 56.4"	15.19	7.61	7.58
B3	N 04º 51' 58.7", E 007º 00' 48.3"	11.63	3.78	7.85
B4	N 04º 46' 50.7", E 007º 02' 59.5"	11.61	5.62	5.99
B5	N 04º 48' 10.6", E 007º 02' 52.2"	1.93	1.79	0.14
B6	N 04º 50' 07.3", E 007º 04' 16.3"	39.33	17.27	22.06
B7	N 04º 52' 05.1", E 007º 04' 24.6"	29.31	12.20	17.11
B8	N 04º 52' 21.5", E 007º 02' 40.0"	21.30	8.86	12.44
B9	N 04º 53' 40.0", E 007º 02' 28.7"	19.52	5.27	14.25
B10	N 04º 55' 42.6", E 007º 00' 39.8"	30.87	7.71	23.16
B11	N 04º 53' 21.4", E 006º 58' 52.5"	14.44	5.52	8.92
B12	N 04º 50' 08.4", E 006º 58' 36.1"	18.29	8.25	10.04
B13	N 04º 50' 25.5", E 007º 00' 16.3"	16.42	7.83	8.59
B14	N 04º 52' 08.8", E 007º 06' 32.4"	31.05	9.91	21.14
B15	N 04º 53' 11.7", E 007º 05' 46.7"	26.37	7.45	18.92
B16	N 04º 48' 40.6", E 006º 57' 20.2"	7.53	7.14	0.39
B17	N 04º 48' 47.8", E 006º 56' 18.4"	8.01	5.38	2.63
B18	N 04º 45' 01.5", E 007º 02' 23.7"	10.88	8.35	2.53
B19	N 04º 45' 52.9", E 007º 01' 09.5"	16.49	13.67	2.82
B20	N 04º 48' 22.8", E 006º 59' 02.3"	16.55	11.37	5.18

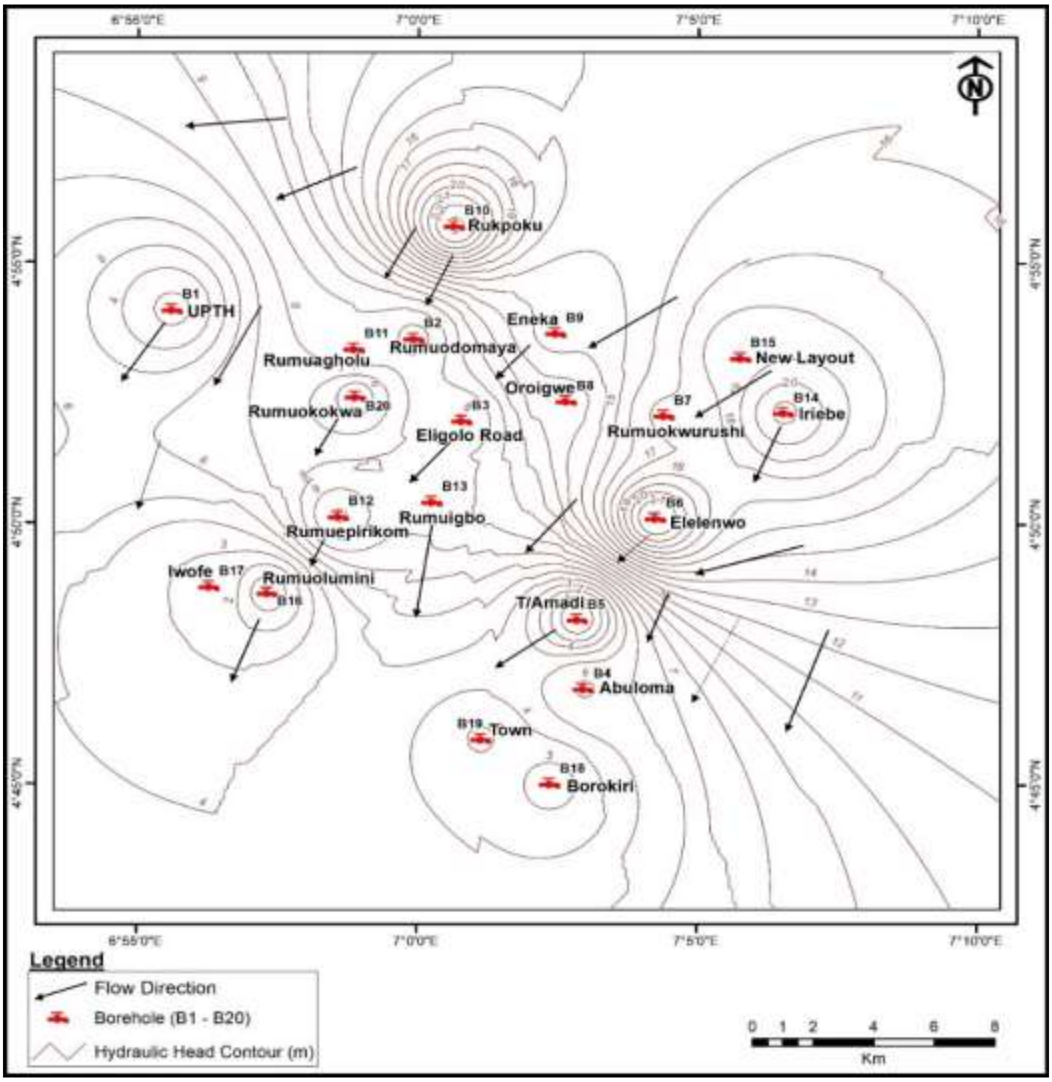

Figure 4: Contour map of groundwater hydraulic heads showing flow direction

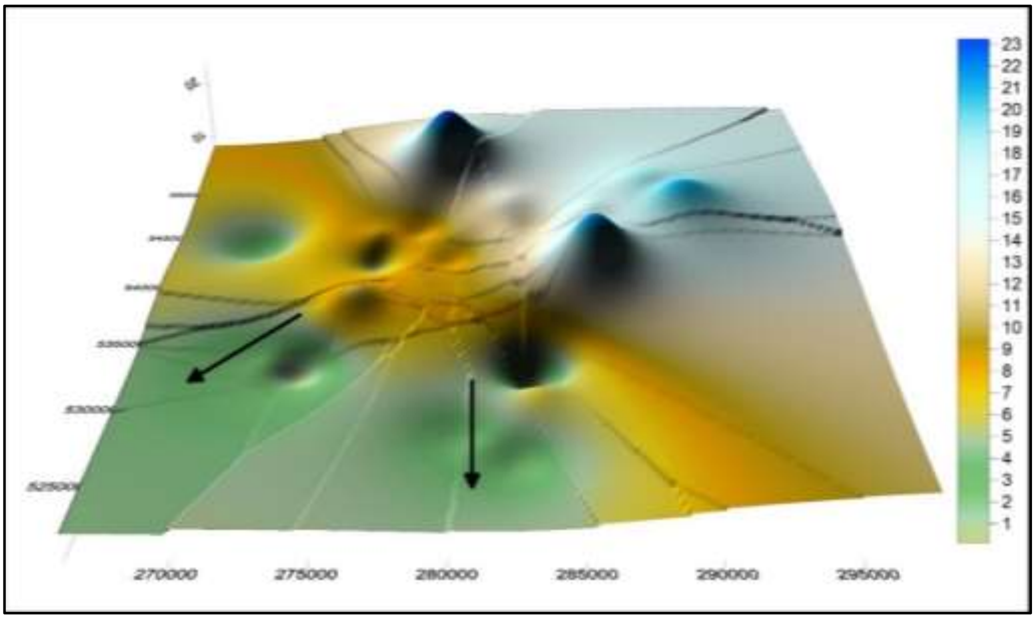

Figure 5: 3D contour map of groundwater hydraulic heads showing flow direction

5. Conclusion and Recommendations

The research has clearly revealed that the groundwater in Port Harcourt flows from the northern and eastern directions to the southern and south-western directions. This implies that the southern and south-western directions of the study area are more prone to groundwater contamination hence, landfills and dumpsites should be sited at these areas for the sake of abating groundwater contaminations by leachates. On the other hand, boreholes meant for potable water supply should be drilled at the northern and eastern parts of the study area at least 30m away from septic tanks. Also, the government should make provision of a functioning municipal water supply to minimize the practice of borehole drilling by each household. Notwithstanding, potable groundwater within the study area should be abstracted at the second and possibly third and fourth aquifers which are confined, to avoid contamination by leachates.

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