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Integrated Hydrogeophysical And Biogeochemical Characteristics Of Groundwater Sources In Ewekoro Communities, South-West Nigeria

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***Abstract*—The water quality status of boreholes and hand-dug wells in Ewekoro community was investigated in this study. Leachate in the subsurface groundwater system originating from point or non-point sources can be delineated through an integration of qualitative and quantitative methods. This study was designed to assess and present the extent of leachate and pollution from Ewekoro community. Qualitative assessment was determined using hydrogeophysical methods. The depth to the aquifer varies from 13.8m to 97.4m while the longitudinal unit conductance (S) and hence, the protective capacity (P_c) values in the study areas are generally less than 1.0 Siemens (P_c < 1.0 Siemens) except in two locations; they are classified as low and are characteristics of depositional successions of overburden layers with no significant impermeable clay/shale overlying rock. Quantitative assessment was also achieved by the integration of biogeochemical analyses of the water samples collected from 25 boreholes and 25 hand-dug wells at various sampled points across the residential vicinity of the study area. The analyses reveal the presence of macroelements, salts (like sulphates, nitrates and chlorides), heavy metals, and physico-chemical parameters in the water and their strong correlations justified the provenance. As part of the quantitative evaluation, physical parameters (Acidity, Total Dissolved Solids, Dissolved Oxygen, Biochemical Oxygen Demand, Salinity, Total Hardness, Turbidity, Electrical Conductivity EC and Temperature, Alkalinity, Chloride, Bicarbonate, Cadmium, Zinc and Iron) of the water samples were also determined. Most quality determinants in the sampled water are within the set guidelines including WHO and NESREA except DO, BOD, ALK, Cl^-, HCO_3^-, Cd^{2+}, Zn^{2+} and Fe^{3+}. High BOD_5, Coliform Count and BOD_5:NO_3^- ratios of groundwater samples are indicative of organic pollution due to faecal contamination.**

Keywords*—*Electrical conductivity, Borehole, Protective capacity, Qualitative assessment.

Introduction

In all the humanly endowed earthly resources, water has been proven to be one of the most abundant resources on which life on earth depends; in some places, availability of water is critical, limited and renewable. Water that is of a good drinking quality is important to human physiology, and man's continued existence depends so much on its availability (Lamikanra, 1999; FAO, 1997). The quality of water for drinking deteriorates due to inadequacy of treatment plants, direct discharge of untreated sewage into rivers and stream, and inefficient management of piped water distribution system (UNEP, 2001; Ishola, 2019). Each year about two million people die as a result of poor sanitation and contaminated water, ninety percents (90%) of the victims are children [Anon, 2009]. These hazardous effects emanate from the presence of toxic elements of environmental concern in groundwater system; elements such like Pb, Cd, As and Cr. Many of these metals have been found to act as biological poisons even at low concentration (parts of per billion—ppb) levels. Bairds, 1995 also observed that the elements are toxic in the form of cations and when bonded to short chains of carbon atoms may not be toxic as free elements. Even most celebrated metals with important commercial uses are also not left out and hence undesirable for indiscriminate release into the environment. This research work aims to showcase the effectiveness of integrating non-invasive hydogeophysical methods with widely employed biogeochemical approach with a view to determining the possible presence and levels of vulnerability to contaminant seepages in groundwater of Ewekoro communities

Material and Methods

Study Area

Ewekoro community in Ogun State is one of the mills of West African Portland Cement Company (WAPCO) and Dangote group Cement Company. It is a sleepy neighbouring town to Papalanto, a name known for sugarcane plantation. It lies between latitude $6^0 53^1$N and longitude $3^0 14^1$E. The sedimentary rocks of Ogun State consist of Ewekoro formation and Abeokuta formation. The Ewekoro formation is fossiliferous and consists of economic deposits of limestones that is quarried by WAPCO. (Omatshola *et al.*, 1981). Ewekoro cement production facility is located 5 kilometres north of Ewekoro town (6°55'N and 3°12'E). Also, it is approximately 64 kilometers north of Lagos and 42 kilometers south of Abeokuta and within the tropical rainforest belt of Nigeria. Farming settlements such as Olapeleke (West), Itori (North), Elebute and Alaguntan (East) which predate the factory are located within 10 km radius of the production facility. The settlements are perennially drained by Itori, Ewekoro, Eshe, Elebute and Alaguntan Rivers. Only Alaguntan River receives waste water directly from the cement plant (WAPCO, 2001).

The rock is soft and friable but in some places cemented by ferruginous and siliceous materials. The lithological units in Ewekoro formation are clayey sand, clay, shale, marl, limestone and sandstone (Fig. 1).

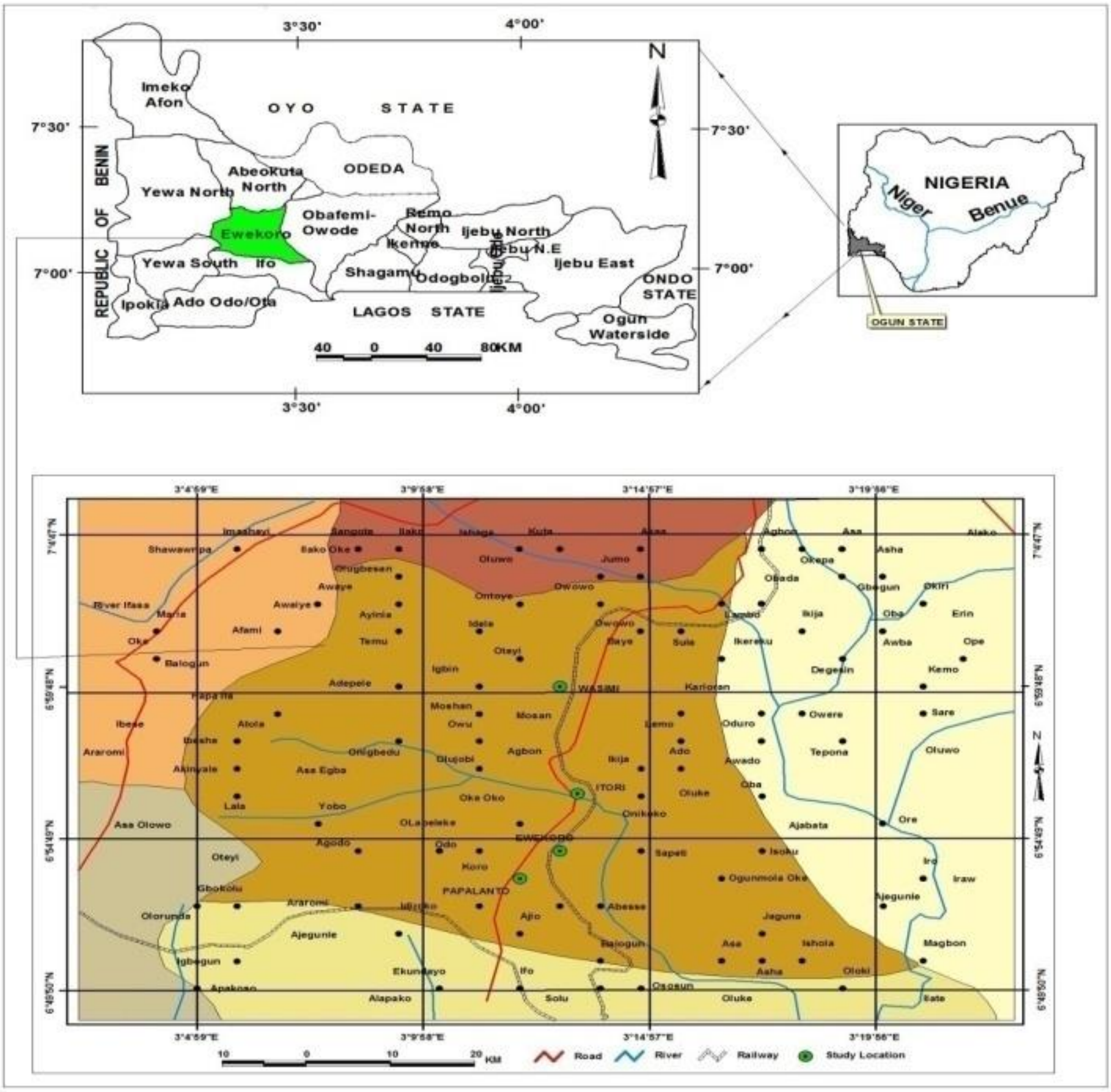


Fig. 1: Inset map showing the study areas within Nigeria continental domain (after Billman, 1992).

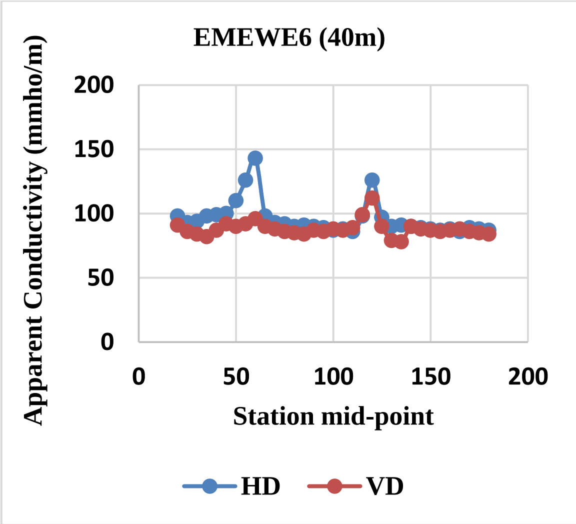
Data Source

Electromagnetic profiles (using the Geonics EM34-3 equipment) were selectively carried out in autonomous communities in Ewekoro to outline shallow conductive hydrogeological structures probably connected with local water circulation and protected zones from contamination. The main conductivity contrasts, roughly can now be interpreted as the shallow expression of fractures affecting the sedimentary filling of the hydrogeological structure both Vertical Electrical Sounding (VES) and 2-D geoelectrical resistivity surveys using both Schlumberger and Wenner arrays were respectively adopted (The basic field equipment used for the study is AGI Super Sting Earth Resistivity meter which displays apparent resistivity value digitally as computed from Ohm’s law. The crossplots of apparent conductivity on the different spacing enabled a view of how the conductivity varies with depth. Qualitative analysis and interpretation was carried out on the plotted data. The locations of higher conductivity are the point of interest for VES investigation. The acquired VES data were then used as initial models for computer iterative modeling on a Win-Resist program to obtain model geoelectric parameters for the delineated layers (Vander Velpen, 2004) while processing and inversion of the 2D-ERT data were carried out with RES2DINV software. The software plots the field or measured data pseudosection and generates a calculated or theoretical model. It then carries out inversion by comparing both the measured and calculated model to generate an inverted model which is a representative of the true subsurface resistivity at different depth investigated. Similarly, the observed 2D apparent resistivity dataset for each traverse were processed and inverted concurrently using RES2DINV inversion code (Loke and Barker, 1996).

Water samples were strategically collected from existing and functional boreholes and hand-dug wells at different sampling points within Ewekoro communities for physico-chemical analyses and biogeochemical examinations. Heavy metal concentrations and bacteriological examination were measured in the laboratory using standard procedures of inductively coupled optical emission spectrophotometry and pour plate techniques (APHA, 1995). Descriptive and Multivariate analyses were performed on a set of water quality data.

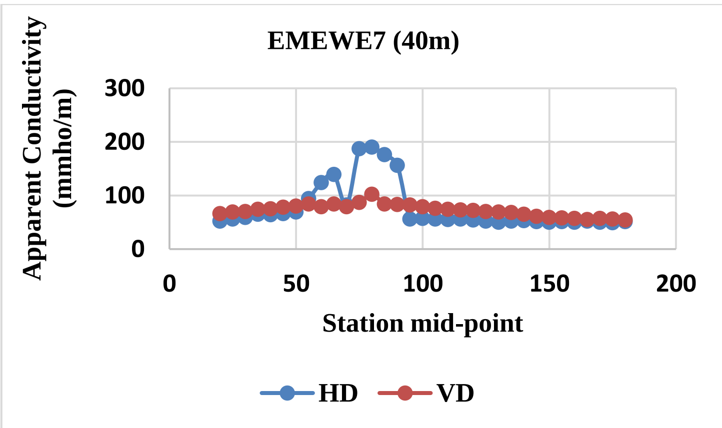
Results and Discussion

The EM traverse displays appreciable variation in conductivity while the areas where there are few recognizable positive peaks and broad anomalies were delineated against their conductivity values. Zones with peak positive vertical dipole anomalies are inferred conductive, typical of water–filled fissures (Alvin et al., 1997), or effect of appreciable weathering (Beeson and Jones, 1988). The calculated true conductivity values for the first and second layer with their corresponding depth values were recorded for both horizontal and vertical dipole orientations in all the traverses. The highest true conductivity value of 173.39 mS/m was recorded by Horizontal Dipole in the 2nd layer for EMEWE6 while the lowest true conductivity value of 45.84 mS/m was recorded by Vertical Dipole in the 1st layer for EMEWE7 (Fig. 2 and Fig. 3).



	True Conductivity (mS/m) HD	VD	Depth(m) HD	VD
1st Layer	137	77.05	21	18.5
2nd Layer	173	91.28	-	-

Figure 2: Plot and values of apparent and real conductivity of horizontal dipole orientations along Ewekoro (Profile 6)



	True Conductivity (mS/m) HD	VD	Depth(m) HD	VD
1st Layer	65.37	45.84	9.1	37
2nd Layer	86	75.04	-	-

Figure 3: Plot and values of apparent and real conductivity of horizontal dipole orientations along Ewekoro (Profile 7)

The high conductivity values obtained on both Profiles is indicative of the probable invasion of the subsurface by the contaminant plume. The contaminant plume is associated to leachates or possible contaminant seepages emanating from the exotic or decaying materials from the surface gradually infiltrating through the overlying rock layers down to the subsurface. The results of the horizontal and vertical dipole orientations on both Profiles are highly and linearly correlative with negligibly small variation displayed on the plots presented in Fig. 2 and 3.

All the study locations displayed less 1.0 protective capacity values except VESEWE9 and VESEWE17 whose protective capacities are greater than 1.0 Siemens with VESEWE17 being the investigated location with the highest protective capacity. The values range from 7.7002×10^{-3} Siemens to 1169.48×10^{-3} Siemens.

Table 1: Descriptive Statistics showing the Concentration of Physico-Chemical and Elemental Parameters of Ewekoro Well Water Sample

Parameter	Min	Max	Range	Mean±SD	WHO	NESREA	NSDWQ	USEPA	NAFDAC
pH	6.60	7.67	1.07	6.97±0.32	6.5-9.5	7.00-8.50	6.50-8.50	6.50-8.50	6.50-8.50
Temperature °C	24.00	28.00	4.00	26.00±1.44	27.00	NA	NA	27.00	27.00
Electrical Conductivity (μScm^{-1})	558.00	941.00	383.00	720.36±93.68	1200	NA	900	1200	1000
Dissolved Oxygen (mgL^{-1})	6.70	21.48	14.78	10.30±5.69	7.5	NA	7.5	NA	NA
Chemical Oxygen Demand (mgL^{-1})	8.96	34.92	25.96	28.06±7.58	NA	NA	NA	NA	NA
Total Dissolved Solids (mgL^{-1})	0.28	9.70	9.42	4.99±3.89	100	1500	500	500	500
Total Suspended Solids (mgL^{-1})	0.23	4.95	4.72	0.85±1.04	>10	>10	NA	NA	NA
Total Solids (mgL^{-1})	0.33	1.35	1.00	0.90±0.27	1500	NA	NA	NA	NA
Turbidity (NTU)	0.11	0.77	0.65	0.32±0.25	<4	5.0	5.0	5.0	5.0
Alkalinity (mgL^{-1})	28.42	2210.10	2181.60	299.12±407.89	200	500	100	100	100
Total Hardness (mgL^{-1})	14.00	32.63	18.63	25.74±4.81	<200	100-300	500	NA	100
THC	0.01	0.28	0.28	0.21±0.07	NA	NA	NA	NA	NA
Na^{2+} (mgL^{-1})	27.99	48.98	20.99	43.45±5.80	<200	NA	200	NA	200
K^{+} (mgL^{-1})	31.75	61.46	29.71	55.30±7.66	250	200	NA	200	10
Ca^{2+} (mgL^{-1})	10.60	29.84	19.24	24.58±6.42	100	75	NA	75	75
Mg^{2+} (mgL^{-1})	2.80	4.96	2.16	3.77±0.84	20	15	NA	20	20
Cl^{-} (mgL^{-1})	57.20	379.32	322.12	234.57±126.15	250	200	250	100	100
NO_3^{-} (mgL^{-1})	0.11	0.13	0.02	0.13±0.006	50	45	NA	10	10
NO_2^{-} (mgL^{-1})	0.01	0.04	0.02	0.02±0.008	<3.0	NA	NA	NA	NA

SO_4^{2-} (mgL^{-1})	7.70	19.20	11.50	11.70±2.84	400	500	200	250	100
NH_4^+ (mgL^{-1})	0.58	1.79	1.21	1.43±0.36	1.50	NA	NA	NA	NA
PO_4^{2-} (mgL^{-1})	7.84	11.70	3.86	10.13±1.122	NA	NA	NA	NA	NA
HCO_3^-(mgL^{-1})	71.70	1108.7	1037.0	408.22±445.40	100	NA	NA	NA	NA
$MgCO_3$ (mgL^{-1})	8.94	13.92	4.98	12.10±1.50	10	NA	NA	NA	NA
Cu^{2+}(mgL^{-1})	0.01	0.05	0.04	0.03±0.01	2.0	NA	1.0	1.3	1.0
Pb^{2+}(mgL^{-1})	0.00	0.01	0.01	0.001±0.002	0.01	0.01	0.01	0.01	0.01
Cd^{2+}(mgL^{-1})	0.00	0.04	0.04	0.004±0.01	0.003	0.003	0.001	0.005	0.005
Mn^{2+}(mgL^{-1})	0.01	0.07	0.06	0.04±0.02	0.1	0.2	0.5	0.4	2.0
Zn^{2+}(mgL^{-1})	0.67	1.68	1.01	1.41±0.32	0.01	NA	NA	NA	NA
Fe^{3+}(mgL^{-1})	0.02	1.35	1.33	0.65±0.46	0.3	0.3	0.3	0.3	0.3
Ni (mgL^{-1})	0.00	0.03	0.03	0.007±0.01	0.02	0.05	NA	NA	0.05
S(mgL^{-1})	0.16	5.50	5.34	3.16±2.05	250	NA	NA	NA	NA
Al^{3+}(mgL^{-1})	0.00	0.01	0.01	0.003±0.005	0.2	NA	NA	0.2	0.5
I(mgL^{-1})	0.02	0.06	0.04	0.04±0.01	NA	NA	NA	NA	NA
Si(mgL^{-1})	0.00	0.01	0.01	0.002±0.004	NA	NA	NA	NA	NA

In the entire study locations where the longitudinal conductance (S) and hence, the protective capacity (P_c) values in the study areas are less than 1.0 Siemens (P_c < 1.0 Siemens); they are classified as low and are characteristics of depositional successions of overburden layers with no significant impermeable clay/shale overlying rock. Such subsurface model is an indication of high infiltration rates from precipitation as well as surface contaminants into the aquifer system. However, the investigated locations where the protective capacity values are greater than 1.0; P_c < 1.0 Siemens (VESEWE9 and VESEWE17); imply that these locations have considerable layers of Clay separating the subsurface aquiferous zones (Table 1). In addition to high transmissivity and low protective capacity values in most of the investigated locations in the study area, the aquifers are very close or relatively close to the surface (<100m) and thus prone or susceptible to contamination over large areas once the aquifer receives a load of contaminant dose from surface to near surface.

Nevertheless, groundwater potential in this study areas is high due to high transverse unit resistance (R) is suitable for the development of boreholes of potable water supply (Ishola, 2019).

Borehole	DO (mg/L)	BOD (mg/L)	COLOUR (TCU)	THBC ($\times10^2$cfu/ml)	TCC (MPN/100ml)	FCC ($\times10^2$ cfu/ml)
MAX	21.48	32.24	10	7.8	18	1.3
MIN	6.7	16.92	5	0	0	0

Table: 2: Bacteriological counts of borehole water sample in Ewekoro, Southwest Nigeria

Table 3: Bacteriological counts of well water sample in Ewekoro, Southwest Nigeria

Well	DO (mg/L)	BOD (mg/L)	COLOUR (TCU)	THBC ($\times10^2$cfu/ml)	TCC (MPN/100ml)	FCC ($\times10^2$ cfu/ml)
MAX	8.2	18.80	15	15.7	1124	6.7
MIN	7.10	16.90	5	1.8	15	0

Key: DO = Dissolved Oxygen

BOD= Biological Oxygen Demand
THBC = Total Heterotrophic Bacteria Counts
TCC = Total Coliform Counts
FCC = Faecal Coliform Counts

Reasonable correlation exists between the 2D inverse models and the geoelectric layered parameters obtained from the soundings. The lateral continuities of geoelectric layer (geoelectric-lithology) and near-surface heterogeneity observed in the resistivity soundings are clearly depicted in the inverted 2D resistivity images. It should be noted that the topsoil delineated in the resistivity soundings is not distinctly observed in the 2D images due to its small thickness value range of (0.4m-1.7m) averaging 1.11m in Ewekoro relative to the minimum electrode spacing of 10.0m used for the 2D survey. Profile 2 inverse resistivity model equally revealed very low resistivity anomaly at horizontal distances between 15m to 59m, 96m to 123m and 148m to 170m as three principal condensed regions of very high conductivity with resistivity values below 1.95 Ωm from the surface of the section to depths of 20m, 15m and 15m respectively. These areas indicate possible leachate accumulations in the Clayey sand bed which displayed a wide and continuous spread of low resistivity zones which laterally extends from 15m to 200m. The relatively low resistivity values encountered can be attributed to different degrees of mineralogical composition of the solid rock underlying the Clay layers at the base of the section (Fig. 4).

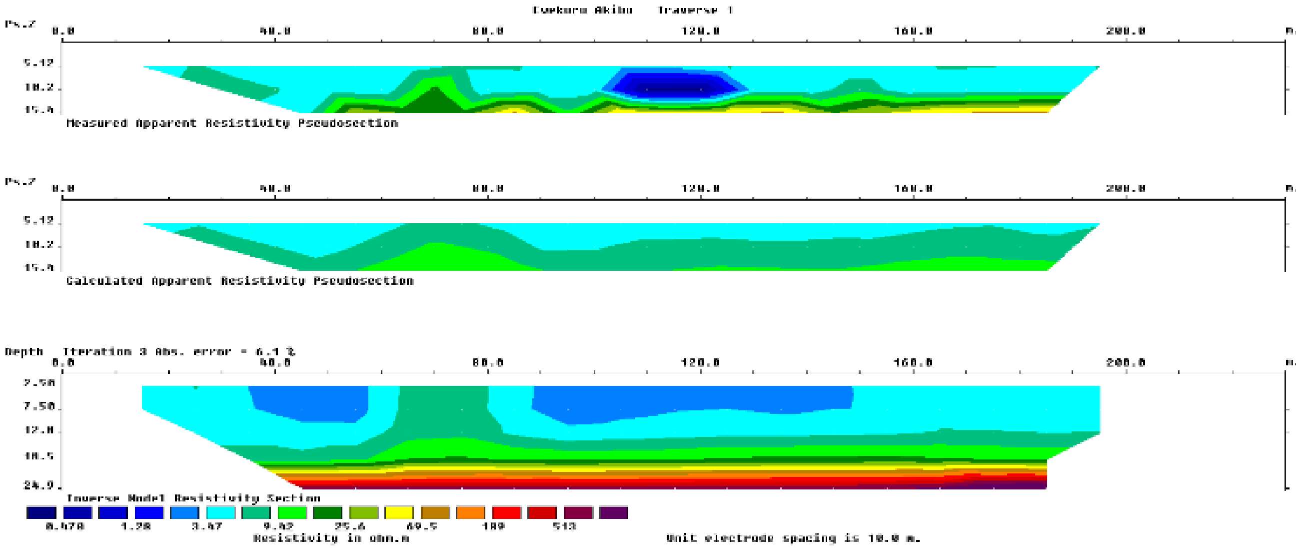


Figure 4: Typical 2D-ERT inverse model along Ewekoro (Profile 1 and 2)

Geo-electric interpretation of sub-surface lithology along Ewekoro traverse 1 (Profile 1 and 2)

Profile 1 inverse resistivity model (Fig. 4) revealed very low resistivity anomalies below 3.47Ωm at lateral positions between 35m to 58m and 90m to 150m from the surface of the section to depths of about 10m. Highly conductive zones were noticed from the surface to depths of about 17m at lateral distances of approximately 15m to 65m and 80m to 200m. The conductive zone is inferred to be typically Clay underlain by Clayey sand with different degree of saturation. Bedrocks with higher resistivity values above 513 Ωm constitute the base of the section.

Profile 2 inverse resistivity model equally revealed very low resistivity anomaly at horizontal distances between 15m to 59m, 96m to 123m and 148m to 170m as three principal condensed regions of very high conductivity with resistivity values below 1.95 Ωm from the surface of the section to depths of 20m, 15m and 15m respectively. These areas indicate possible leachate accumulations in the Clayey sand bed which displayed a wide and continuous spread of low resistivity zones which laterally extends from 15m to 200m. The relatively high resistivity values encountered can be attributed to different degrees of mineralogical composition of the solid rock underlying the Clay layers at the base of the section (Fig. 4).

The mean values of physicochemical parameters and that of heavy metals in groundwater samples (Boreholes and Wells) in comparison with various international standards which include World Health Organisation (WHO), United State Environmental Agency (USEPA), National Standards for drinking water Quality (NSDWQ) and National Environmental Standards and Regulation Enforcement Agency (NESREA) are shown in Table 1.0. The concentration of most of the quality variables determined are within the permissible limits. The mean TDS values of 4.99±3.89 and 6.75±3.02 for boreholes and wells are well below the set standards including NESREA and WHO acceptable limits in drinking water. Although the mean level of chloride was within allowable limits of 250 mg/L in Hand-dug wells but over 44% of the Borehole water sample studied were with chloride values higher than the approved 250 mg/L while all the water samples (Boreholes and Wells) are far higher than 40.0 mg/L suggesting input from salt water intrusion from neighboring water body. All trace metals analysed are also within allowable limit, going by the standards employed except Cadmium (0.004 mg/L), Zinc (11.41 mg/L) and Iron (0.65 mg/L) in boreholes and Manganese (0.15 mg/L), Zinc (1.43 mg/L) and Iron (0.56 mg/L) in hand-dug wells which were slightly higher than the approved standards including WHO and NESREA allowable limits. Cadmium is one of the pollutants of priority in groundwater assessment and monitoring by environmental protection agency (USEPA, 2007). The average daily intake of cadmium is estimated as 0.15 μg from air and 1.0 μg from water. Although Cd is eventually excreted, however, it is biopersistent and, once absorbed by an organism, remains resident over decades in human system. Earlier stresses of pregnancy and lactation, aging, Itai-Itai diseases, osteoporosis, anosmia, cardiac failure, cancers, cerebrovascular infections, emphysema, osteoporosis, proteinuria and cataract formation in the eyes, reduced bone mineralization and hydroxyl-apatite formation are the possible health implications caused by Cadmium. The major sources of Cd, are atmospheric deposition, corrosion of galvanized pipes, erosion of natural deposits, discharge from metal refineries, runoff from waste batteries and paints and through fertilizer application in agricultural soil (Lalor, 2008; Jin *et al.,* 2002; Ahmed, 1998). The source of Zinc in the groundwater of the study area could be as a result of the Infiltration and chemical precipitates from soils and sediments and the influence of Mining, grinding of ores and the subsequent processing in waterways. Growth retardation, delayed sexual and skeletal maturation, alteration in cell-mediated immunity, impaired resistance to infection, anorexia, impaired taste, delayed wound healing, behavioural effects and skin lesions, gastrointestinal irritation and vomiting are the clinical conditions attached to the accumulated Zinc intakes (Monterroso *et al.*, 2003; Black, 2003, Khattack *et al.,* 2005; Fasunwon *et al.*, 2008). Natural weathering of bed rocks, sediments and consequent mineralization are the possible source of Iron invasions in the groundwater of the study area. Also, influence from discharge from steel/metal factories, smelting, plastic and fertilizer factories, petroleum products, fire retardants and ceramics could also infiltrate the underground water system. Nutritional disorder, anaemia in infancy, childhood and during pregnancy, hereditary haemo-chromatosis, breast cancer and hormonal cancer are the major health issues accompany high level Iron intakes (Marjani *et al*., 2009). Chromium was completely absent in all the investigated borehole water samples but was detected in a small concentration level (0.0008 ± 0.003) in hand-dug wells. Other Physico-chemical parameters analyzed further reveal the portability of the groundwater in the study area. Toxic metals from cement factories are capable of changing salt content of water, hence seriously disrupt aquatic communities and also decreases quality of water used for drinking and irrigation purposes (Gbadebo and Bankole, 2007). The groundwater studied can be classified as a fresh moderately hard. The alkalinity level of water under investigation requires proper treatment before consumption (Ragunath, 1987).

Conclusion

Integration of hydrogeophysical and geochemical methods has been used to assess and present the subsurface conditions and distribution of trace elements and heavy metals in groundwater environment of Ewekoro. The applied geophysical methods were able to delineate the contaminant plume beneath the investigated locations of the study area. The integrated methods have proven to be effective tools for groundwater quality assessment. The electromagnetic method detected the shallow conductive zones connected with the local water circulations with recorded true conductivity which ranges from 45.84 mS/m in the first layer to 173.39 mS/m in the second layer for vertical and Horizontal Dipole moment respectively. ERT and VES indicated a polluted depth of over 24m beneath the subsurface which coincides with the upper section of the second aquifer in the study area which serves as an indication for a possible impairment of the first groundwater harness by majority of the inhabitants through shallow wells in the same vein, results of the geochemical analyses determined from both groundwater sources also agree to the contamination status of the study area having elevated concentrations of some macro-elements and heavy metals coupled with high BOD_5 and Coliform Count (Table 2 and 3)which are indicative of organic pollution due to faecal contamination. The continuous accumulation of these metals, if not checked could result in pollution status with possible lethal effect to both terrestrial and aquatic organisms within the environment and beyond. Hence, there is a need for strict compliance on environmental rules and regulations by the cement production factory, to ensure safety of man and the environment.

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