Groundwater quality in parts of Ado-Ekiti Metropolis, South-Western Nigeria

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Abstract- Twenty-five (25) samples of groundwater sourced from boreholes and hand-dug wells were analyzed for twenty-three (23) physical and chemical parameters namely; Total hardness, Total dissolved solids (TDS), Conductivity, pH, Colour, Alkalinity, Turbidity, Nitrate (NO_3^{2-}), phosphate (PO_3^{2-}), Sulphate (SO_4^{2-}), Fluoride (Fl^-), Bicarbonate (HCO^{3-}), Calcium (Ca), Potassium (K), Magnesium (Mg), Zinc (Zn), Sodium (Na), Iron (Fe), Manganese (Mn), Copper (Cu), Lead (Pb), Aluminum (Al) and Chloride (Cl) to determine their levels of portability and if the physico-chemical parameters fall within acceptable levels.

Results show that most of the physical and chemical parameters are within acceptable limits as recommended by some regulatory organizations including the Nigeria Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO). It was also observed that the order of abundance of the various cations was $Ca^{2+} > Mg^{2+} > K^+ > Na^+ > Fe^{2+}$ for well and borehole samples and $SO_4^{2->}$ $Cl^- > NO_3^- > PO_4^{3-} > HCO_3^- > Fl^-$ for the anions which generally agrees with the empirical pattern of mobility in secondary environment in natural water. The order of dominance of the trace elements was found to be Mn > Zn > Cu > Pb > Al and it is similar in both hand-dug well and borehole water samples. T-test results also showed that the differences in the concentrations of the measured parameters in both sample types (hand-dug wells and boreholes) are not significant. It was also observed that Mg-type water is predominant for cation concentration while Chloride and Sulphate type waters are predominant for the anion concentration for the two sample types. In addition, the Water Quality Index (WQI) values revealed that all the borehole water samples fall under the medium category while a few of the well samples fall under the Bad category and the rest under the Medium category.

Conclusively, the groundwater in some parts of Ado-Ekiti can be considered as safe for domestic, agricultural and industrial usage although purification procedures should be carried out on some of the waters.

Index Terms- Groundwater, hand-dug wells, borehole, physicochemical

I. Introduction

Water is one of the most important endowments of nature. It is a priceless commodity without which plants and animals cannot survive hence it is an element that demands rigorous scientific qualification and analysis (Brown, 1971). Making up more than two-thirds of the weight of the human body, water regulates the metabolism and mechanics of the body.

Water occurs either as surface water in the form of streams, lakes, glaciers, oceans and seas which makes up about 94% of the total volume of water in the world or as subsurface/groundwater; which is the subject of this study. It is defined as water found below the surface of the ground and constitutes about 4% of the remaining volume of water. Groundwater constitutes the largest reserve of drinkable water in human habitats, hence, it is of major importance to civilization. Its mild susceptibility to bacterial pollution sets it apart from other sources of water because the soil and rocks which serve as conduit and storage, filters out most of the bacteria. The microbial load of groundwater is significantly low and very rarely exceeds tolerable level (David and Dewiest, 1966). In parts of Africa, Asia, Central and South America, the dependence on groundwater cannot be overemphasized and the past five decades have seen an unmatched development of groundwater resource. Globally, it is estimated that over two billion persons source their drinking water supply from aquifers (Morris et al., 2003).

Ado-Ekiti, the capital city of Ekiti State in Southwest Nigeria with an estimated population of 1million people has a landmass of about 5435 sq.km. (NIMET, 2007). The town is linked with a fairly good road network which provided easy access to the sampling points. The increase in population and technological development has put a strain on the available water resources hence more boreholes and wells are being sunk to alleviate the water problems. Some workers have previously investigated the groundwater quality in Ado-Ekiti metropolis. Awopetu and Baruwa (2017) carried out an appraisal of the groundwater quality in Ado-Ekiti. Using samples collected from ten hand dug wells, they observed that most physico-chemical and bacteriological parameters analyzed were observed to be inconsistent with the Nigerian standard for drinking water quality as well as that of the World Health Organization (WHO).

Oyedele et al., (2019) characterized shallow basement aquifers in parts of Ado-Ekiti and carried out a groundwater quality assessment using samples collected from hand dug wells. The relative mean concentration of the cations were observed to be in the order $Na^+>Mg^{2+}>Ca^{2+}>K^+$ while the anions were in the order $Cl^->HCO_3^->SO_4^{2-}>NO_3^-$. Bacteriological analyses revealed that E. Coli tested positive in all the samples although their colonies were classified dominantly as satisfactory pollutant free state. Anthropogenic activities (such as waste disposal), Weathering, ion-exchange processes were posited to have great influence on the groundwater quality.

1.1. Location of Study area

Ado-Ekiti is in the south-western part of Nigeria lying between latitudes 07º36´N and 07º49´N and longitudes 05º13´E and 05º16´E. (Figure 1)

1.2. Geology of Study Area

Metamorphic Rocks of the Precambrian basement complex underlay the subsoil. These rocks show great variations in grain size and mineral composition. They range from quartz gneisses to schists consisting essentially of quartz with small amounts of white micaceous minerals. In terms of structure and grain size, the rocks vary from coarse grained pegmatites to medium grained gneisses. (Smyth and Montgomery, 1962). The study area is mainly underlain by crystalline rocks which Rahaman (1988) grouped into four lithologic units namely;

I Migmatite-Gneiss-Quartzite complex
II Charnokitic, gabbroic and dioritic rocks
III The older granite suite and
IV Unmetamorphosed dolerite dykes

The dominant lithologies include coarse grained charnokites, fine to medium grained granite, porphyritic biotite hornblende granite and superficial deposits of clay and quartzite. Omotoyinbo (1994) suggested a contemporaneous relationship between the fine grained charnockite and the porphyritic biotite hornblende granite due to their association.

The colour of the charnokitic rock ranges from dark-green to greenish-grey with milky quartz and greenish feldspar. The coarse grained charnockite in Ado-Ekiti bears a striking similarity to the exposures Oyawoye (1972) described as 'Bauchite' which are found in Bauchi, Nigeria.

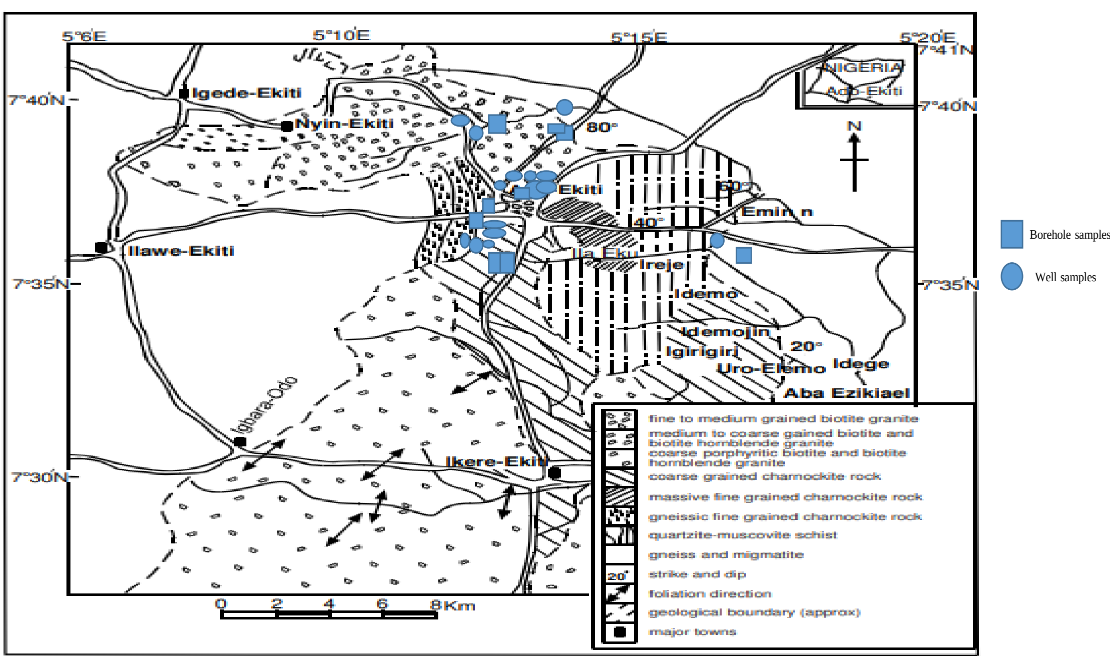

Figure 1: Geological map of Ado-Ekiti showing the sampling points (adapted from Olarewaju et al., 1987)

1.3. Hydrogeological setting of the study area

The study area is underlain by the crystalline basement complex rocks of south-western Nigeria which comprises of granites, migmatite gneisses, charnockites and quartzites. The soil types are categorized into top, loamy and clayey soils. The location of most of these rock types in lowland and highland terrains is responsible for the high runoff and very low infiltration rate. The intensity of fracturing of the underlying rock and degree of weathering determine the hydrogeological characteristics of these rock types especially within the tropical rain forest belt. The fracturing responses of rocks to mechanical deformation coupled with the development of secondary porosity and permeability due to weathering make up the good aquifer properties needed to store and transmit water. This could be responsible for the varying hydrogeological properties of the different rock types in the area hence, the quartzite belts are considered as good aquifer materials. Although the aquifers may contain groundwater in large quantity, the capacity of each well may be low due to intense anisotropy which results in diminished transmissivity within each well, hence, the capacity of the wells do not reflect the total groundwater potential of the area within the basement complex.

The hydraulic barriers of the boundaries, geology of the area, hydrogeologic structures (such as groundwater divides, ground flow, aquifer thickness and extent) and hydraulic parameters of porosity, permeability and stability are factors that determine the storage and circulation of groundwater.

Surface precipitation (rainfall, snow, hail etc.) and lateral flow from rivers and their tributaries are the means by which groundwater is recharged. The Ureje River is the prominent river in the area.

1.4. Water quality

Water quality encompasses the condition of water relative to the requirements of plants, human, animals and other biotic species as well as the physical, chemical and biological characteristics of water. Water quality is also often defined by the simple property of ‘pollution’ i.e. whether water is polluted or not. Pollution may be geogenic, anthropogenic or both. What use water is intended for determines the parameters for measuring its quality although it is often focused on human consumption, industrial use and the environment.

Groundwater quality is as important as its quantity (Hamill and Bell, 1986) and although it is located in the subsurface beyond human view, yet it is subject to pollution. Typical sources of groundwater pollutants are septic tank disposal systems, landfills, sewage treatment lagoons, industrial sources and chemical plants. High concentrations of some dissolved mineral constituents can be dangerous to plant and human health e.g. excess Sodium in water can be fatal for people with cardiac issues while Boron which is good for plants in small amounts could be toxic if the concentration increases slightly. It is very important to know the dosage of each of these elements that is permissible to our systems. Careful analysis of the physical and chemical constituents of groundwater is necessary to determine the quality of the water hence routine chemical and biological analyses are carried out on municipal and industrial water supplies.

Health organizations including World Health Organization (WHO), United States Public Health Services (USPHS) and Nigerian Standard for Drinking Water Quality (NSDWQ) have laid down various guidelines for water quality requirements based on the uses. Table 1 is an excerpt from the water quality standard of the WHO.

Table 1: An excerpt from the water quality standard of the World Health Organization (WHO)

Element/Substance	Symbol/Formula	Normally found in freshwater/surface water/groundwater	Health based guideline by the WHO
Aluminum	Al		0.2mg/l
Ammonia	NH4	< 0.2mg/l (up to 0.3mg/l in anaerobic waters)	No guideline
Antimony	Sb	< 4 µg/l	0.005mg/l
Arsenic	As		0.01mg/l
Barium	Ba		0.3mg/l
Beryllium	Be	< 1µg/l	No guideline
Boron	B	< 1mg/l	0.3mg/l
Cadmium	Cd	< 1µg/l	0.003mg/l
Chloride	Cl		250mg/l
Chromium	Cr3+, Cr6+	< 2µg/l	0.05mg/l
Copper	Cu		2mg/l
Cyanide	CN_		0.07mg/l
Fluoride	F	< 1.5mg/l (up to 10)	1.5mg/l
Hardness	Mg/l CaCO3)		No guideline
Hydrogen sulphide	H2S		No guideline
Iron	Fe	0.5-50mg/l	No guideline
Lead	Pb		0.01mg/l
Manganese	Mn		0.5mg/l
Mercury	Hg	< 0.5µg/l	0.001mg/l
Molybdenum	Mb	< 0.01mg/l	0.07mg/l
Nickel	Ni	< 0.02mg/l	0.02mg/l

Nitrate and nitrite	NO3, NO2		50mg/l total nitrogen
Selenium	Se	<< 0.01mg/l	0.01mg/l
Silver	Ag	5-50 µg/l	No guideline
Sodium	Na	< 20mg/l	
Uranium	U		1.4mg/l
Zinc	Zn		3mg/l

II. MATERIALS AND METHOD

1.5. Sampling

For this study, Twenty-five (25) groundwater samples {Nine (9) borehole samples and sixteen (16) samples from hand-dug wells} were collected from the study area and twenty-three physico-chemical parameters including Total dissolved solids (TDS), conductivity, total hardness, pH, colour, alkalinity and turbidity, Nitrate (NO_3^{2-}), Phosphate (PO_3^{2-}), Sulphate (SO_4^{2-}), Fluoride (Fl), Bicarbonate (HCO^{3-}), Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn), Lead (Pb), Aluminum (Al) and chloride (Cl) were measured to determine the concentration of the various elements present in the water samples. These results were then compared with various standards to determine the portability of the samples. The hand-dug wells differ in character in that some were cased while others were not cased. This may affect the physical and chemical properties of the water in the wells.

A sampling plan that traversed the whole area had been drawn prior to sample collection so that the samples collected will represent all the rock types in the area. All the samples were collected within a two-day period to reduce the effect of temporal variation on the water chemistry. The samples were collected in clean 75cl water containers and well labelled and preserved until they were analyzed. The sampling points were located using Global Positioning System (GPS) equipment and the coordinates are presented in table 2. The samples were designated (B) to indicate samples obtained from machine drilled boreholes and (W) hand dug wells.

Table 2: Sampling Points

Location	Coordinates	Source/Label	Description
1	N 07º 37.097´ E 005º 13.070´	Borehole/B1	Opposite Saint Thomas Aquinas Catholic Primary School, Irona Street.
2	N 07º 39.734´ E 005º 12.549´	Well/W1	The Nigerian Police Force Headquarters, Basiri Street, Iyin Road.
3	N 07º 36.662´ E 005º 13.355´	Well/W2	No 62A, Okebola Street, beside Intercontinental bank plc.
4	N 07º 36.646´ E 005º 13.337´	Well/W3	Okebola Street, Ikere Road
5	N 07º 36.731´ E 005º 13.299´	Borehole/B2	Kay Calax Hotels, Opposite Ade-Tade Hospitals complex.
6	N 07º 35.747´ E 005º 17.548´	Borehole/B3	Lagos female Hall, The Federal polytechnic, Ado-Ekiti
7	N 07º 36.275´ E 005º 17.330´	Well/W4	Annex Male Hall, The Federal Polytechnic, Ado-Ekiti.
8	N 07º 35.835´ E 005º 12.843´	Well/W5	Bamgboye Street, off Ikere road, Ado-Ekiti
9	N 07º 35.816´ E 005º 12.811´	Dam W6	Ureje Waterworks Dam, Ado-Ekiti
10	N 07º 35.388´ E 005º 13.042´	Well/W7	Arowolo Street along Alaafia bakery road, opposite Akure garage
11	N 07º 35.380´ E 005º 12.997´	Borehole/B4	FESTMAG Hotels, Alaafia street
12	N 07º 35.337´ E 005º 12.999´	Borehole/B5	Behind SMA Motors, Akure Road, Ado-Ekiti.

13	N 07º 35.156´ E 005º 13.224´	Well/W8	NO 5, Olujoda Street, Behind New Coca Cola, Off Ikere Road, Ado-Ekiti
14	N 07º 37.193´ E 005º 13.290´	Well/W9	NO 24, Isato Street, Behind Kings Market
15	N 07º 37.177´ E 005º 13.283´	Well/W10	NO 26, Isato Street, Behind Kings Market
16	N 07º 37.062´ E 005º 13.609´	Well/W11	Alhaji Imoyomi mosque, Ilusunja Street
17	N 07º 36.972´ E 005º 13.756´	Well/W12	Idemo compound, Idemo Street, Polytechnic road
18	N 07º 36.977´ E 005º 13.746´	Well/W13	Behind Idemo Compound, Poly Road
19	N 07º 36.927´ E 005º 13.780´	Borehole/B6	Poly Road, Ado-Ekiti
20	N 07º 37.308´ E 005º 13.535´	Well/W14	Mary Immaculate girl's grammar school, old garage, Ado-Ekiti
21	N 07º 38.225´ E 005º 13.839´	Borehole/B7	NO 169, Dayo Fajuru Road, Housing Estate Road, Oke-Ila, Ado-Ekiti
22	N 07º 38.205´ E 005º 13.834´	Borehole/B8	Oke Ila Street, Ado-Ekiti
23	N 07º 39.482´ E 005º 13.906´	Well/W15	145, Opopogbooro Street, opposite Dave Hotel, University Road, Ado-Ekiti
24	N 07º 39.436´ E 005º 13.949´	Borehole/B9	M.R.S. Filling Station, beside Dave Hotel, University Road, Ado-Ekiti
25	N 07º 39.390´ E 005º 13.642´	Well/W16	NOVA Road, Adebayo Street, Ado-Ekiti

1.6. Physical analysis

1.6.1. pH determination

pH is the measure of the degree of acidity or alkalinity of water in which pure water has a pH value of 7. Values greater than 7 indicate alkalinity while values lower than 7 indicate acidity. It is mathematically defined as the negative logarithm of the hydrogen ion concentration. For accuracy, the pH meter was standardized with buffers of 7.00 and 4.00 pH values before the probe was inserted into the samples and the values read off the meter.

1.6.2. Determination of Total Dissolved Solids (TDS)

Total dissolved solids (TDS) is the concentration of dissolved substances (mostly salts) in water. This analysis was carried out using a conductivity meter

1.6.3. Determination of conductivity

Conductivity is defined as the estimate of a material's ability to conduct electric current. This is made possible by the presence of ions of some salts in water. The volume of electricity that can be conducted depends on the concentration of the ions

1.6.4. Determination of Total Hardness

Presence of calcium and magnesium salts determines to a large extent the hardness of natural waters while the concentration of iron, aluminum and other metals in the water contributes a small measure to its hardness. Temporary hardness which results from the bicarbonates and carbonates of calcium and magnesium can be removed by boiling of the water. The higher the concentration of these salts, the harder it is said to be. For this research, separate analyses was done to determine the concentration of calcium and magnesium salts in the samples. The two values were then added together to determine the hardness.

Total Hardness = Ca^{2+} (ppm) hardness + Mg^{2+} (ppm) hardness

These analyses were carried out at the Central Laboratory of Obafemi Awolowo University, Ile-Ife.

1.6.5. Cations determination

These analyses were carried out using the Buck 205 Scientific Atomic Absorption Spectrophotometer which was developed at the division of chemical physics of the commonwealth Scientific and Industrial Research Organization (CISPRO), Australia by Walsh

(SpectrochemaicaActa, 1995). The equipment was designed to measure the concentration of metals in solution such as water, soil, blood, serum etc. It provides integrated measurements in absorbance or emission intensity as well as sample concentration in comparison to standard solutions.

The sample solution is aspirated into a flame and the sample element is converted into atomic vapour. The flame therefore contains some of the atoms of the elements of interest. Some of these atoms become thermally excited and absorb the radiation given off by the hollow cathode lamp which consists of a cylindrical hollow cathode made of the element to be determined or an alloy of it. The radiation goes into a monochromator where the particular resonance line required is isolated and any absorption off the resonance line due to the atomic vapor in the flame is measured by means of a photomultiplier. Apart from the sulphate, nitrate, phosphate and chloride analyses which were carried out at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, other analyses were done at the International Institute for Tropical Agriculture (IITA), Ibadan, Oyo State.

III. RESULTS AND DISCUSSIONS

1.7. Physical parameters

The physical parameters determined include pH, conductivity, TDS, turbidity and total hardness.

For this study, the pH values ranged from 5.04 to 7.47 (Well samples) and from 4.39 to 7.54 (Borehole samples). A mean value of 6.51±0.72 (Well) and 6.27±1.04 (Borehole) indicates an almost neutral (weakly acidic) to slightly basic nature of the samples. These values fall within the (WHO, 1971, 1993) maximum permissible range of 6.5 to 9.2 and within the acceptable limit of drinking water supply of USEPA (1976) which is 5.0 to 9.0.

The total hardness (TD) values for well samples ranged from 8.56 to 20.37mg/l with a mean of 14.85±4.24 and from 9.40 to 17.2mg/l for borehole water samples with a mean of 13.29±2.72. All these values fall way below the maximum acceptable level of 500mg/l recommended by WHO (1971) for drinking water. On the basis of these values, the water samples can be described as soft following Sawyer and McCarty's (1967) classification of water.

Conductivity is a measure of the conducting ionic species in a sample solution. It had a range of values between 180 to 2012µS/cm and a mean of 709.82±616.71 µS/cm for the well samples, while the borehole samples had a range of 212 to 851 µS/cm and a mean of 336.13±212.4 µS/cm. the mean conductivity of both sample types exceeds the permissible level of 250 µS/cm recommended by WHO (1971) for drinking water although no health implication was given for this anomaly.

Alkalinity values ranged from 0.016-0.037mg/l and 0.016-0.039mg/l for well and borehole samples respectively. Calculated means had values of 0.022±0.0059mg/l and 0.0228±0.008mg/l for well and borehole samples respectively.

Total dissolved solids (TDS) values ranged from 91-1000mg/l and 107-429mg/l for well and borehole water samples respectively. The calculated means were 357.118±306.17mg/l and 170.125±106.5mg/l respectively. These values are below the permissible standards recommended by both WHO (1971) and NSDWQ (2007). When considered individually, some of the wells had TDS values greater than the 500mg/l limit recommended by NSDWQ (2007) as shown on table 7. A comparison of some selected physic-chemical parameters in both well and borehole samples are shown in Figure 2.

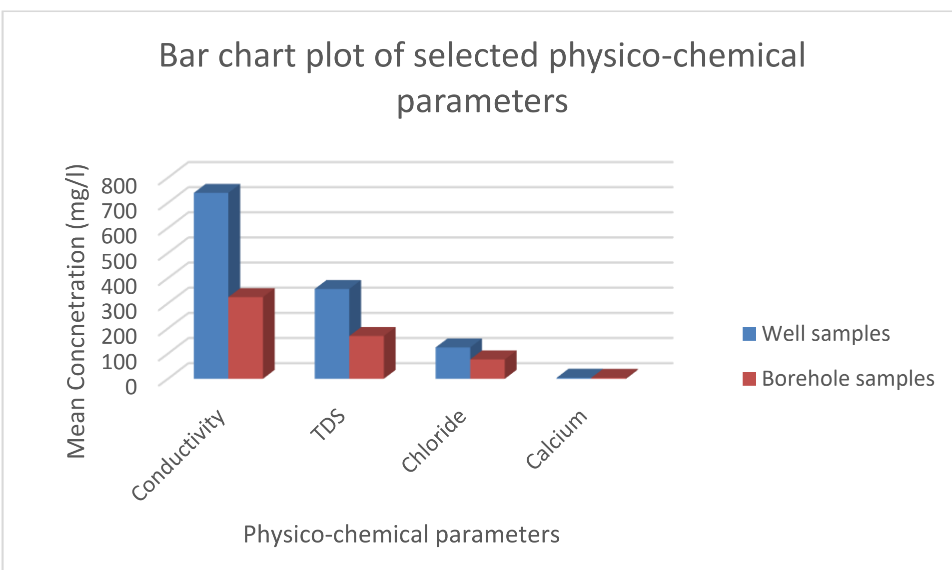

Figure 2: Bar chart plot of selected physic-chemical parameters

1.8. Chemical parameters

1.8.1. Cations

1.8.1.1. Calcium Ion

Calcium is the most abundant cation in the samples with values ranging from 2.191-6.151 mg/l and 3.051 - 6.151 mg/l for well and borehole samples respectively. The means are 4.318±1.36 mg/l and 4.14±0.98 mg/l respectively. These mean values fall below the maximum permissible limit of 250mg/l recommended by the WHO (1971).

1.8.1.2. Magnesium ion

Analysis revealed concentration values within the range of 0.751-1.956 mg/l and 0.432-1.751 for well and borehole water samples respectively. The calculated means are 1.095±0.29 mg/l and 0.967±0.34 mg/l for well and borehole water samples. These values although below the WHO (1971) specified permissible limit if 100mg/l, they exceed the maximum permitted concentration values recommended by the NSDWQ (2007) of 0.2mg/l although no specific health hazards from excess intake of magnesium were specified.

1.8.1.3. Potassium ion

Potassium concentration ranges from 0.139-0.418 mg/l and 0.116-0.401 for well and borehole samples respectively. The mean concentrations are 0.31±0.09 mg/l and 0.266±0.09 mg/l respectively. None of the standards used for this study specify a permissible limit for potassium concentration. Salts of potassium form electrolytes which assist the kidneys in regulating fluid levels and the balance of acids and bases in the body.

1.8.1.4. Sodium ion

The concentration of sodium in the groundwater samples range from 0.079-0.126mg/l and 0.113-0.141 mg/l with means of 0.11±0.028 mg/l and 0.109±0.020 mg/l for well and borehole water samples respectively. These means fall below the permissible limits of 250mg/l recommended by WHO (1971) and NSDWQ (2007). Sodium chloride also helps regulate fluid levels and the balance of acids and bases.

1.8.1.5. Iron ion

At certain concentrations is water, iron causes coloration, taste and encourages bacterial growth. It also causes scaling in pipes, stains clothing and cooking utensils (Ezeigbo, 1988). For this study, the iron concentration range from 0.008-0.071 mg/l and 0.009-0.081 mg/l for well and borehole samples respectively. Mean values of 0.037±0.021 mg/l and 0.032±0.025 mg/l were derived for well and borehole samples respectively. These values fall below the maximum permissible limit of 1.0 mg/l recommended by WHO (1971) and also fall below the 0.3 mg/l mark given by the NSDWQ (2007).

1.8.1.6. **Mean concentration of cations**.

To determine the order of dominance of the various ions present in the samples, the mean (average) concentrations of the five cations tested for were plotted on a bar chart. The order was found to be $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+} > Fe^{2+}$. This order generally agree with the empirical pattern of mobility in secondary environment in natural water (Krauskopf, 1967).

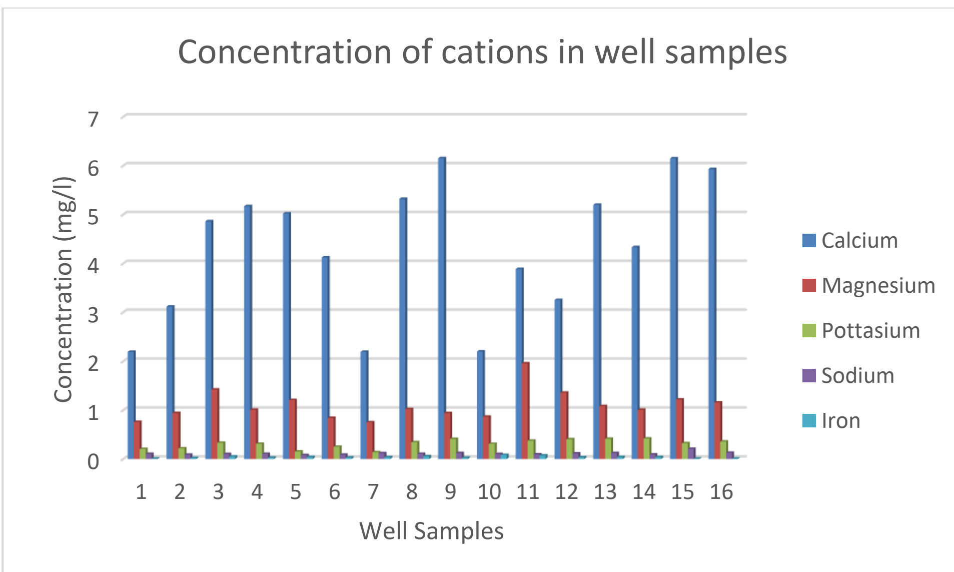

Figure 3: Concentration of cations in well samples

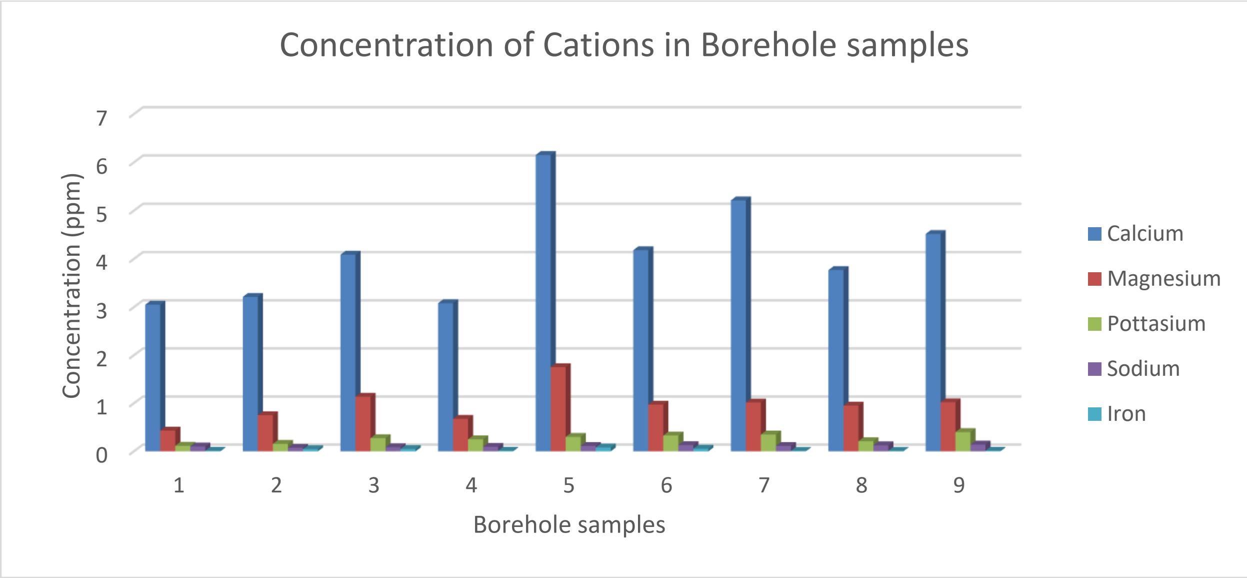

Figure 4: Concentration of cations in Borehole samples

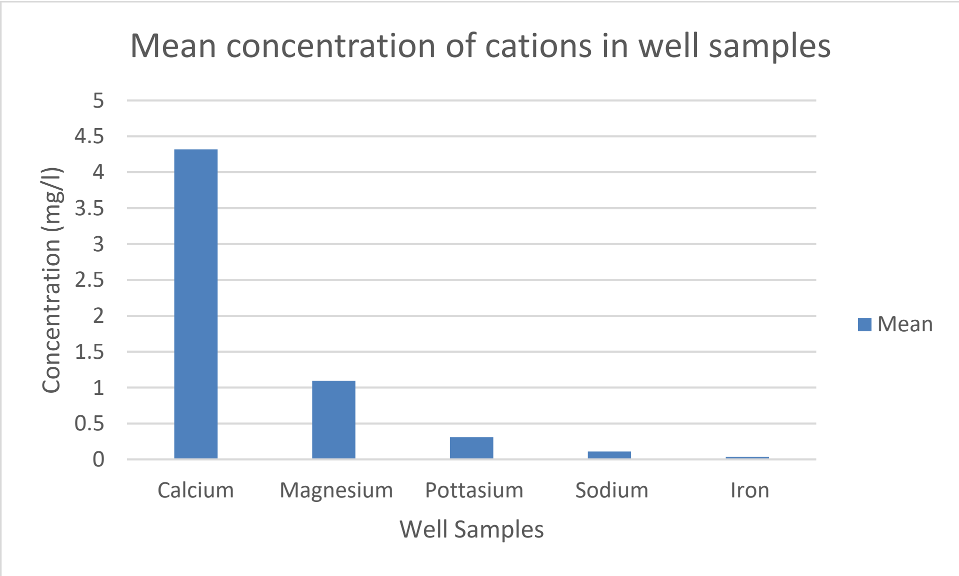

Figure 5: Mean concentration of cations in well samples

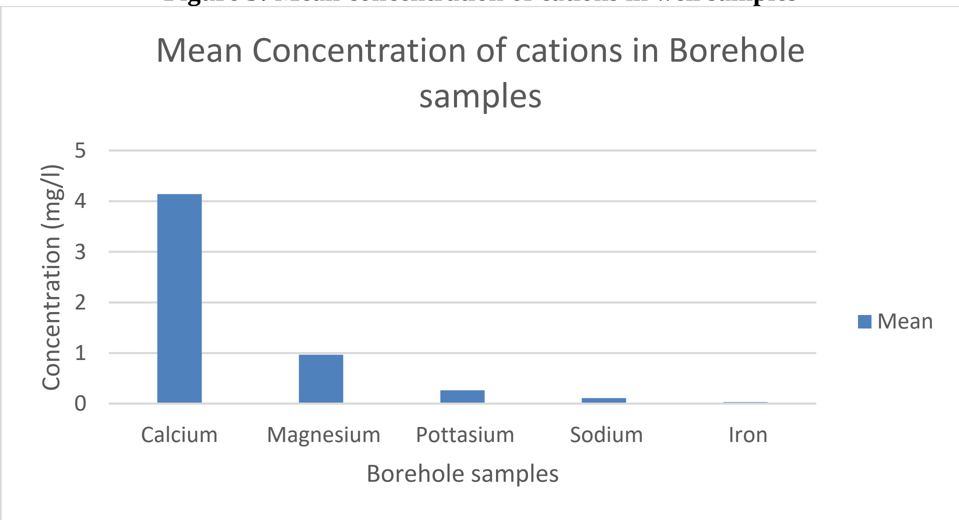

Figure 6: Mean concentration of anions in borehole samples

1.8.2. Anions

1.8.2.1. Sulphate ion

For this study, the concentration of sulphate ion ranged from 58.21-186.62 mg/l and 46.91-133.01 mg/l for well and borehole samples respectively. The mean values were 124.567±40.85mg/l and 95.475±30.64 mg/l for well and borehole samples. These values fall below the permissible limit of the WHO (1971) but exceed the 10mg/l limit recommended by USEPA (1976) for domestic water supply. The mean values obtained for the well samples also exceed the limit recommended by the NSDWQ (2007).

1.8.2.2. Phosphate ion

Phosphate occurs in water as compounds. Its concentration in the well samples ranged from 1.663-5.332 mg/l and 1.34-3.743 for the borehole samples. The mean values obtained are 3.559±1.17 mg/l and 2.728±0.88 mg/l for well and borehole samples respectively. There are no specified limits for phosphate concentration.

1.8.2.3. Nitrate ion

Nitrate concentration in the groundwater samples analyzed fall within the range of 11.6-61.623 mg/l for well samples and 10.291-32.538 mg/l for borehole samples. The means are 32.98±16.68 mg/l and 21.907±7.97 mg/l respectively. These means fall below the 50mg/l WHO (1993) and NSDWQ (2007) limits. Nitrate in concentrations greater than 50ppm is undesirable in water used for domestic purposes as it can cause asphyxia (blue-baby syndrome) and cyanosis in infants under three months old. Hence, samples W5, W6, W11, W12 and W13 with nitrate concentrations greater than 50mg/l should be treated before use.

1.8.2.4. Chloride ion

Hall and Chapman (1997) posits that water containing less than 150mg/l of chloride is satisfactory for most purposes. For this study, the concentration of chloride in the well water samples range from 65.109-260.834 mg/l with a mean values of 124.613±70.65mg/l while the range for borehole samples is 61.101-88.902 mg/l with a mean of 77.1±8.77 mg/l. These means fall below the highest desirable level and the maximum permissible range of 200mg/l and 600mg/l respectively recommended by the WHO (1971). They are also acceptable by USEPA (1976) and NSDWQ (2007).

1.8.2.5. Fluoride ion

Fluoride concentration ranged from 0.049-0.072 mg/l for well water samples with a mean of 0.062±0.01mg/l. For borehole samples, the concentration ranged from 0.003-0.081 mg/l with a mean of 0.042±0.03mg/l. These means fall below the permissible limit of 1.5mg/l recommended by WHO (1971) and NSDWQ (2007).

1.8.2.6. Bicarbonate ion

The concentration of bicarbonate ion in the samples obtained from hand-dug wells ranged from 0.003-0.009 mg/l with a mean value of 0.006±0.002 mg/l while that of borehole samples ranged from 0.001-0.009 mg/l with a mean of 0.006±0.003 mg/l. no recommended limit was given by WHO and other standards used for this study.

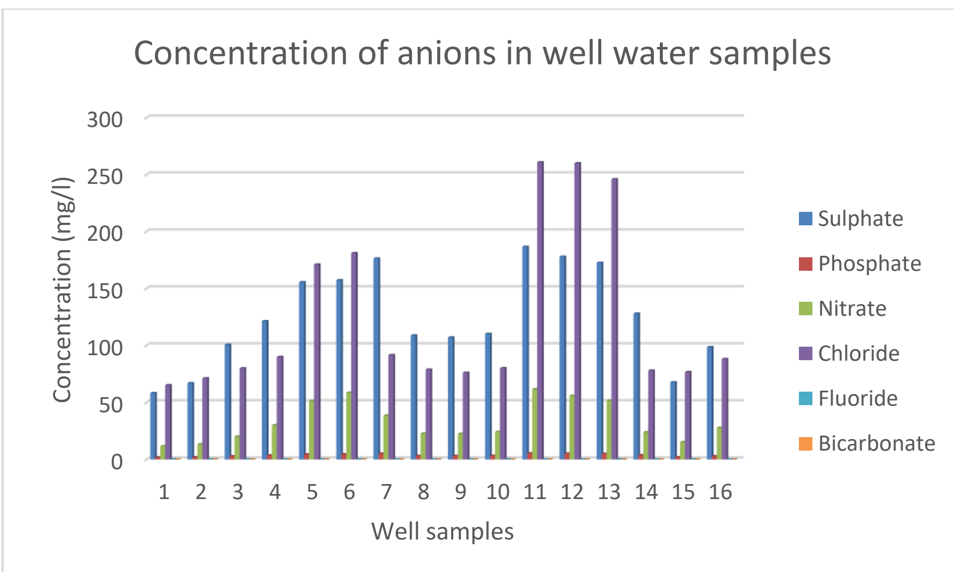

Figure 7: Concentration of anions in well water samples

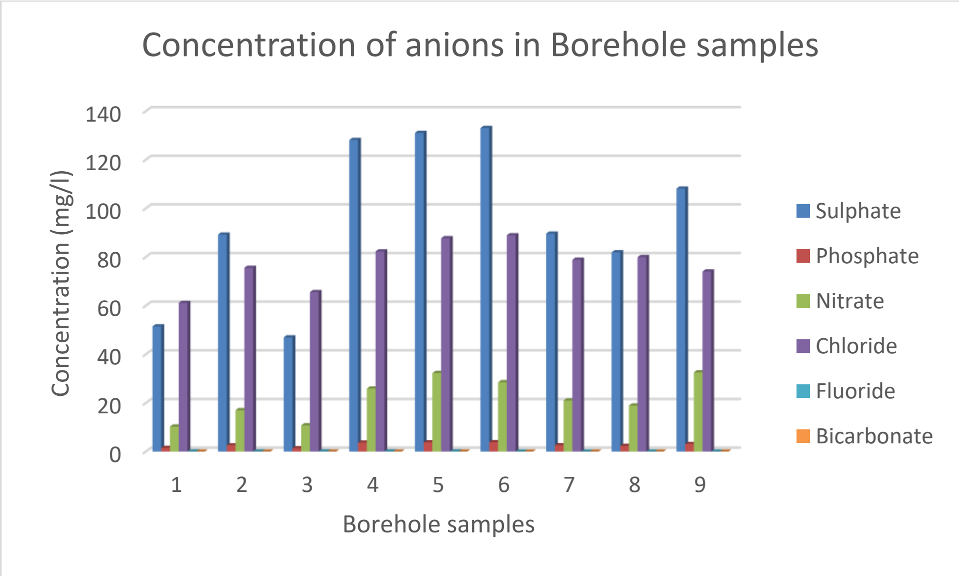

Figure 8: Concentration of anions in Borehole samples

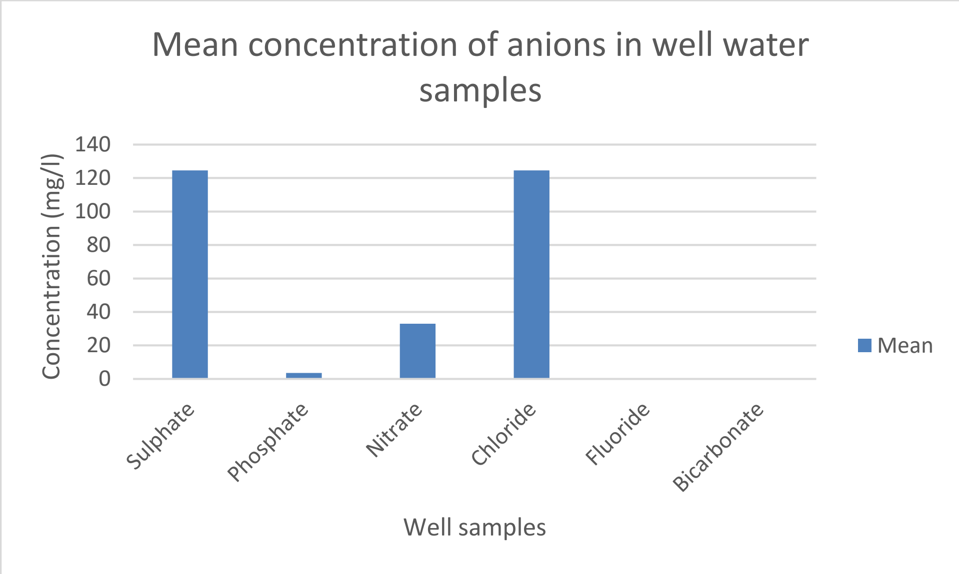

Figure 9: Mean concentration of anions in well water samples

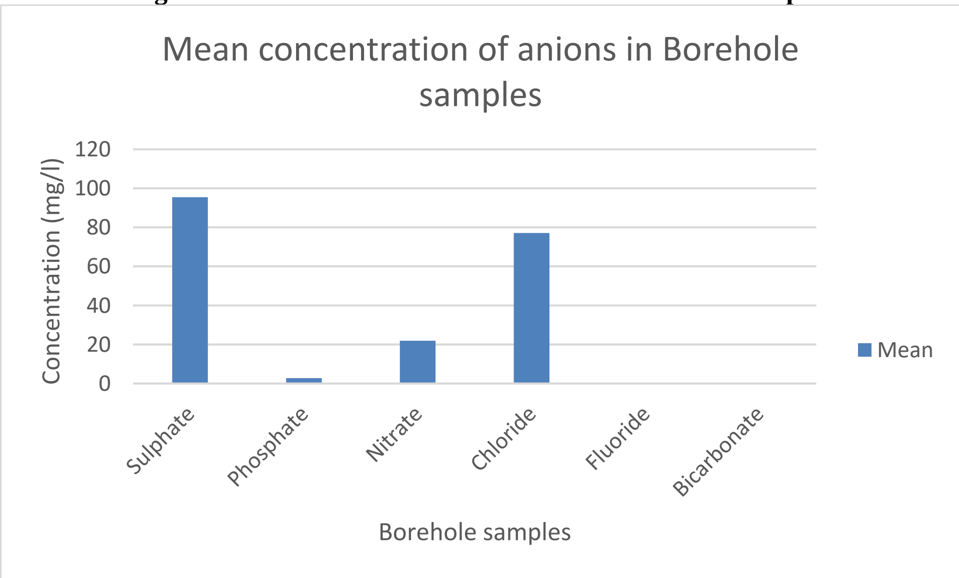

Figure 10: Mean concentration of anions in Borehole samples

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1.8.3. Trace elements

1.8.3.1. Copper

The detected range of copper concentration in the study area was 0.006-0.016 mg/l and 0.005-0.013 mg/l for well and borehole water samples respectively. The means were 0.011±0.003mg/l and 0.009±0.002 mg/l respectively. These values fall well below the permissible limits recommended by WHO (1971), USEPA (1976) and NSDWQ (2007).

1.8.3.2. Zinc

The concentration of Zinc ranged from 0.011-0.041 mg/l and 0.011-0.061 mg/l with means of 0.023±0.011mg/l and 0.026±0.019mg/l for well and borehole samples respectively.
They also fall below the permissible limits of the standards used.

1.8.3.3. Lead

For well and borehole samples respectively, lead had a range of concentration of 0.001-0.005mg/l with a mean value of 0.003±0.001mg/l and 0.002-0.005mg/l with a mean of 0.003±0.001mg/l all within the acceptable limits recommended by WHO (1971) and NSDWQ (2007).

1.8.3.4. Aluminum

Concentration values for Aluminum fall within the range of 0-0.004mg/l for well samples with a calculated mean of 0.001±0.001mg/l while the borehole samples had a range of 0.001-0.003mg/l with a mean of 0.002±0.001mg/l. These means fall below the permissible limits recommended by WHO (1971) and NSDWQ (2007).

1.8.3.5. Manganese

These had values between 0.031-0.102mg/l with a mean of 0.054±0.017mg/l and 0.026-0.073mg/l and a mean of 0.051±0.016mg/l for well and borehole water samples respectively. They fall within the acceptable limits of the WHO (1971) and NSDWQ (2007) although the mean of the well water samples exceed the 0.05mg/l limit recommended by USEPA (1976) for domestic water use.

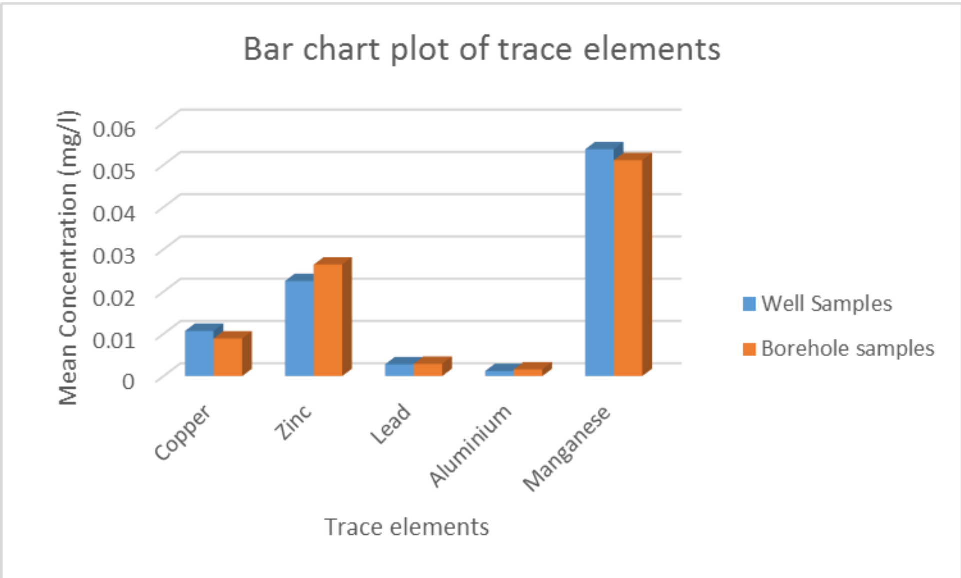

Figure 11: Bar chart plot of trace elements

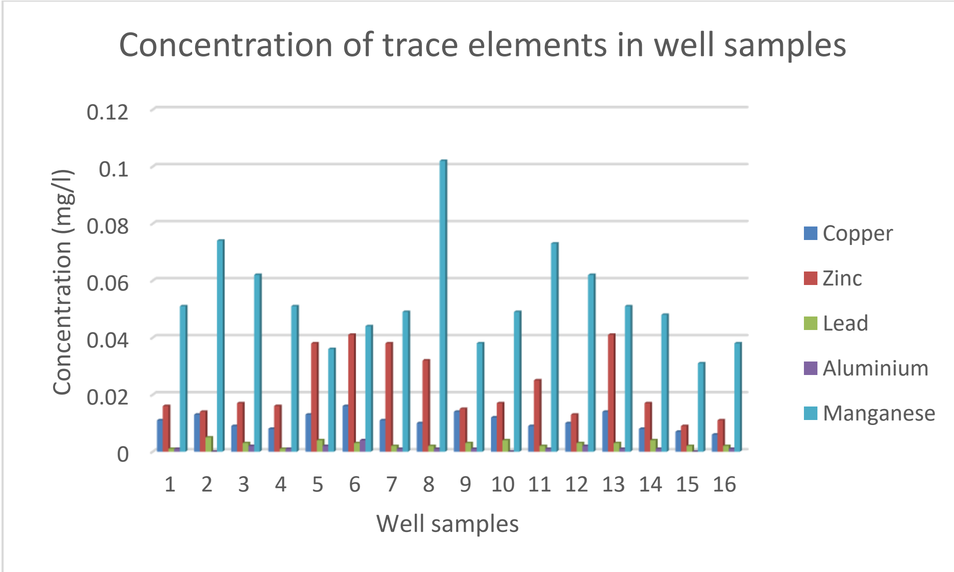

Figure 12: Concentration of trace elements in well samples

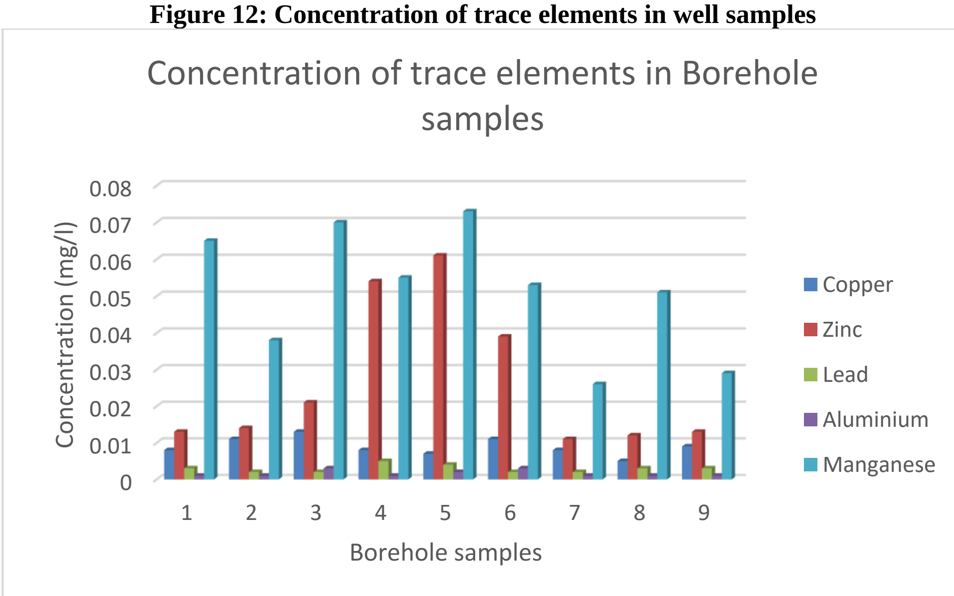

Figure 13: Concentration of trace elements in Borehole samples

1.8.3.6. Mean concentration of trace elements

To determine the order of dominance of the trace elements, the mean concentration was plotted on a bar chart. The order was Mn>Zn>Cu>Pb>Al and it is similar for both well and borehole water samples.

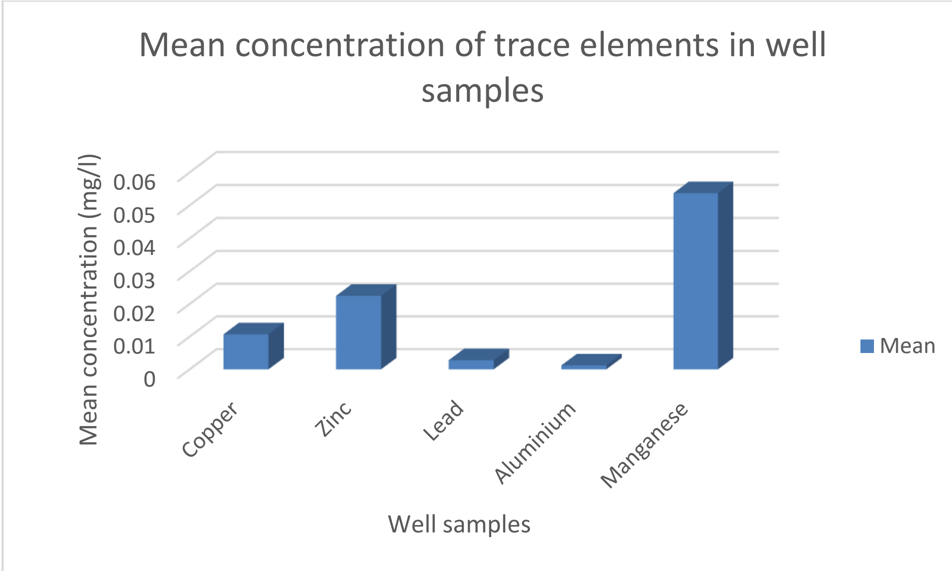

Figure 14: Mean concentration of trace elements in well samples

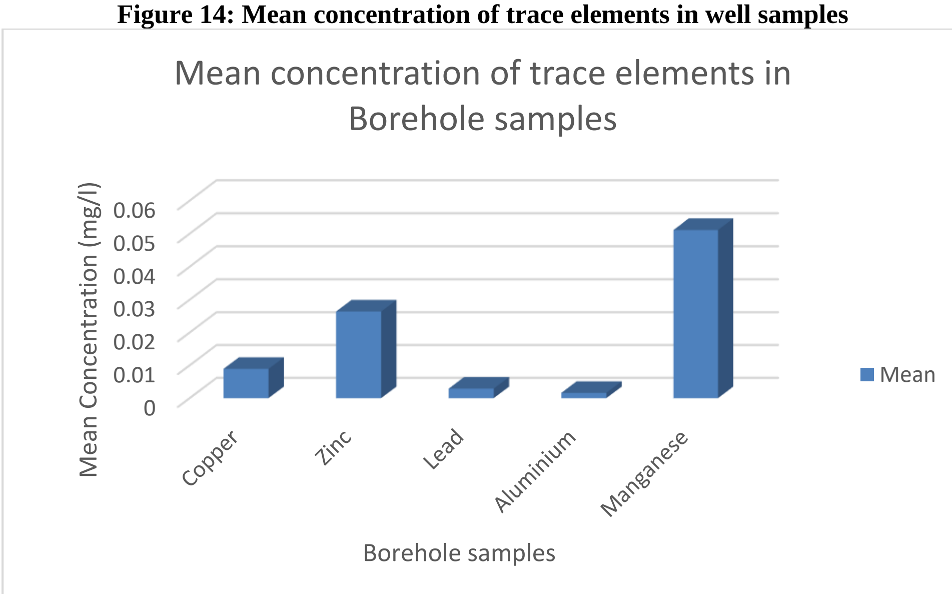

Figure 15: Mean concentration of trace elements in Borehole samples

Table 3: Comparison of results with WHO (1971, 1993) guidelines for drinking water

WHO DRINKING STANDARDS			THIS STUDY			
PARAMETERS	HIGHEST DESIRABLE LEVEL	MAXIMUM PERMISSIBLE RANGE	WELLS (N=16)		BOREHOLES (N=9)	
			RANGE	MEAN	RANGE	MEAN
PH	7-8	6.5-9.2	5.04-7.47	6.51±0.72	4.39-7.54	6.27±1.04
Conductivity (µS/cm)	-	250*	180-2012	709.82±616.71	212-851	336.13±212.4
Turbidity (NTU)	5	25				
Total hard. (mg/l)	150-500*		8.56-20.37	14.85±4.24	9.40-17.2	13.29±2.72
Calcium (mg/l)	75	200	2.19-6.151	4.32±1.35	3.051-6.151	4.14±0.98

Magnesium(mg/l)	30	100	0.751-1.956	1.095±0.292	0.432-1.751	0.97±0.344
Potassium(mg/l)			0.139-0.418	0.31±0.089	0.116-0.401	0.27±0.087
Sodium(mg/l)		200	0.079-0.207	0.11±0.029	0.075-0.141	0.11±0.02
Manganese(mg/l)		0.5	0.031-0.10	0.054±0.017	0.026-0.073	0.051±0.016
Iron(mg/l)	0.3	1.0	0.008-0.083	0.037±0.021	0.009-0.081	0.03±0.025
Copper(mg/l)		2	0.006-0.016	0.011±0.003	0.005-0.013	0.009±0.002
Zinc(mg/l)		3	0.009-0.041	0.023±0.011	0.011-0.061	0.026±0.019
Lead(mg/l)		0.01	0.001-0.005	0.003±0.001	0.002-0.005	0.003±0.001
Fluoride(mg/l)		1.5	0.049-0.072	0.06±0.001	0.003-0.081	0.042±0.03
Bicarbonate(mg/l)			0.003-0.009	0.001±0.002	0.001-0.009	0.006±0.03
Total dissolved solids (mg/l)	500	1500	91-1000	357.12±306.17	107-429	170.125±106.5
Chloride(mg/l)	200	600	65.11-260.83	124.61±70.65	61.1-88.902	77.1±8.77
Nitrate(mg/l)		50*	11.6-61.62	32.98±16.68	10.29-32.538	21.91±7.97
Phosphate(mg/l)			1.66-5.33	3.56±1.17	1.34-3.8	2.73±0.88
Sulphate(mg/l)	200	500*	58.21-186.62	124.57±40.85	46.91-133.01	95.48±30.64
Alkalinity(mg/l)		0.2	0.016-0.037	0.022±0.0059	0.016-0.039	0.0228±0.008
Aluminum(mg/l)			0.0-0.004	0.001±0.0001	0.001-0.003	0.002±0.001

Table 4: Comparison of results with groundwater samples from Modakeke/Ile-Ife, Osun State (Ako et al, 1990)

Parameters	Modakeke/Ile-Ife (n=50)		This Study			
			Wells (n=16)		Boreholes (n=9)	
	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD
TDS	1.26-7660	1.3±186	91-1000	357.118±306.17	107-429	170.125±106.5
PH	5.80-8.4	6.89±10.0	5.04-7.47	6.514±0.72	4.39-7.54	6.269±1.04
Conductivity	39-1990	511.2±62.2	180-2012	709.83±616.71	212-851	336.13±212.4
Total hardness	6.4-286.5	98.7±10.4	8.564-20.368	14.85±4.24	9.397-17.196	13.291±2.72
Ca^{2+}	0.83-12.8	30.27±3.75	2.19-6.151	4.32±1.35	3.051-6.151	4.14±0.98
Mg^{2+}	0.00-34.45	5.65±0.89	0.751-1.956	1.095±0.292	0.432-1.751	0.97±0.344
Fe^{2+}	0.00-6.22	0.41±0.13	0.008-0.083	0.037±0.021	0.009-0.081	0.03±0.025
Na^{+}	0.83-86.21	21.61±2.89	0.079-0.207	0.11±0.029	0.075-0.141	0.11±0.02
K^{+}	1.35-143.83	35.89±4.76	0.139-0.418	0.31±0.089	0.116-0.401	0.27±0.087
SO_4^{2-}	39.4-170.3	30.94±4.46	58.21-186.62	124.57±40.85	46.91-133.01	95.48±30.64

HCO_3^-	5.50-239	106.1±17.95	0.003-0.009	0.001±0.002	0.001-0.009	0.006±0.03
Cl^-	0.00-10.6	1.89±0.80	65.11-260.83	124.61±70.65	61.1-88.902	77.1±8.77
NO_3^-	0.00-14.25	4.55±0.79	11.6-61.62	32.98±16.68	10.29-32.538	21.91±7.97
F^-	-	-	0.049-0.072	0.06±0.001	0.003-0.081	0.042±0.03
PO_4^{3-}	0.0-0.61	0.06±0.02	1.66-5.33	3.56±1.17	1.34-3.8	2.73±0.88

Table 5: Comparison of results with USEPA (1976) standards

USEPA Standards		This Study	
CONSTITUENT	Domestic water supply	Wells (n=17)	Boreholes (n=8)
pH	5.0-9.0	5.04-7.47	4.39-7.54
Hardness (mg/l)	-	8.564-20.368	9.397-17.196
Chloride (mg/l)	250	65.109-260.834	61.101-88.902
Sulphate (mg/l)	10	58.21-186.621	46.911-133.009
Copper (mg/l)	1	0.006-0.016	0.005-0.013
Iron (mg/l)	0.3	0.008-0.083	0.009-0.056
Lead (mg/l)	0.05	0.001-0.005	0.002-0.005
Manganese (mg/l)	0.05	0.031-0.102	0.026-0.073

Table 6: Comparison of results with hardness classification of water (After Sawyer and McCarty, 1967)

Hardness (mg/l)	Water classification	This study	
		wells	boreholes
0-75	Soft	8.564-20.368	9.397-17.196
75-150	Moderate		

150-300	Hard		
>300	Very hard		

Table 7: Comparison of results with NSDWQ (2007) standards

NSDWQ Standards			This study	
Parameter	Maximum permitted	Health impact	Wells (n=17)	Boreholes (n=8)
pH	6.5-8.5		5.04-7.47	4.39-7.54
Hardness (as $CaCO_3$) (mg/l)	150		8.564-20.368	9.397-17.196
Chloride (mg/l)	250		65.109-260.834	61.101-88.902
Conductivity (µs/m)	1000		180-2012	212-851
Copper (mg/l)	1	Gastrointestinal disorder	0.006-0.016	0.005-0.013
Fluoride (mg/l)	1.5	Fluorosis, skeletal tissue (bones and teeth) morbidity	0.049-0.077	0.049-0.081
Iron (mg/l)	0.3		0.008-0.083	0.009-0.056
Lead (mg/l)	0.01	Cancer, interference with vitamin D metabolism, affect mental development in infants	0.001-0.005	0.002-0.005
Magnesium (mg/l)	0.20	Consumer acceptability	0.751-1.956	0.432-1.136
Manganese (mg/l)	0.2	Neurological disorder	0.031-0.102	0.026-0.07
Aluminium (mg/l)	0.2	Potential neuro-degenerative disorders	0.0-0.004	0.001-0.003
Nitrate (mg/l)	50	Cyanosis and asphyxia (blue-baby syndrome) in infants under 3months	11.6-61.623	10.291-32.538
Sodium (mg/l)	200		0.079-0.122	0.075-0.141
Sulphate (mg/l)	100		58.21-186.621	46.911-133.009
TDS (mg/l)	500		91-1000	107-429
Zinc (mg/l)	3		0.009-0.061	0.011-0.054

1.9. Comparison of means

To determine if the difference between the calculated means for the well and borehole samples was statistically significant, the T-test was adopted and the values calculated using the relation:

$$T = \frac{X1 - X2}{Sp\sqrt{\frac{1}{n1}+\frac{1}{n2}}}$$

Where,
T = T calculated
X = Mean
$Sp^2 = \frac{(n1-1)S_2{}^2 + (n2-1)S_2{}^2}{n1+n2-2}$
S^2 = Variance
V= degree of freedom (V= n1 + n2 – 2)
n= number of samples
All T values obtained were tested for at a significance level of 5% (95% confidence level) Results are shown in Table 8.

Table 8: Comparison of chemical quality of well and borehole water samples in Ado-Ekiti using T-test (at 5% significance level)

Parameter	Wells (n=16)	Boreholes (n=9)	t_c	t_t	Remarks
pH	6.514±0.72	6.269±1.04	0.69	2.07	Insignificant
Conductivity	709.824±616.71	336.125±212.4	1.65	2.07	Insignificant
Turbidity	0.01± 0.0019	0.024± 0.03	1.97	2.07	Insignificant
Alkalinity	0.022± 0.0059	0.023 ±0.008	0.72	2.07	Insignificant
Bicarbonate	0.0057± 0.0019	0.0053 ±0.003	0.41	2.07	Insignificant
TDS	357.118±306.17	170.125±106.5	1.62	2.07	Insignificant
Total Hardness	14.847± 4.24	13.291± 2.72	0.94	2.07	Insignificant
Chloride	122.419 ±71.17	75.78± 8.98	1.80	2.07	Insignificant
Sulphate	124.946± 40.88	91.033 ±31.69	2.06	2.07	Insignificant
Phosphate	3.57 ±1.17	2.601± 0.91	2.05	2.07	Insignificant
Nitrate	32.939± 16.68	20.611± 8.03	1.97	2.07	Insignificant
Calcium	4.426 ±1.42	3.889± 0.76	0.99	2.07	Insignificant
Magnesium	1.134 ±0.33	0.87± 0.23	1.99	2.07	Insignificant
Iron	0.0394± 0.023	0.026± 0.02	1.42	2.07	Insignificant
Potassium	0.309 ±0.089	0.261± 0.1	1.2	2.07	Insignificant
Sodium	0.110 ±0.028	0.109± 0.02	0.09	2.07	Insignificant
Fluoride	0.063 ±0.0087	0.066 ±0.01	0.8	2.07	Insignificant
Manganese	0.0548 ±0.018	0.048± 0.02	0.83	2.07	Insignificant
Copper	0.0105± 0.0029	0.009± 0.002	1.3	2.07	Insignificant
Zinc	0.0248± 0.015	0.022± 0.016	0.44	2.07	Insignificant
Lead	0.0028 ±0.0011	0.0028± 0.001	0.00	2.07	Insignificant
Aluminium	0.0012±0.00097	0.0015±0.0009	0.74	2.07	Insignificant

1.10. Pearson linear correlation

Some group of elements respond similarly to a given set of environmental conditions. The Pearson linear correlation of elements measures the linear relationship between different pairs of elements. The correlation coefficient, r, ranges from -1 to +1 with +1 indicating perfect positive correlation and -1 representing perfect negative correlation while a zero value indicates that there is no correlation.

This study shows both positive and negative correlations. The correlation coefficient for well samples varied from -0.496 between pH and Alkalinity to +1.00 between TDS and conductivity as shown on Table X. For the borehole samples, ‘r’ ranged from 0.935 between pH and Alkalinity to +1.00 between Sulphate and Phosphate as seen on Figures 20 and 21. The following group of parameters showed strong correlation based on the ‘r’ values.

I. Total hardness-Mg^{2+}

Presence of dissolved calcium and magnesium salts is responsible for hardness in waters hence the strong positive correlation between hardness and magnesium in both well and borehole samples. This is shown in the ‘r’ values which are 0.898´´ and 0.631´´ for well and borehole waters respectively. Hence an increase in the Mg^{2+} concentration will result in an increase in the hardness of the water.

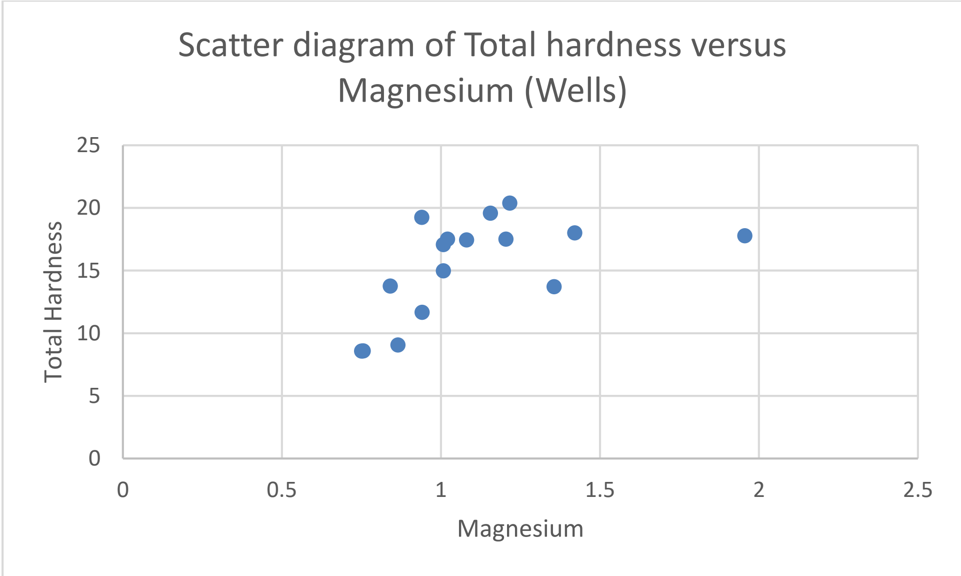

Figure 16: Scatter diagram of Total Hardness versus Magnesium (wells)

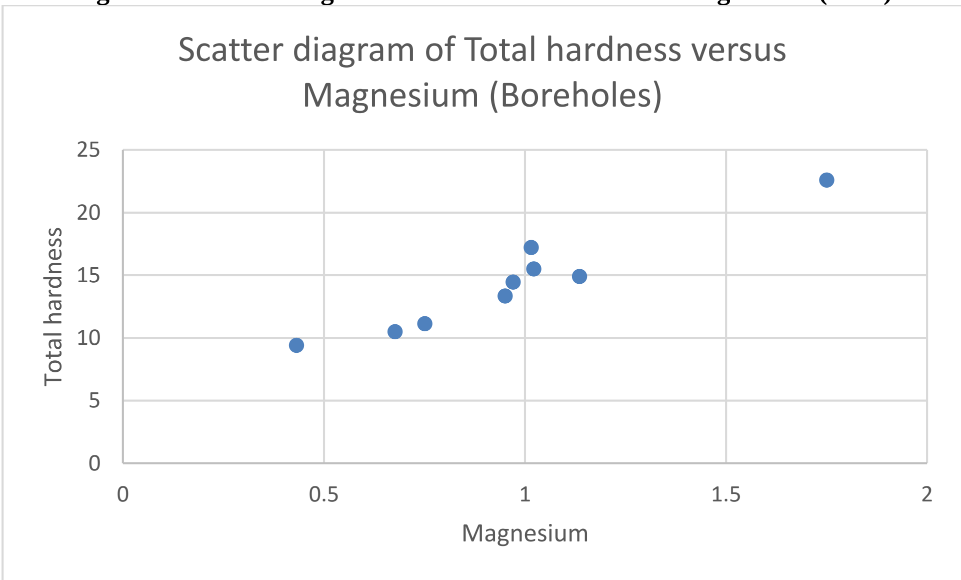

Figure 17: Scatter diagram of Total Hardness versus Magnesium (Boreholes)

II. Conductivity –TDS

The amount of dissolved salts present in water can directly affect its conductivity. This is seen in the strong positive correlation between the two parameters in well and borehole waters. For well water, r = 1.000´´ indicating perfect positive correlation while r = 0.999´´ for borehole water.

III. Phosphate-Sulphate

The correlation between phosphate and sulphate gave r values of 1.000´´ in both well and borehole waters. This perfect correlation can be attributed to the fact that their concentrations in the waters are inversely proportional.

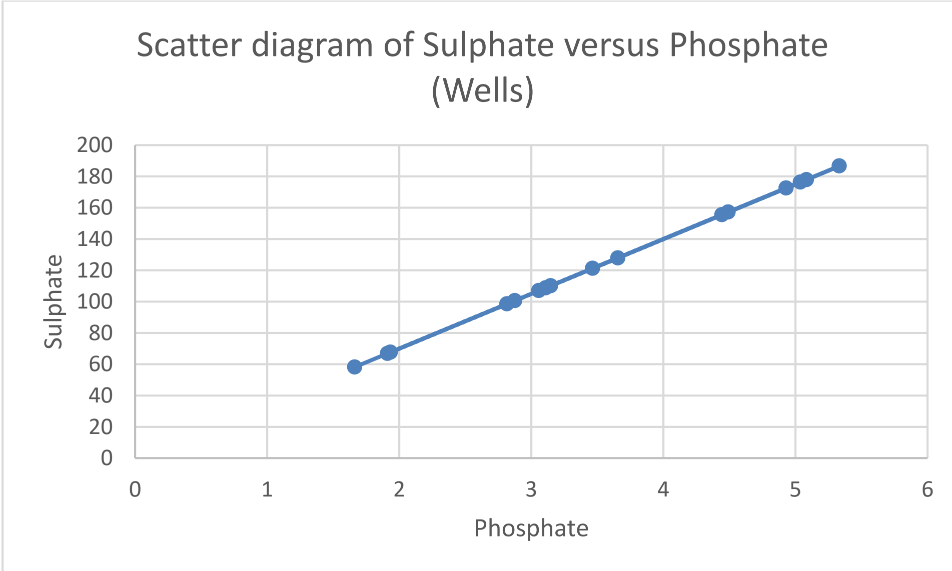

Figure 18: Scatter diagram of Sulphate versus Phosphate (wells)

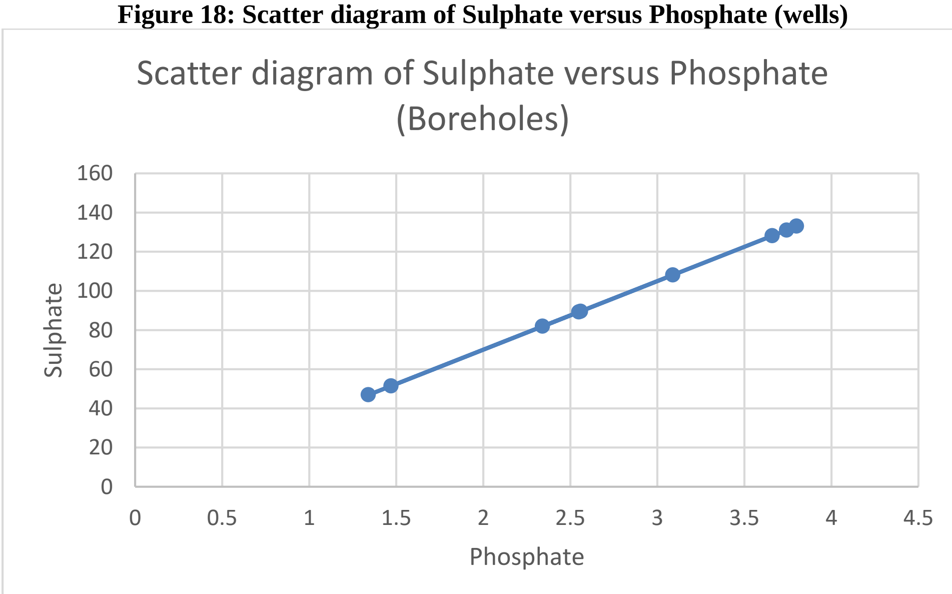

Figure 19: Scatter diagram of Sulphate versus Phosphate (Boreholes)

	PH	Cond.	Alk	Bicarb	TDS	TH	Cl^-	SO_4^{2-}	NO^{3-}	Ca^{2+}	Mg^{2+}	Fe^{2+}	Na^+	Turb	Fl-	PO_3^{4-}
PH	1															
Cond.	.568′	1														
Alk	-.496′	-.363	1													
Bicarb	.033	-.176	-.245	1												
TDS	.566′	1.000′′	-.356	-.181	1											
TH	.104	-.013	.397	.225	-.017	1										
Cl^-	.389	.375	-.16	-.059	.369	.079	1									
SO_4^{2-}	.314	.268	-.256	.114	.258	.02	.790′′	1								
NO^{3-}	.275	.232	-.164	.085	.23	.079	.908′′	.920′′	1							
Ca^{2+}	.091	-.119	.391	.29	-.122	.954′′	-.074	-.102	-.047	1						
Mg^{2+}	.088	.267	.219	-.052	.263	.631′′	.433	.323	.368	.369	1					
Fe^{2+}	.148	.379	-.269	-.203	.373	.078	.197	.424	.287	-.094	.483′	1				
Na^+	.302	.009	.03	.427	.012	.34	-.173	-.292	-.287	.389	.046	-.356	1			
Turb.	-.447	-.298	.184	.338	-.294	-.07	-.222	-.346	-.285	-.024	-.155	-.185	.253	1		
Fl^-	.008	-.179	.015	.039	-.178	.16	-.105	-.308	-.136	.206	-.037	.083	.163	.103	1	
PO_3^{4-}	.314	.268	-.256	.136	.258	.02	.790′′	1.000′′	.920′′	-.102	.323	.424	-.292	-.308	-.308	1

Figure 20: Correlation results for well samples.

	PH	Cond.	Alk	Bicarb	TDS	TH	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	Fe^{2+}	Na^+	Turb.	Fl-	PO_3^{4-}
PH	1															
Cond.	.58	1														
Alk	-.935	-.467	1													
Bicarb	-.005	-.281	-.072	1												
TDS	.553	.999′′	-.432	-.28	1											
TH	.654	.225	-.727	.662	.205	1										
Cl^-	.720′	.585	-.621	-.458	.563	.273	1									
SO_4^{2-}	.529	.547	-.426	-.507	.536	.105	.880′′	1								
NO_3^-	.61	.477	-.547	-.143	.464	.355	.722′	.894′′	1							
Ca^{2+}	.55	.188	-.587	.725	.174	.975′′	.24	.105	.358	1						
Mg^{2+}	.764′	.265	-.896	.434	.236	.898′′	.298	.088	.296	.778′	1					
Fe^{2+}	.143	.56	-.294	-.281	.554	.084	.127	.03	-.122	-.035	.309	1				
Na^+	.628	.489	-.466	.319	.485	.491	.388	.412	.672	.529	.339	-.331	1			
Turb.	-.002	-.242	-.003	.487	-.246	.531	.144	-.006	-.003	.649	.215	-.24	-.01	1		
Fl^-	-.234	-.064	.107	.248	-.063	.115	-.38	-.684	-.786′	.08	.167	.538	-.52	.235	1	
PO_3^{4-}	.529	.547	-.426	-.507	.536	.105	.880′′	1.00′′	.894′′	.105	.088	.03	.412	-.006	-.682	1

Figure 21: Correlation results for borehole samples.

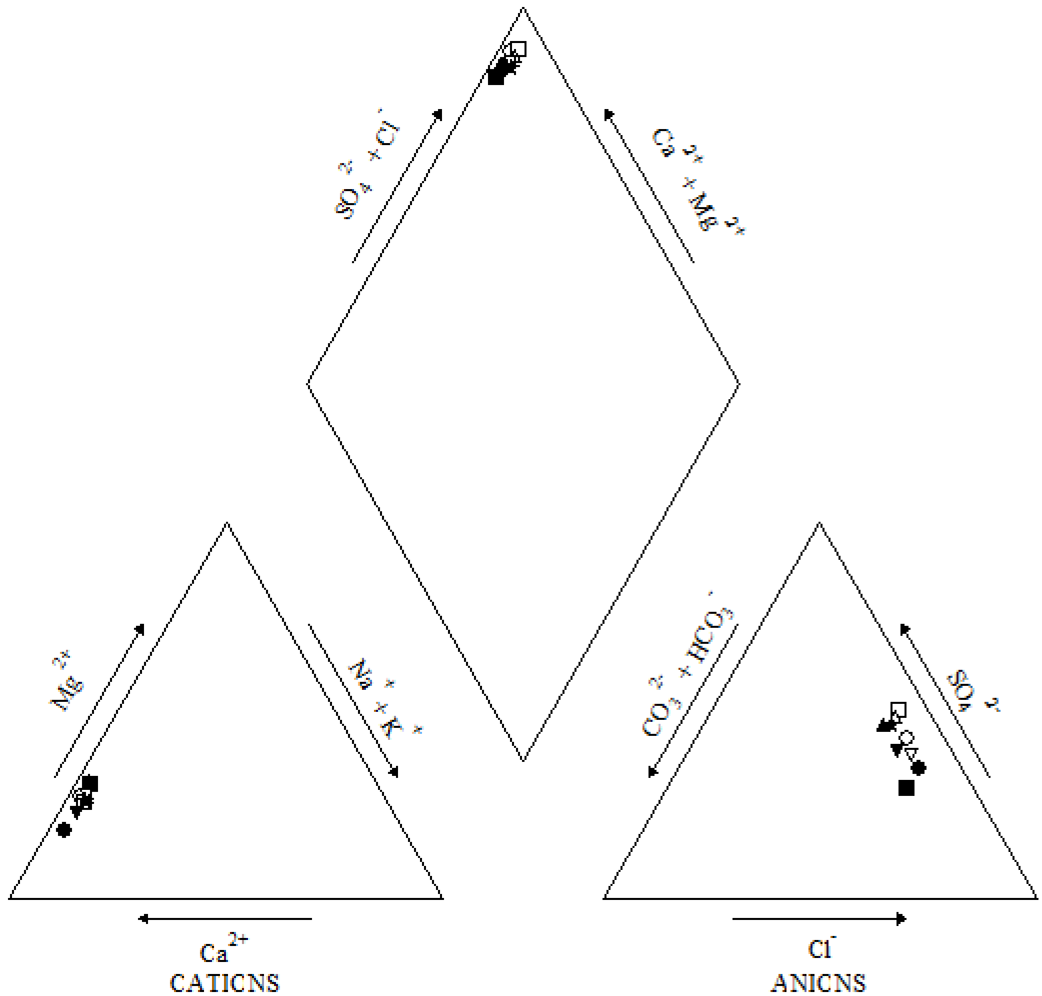

Figure 22: Hydro-geochemical classification of the borehole waters using pier trilinear plot (b1-b9) (Modified from Back, 1966)

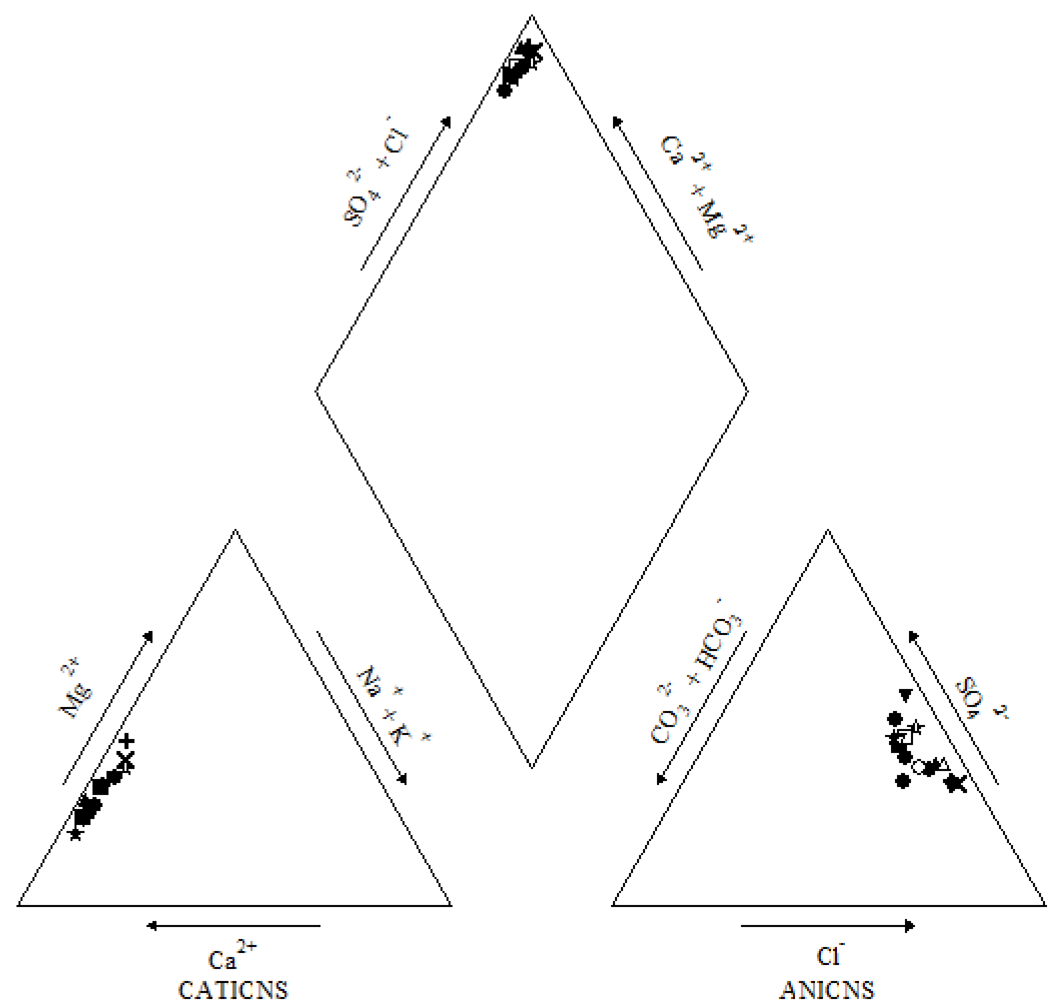

Figure 23: Hydro-geochemical classification of the well waters using piper trilinear plot (w1-w16) (Modified from Back, 1966)

3.5. Mathematical Assessment of the quality of the waters using combined data

To estimate water quality using a comparison of a set of parameters, a standard index which combines nine pollutant parameters namely; Dissolved oxygen (DO), fecal coliforms, pH, Biochemical oxygen demand (BOD), nitrates, phosphates, temperature, turbidity and total solids into one numerical indicator {Water Quality Index (WQI)} was designed by the National Sanitation Foundation (NSF) (Ott, 1978).

The computer application used for the computation of WQI for this study allowed for the use of five pollutant parameters since fecal coliforms, BOD and Dissolved Oxygen were not determined. The WQI for both well and borehole samples are shown in Table 9

Table 9: Water Quality Index for both well and borehole samples

Sample code	WQI values
W1	57
W2	51
W3	49
W4	56
W5	48
W6	50
W7	49
W8	56

W9	59
W10	53
W11	53
W12	45
W13	47
W14	47
W15	58
W16	63
B1	52
B2	51
B3	51
B4	64
B5	55
B6	56
B7	59
B8	65
B9	57

W: Well water samples B: Borehole water samples

Table 10: Water quality legend (Ott, 1978)

WQI values	Legend
0-25	Very bad
26-50	Bad
51-70	Medium
71-90	Good
91-100	Excellent

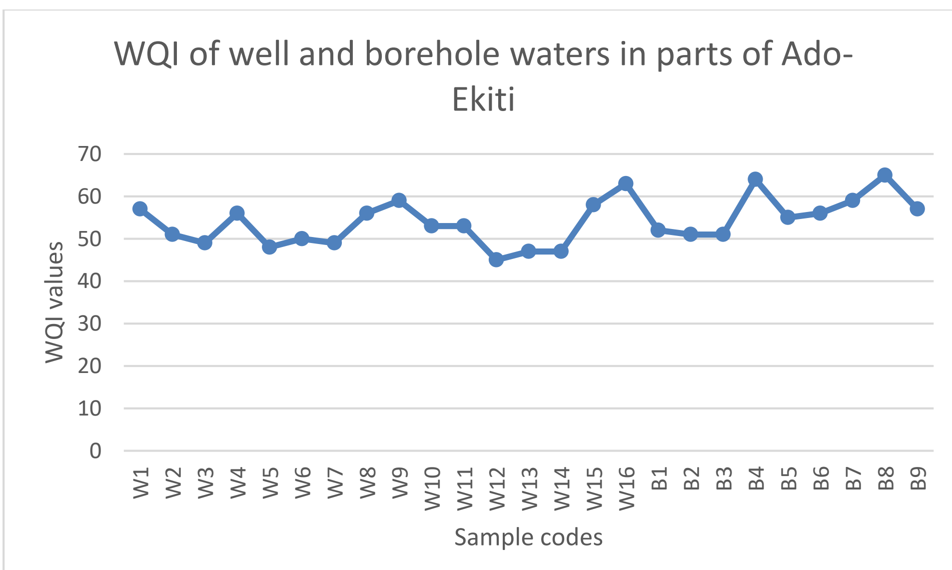

Figure 24: Water Quality Index (WQI) of well and borehole waters in parts of Ado-Ekiti

Codes: Wi = hand dug well
Bi = Borehole water samples

Table 10 revealed that none of the samples fall within the 'good' to 'excellent' category but all the samples obtained from borehole had WQI values greater than 50 while samples W3, W5, W7, W12, W13, W14 all obtained from hand dug wells fall under the 'Bad' category.

3.6. Agricultural uses

Table 13 shows the water quality criteria for livestock (UNESCO, 1972). From the table, it is evident that the maximum concentrations of the ions and trace elements fall below the upper limit recommended by UNESCO. Hence, the groundwater in Ado-Ekiti is suitable for use in livestock breeding.

For irrigation purposes, high salt concentration in soils may harm plant growth hence, salt index is adopted in classification of groundwater. It is expressed as;

Salt Index (SI) = Na^+ - 24.5 – 4.85 (Ca^{2+})

Negative SI values indicate suitability for irrigation and table 14 shows that all the values obtained for this study are negative indicating suitability for irrigation.

Hardening of soils and reduction in soil permeability have been attributed to the presence of sodium in irrigation water. This phenomenon is described as sodium hazard. It is a result of the substitution of calcium and magnesium ions by sodium ions on clay minerals and colloids (Chapman, 1977). The extent of the exchange which is the amount of sodium absorbed by soil, can be estimated from the Sodium Adsorption Ratio (SAR), which is defined as

$$SAR = \frac{Na^{2+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

Table 15 shows the SAR values obtained for well and borehole water samples and are compared with the Sodium hazard standard and SAR classification of water (after Sawyer and McCarty, 1967) to show that the waters are soft and have low sodium hazard.

Table 11: Classification for irrigation using electrical conductivity (µs/cm) (after Todd, 1980)

		This study (µs/cm)	
Water class	Electrical resistance (µs/cm)	Well range	Borehole range
Excellent	<250		
Good	250-750		
Permissible	750-2000		212-851
Doubtful	2000-3000	180-2012	
unsuitable	>3000		

Table 12: Water classification based on TDS (after Gorrel, 1965)

Classification after Gorrel (1965)		This Study (mg/l)	
Water classification	Concentration of TDS in mg/l	Wells	Boreholes
Freshwater	0-1000	91-1000	107-429
Brackish water	1000-10000		
Salty water	10000-100000		
brine	>100000		

Table 13: Water quality criteria for livestock (UNESCO, 1972)

		This study	
Substance (mg/l)	Upper limit	Wells	Boreholes
TDS	10000	91-1000	107-429
SO_4^{2-}	1000	58.21-186.62	46.911-133.01
Fl	2.40	0.049-0.072	0.049-0.081
Pb	0.05	0.001-0.005	0.002-0.005

Table 14: Salt index values of groundwater from parts of Ado-Ekiti

Sample code	SI values
W1	-35.03
W2	-39.53
W3	-47.98
W4	-49.48
W5	-48.77
W6	-44.40
W7	-35.01
W8	-54.22
W9	-50.21
W10	-54.21
W11	-35.06
W12	-43.26
W13	-40.15
W14	-49.59
W15	-45.47
W16	-54.12
B1	-53.14
B2	-39.2
B3	-39.1
B4	-44.24
B5	-39.35
B6	-44.65
B7	-49.66
B8	-42.65
B9	-46.27

Wi = Well water samples
Bi = Borehole water samples

Table 15: SAR values of groundwater from Ado-Ekiti

Sample code	SAR values
W1	0.086
W2	0.06
W3	0.057
W4	0.06
W5	0.045
W6	0.055
W7	0.099
W8	0.057
W9	0.059
W10	0.065
W11	0.082
W12	0.056
W13	0.074
W14	0.068
W15	0.056
W16	0.11
B1	0.067
B2	0.077
B3	0.053
B4	0.053
B5	0.069
B6	0.081
B7	0.064

B8	0.082
B9	0.085

Wi = Well water samples
Bi = Borehole water samples

Table 16: Comparison of results with Sodium Hazard Standard and SAR classification (after Sawyer and McCarty, 1967)

SAR classification			This Study	
SAR values	Sodium (Alkali) Hazard	Description	Wells	Boreholes
0-10	Low	Soft water	0.045-0.11	0.053-0.085
11-18	Medium	Slightly hard		
19-25	High	Moderately hard		
26	Very high	Very hard		

Groundwater quality depends on the substances dissolved in the water and certain other properties and characteristics that these substances impart to water (Singh et al., 2000). The chemical constituents of groundwater depend on the source, movement and environment of the water (Domenico, 1972). Primarily, soluble salts found in water originate from solution of rock materials (Foster, 1942) and the presence of chemical constituents in water has been found to result from leaching of the underlying bedrock or the overburden (Pescod, 1977). These all point to the fact that rock mineralogy has a great influence on the groundwater quality of an area. In this study, the concentrations of most of the studied parameters are slightly higher in the well water samples. This is due to the shallower depths of the hand-dug wells. Boreholes which are at greater depths produce safer waters as revealed in the WQI curve in Figure 9.

The presence of sodium and potassium in the groundwater can be explained with the lithology of the study area. The sodium is sourced from the weathered granites and charnockitic rocks that contain plagioclase feldspars while the potassium is connected to rocks made of orthoclase feldspars e.g. weathered microcline that infiltrate the groundwater. The magnesium ion can be attributed to the presence of feldspars as well as ferromagnesian minerals.

The mean concentration of nitrates in the well water samples is higher than in the samples obtained from the boreholes, this could be due to the fact that some of the wells are dug close to sewage disposal systems. More so, nitrates in fertilizers and manure can leach through the soil into the groundwater. This situation is limited in boreholes due to their greater depths.

The presence of sulphate ions may be attributed to the combustion of fossil fuels such as petroleum and coal. Owing to the fact that a negligible amount of sulphate ion is found in most minerals, its presence in water is unlikely to be from the bedrocks in the area

The chloride content may be due to the presence of soluble chlorides from rocks, connate or juvenile waters or contamination by domestic or industrial sludge.

Overall, the groundwater in the study area can be considered as safe for domestic, agricultural and Industrial usage although purification procedures are still recommended.

IV. CONCLUSIONS

Due to the ever increasing growth in population in the study area, there is an added strain on the available water resources leading to an increase in groundwater exploration. The results of this study will go a long way in establishing the portability of the waters for domestic, agricultural and industrial purposes.

The type of water that predominates in the study area is Ca^{2+}-Cl^{-}-$SO4^{2-}$ type which has been attributed to the geology of the area in which the major rock types are charnockites and granites with superficial deposits of clay and quartzites. The water type could also have been influenced by domestic and industrial effluents that may leach into the aquifer systems. Other contributing factors may include combustion of fossil fuels such as coal and petroleum.

The mean values of most of the parameters measured falls below the permissible limits recommended by WHO (1971, 1993), NSDWQ (2007) and USEPA (1976) except in isolated cases where conductivity, TDS and nitrate concentrations exceeded the limits.

Trace element concentrations also fall within the acceptable range recommended by WHO (1971, 1993) although the mean concentration of manganese exceeds the 0.05mg/l limit recommended by USEPA (1976) for domestic water use.

The Water Quality Index (WQI) which was carried out using turbidity, pH, nitrates, phosphate and TDS as test parameters revealed that about 35% of the well waters gave values that fall within the 'Bad' range on the water quality legend while the remaining 65% were within the 'medium' range. All the borehole waters had WQI values within the 'medium' range. In other to obtain a more conclusive results, it is recommended that subsequent works carried out should include tests for the amount of fecal coliform, Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO).

T-test carried out revealed that there is no significant difference between the concentrations of the various parameters in the well and borehole waters.

Comparison of the results with sodium hazard standards and SAR classification (After Sawyer and McCarty, 1967) revealed that the groundwater has low sodium level. The waters can also be described as soft.

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