



GROUNDWATER RESOURCE POTENTIALS USING FREQUENCY DOMAIN ELECTROMAGNETIC METHOD AND ASSOCIATED WATER QUALITY TECHNIQUES IN EWEKORO COMMUNITIES, SOUTH-WEST NIGERIA



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Abstract:

The relevance of geophysical investigation and biochemical inputs in groundwater exploration and development cannot in anyway be ignored or underrated in any society. Groundwater investigation and water quality status of existing boreholes and hand-dug wells in Ewekoro community, South-West Nigeria was investigated. Qualitative assessment was determined using Frequency Domain Electromagnetic method (FDEM) using GEONICS EM-34; The FDEM detected the shallow conductive zones connected with the local water circulations with recorded true conductivity which ranges from 45.84 mmho/m in the first layer to 173.39 mmho/m in the second layer. 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. As part of the quantitative evaluation, physical parameters (pH, TDS, DO, BOD salinity, total hardness, turbidity, electrical conductivity EC and temperature) of the water samples were also determined. Standard Analytical Methods were employed for all analyses and the results were compared with both National and International water quality standards including World Health Organisation (WHO), and National Environmental Standard Regulation Agency (NESREA). Most quality determinants in the sampled water are within the set guidelines except DO, BOD, ALK, Cl⁻, HCO₃⁻, MgCO₃⁻, Cd²⁺, Zn²⁺ and Fe³⁺. The overall ionic dominance pattern for the borehole and hand-dug well follows the same trend; K⁺ > Na²⁺ > Ca²⁺ > Fe³⁺ > Mn²⁺ > Cd²⁺ and Cl⁻ > PO₄³⁻ > NO₃⁻ > NO₂⁻. The hygienic condition of the water bodies was found to be poor. The results therefore imply that water bodies in Ewekoro are polluted and pose potential risk to humans.

Key words:

Electromagnetic, layer, Dipole spacing, Conductivity, shallow

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. Shortage of water could lead to disease outbreak and economic loss, hence water is a necessity, it is a unique liquid and without it life is impossible. Water plays a significant role in the proper functioning of the earth's ecosystem. Man uses water for various purposes which include drinking, transportation, industrial and domestic, irrigation in agriculture recreation, fisheries, and waste disposal among others (Shittu *et al.*, 2008; Ajayi and Akonai, 2005). Water of a good consumption 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; Ajayi and Adejumo, 2011). The contaminated water therefore has critical impact on all biotic components of the ecosystem and this could affect its use for other purposes. Over two million people die each year due to poor sanitation and contaminated water where 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 [Okoronkwo, et al., 2005; Bunce, 1990]. Bairds, 1995 also observed that elements are toxic in the form of cations and when bonded to short chains of carbon atoms may not be toxic as free elements. This research work aims to

showcase the effectiveness of integrating non-invasive hydrogeophysical methods with widely employed biogeochemical approach in environmental assessment of Ewekoro communities. Bacteria spores find themselves in water through air, sewage, organic waste, dead plants and animal; at times almost all microorganisms may be found in water, but bacteria appeared to be the major water pollutants. Majority of the bacteria found in nature live on dead decaying organic matter as saprophytes (Ishola, 2019). Aside from the beneficial roles played by bacteria like assisting in the digestion of poisons from food and water; presence of other species could cause various diseases to man and other animals. Water obtained from wells, boreholes, streams and river are never chemically pure, even rain water contains dissolved materials from the air as well as suspended dust intermixed with active microorganisms (Prescott et al., 2008). Impurities in water may be floating as suspended matter consisting of insoluble materials of greater density than water which could be removed by sedimentation and in the form of bacteria. Microbiological examination is usually intended to identify water sources which have been contaminated with potential disease-causing microorganisms. Such contamination generally occurs either through improperly treated sewage or improperly functioning sewage treatment system. Chemical analysis can however determine whether water is polluted and provides other useful information (APHA, 1998). Aside from the hazardous effects emanating from the presence of aforementioned toxic elements of environmental concern in groundwater system which necessitated the determination of the physico-chemical parameters of the water sources, its presence in groundwater also serves as water quality determinant factor.

Study Area

Ewekoro community in Ogun State is a home to cement manufacturing industries and renowned for sugarcane plantation. It lies between latitude 6°53'N and longitude 3°14'E (Ishola, 2019).

The sedimentary rocks of Ogun State consist of Ewekoro formation and Abeokuta formation (Fig. 1 and Fig. 2). The Ewekoro formation is fossiliferous and consists of economic deposits of limestones that is quarried by West African Portland Cement Company, WAPCO (Omatshola *et al.*, 1981)

The study areas is generally a low lying to gentle undulating terrain that falls within the humid tropical

climate characterized by two distinct seasons predominant in the tropics in the southern part of Nigeria namely, the wet and dry seasons. The wet season usually occur from March to October, the climate is dominated by the tropical maritime airmass or moisture laden Southwest winds from the Atlantic Ocean that produces heavy rainfall; most of the rainfall comes in torrential showers resulting in high run-off while the dry season occurs from November to late February or early March under the influence of the dry continental airmass or North-Easterly winds from Sahara desert (Ishola, 2019).

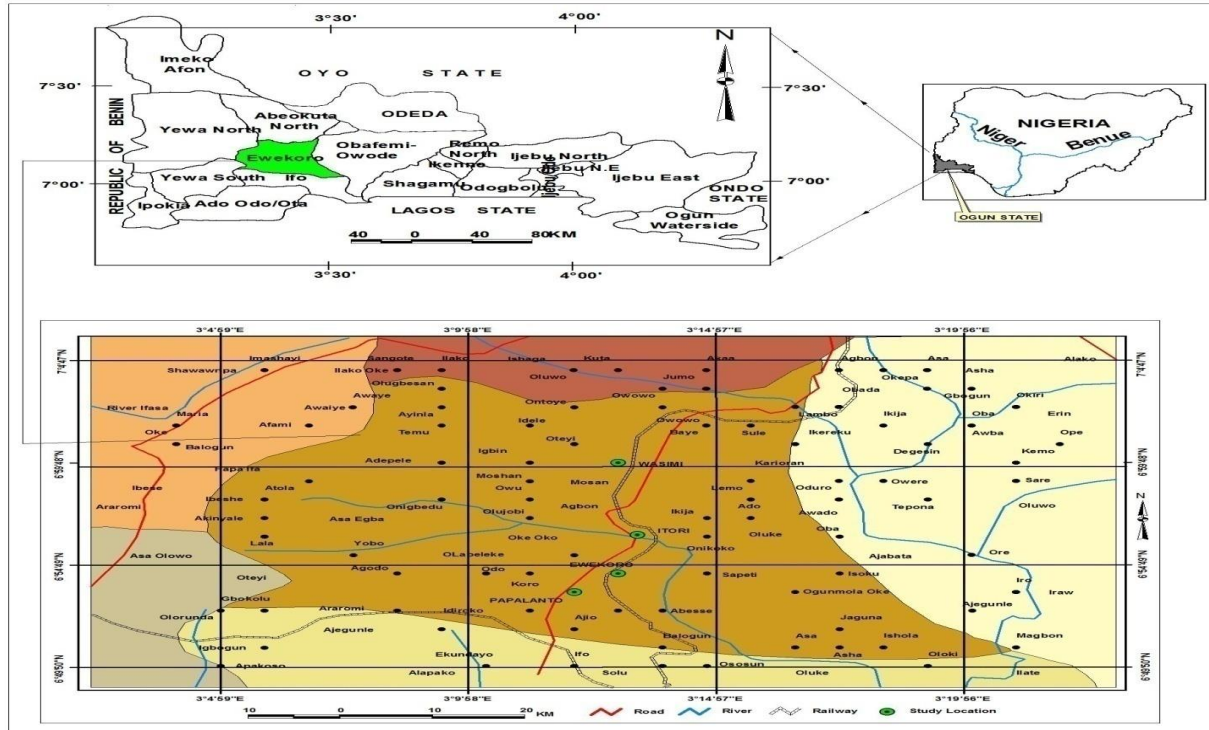


Fig. 1: Inset Map showing the Study Areas in Ogun State within Nigeria Continental Domain using Esri Data/Nigeria Political Information in Arcview GIS 3.2A Environment (Ishola, 2019).

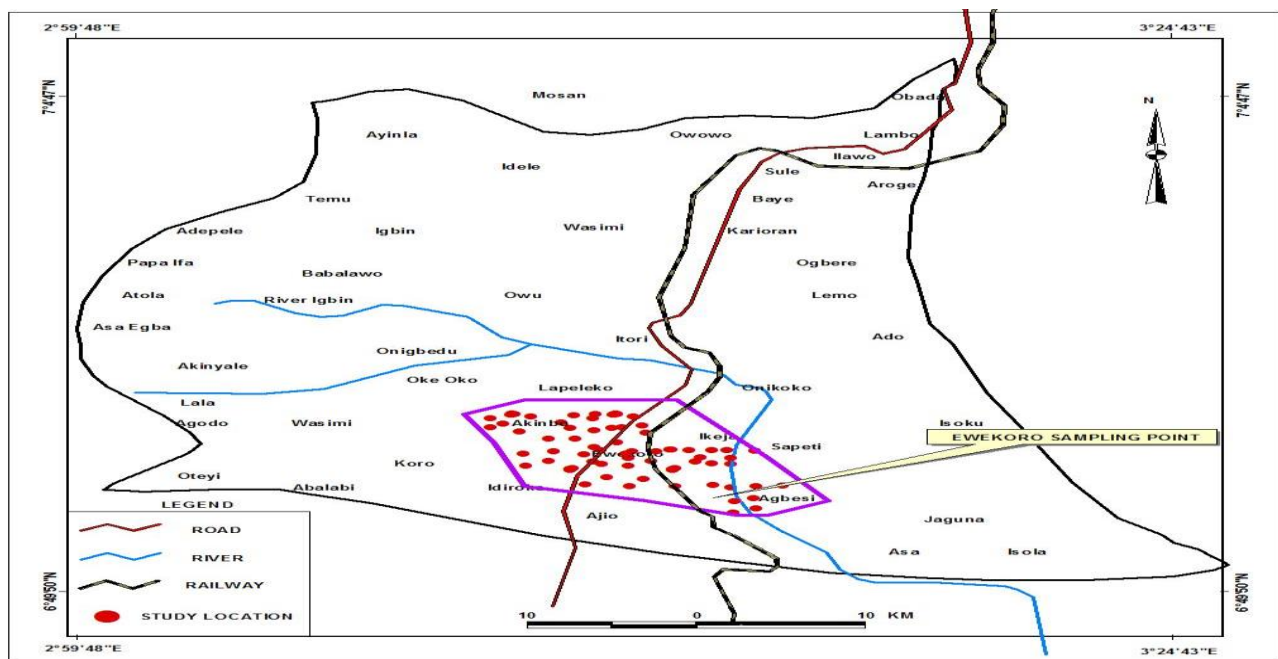


Fig. 2: Data Acquisition Map showing the Investigated Locations in Ewekoro Study Area in Ewekoro LGA, Ogun State Southwest Nigeria (Ishola, 2019).

Materials And Methods

Hydrogeophysical Survey for Data Acquisition

Data Acquisition (Electromagnetic Ground Conductivity Survey)

Electromagnetic profiles (using the Geonics EM34-3 equipment) were selectively carried out in Ewekoro to outline shallow conductive hydrogeological structures probably connected with local water circulation and fluid conductivity (Ugwu, and Nwosu, 2009). The data was acquired along 5 North-South profiles with 2 electromagnetic measurements along a traverse; 5 traverses whose lengths varied between 160 and 200m to show conductivity changes with distance and depth in each location with an intercoil spacing of 10m, 20m, and 40 m. The distance between measurement points was 500 m. At each site two measurements were made using both, horizontal and vertical dipole mode. The main conductivity contrasts, roughly can now be interpreted as the shallow expression of fractures affecting the sedimentary filling of the hydrogeological structure (Mamah and Eze, 1988; Ishola et al., 2021).

Hydrogeochemical Analyse

Collection, Preservation and Analyses of Groundwater Samples

Water samples were strategically collected from existing and functional 25 boreholes and 25 hand-dug wells at different sampling points within Ewekoro communities. Physico-chemical analyses of the water samples were carried out to identify and quantify the physical properties and chemical components of water. This includes pH, cations, anions, trace elements. Sample containers (glass or plastic bottles) were pre-cleaned, dried and stored in a dust free environment as described by Udousoro (1997). The samples for physicochemical parameters and metals determination were stored in 2L plastic bottles while samples for Dissolved Oxygen (DO) and Biochemical

Oxygen Demand (BOD) analyses were stored in glass bottles. Borehole water samples from the study area whose depth ranges from 35m to 75m with an average depth of 51m were collected from taps and were allowed to run and flow out for five minutes before sample collection for physicochemical parameters while well water samples were obtained by using a clean fetching bowl to draw out water. The first three bowls fetched were discarded, while the fourth sample was aseptically poured into a sterile sample bottle. For DO, BOD and bacteriological determinations, the mouth of the tap was heated for five minutes with a spirit lighter to destroy microorganisms, and the tap water allowed to run freely for 5 minutes prior to sample collection.

Samples collected were immediately stored in clean air tight, leak proof plastic bottles and labeled appropriately while Samples for metals were preserved using 1 ml concentrated HNO₃ per litre of sample. All water samples were stored in an insulated cooler containing ice (maintained at 4 °C) and delivered to the laboratory. Physico-chemical properties (Electrical Conductivity (EC), Total Dissolved Solids (TDS), Temperature, Dissolved Oxygen (DO) and pH were determined in-situ using Hannah Combo TDS/pH/EC/Temperature meter series multi-parameters (model HI991300), whereas Hannah (model HI9147) equipment was used for DO in order to ensure that they are not subjected to alteration such as temperature while BOD was measured with JYD-IA DO meter after five days incubation. Other physicochemical parameters evaluation and metals levels were measured in the laboratory using standard procedures (APHA, 1995 and APHA, 1998).

The same procedures were repeated for other water samples. These measured parameters were compared with WHO, 2011a and WHO, 2011b. The geographical coordinates of sample points were also taken with GPS

mete and their location is indicated on the data acquisition map. Water samples for anion determination were collected in 500 ml bottles, unfiltered and unpreserved, and stored below 8 °C prior to analysis. Ion Chromatography (IC) was used to analysed for anions. Nitrate, Phosphates, Bicarbonate, Chloride and Sulphate were measured after chromatography separation using conductivity detectors. Heavy metals and trace metals were determined using the Inductively Coupled Mass Spectrometer (ICP-MS) and Inductively Coupled Optical Emission Spectrometry (ICP-OES) using water quality standard procedures (USEPA, 2002). In order to improve accuracy and to prevent cloudiness of the water, water samples were filtered to less than 0.45 µm using a Pall Corporation GN-6 metricell sterilised membrane. Minute particles of clay sizes were removed before analysis. ICP-OES is useful in measuring higher concentrations, such as high levels of contamination. When lower levels of contamination are present, ICP-MS provide lower detection limits for measurement. In addition, cell-based ICP-MS provides an additional tool for the removal of interferences that might prevent detection of a contamination incident. These analyses were ultimately carried out in order to study how concentration of elements in water samples has been affected by the activities in the study area (Ishola, 2019). SPSS Statistics 20.00 was used for Pearson's correlation coefficients analysis.

Results and Discussions

Table 1: Apparent and Real Conductivity of Horizontal Dipole Orientations in Ewekoro

| Location | Investigated Layers | True Conductivity (mS/m) | | Depth(m) | |
|---------------------------|-----------------------|--------------------------|--------|----------|-------|
| | | HD | VD | HD | VD |
| Traverse 1 (Profile 1) | 1 st Layer | 78 | 92.5 | 9.8 | 18 |
| | 2 nd Layer | 80.4 | 97.5 | - | - |
| Traverse 1 (Profile 2) | 1 st Layer | 120.42 | 88.54 | 9 | 11.2 |
| | 2 nd Layer | 122.47 | 95.08 | - | - |
| Traverse 2 (Profile 3) | 1 st Layer | 132.88 | 55.27 | 10.5 | 10.25 |
| | 2 nd Layer | 143.48 | 81.97 | - | - |
| Traverse 2 (Profile 4) | 1 st Layer | 138.43 | 100.08 | 7.3 | 12.4 |
| | 2 nd Layer | 167 | 103.28 | - | - |
| Traverse 3 (Profile 5) | 1 st Layer | 133.22 | 89.74 | 14 | 11.4 |
| | 2 nd Layer | 147.82 | 93.42 | - | - |
| Traverse 3 (Profile 6) | 1 st Layer | 65.37 | 45.84 | 9.1 | 37 |
| | 2 nd Layer | 86 | 75.04 | - | - |
| Traverse 4 (Profile 7) | 1 st Layer | 65.37 | 45.84 | 9.1 | 37 |
| | 2 nd Layer | 86 | 75.04 | - | - |
| Traverse 4 (Profile 8) | 1 st Layer | 123 | 71.78 | 17 | 16 |
| | 2 nd Layer | 159 | 181.18 | - | - |

Electromagnetic Profiling Survey Results of Ewekoro

The 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; Ishola, 2019). The higher the peak the deeper the rock fractured (Ugwu and Nwosu, 2009; Ishola et al, 2021). These zones are considered priority areas for depth sounding. These locations could be inferred as zones of interests in groundwater exploitation and consequently described as weathered to highly weathered/fractured zones which may serve as suitable aquiferous regions for water supply needs of the study area (MacDonald *et al.*, 2005). Figure 5d is a typical conductivity profile across the study area at EMT₄ conducted NW-SE of Ewekoro. At a lateral distance of about 180m-200m along the section shows points of inflections. 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 (Table 1).

| | | | | | |
|--------------------------------|-----------------------------|--------|-------|-----|------|
| Traverse 5 (Profile 9) | 1st Layer | 86.29 | 94 | 7.6 | 18.2 |
| | 2nd Layer | 122.99 | 104 | - | - |
| Traverse 5 (Profile 10) | 1st Layer | 89.6 | 89.2 | 9.7 | 12.3 |
| | 2nd Layer | 98.4 | 90.54 | - | - |

Characterization of Subsurface Lithology of Hydrogeological Environment of Ewekoro

In 10m Dipole Spacing, Conductivity of 60mmho/m to 200mmho/m were recorded for traverse 2, 52mmho/m to 150mmho/m for traverse 3, 80mmho/m to 200mmho/m for traverse 4, and 60mmho/m to 214mmho/m traverse 5. In 20m Dipole spacing, Conductivity of 42mmho/m to 210mmho/m were recorded for traverse 2, 25mmho/m to 202mmho/m for traverse 3, 50mmho/m to 198mmho/m for traverse 4 and 25mmho/m to 210mmho/m for traverse 5. In 40m Dipole spacing, Conductivity of 48mmho/m to 198mmho/m were recorded for traverse 2, 60mmho/m to 150mmho/m for traverse 3, 48mmho/m to 200mmho/m EMT₄ for traverse 4 and 43mmho/m to 192mmho/m EMT₅ for traverse 5

The results of the Physico-Chemical and Elemental parameters of groundwater (borehole) in Ewekoro are shown in Table 2a and Table 2b for boreholes and wells respectively. The mean value of pH for Ewekoro was 6.97±0.32 while that of temperature was 26.00±1.44. The standard deviation values for both parameters showed that the variation between the measured values do not vary much. The standard deviation (SD) was higher than the mean Alkalinity value Ni, Al³⁺, HCO₃⁻, Alkalinity and Pb²⁺

with the values of 0.007±0.01, 0.003±0.005, 408.22±445.40, 299.12±407.89 and 0.001±0.002 respectively as the presence of HCO₃⁻ proves the high Alkalinity status. Highest mean value of 403.81±445.40 was recorded HCO₃⁻ followed by 234.57±126.15 for Cl⁻ and the least mean value of 0.001 ± 0.002 was recorded for Pb²⁺. COD, BOD and DO exhibited an increasing order level of concentrations of COD>BOD>DO. Cr was undetected in all the investigated boreholes. The high value of standard deviation over the mean value revealed a wide variation in the distribution of elemental constituents of the sampled parameters in the hydrogeologic environment of the study area. Very high variability in the concentration of both the physico-chemical and elemental parameters (e.g HCO₃⁻, Ni, Al³⁺, Pb²⁺) resulted in the standard deviation being higher than the mean values for such elements (Table 2a and Table 2b). 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). Very weak negative correlations observed in the matrix of physico-chemicals and metals in the analyzed groundwater samples could indicate possible varying anthropogenic sources of metals in the aquifer. This is complemented by the dominance of HCO₃⁻ as shown in Fig.3

Table 2a: Descriptive Statistics showing the Concentration Values of Physico-Chemical and Elemental Parameters of Ewekoro Boreholes in Comparison with Other Standards

| Parameters | Min | Max | Range | Mean±SD | WHO (mg/L) | NESREA (mg/L) | NSDWQ (mg/L) | USEPA (mg/L) | NAFDAC (mg/L) |
|---|--------|---------|---------|----------------------|------------|---------------|--------------|--------------|---------------|
| 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 |
| TEMP(°C) | 24.00 | 28.00 | 4.00 | 26.00±1.44 | 27 | NA | NA | 27 | 27 |
| EC(µScm⁻¹) | 558.00 | 941.00 | 383.00 | 720.36±93.68 | 1200 | NA | 900 | 1200 | 1000 |
| DO (mg/L) | 6.70 | 21.48 | 14.78 | 10.30±5.69 | 7.5 | NA | 7.5 | NA | NA |
| BOD (mg/L) | 16.92 | 32.27 | 15.35 | 22.26±4.82 | 10 | NA | 10 | NA | NA |
| COD (mg/L) | 8.96 | 34.92 | 25.96 | 28.06±7.58 | NA | NA | NA | NA | NA |
| TDS (mg/L) | 0.28 | 9.70 | 9.42 | 4.99±3.89 | 100 | 1500 | 500 | 500 | 500 |
| TSS (mg/L) | 0.23 | 4.95 | 4.72 | 0.85±1.04 | > 10 | >10 | NA | NA | NA |
| TS (mg/L) | 0.35 | 1.35 | 1.00 | 0.90±0.27 | 1500 | NA | NA | NA | NA |
| TURB (NTU) | 0.11 | 0.77 | 0.65 | 0.32±0.25 | < 4 | 5.0 | 5.0 | 5.0 | 5.0 |
| ALK (mg/L) | 28.42 | 2210.10 | 2181.68 | 299.12±407.89 | 200 | 500 | 100 | 100 | 100 |
| TH (mg/L) | 14.00 | 32.63 | 18.63 | 25.74±4.81 | < 200 | 100 -300 | 500 | NA | 100 |
| THC (mg/L) | 0.01 | 0.28 | 0.28 | 0.21±0.07 | NA | NA | NA | NA | NA |
| Na²⁺ (mg/L) | 27.99 | 48.98 | 20.99 | 43.45±5.80 | < 200 | NA | 200 | NA | 200 |
| K⁺ (mg/L) | 31.75 | 61.46 | 29.71 | 55.30±7.66 | 250 | 200 | NA | 200 | 10 |
| Ca²⁺ (mg/L) | 10.60 | 29.84 | 19.24 | 24.58±6.42 | 100 | 75 | NA | 75 | 75 |
| Mg³⁺ (mg/L) | 2.80 | 4.96 | 2.16 | 3.77±0.84 | 20 | 15 | NA | 20 | 20 |
| Cl⁻ (mg/L) | 57.20 | 379.32 | 322.12 | 234.57±126.15 | 250 | 200 | 250 | 100 | 100 |
| NO₃⁻ (mg/L) | 0.11 | 0.13 | 0.02 | 0.13±0.006 | 50 | 45 | NA | 10 | 10 |
| NO₂⁻ (mg/L) | 0.01 | 0.04 | 0.02 | 0.02±0.008 | < 3.0 | NA | NA | NA | NA |
| SO₄²⁻ (mg/L) | 7.70 | 19.20 | 11.50 | 11.70±2.84 | 400 | 500 | 200 | 250 | 100 |
| NH₄⁺ (mg/L) | 0.58 | 1.79 | 1.21 | 1.43±0.36 | 1.50 | NA | NA | NA | NA |

| | | | | | | | | | |
|---|-------|---------|---------|----------------------|-------|-------|-------|-------|-------|
| PO₄³⁻ (mg/L) | 7.84 | 11.70 | 3.86 | 10.13±1.122 | NA | NA | NA | NA | NA |
| HCO₃⁻ (mg/L) | 71.70 | 1108.75 | 1037.05 | 408.22±445.40 | 100 | NA | NA | NA | NA |
| MgCO₃ (mg/L) | 8.94 | 13.92 | 4.98 | 12.10±1.50 | 10 | NA | NA | NA | NA |
| Cu²⁺ (mg/L) | 0.01 | 0.05 | 0.04 | 0.03±0.01 | 2.0 | NA | 1.0 | 1.3 | 1.0 |
| Pb²⁺ (mg/L) | 0.00 | 0.01 | 0.01 | 0.001±0.002 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Cd²⁺ (mg/L) | 0.00 | 0.04 | 0.04 | 0.004±0.01 | 0.003 | 0.003 | 0.001 | 0.005 | 0.005 |
| Mn²⁺ (mg/L) | 0.01 | 0.07 | 0.06 | 0.04±0.02 | 0.1 | 0.2 | 0.5 | 0.4 | 2.0 |
| Zn²⁺ (mg/L) | 0.67 | 1.68 | 1.01 | 1.41±0.32 | 0.01 | NA | NA | NA | NA |
| Fe³⁺ (mg/L) | 0.02 | 1.35 | 1.33 | 0.65±0.46 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Ni (mg/L) | 0.00 | 0.03 | 0.03 | 0.007±0.01 | 0.02 | 0.05 | NA | NA | 0.05 |
| S (mg/L) | 0.16 | 5.50 | 5.34 | 3.16±2.05 | 250 | NA | NA | NA | NA |
| Al³⁺ (mg/L) | 0.00 | 0.01 | 0.01 | 0.003±0.005 | 0.2 | NA | NA | 0.2 | 0.5 |
| I (mg/L) | 0.02 | 0.06 | 0.04 | 0.04±0.01 | NA | NA | NA | NA | NA |
| Si (mg/L) | 0.00 | 0.01 | 0.01 | 0.002±0.004 | NA | NA | NA | NA | NA |

KEY

| | | |
|--------|---|---|
| NA | – | NOT AVAILABLE IN THE NATIONAL GUIDELINES AND STANDARDS DRINKING WATER QUALITY |
| WHO | – | WORLD HEALTH ORGANISATION |
| NESREA | – | NATIONAL ENVIRONMENTAL STANDARD REGULATION AGENCY |
| USEPA | – | UNITED STATE ENVIRONMENTAL PROTECTION AGENCY |
| NSDWQ | – | NATIONAL STANDARDS FOR DRINKING WATER QUALITY |
| NAFDAC | – | NATIONAL FOOD AND DRUG ADMINISTRATION AND CONTROL |

Table 2b: Descriptive Statistics showing the Concentration Values of Physico-Chemical and Elemental Parameters of Ewekoro Hand-Dug Wells in Comparison with Other Standards

| Parameters | Min | Max | Range | Mean±SD | WHO (mg/L) | NESREA (mg/L) | NSDWQ (mg/L) | USEPA (mg/L) | NAFDAC (mg/L) |
|--|--------|---------|---------|----------------------|------------|---------------|--------------|--------------|---------------|
| PH | 6.80 | 7.83 | 1.03 | 7.21±0.33 | 6.5 – 9.5 | 7.00-8.50 | 6.50-8.50 | 6.50-8.50 | 6.50-8.50 |
| TEMP | 25.00 | 32.00 | 7.00 | 27.40±1.89 | 27 | NA | NA | 27 | 27 |
| EC | 550.00 | 917.00 | 367.00 | 726.28±126.10 | 1200 | NA | 900 | 1200 | 1000 |
| DO (mg/L) | 7.10 | 8.21 | 1.11 | 7.61±0.30 | 7.5 | NA | 7.5 | NA | NA |
| BOD (mg/L) | 16.91 | 18.86 | 1.95 | 18.06±0.71 | 10 | NA | 10 | NA | NA |
| COD (mg/L) | 21.60 | 34.80 | 13.20 | 30.63±3.91 | NA | NA | NA | NA | NA |
| TDS (mg/L) | 0.86 | 8.96 | 8.10 | 6.75±3.02 | 100 | 1500 | 500 | 500 | 500 |
| TSS (mg/L) | 0.21 | 0.66 | 0.45 | 0.32±0.16 | > 10 | >10 | NA | NA | NA |
| TS (mg/L) | 0.52 | 1.15 | 0.63 | 0.95±0.19 | 1500 | NA | NA | NA | NA |
| TURB (NTU) | 0.11 | 1.09 | 0.98 | 0.68±0.38 | < 4 | 5.0 | 5.0 | 5.0 | 5.0 |
| ALK (mg/L) | 142.10 | 1482.60 | 1340.50 | 490.24±496.73 | 200 | 500 | 100 | 100 | 100 |
| TH (mg/L) | 9.76 | 28.78 | 19.02 | 23.06±6.99 | < 200 | 100 -300 | 500 | NA | 100 |
| THC (mg/L) | 0.01 | 0.35 | 0.34 | 0.17±0.10 | NA | NA | NA | NA | NA |
| Na²⁺ (mg/L) | 24.10 | 51.84 | 27.74 | 43.17±9.24 | < 200 | NA | 200 | NA | 200 |
| K⁺ (mg/L) | 32.41 | 65.76 | 33.35 | 54.54±11.82 | 250 | 200 | NA | 200 | 10 |
| Ca²⁺ (mg/L) | 3.98 | 26.32 | 22.34 | 17.75±7.03 | 75 | NA | NA | 75 | 75 |
| Mg³⁺ (mg/L) | 2.74 | 12.11 | 9.37 | 5.06±2.45 | 20 | 15 | NA | 20 | 20 |
| Cl⁻ (mg/L) | 71.60 | 225.64 | 154.04 | 164.49±71.08 | 250 | 200 | 250 | 100 | 100 |
| NO₃⁻ (mg/L) | 0.11 | 0.13 | 0.02 | 0.12±0.005 | 50 | 45 | NA | 10 | 10 |
| NO₂⁻ (mg/L) | 0.01 | 0.03 | 0.02 | 0.02±0.006 | < 3.0 | NA | NA | NA | NA |

| | | | | | | | | | |
|--------------------------------------|-------|--------------|--------|----------------------|-------|-------|-------|-------|-------|
| SO ₄ ²⁻ (mg/L) | 8.11 | 18.88 | 10.77 | 10.97±2.78 | 400 | 500 | 200 | 250 | 100 |
| NH ₄ ⁺ (mg/L) | 0.48 | 1.61 | 1.13 | 1.10±0.31 | 1.50 | NA | NA | NA | NA |
| PO ₄ ³⁻ (mg/L) | 8.27 | 11.78 | 3.51 | 9.11±0.90 | NA | NA | NA | NA | NA |
| HCO ₃ ⁻ (mg/L) | 71.05 | 741.33 | 670.28 | 248.43±247.69 | 100 | NA | NA | NA | NA |
| MgCO ₃ (mg/L) | 8.92 | 13.41 | 4.49 | 11.62±1.57 | 10 | NA | NA | NA | NA |
| Cu ²⁺ (mg/L) | 0.02 | 0.10 | 0.08 | 0.05±0.02 | 2.0 | NA | 1.0 | 1.3 | 1.0 |
| Pb ²⁺ (mg/L) | 0.00 | 0.0007 | 0.0007 | 0.0007±0.0005 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Cd ²⁺ (mg/L) | 0.00 | 0.02 | 0.02 | 0.002±0.005 | 0.003 | 0.003 | 0.001 | 0.005 | 0.005 |
| Mn ²⁺ (mg/L) | 0.02 | 1.47 | 1.45 | 0.15±0.40 | 0.1 | 0.2 | 0.5 | 0.4 | 2.0 |
| Zn ²⁺ (mg/L) | 0.86 | 1.94 | 1.08 | 1.43±0.25 | 0.01 | NA | NA | NA | NA |
| Fe ³⁺ (mg/L) | 0.00 | 1.29 | 1.29 | 0.56±0.38 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Cr (mg/L) | 0.00 | 0.01 | 0.01 | 0.0008±0.003 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Ni (mg/L) | 0.00 | 0.02 | 0.02 | 0.005±0.006 | 0.02 | 0.05 | NA | NA | 0.05 |
| S (mg/L) | 1.32 | 4.62 | 3.30 | 2.78±1.20 | 250 | NA | NA | NA | NA |
| Al ³⁺ (mg/L) | 0.00 | 0.0009 | 0.0009 | 0.0009±0.001 | 0.2 | NA | NA | 0.2 | 0.5 |
| I (mg/L) | 0.02 | 0.06 | 0.04 | 0.04±0.01 | NA | NA | NA | NA | NA |
| Si (mg/L) | 0.00 | 0.0002 | 0.0002 | 0.0002±0.0004 | NA | NA | NA | NA | NA |

KEY

- NA – NOT AVAILABLE IN THE NATIONAL GUIDELINES AND STANDARDS DRINKING WATER QUALITY
- WHO – WORLD HEALTH ORGANISATION
- NESREA – NATIONAL ENVIRONMENTAL STANDARD REGULATION AGENCY
- USEPA – UNITED STATE ENVIRONMENTAL PROTECTION AGENCY
- NSDWQ – NATIONAL STANDARDS FOR DRINKING WATER QUALITY
- NAFDAC – NATIONAL FOOD AND DRUG ADMINISTRATION COMMISSION

coliform. The temperature of any water body affects the rate of proliferation of microorganisms (Pelczar, 2005).

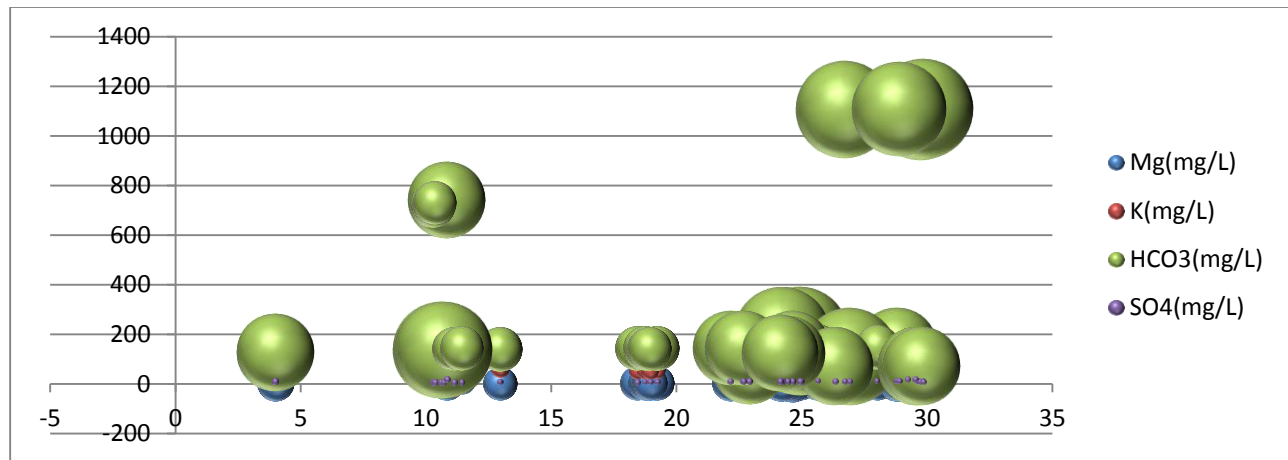


Fig 3: Dominance of HCO₃⁻ among the analyzed Parameters in Ewekoro

Conclusion

The applied geophysical method using frequency domain electromagnetic technique was 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. Simple descriptive statistical analyses of geochemical 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. Physico-chemical parameters like and trace metal such as Dissolved Oxygen, Biochemical Oxygen Demand, Alkalinity, Chlorine, Bicarbonates, Cadmium, Manganese, Zinc and Iron were observed higher than the allowable limit in groundwater. All trace metals analyzed are also within allowable limit, going by the standards employed except Cadmium, Zinc and Iron 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 with revealed dominance of HCO₃⁻ in both water sources. 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 avoiding drilling and use of shallow wells and even deep wells should be sited far (about 30m) from a soak away pit so as to ensure safety of lives and environment.

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