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Aquifer Characteristics and Groundwater Vulnerability in Parts of Warri, Delta State, Nigeria.

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Abstract

Pumping tests are the most important tools for assessing aquifer characteristics. Pumping tests assess the response of groundwater in an aquifer to pumping. Oil exploration and exploitation in Warri and environs have brought about an increase in the population of industries in the area. These have resulted to an upsurge in groundwater abstraction, which if unchecked can endanger the health of the aquifers. The aquifer system in the study area is largely unconfined and comprises of coastal plain-sand also known as the Benin Formation. The aquifer characteristics and groundwater vulnerability of parts of Warri, Niger Delta was investigated via pumping test and hydrochemical analyses respectively. The transmissivity ranges from $876.1m^2$/day to $2022.0m^2$/day while specific capacity varies from $41.84m^3/h/m$ to $96.30m^3/h/m$. The well yield is of the order of 200cm/h to 208cm/h. These findings indicate that the area has good groundwater potentials and high aquifer recharge. The borehole logs give a good lithostratigraphic profile of the subsurface rocks in the area. Majority of the bacteriological and physico-chemical parameters analyzed were below the guideline values of the Nigerian Industrial Standard (NIS, 2007) and the World Health Organization (WHO, 2006) except coliform count in locations 2 and 3; chromium in locations 3, 4, 6 and 7 as well as lead in locations 4 and 5 with values slightly above the guideline values. Based on the results, the groundwater vulnerability in the area was categorized into low and high regions.

Keywords: Pumping test, Aquifer hydraulic parameters, Physico-chemical analyses, Bacteriological analyses and Warri.

Introduction

In the last decade, there has been an increase in the exploitation of groundwater for water supply needs of many communities in Nigeria. Groundwater is not only feasible, but also the most economic source of portable water for urban and rural communities in Warri, Delta State. Groundwater has become contaminated mostly as a result of poorly designed hazardous waste disposal system, leakage from underground storage tanks, gas-flaring resulting in the formation of acid-rain, accidental oil spills and application of fertilizer and pesticides in agriculture. The chemicals trapped in the subsurface constitute a major long-term contamination source for the groundwater system, resulting in a threat to the groundwater supply and a direct risk to human health. Vulnerability is a cost-effective method of assessing groundwater quality and it is an important tool for a comprehensive sustainable management of groundwater resources. It is also useful for future hydrogeological planning and quite appreciable in Environmental Impact Assessment (Amadi, 2007). The need to undertake a comprehensive study of the pollution status of the ground water in parts of Warri, Niger Delta cannot be over-emphasized. The strategic position of the area to the country has lead to increased industrial expansion and upsurge in population.

The study is aimed at assessing the characteristics of the aquifers in Warri area and the vulnerability of the groundwater to pollution. The study is also targeted at providing useful information to be used for optimum groundwater development, utilization and management in the area and Niger Delta in general. The tendency of the pollutants infiltrating through the porous and highly permeable materials into the shallow water table thereby contaminating the groundwater cannot be completely ignored. Hence the need to study the aquifer characteristics as well as the pollution status of the ground water resources in the area is a right step in the right direction.

Study Area Description

The area under study is Warri and environs, Delta state. It lies between latitude 5^0 35^1N and 5^0 52^1N of the Equator and longitude 5^0 48^1E and 6^0 08^1E of the Greenwich Meridian with total area of about 340km^2. It is within the Benin formation of the Niger Delta Basin. The area is a low-land with an average elevation of 20m above sea level. It has an annual temperature of about 29^0C, relative humidity of 90% and a mean annual rainfall of about 2,300mm (Aston-Jones, 1998).

Geology and Hydrogeology of the Area

Warri falls within the Niger Delta (Fig.1), the largest basin in West Africa and the most prolific delta in Africa. It is situated on the continental margin of the Gulf of Guinea in equatorial West Africa between latitude 4^0N to 7^0N and longitude 5^0E to 8^0E covering an area of about 108900km^2. It extends from the Calabar flank and the Abakaliki Trough in eastern Nigeria to the Benin flank in the west and it opens to the Atlantic Ocean in the south. The development of the Niger Delta resulted from the formation of the Benue trough as a failed arm of a triple junction associated with the separation of the Africa and South American plates and subsequent opening of the South Atlantic (Whiteman, 1982). The Benue-Abakaliki trough was filled with sediments during the early Cretaceous time, which later underwent folding, faulting and uplift with subsidence of the adjacent Anambra basin to the West and Afikpo syncline to the East during the santonian. The Niger Delta consists of three diachronous units, namely from bottom, Akata, Agbada and Benin Formations (Weber and Daukoru, 1975).

The study area is underlain by the Quaternary Warri deltaic sand (Etu-Efeotor and Akpokodje, 1990). The sediments consist of alternating sequence of gravel, sand, silt and clay (Table 1). Texturally, the dominant sand ranges from fine to coarse and exhibits fining upward sequence. Small proportions of gravels and limited number of thin clay horizons are sometimes present at greater depths (Avbovbo, 1978). Two main aquiferous units have been identified in Warri. The shallowest aquifer of 2m to 5m depth occurs within the unconfined superficial alluvium comprising of sandy/silty layers. Hand dug wells exploit water from this aquifer. Deeper, confined and prolific aquifers are encountered at about 55m. This aquifer consists of medium to coarse grained sand and gravel. Industrial and public boreholes derived their source from the second aquifers. Water level in Warri and environs fluctuates in response to climatic conditions. Average water level in the dry season is 3.0m while it rises to the ground level during the rainy season. The present morphology of the Niger Delta is highly influenced by the regular strong south western prevailing wind and the regular pattern of long-share currents (Etu-Efeotor and Akpokodje, 1990). This is because the Niger Delta faces a high energy dynamic environment of the Atlantic Ocean. The strength of these currents diverts the sediment brought into the sea by the rivers, distributing them along the coast and preventing the formation of a bird-foot-type delta. This gives the Delta its present acute marginal shape. The quality and abundance of reservoir throughout the tertiary sequence of the Delta indicates that there has always been a major sand contribution from the shield area (Avbovbo, 1978).

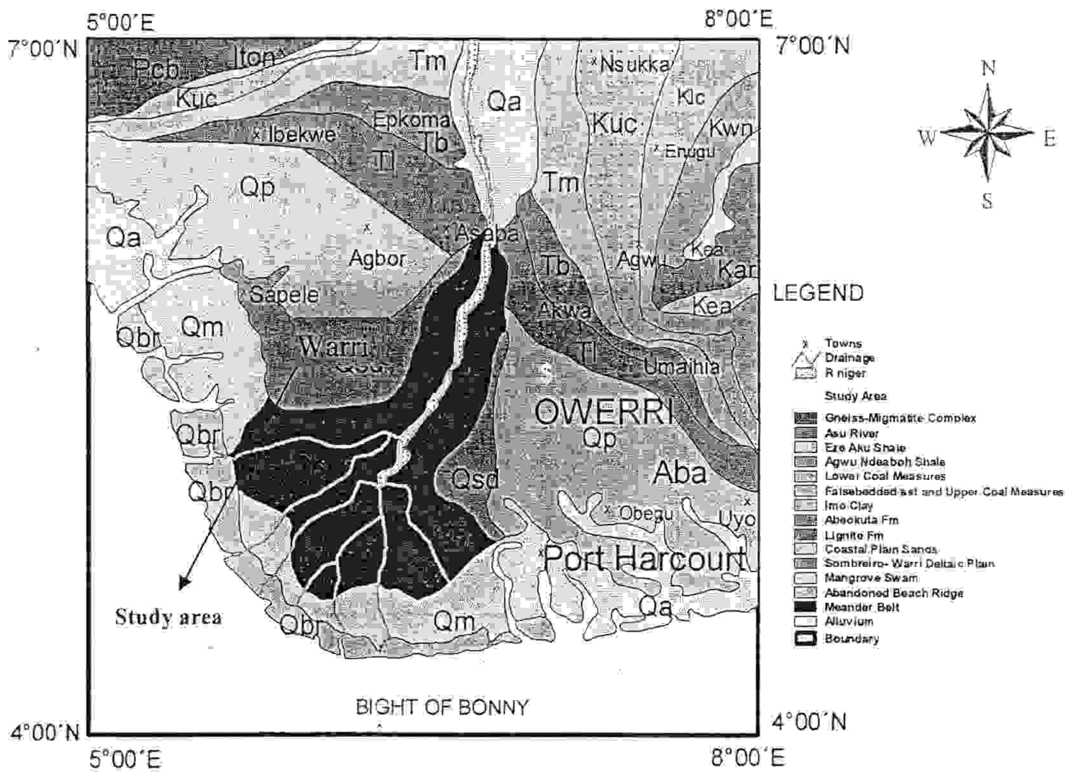

Fig.1 Geological map of Niger Delta Showing Study Area (Adapted from GSN, 1994)

Stratigraphy of Niger Delta

The stratigraphy of Niger Delta Basin is divided into three diachronous units of Eocene to Recent age that form a major regressive cycle. The upper most units, the Benin

Formation comprises of continental/fluviatile and backswâmp deposits up to 2500m thick (Short and Stauble, 1967). The Benin formation extends from the west across the whole Niger Delta Basin and southward beyond the present coastline. It is over 90% sandstone with shale intercalations. It is coarse grained, gravelly, locally fine grained, poorly sorted sub-angular to well rounded and bears lignite streaks and wood fragments. It ranges from Miocene to recent. The Deltaic and Benin Formation are the aquiferous formation in the Niger Delta. These are underlain by the Agbada Formation of paralic, brackish to marine, coastal and fluvio-marine deposits, organized into coarsening upward off-lap cycles. The underlying Akata Formation comprises up to 6500m of marine pro-delta clays (Whiteman, 1982), gave a correlation of subsurface and surface formation in the Niger Delta as shown in Table 2.

Table 1: Quaternary deposits of the Niger Delta (After Etu-Efeotor and Akpokodje, 1990).

Geologic Units	Lithology	Age
Alluvium.	Gravel, sand , clay, silt.	Quaternary
Freshwater backswamp, meander belt	Sand, clay, silt, gravel.	
Mangrove & saltwater/backswamps.	Sand, clay, some silt.	
Active/abandoned beach ridges.	Sand, clay, some silt.	
Sombeiro-Warri deltaic plain	Gravel, sand, clay, silt.	

Table 2: Correlation of subsurface and surface Formations of the Niger Delta Basin (After Whiteman, 1982)

Subsurface

Youngest Age		Oldest Known Age	Youngest Age		Oldest Known Age
Recent	Benin Forma	Oligocene	Pleistocene	Benin Formation	Miocene
Recent	Agbada Formation	Eocene	Miocene - Ecocene	Ogwashi-Asaba Formation	Oligocene
Recent	Akata Forma	eocene	Late Eocene Paleocene	Imo Shale Nsukka Formation	Eocene Paleocene
Equivalent unknown			Maastrichtian	Ajali Formation	Maastrichtian
			Campanian	Mamo Formation	Campanian
			Campanian	Nkporo Shale	Santonian
			Coniacian	Agwu Shale	Turonian
			Turonian	Eze Aku Shale	Turonian
			Albian	Asu River Group	Albian

Methodology of investigation

The aquifers characteristics in the area have been investigated through 10 pumping test analyses and logging of 10 boreholes (Fig. 2) while the vulnerability studies were carried out via laboratory analyses of the water samples.

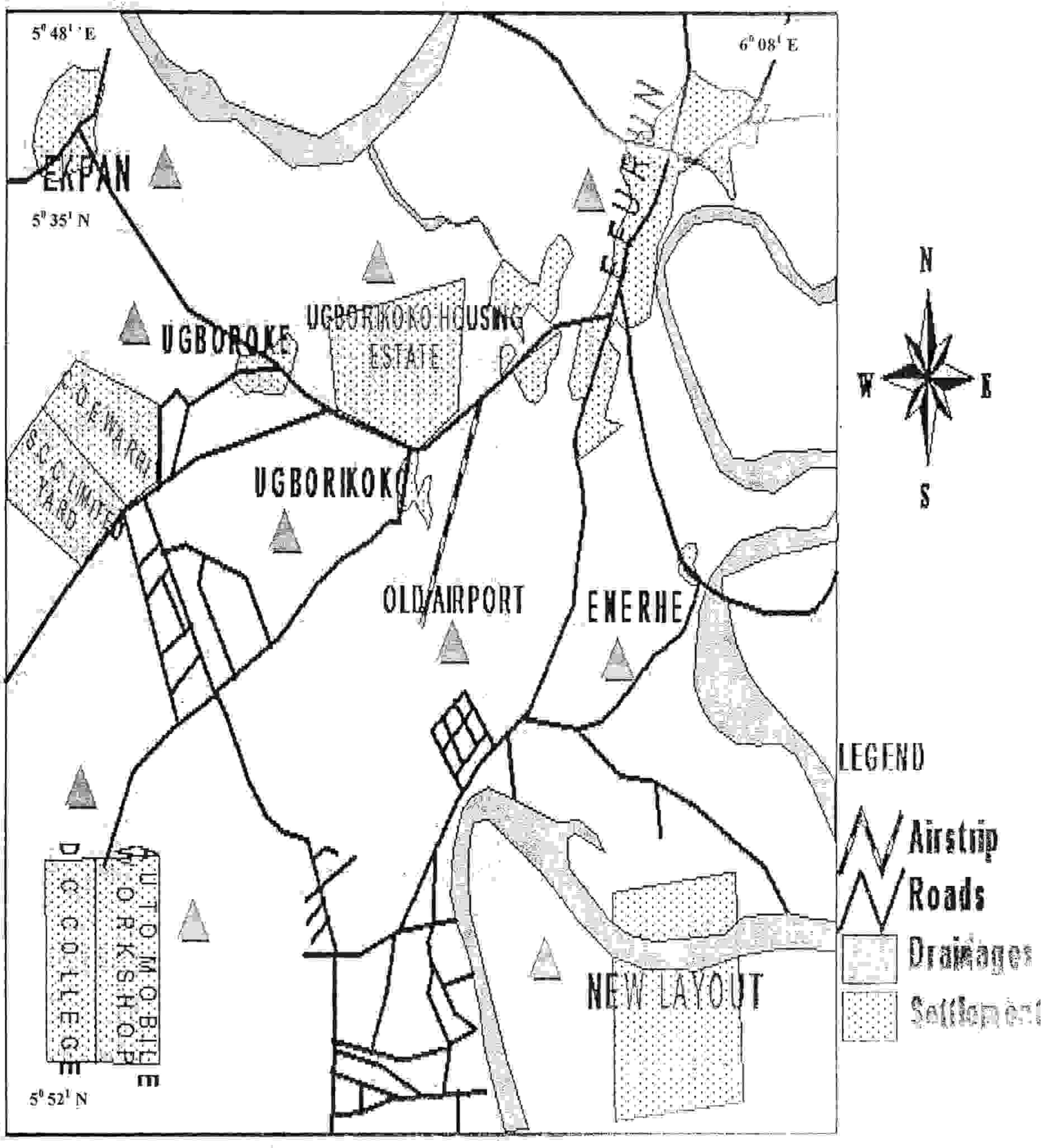

Fig. 2 Map of the Study Area showing Sample Locations ▲ **Sample location**

May, 2009
ISSN 0748-4710

Borehole-logs

The borehole-logs from the area show that the area is dominated by sandy formation (Fig.3). Medium to coarse grained sand with traces of gravel form the aquiferous unit in the area.

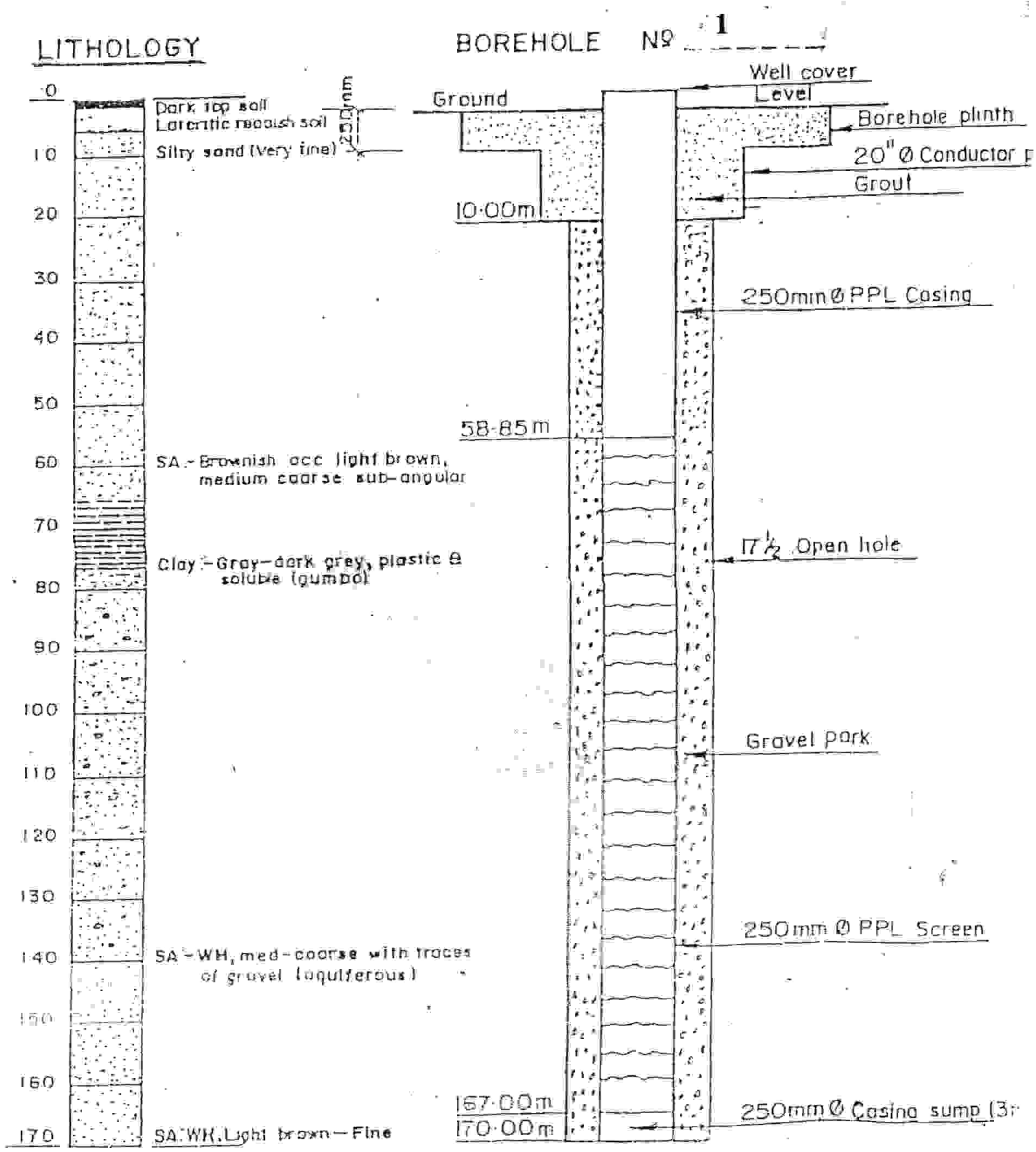

Fig. 3 Borehole-log for the study area.

Pumping Tests

Pumping tests were carried out in 16 locations to obtain information about the aquifer efficiency and performance. The data were used to determine the aquifer yield, specific capacity, transmissivity. Cooper-Jacob (1946) straight line method for constant pumping rate was used in the determination of the transmissivity values because it relates the rate of drawdown to the bulk aquifer and assumes that the aquifer receives no recharge during pumping period. The graph of drawdown/recovery against time is shown in figure 4 while the Cooper-Jacob straight line equation is stated below:

$$T = \frac{264Q}{4\pi\Delta S}$$

Where: T = Transmissivity (m^2/day)

Q = Pumping rate (m^3/day); Δs = Slope/ log cycle

The values of Q were determined in the field as pumping was in progress while the values of Δs were determined from the slope along drawdown.

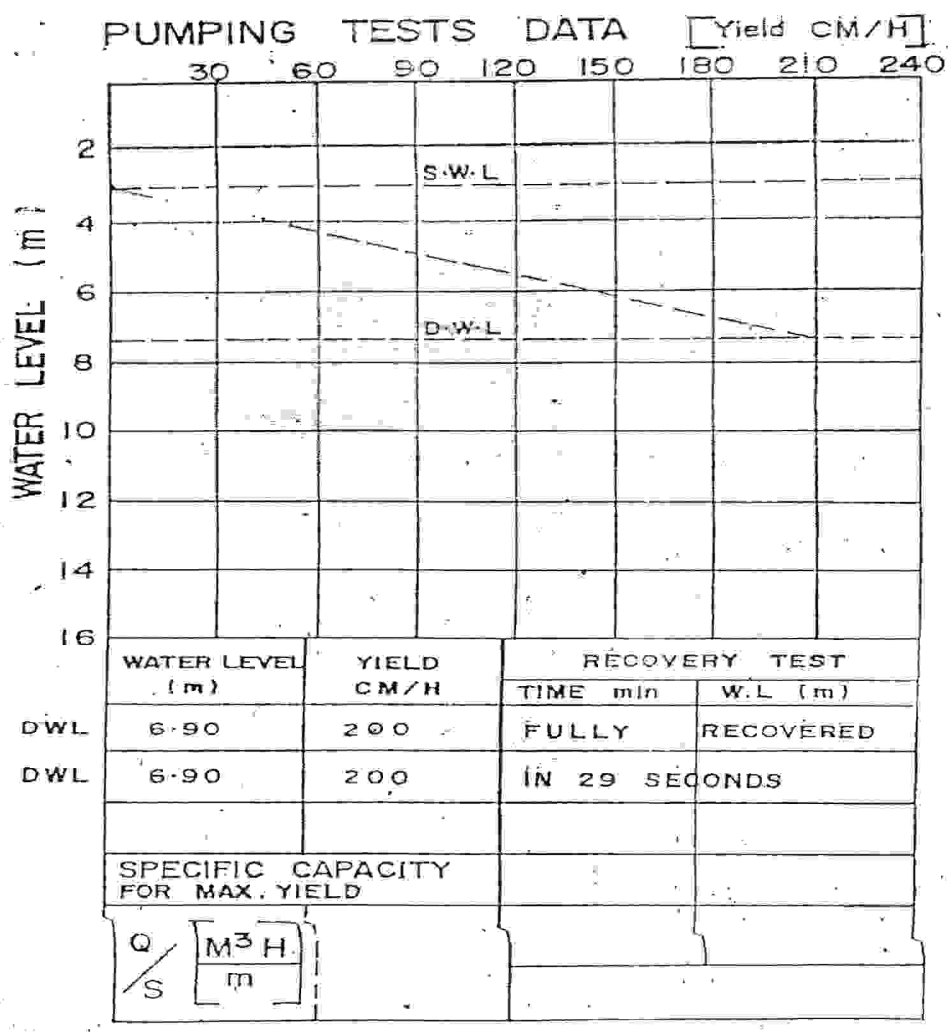

Fig.4. Drawdown and Recovery graph for WARRI

Table 3: Summary of Results of Transmissivity, Specific Capacity, Yield and Slope.

Sample Location	Transmissivity (m^2/day)	Specific Capacity (m^2/day)	Yield	Slope (Δs)
Ekpan	1578.9		200	4.15
Airport Junction	1414.4	67.34	200	2.16
Enerhe	2022.0	96.30	208	2.66
Motor Park Effurun	1053.0	50.18	208	2.97
D.D.P.A Estate	1733.3	82.53	208	2.52
Ugboroke	1049.0	49.93	200	4.01
Airport Premises	1722.1	81.97	200	2.44
Bendel Estate	876.1	41.84	200	4.78
Ugborikoko	1077.1	51.41	200	3.89
S.C.C	1324.1	63.03	208	3.3

Table 4: Gheorghe and Krawny Standards for Aquifer Transmissivity.

Gheorghe		Krawny		K m/day
T	Potential	T	Potential	0.01-0.2
› 500 m²/day	High	› 1,000	Very High	10^{-8} - 10^{-2}
50– 500m²/day	Moderate	100-1,000	High	0.1-1
5-50 m²/day	Low	10-100	Intermediate	1-5
0.5-5 m²/day	Very Low	1-10	Low	5-20
‹ 0.5 m²/day	Negligible	0.1-1	Very Low	20-100
			Imperceptible	100-1,000
				5-100
				0.001-0.1

Piper Diagram.

Piper diagram is an effective means separating analytical data for critical study with respect to sources of the dissolved constituents in water. The concentration of 8 major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^{2-}, HCO^-_3 and SO_4^{2-}) are represented on a trilinear

May, 2009
ISSN 0748-4710

diagrams by grouping the (K^+ with Na^+) and the (CO_3^{2-} with HCO_3^-), thus reducing the number of parameters for plotting to 6. On the piper diagram, the relative percentages of the cations and anions are plotted in the lower triangles, and the resulting two points are extended into the central field to represent the total ion concentration. The degree of mixing between waters can also be shown on the piper diagram (Figure 5). It was used to classify the hydro-chemical facies of the water samples according to their dominant ions. The results show that water samples in study area are Calcium/Magnesium-Bicarbonate type.

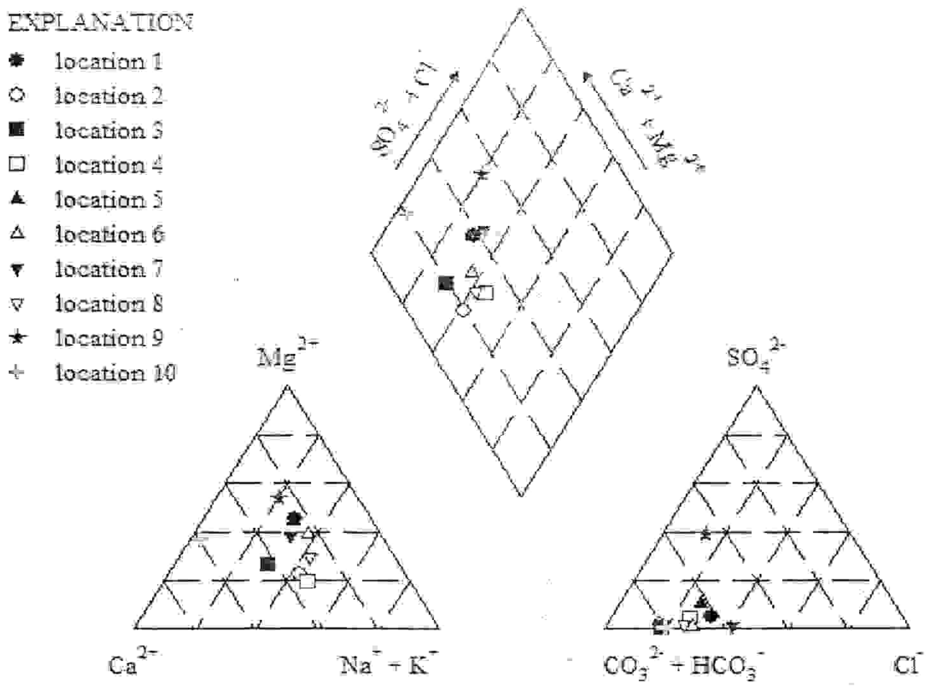

Fig. 5 Hydrogeochemical classification of borehole water in Warri using Piper diagram.

Physico-chemical and Bacteriological results

The results of physico-chemical and bacteriological analyses are summarized in table 5. Majority of the bacteriological and physico-chemical parameters analyzed were below the guideline values of the Nigerian Industrial Standard (NIS, 2007) and the World Health Organization (WHO, 2006) except coliform in locations 2 and 3; chromium in locations 3, 4, 6 and 7 as well as lead in locations 4 and 5 with values slightly above the guideline values. Based on the results, the groundwater vulnerability in the area was categorized into low and high regions. Human activities in the area might be responsible for their anomalous concentration. Leachate from the automobile workshop might infiltrate through the overlying permeable formation into the shallow water table thereby altering the natural groundwater chemistry.

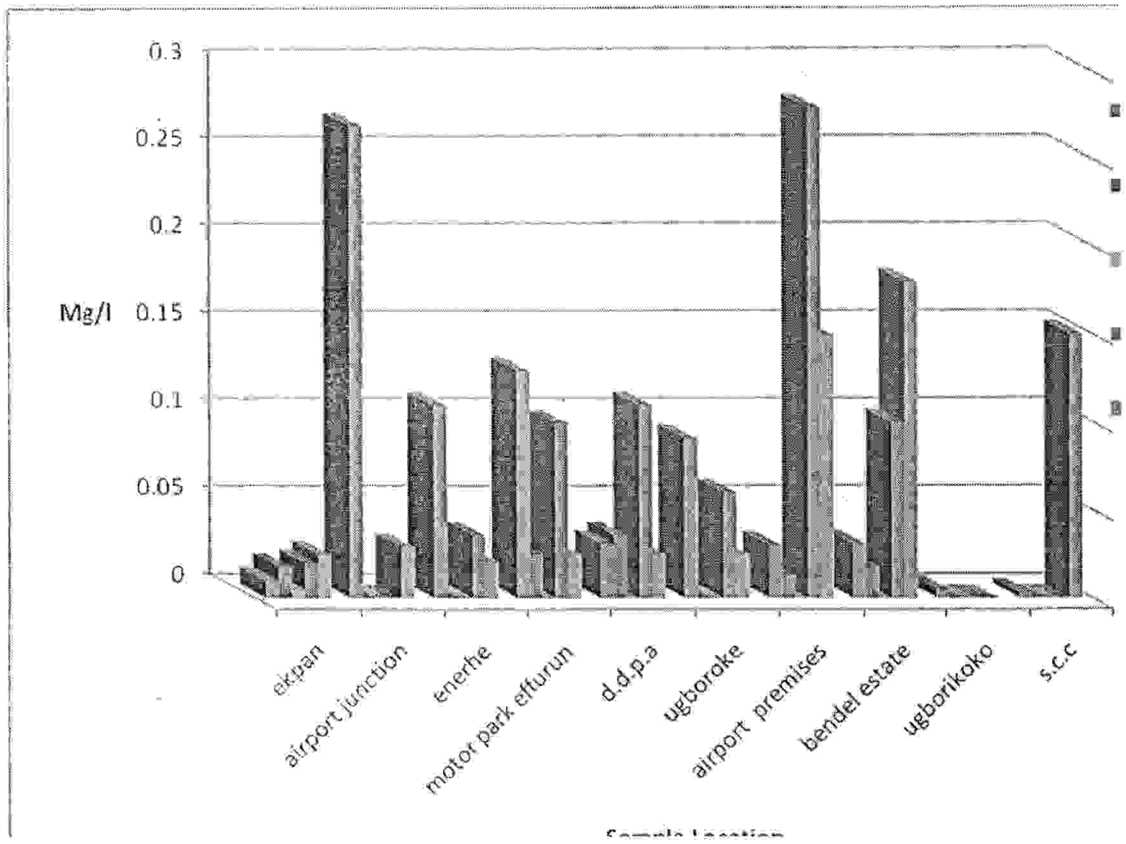

Fig 6 Concentration in (mg/l) of Fe^{2+}, Cr^{6+}, Hg, Pb and Mn of borehole water samples in Warri.

Groundwater Vulnerability Map

Groundwater vulnerability according to Albert and Margat (1970) is the possibility of percolation and diffusion of contaminant from ground-surface into the natural water table reservoir under natural conditions while Olmer and Rezec (1974) defined Vulnerability of groundwater as the degree of endangering, determined by natural conditions and independent of present source of pollution. Vulnerability is a useful technique of assessing groundwater quality and it plays an important role in efficient management of groundwater resources (Amadi, 2007).

The results of the bacteriological and physico-chemical analyses carried on the borehole samples were used to develop a groundwater vulnerability map (Fig.7). The study area was grouped in high and low vulnerability area. The southern part, hosting the automobile workshop, D.D.P.A estate, Airport premises and the new industrial layout constitute the high vulnerability area while the northern part comprising of Ekpan, Ugboroke and Ugborikoko housing estate make up the low vulnerability area.

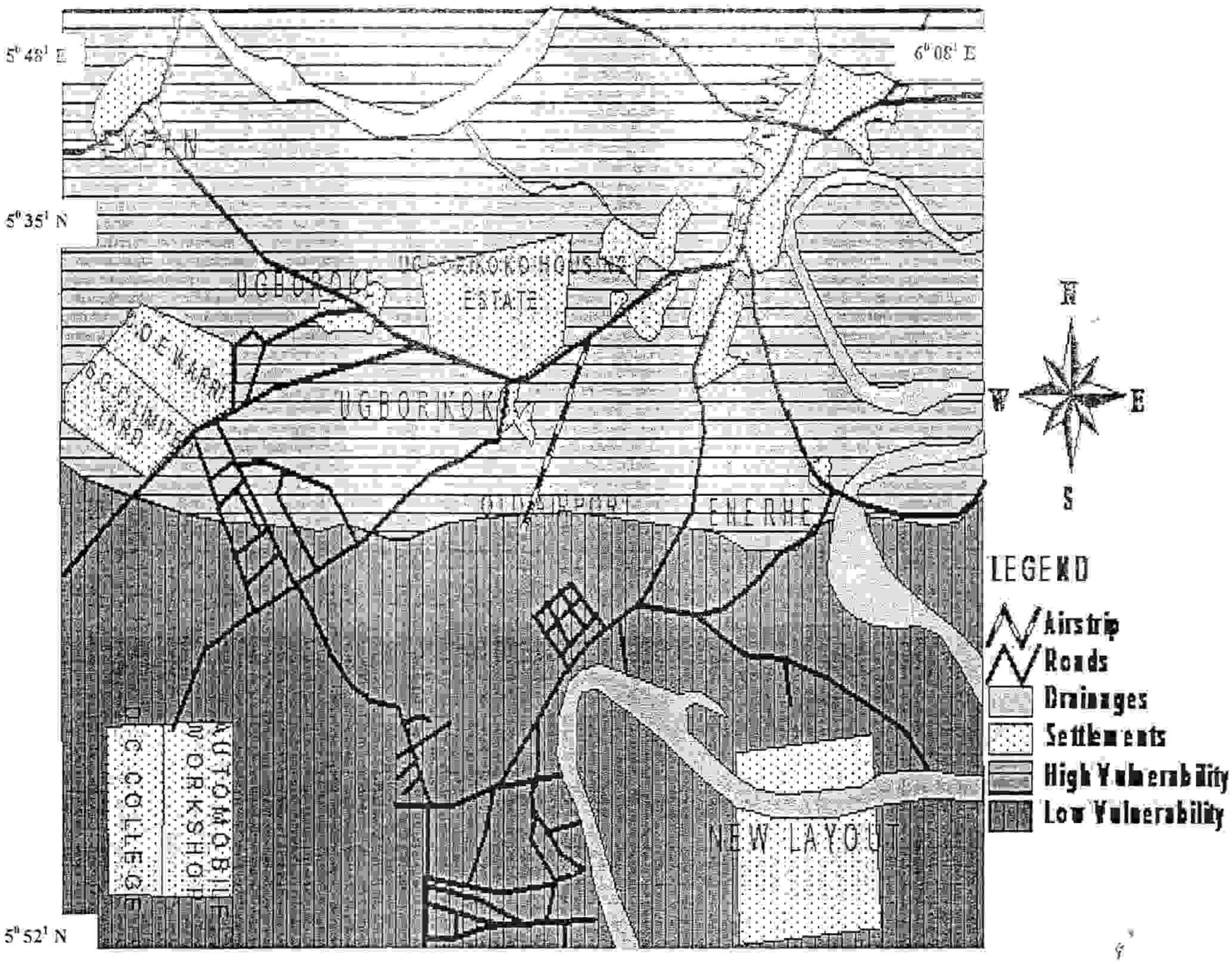

Fig.7 Groundwater Vulnerability Map

Discussion

The aquifer systems in the area are largely unconfined. The area has a good groundwater potential as evidenced by the transmissivity, specific capacity and aquifer yield. The unsaturated zone materials are mainly sandy and gravelly facies with high permeability rates. The highly permeable overburden and shallow water table are indications that contaminant would migrate easily into the aquifer system. The permeability and porosity

May, 2009
ISSN 0748-4710

of the aquifer materials enhance both vertical and horizontal movement of contaminant in the groundwater system. The groundwater vulnerability in the area was grouped into low and high. Dumping of refuse at the banks of river Ekpan should stop completely while the automobile workshop should be relocated out of the town.. Groundwater quality management through education of the public on health implications of water pollution and enforcement of necessary law that would help the protection of groundwater system is advocated. The existing unplanned dumpsite should be abandoned and landfill remediation measures enforced.

Conclusion and Recommendation

The vulnerability map of the area has been categorized into high and low respectively. An appropriate management programme is developed (Fig.8a & 8b) and should be implemented to address the adverse effects of man's activities on groundwater quality in area of high vulnerability. Future dumpsites and soakaway should meet the design standard recommended in figure (8a & 8b) to prevent further degradation of the groundwater resources in the area. The result of bacteriological analyses shows high coliform count in locations 2 and 3. Therefore, boiling of water is advocated in these locations. National and or public health authorities should establish drinking water norms and standards and develop an efficient water resources management. Periodic checks of the chemical quality and bacteriological quality of selected boreholes and streams are to be carried out in the area.

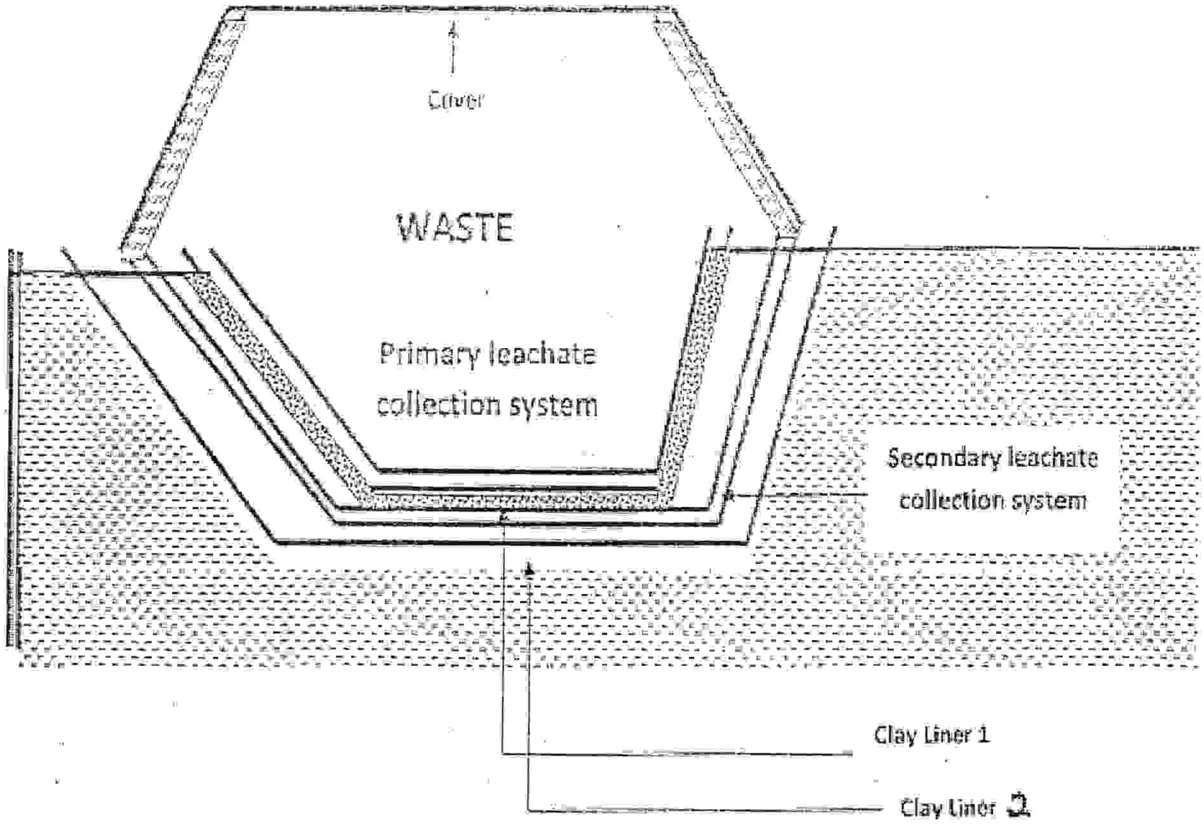

Fig.8a Schematic diagram showing the multiple barrier concept for area with high vulnerability

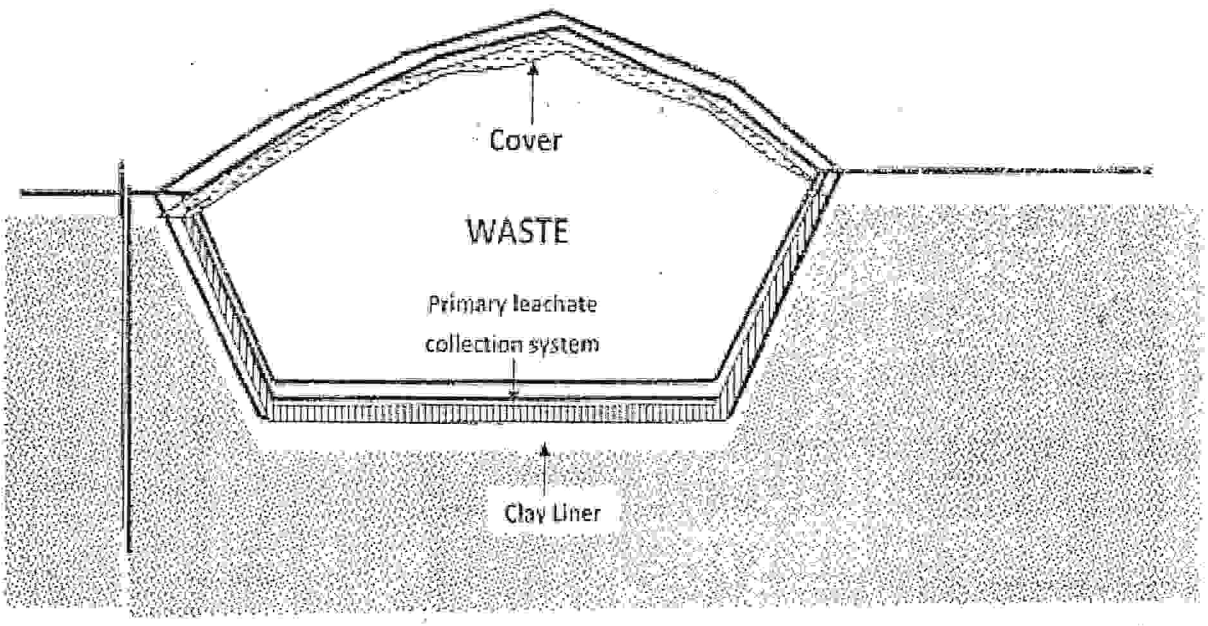

Fig.8b Schematic diagram showing a hydraulic concept for area with low Vulnerability

May, 2009
ISSN 0748-4710

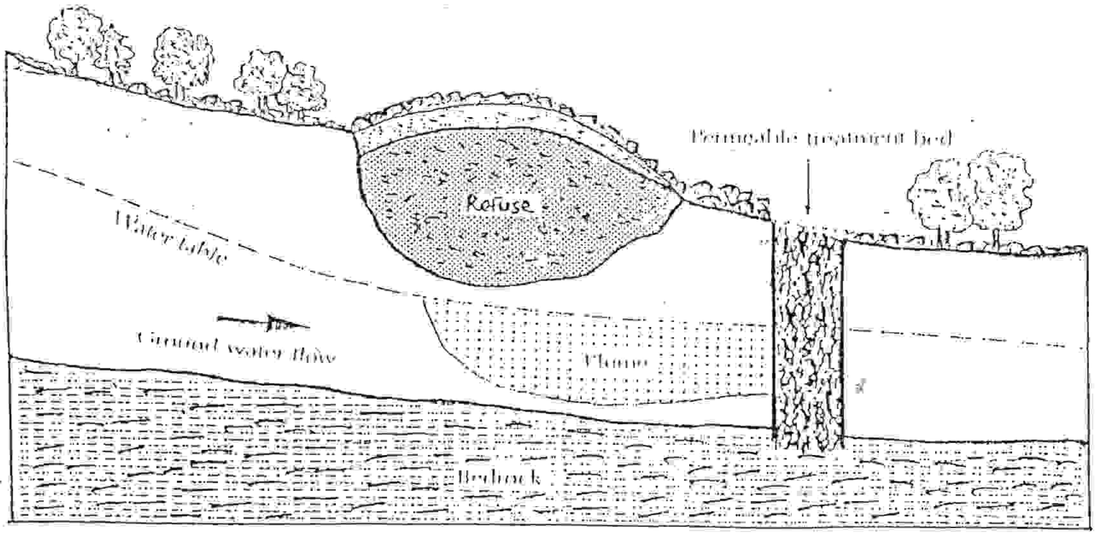

Fig A: Schematic diagram showing an insitu treatment concept where nutrients are injected into the aquifer to promote bioreclaimation. It is to be adopted in areas of moderate Groundwater Vulnerability

Fig B Phytoremediation Technique Proposed for Low Vulnerability Area

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Table 5. Summary of results of Physico-chemical and Bacteriological analyses.

S/N	Sample Location	Ekpan	Airport Junction	Enerhe	Motor Park Effurun	D.D.P.A Estate	Ugboroke	Alport Premises	Bendel Estate	Ugborikolo	SCC Premises	Range	Mean
	Samples→ parameter↓	1	2	3	4	5	6	7	8	9	10		
1	Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear		
2	pH	6.44	6.5	6.4	6.55	6.52	6.80	6.83	7.30	6.80	6.68	6.40-7.30	6.68
3	Conductivity	52.00	177	36	51.50	50.00	45.00	50.00	48.50	70.00	50.00	45.00-177.00	63.0
4	Turbidity	5.00	0.0	0.0	5.00	5.00	5.00	5.00	5.00	3.5	4.0	3.5-5.0	3.75
5	TDS	51.5	118.6	24.12	38.50	50.60	38.00	50.20	41.20	84.80	41.40	38.00-118.6	53.9
6	Suspended solids	5.80	0.0	2.00	6.00	4.16	2.00	3.00	4.00	6.20	7.10	2.00-7.10	4.03
7	Total hardness	10.90	59.0	22.0	7.00	12.20	12.00	18.30	9.20	22.50	48.01	9.20-59	22.1
8	Alkalinity	4.20	10.0	6.0	5.00	4.98	5.00	5.21	12.00	4.90	4.72	4.20-12.00	6.201
9	Iron (Fe^{+2})	0.025	0.029	0.021	0.025	0.025	0.025	0.150	0.180	0.00	0.150	0.00-0.025	0.086
10	Nitrate (NO_3)	0.043	0.00037	0.0	0.04	0.036	0.041	0.040	0.042	0.00	0.00	0.36-0.43	0.024
11	Chloride(Cl^-)	21.30	12.5	5.00	14.20	21.30	14.00	21.20	14.25	14.20	14.20	5.00-21.30	15.21
12	Silica (SiO_2)	0.70	0.0	0.0	0.25	0.80	0.40	0.90	0.15	0.31	0.33	0.15-0.90	0.38
13	Calcium (Ca)	4.00	11.5	4.4	4.25	4.20	4.40	6.20	4.50	3.00	32.00	4.00-32.0	8.36
14	Magnesium(Mg^{+2})	7.20	1.22	4.7	2.40	7.20	7.20	8.00	4.30	6.30	19.20	2.40-19.20	8.23

15	Sodium (Na^+)	1.98	7.56	1.33	2.50	2.00	3.12	3.10	3.00	2.50	1.98	0.58-3.12	2.82
16	Potassium (K^+)	3.00	6.70	2.0	3.40	2.90	4.00	3.96	4.06	4.00	0.26	0.26-6.7	3.43
17	Phosphate	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.03	0.06	0.02	0.00-0.06	0.02
18	Sulphate(SO_4^{2-})	3.20	1.0	0.0	2.00	8.00	0.40	0.40	0.80	40.0	0.02	0.040-40.00	5.58
19	Manganese(Mn)	0.010	0.27	0.11	0.13	0.031	0.091	0.030	0.031	0.005	0.003	0.003-0.27	0.07
20	Lead (Pb)	0.018	0.00	0.00	0.025	0.036	0.00	0.013	0.018	0.00	0.00	0.00-0.036	0.01
21	Chromium(Cr^{2+})	0.02	0.00	0.036	0.10	0.11	0.06	0.28	0.10	0.00	0.00	0.00-0.28	0.08
22	Mercury(Hg)	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00-0.005	0.00
23	Arsenic (As)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Bicarbonate(HCO_3^-)	40.0	59.0	22.0	37.0	50.0	34.0	29.0	39.0	49.0	57.0	22.0-59.0	41.60
25	Cadmium (Cd)	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.008	0.0-0.08	0.016
26	BOD	2.10	0.0	0.0	1.55	1.50	1.40	1.46	1.40	1.36	1.80	0-2.10	1.26
27	COD	6.04	0.0	0.0	3.40	3.60	3.00	4.50	3.20	3.07	4.00	0-6.04	3.10
28	Coliform	5.0	26.0	19.0	3.0	4.0	2.0	5.0	4.0	2.0	3.0	2-26	11.80