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PHYSICOCHEMICAL CONSTITUENTS OF GROUNDWATER AND ITS QUALITY IN CRYSTALLINE BEDROCK, NIGERIA

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ABSTRACT

The chemical composition of groundwater depends greatly upon rocks in contact with groundwater. The percolation of groundwater through subsurface rocks provides close contact with the lithologic environment, and this result in the dissolution of soluble minerals as it transports till it reaches an equilibrium point between dissolved and undissolved minerals. The principal water quality problem result from high salinity, enhanced iron, elevated SO_4^{2-}, *high nitrate concentration, excessive* Ca^{2+} *and* Mg^{2+} *which renders the ground water unsafe for various purposes. This study assesses both chemical and physical constituents of shallow wells in Iresa-Apa with a view to determining its quality and suitability for domestic, industrial, and agricultural purposes. Twenty four shallow well (water) samples were analyzed for different parameters based on standard laboratory procedures. The parameters include; temperature, Electrical Conductivity (EC), power of Hydrogen (pH), Total Dissolved Solids (TDS), Total Hardness (TH), turbidity, alkalinity, Total Suspended Solids (TSS), Total Solids (TS),* Mg^{2+}, Ca^{2+}, K^+, Na^+, Fe^{2+}, Cl^-, NO^{3-}, SO_4^{2-} *and* PO_4^{3-}. *The results showed that the abundance of the cation and anion in the area occurred in the order* $Ca^{2+} > Mg^{2+} > Na^+ > K^+ > Fe^{2+}$ *and* $Cl^- > NO_3^- > SO_4^{2-} > F^- > PO_4^{3-}$ *respectively. The mean values of some parameters exceed the permissible level of World Health Organization standard while some are close to the threshold line. It is affirmed that the shallow water in Iresa-Apa is satisfactory for irrigation use, but unfit for domestic, industrial, and livestock management without treatment.*

Key words: Water quality, Physicochemical parameters, Geogenic sources, Anthropogenic sources, Southwestern, Crystalline bedrock, Nigeria.

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1. INTRODUCTION

Water is an essential commodity that sustains the existence and growth of every organism found on Earth. Man is the major consumer of water. Water is indispensable and is utilized in daily activities such as drinking, laundry, agriculture, industry, and in reactor. One of the unavoidable ingredients in life is water [1]. Traditionally, exploitation of water is done in Nigeria by: direct collection of rain water into containers; extraction from streams and rivers; and abstraction from wells and boreholes [2]. Of these three ways, the later has proved to be the best [3–4] because it is considered to be freed from contaminants and ubiquitous [5].

For a sustainable development, it is paramount to have access to safe water source which will be utilized for daily activities. The reliability of water is a result of its physical and chemical constituents. The chemistry of subsurface water is chiefly influenced by geogenic and anthropogenic factors [6]. Geochemical composition of hosting aquifer and rock weathering determines the quality of groundwater. The pore spaces and their interconnectivity may aberrate the groundwater quality through their motley hydrochemical processes [7–8]. Furthermore, groundwater quality can be altered by anthropogenic sources such as industrial pollution, waste disposal facilities, soakaways or latrines, cemeteries [9], agricultural agro-allied products, and many others. It is imperative to know that physicochemical constituents' assessment of groundwater is essential to maintain a sustainable environment.

The study was done in Iresa-Apa, Oyo State, Nigeria. It falls on the crystalline bedrock of South-west Nigeria. This study is vital because it will sensitize the government officials and those in the affairs of the millennium development goal dangers of neglecting these rural areas and concentrating on urban development alone. The aim of this study is to determine the physicochemical constituents in groundwater samples of Iresa-Apa and be able to infer the groundwater's suitability for domestic and agricultural uses. Groundwater quality assessment in either rural or urban settings across the globe had been reviewed and/or carried out by some researchers [10–19]. [20] analyzed the groundwater quality in Igboora. Their result showed that change in season influenced the concentrations of the analyzed parameters, and wells that are in proximity of the waste sites were highly contaminated. They concluded that groundwater needs to be treated before drinking or using for domestic purposes. [3], [21], [22], [23] and [24] monitored the source and level of contamination in Aarada groundwater via multi-criteria approach for two seasons. Their study showed intrusions of contaminant plumes into the hand-dug wells in Aarada. They also reported elevated levels of some parameters in some of the analyzed wells. They inferred that the contamination was due to majorly anthropogenic and minor contribution from geogenic source in Aarada.

2. STUDY AREA, ITS HYDROGEOLOGY AND GEOLOGY

Iresa-Apa is located in Surulere local government, Oyo State, Nigeria. It is bounded by latitude 893006 to 895006 N and longitude 648000 to 651000 E (UTM) with a total area of about 30 km^2 (Figure 1). Accessibility is fairly good through major and minor roads except in few cases where the roads have been deteriorated. Iresa-Apa is well drained by river Oje, this River shows a dendritic river pattern in a relatively lowland which flow towards the south. The area is situated within the tropical climate belt of moderately high temperature and experience rainy and dry seasons in a year. The rainy season (season with downpour) starts from March to October and is characterized by the south-west trade wind. The dry season (season with little or no rain) extends from November to March and is characterized by the North-East trade wind, with annual temperature range of 24 to 25^{0}C. The annual rainfall in the study area varies from an average of 800 mm at the onset of heavy rain to 1500 mm at its peak [25]. The vegetation comprised trees such as oil palm, cashew, mango and food crops like cereals and tubers among others. These crops are planted by the dwellers in the study area.

Four-hydrogeological provinces exist in Nigeria. The provinces are: Precambrian basement; Volcanic; Consolidated; and Unconsolidated sedimentary rocks (Figure 1). Groundwater occurrence in Nigeria varies from province to province. In basement terrain, groundwater accumulates in the fractured and/or weathered rocks. Groundwater occurrence exists within the extremely permeable zones of lava flow in volcanic terrain. In consolidated sedimentary rocks, groundwater is accumulated within the porous media of sandstones or weathered and fractured portions of limestones. Groundwater could be explored within the gravels and sands of unconsolidated sediments. Iresa-Apa is situated on the basement rocks in southwest Nigeria. The basement rocks are composed of metamorphic and crystalline rocks of more than 550 Million years [3, 26–27].

Nigeria, one of the countries in West Africa, which is covered equally by the crystalline rocks of the Basement Complex and sedimentary rocks with the total surface area of 923, 768 km^2. Some of the works from either of the two terrains (basement or sedimentary) are listed in this study [28–38]. The crystalline rocks are divided along the west, south-east as well as north-west zones in the country (Figure 2a). Within these massifs, the sedimentary basins aligned along the north-east to south-west orientation from Lake Chad to the lower Niger Benue river system (Niger Delta) while Bida Basin is associated with the course of the upper Niger River [39]. Regionally, Nigeria falls on the Pan African mobile belt which separates the West African and Congo cratons. The belt which is about 0.6 Ga (billion years) evolved from continental collision between the cratons [39–42]. The latter part of the pan – African orogeny was characterized by brittle deformation which resulted in a very consistent conjugate strike – slip fault system consisting of faults trending northeast – southwest [43]. Geochronologically, the Precambrian rocks of Nigeria are grouped into four major classes: Liberian Orogeny 2800 ± 200 Ma; Eburnean Orogeny 2000 ± 200 Ma; Kibaran Orogeny 1100 ± 112 Ma; Pan – African Orogeny 600 ± 150 Ma. These classes are in consonant with the four-orogenic events that have existed periodically in African Precambrian history [44]. Locally, Iresa-Apa is underlain by Basement Complex which is characterized dominantly by migmatite granite gneiss with minor distribution of biotite and biotite-hornblende gneiss, porphyroblastic gneiss and quartzite [44]. The basement geologic map of Iresa-Apa and its vicinity is presented in Figure 2b.

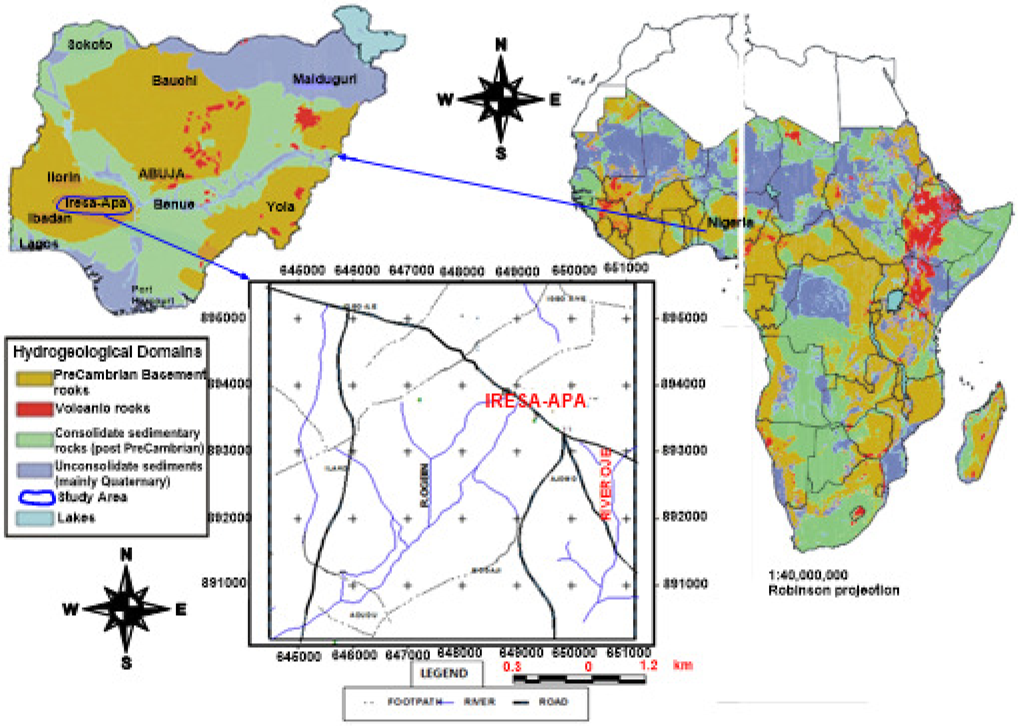

Figure 1 The hydrogeological domains of Nigeria revealing the accessibility of the study area (Reproduced from [26–27]).

3. MATERIALS AND METHOD

Water samples were randomly collected from twenty- four hand-dug wells in the study area. The measurements of power of Hydrogen (pH) and Electrical Conductivity (EC) were done in-situ. The sanitary of the vicinity of the wells, and their proximity to septic tanks and refuse dumps were taken into consideration. The samples were collected into sterilized polyethylene bottles pre-cleaned to remove any form of contaminants in the bottles. The bottles were washed many times with deionized water and later washed with the sampling water. All the samples were well cocked and later transported to the laboratory for analyses in accordance with the guidelines of American Public Health Association (APHA) [47]. This is imperative because such parameters can vary during transportation. The laboratory analysis was carried out at Water Supply and Sanitation Project, Ibadan, Nigeria. The analysis carried out included: Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Solids (TS), Total Hardness (TH), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) magnesium (Mg^{2+}), iron (Fe^{2+}), nitrate (NO_3^-), sulfate (SO_4^{2-}), chloride (Cl^-), phosphate (PO_4^{3-}),and fluoride (F^-). TDS was done by gravimetric technique, TSS by photometric method using direct measurement as subtraction of TDS from TS, TS by spectrophotometry technique, TH by titrimetric method using Ethylene Diamine Tetra Acetate (EDTA), NO_3^- by UV spectrophotometric method, SO_4^{2-} and PO_4^{3-} by spectrophotometric method, Na^+, K^+, Ca^{2+}, Mg^{2+}, and Fe^{2+} by Atomic Absorption Spetcrophotometric technique.

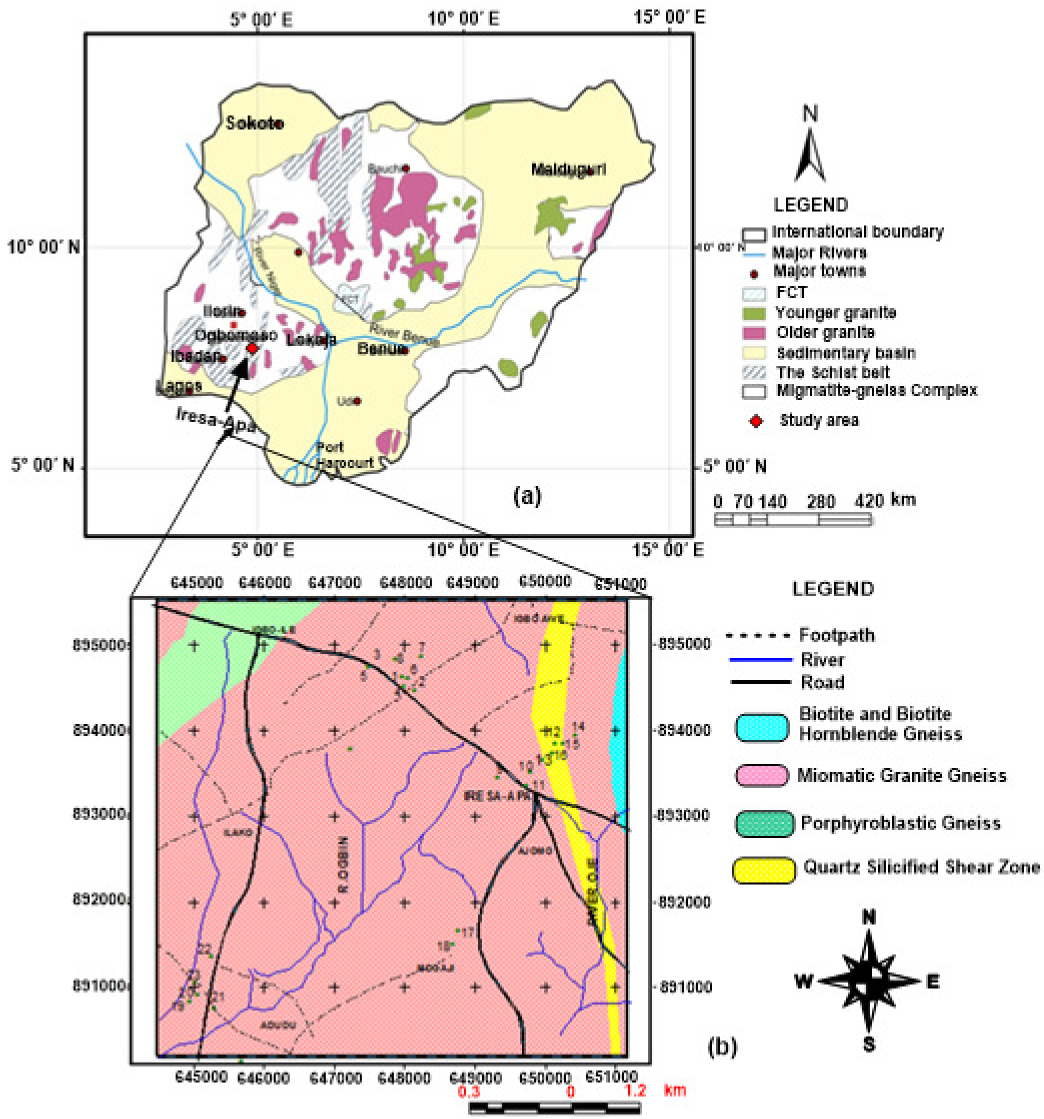

Figure 2(a) Generalized geology of Nigeria (adapted from [45]; **(b)** Basement geologic map around Iresa-Apa (adapted from [46].

4. RESULTS AND DISCUSSION

4.1. Basic description of the physicochemical constituents of groundwater in the study area

The Electrical conductivity of the wells in the study area is presented in Table 1. It ranges from 0.05 to 0.91 mScm^{-1}, with a mean and standard deviation of 0.31 ± 0.2 mScm^{-1} (Table 2). All these fall below the standard limit of 1.00 ms/cm [48–49]. Nevertheless, Well-14 needs proper attention, because in nearer future, it might exceed the maximum limit for domestic purposes. The conductivity of groundwater is net result of the total charged ions present. The samples' TDS vary from 32.50 to 591.5 mgl^{-1}, with an average concentration and standard deviation of 195.81 ± 127.95 mgl^{-1} (Table 2). Total dissolved solids fall within the permissible level of the WHO [48] except well 14 (Table 1) that surpasses the limit of 500 mgl^{-1} recommended by WHO (Table 2). Generally, all the water samples showed TDS values lower than the maximum acceptable limit by WHO [48] (Table 2). High value of TDS can lead to taste, gastro intestinal irritation, and stain to fabric. All pH values obtained fall within the permissible limit but the values showed that the water in the study area is nearly close to the maximum limit of 8.5 (Table 1). The pH ranges from 5.76 to 8.31 (Table 2). The Total Suspended Solids (TSS) varies from 0 to 12 mgl^{-1}; with an average concentration and standard deviation of 1.83 ± 3.21 mgl^{-1}. The average value is below the permissible level but some wells possess high concentration of TSS beyond the recommended value of 10 mgl^{-1} by WHO. The Total Solids (TS) mean of 197.65 ± 128.31 mgl^{-1}fall below the recommended limit but some samples within the locations contain some values greater than the recommended value of 500 mgl^{-1}. Distributions of the analyzed parameters are presented in Table 1. Total hardness is the overall concentration of magnesium and calcium being denoted by their calcium carbonate equivalent. According to WHO regulation, the acceptable level of hardness concentration is 50 mgl^{-1}.The total hardness ranges from 60 to 258 mgl^{-1}; with a mean hardness concentration and standard deviation of 132.5 ± 47.41mgl^{-1}. In a nutshell, the water is categorized as hard. In rocks, calcium and magnesium are present in large amount in plagioclase, pyroxene and olivine.

The sodium ion concentrations range from 1 to 18 mgl^{-1}; with a mean value of 8.67 ± 4.33 mgl^{-1}. It has been noted that many industrial wastes and domestic sewages are rich in sodium and thus increases the concentration of sodium ion (Na^+) in natural water. Also, the concentration of sodium falls within the WHO recommendation for drinking-water quality. Possible sources of sodium ion in water are due to weathered plagioclase, feldspars, atmospheric dusts that are washed down by rain exchangeable sodium from clays. Potassium values range from 0 to 10 mgl^{-1}, and has a mean value of 2.54 ± 2.92 mgl^{-1}. This value fall within the acceptable limit 15 mgl^{-1} of the drinking-water quality set by WHO. Potassium has a low mobility relative to sodium since it enters the certain structures of clay- like minerals during the process of weathering [50]. Its major sources in water are from weathered orthoclase and microcline feldspars, biotite as well as leachates from potassium based fertilizers. Potassium is insignificant from the health point of view though excess quantity may have a laxation effect. The potassium in the samples is attributable to the dominance of microcline and feldspars in the granite gneiss. Also, the dominance of sodium ions over potassium in most of the wells may be attributed to their relative concentrations in the minerals present in the Basement Complex rocks, majorly Migmatite Gneisses. This could be related to exchange with calcium and magnesium.

The concentration of calcium ion in the groundwater of this area showed a wide range of 16.80 to 75.20 mgl^{-1}; with a mean and standard deviation value of 37.03± 12.32 mgl^{-1} (Table 2). The mean value is below the recommended value of 75 mgl^{-1} by WHO but increases beyond this value in well 14. From Table 1, the concentration of calcium in well 10 will soon surpass that of recommended limit. [51] had shown that 1,800 mg/l of calcium have been found not to be capable of causing any impairment in man. Calcium may be released into the groundwater by leaching of calcium bearing minerals such as plagioclase. Its appreciable concentration in the groundwater of the area can be explained geologically. Magnesium values range from 1.96 to 21.56 mgl^{-1} with a mean and standard deviation value of 8.74 ± 5.42 mgl^{-1} (Table 2). These values fall below the 50 mgl^{-1} acceptable limit set by WHO. High concentration of magnesium in water is known to have chronic effect and could result to gastro- intestinal irritation [52]. The magnesium values of water in the study area is moderately low and this might be as a result of natural softening of the water that takes place during percolation which results in exchange with sodium. The iron values vary from 0 to1.67 mgl^{-1} with the mean value of 0.39 ± 0.49 mgl^{-1}. The mean concentrations of iron are below WHO standard of 1 mgl^{-1} but some individual locations surpasses the acceptable limit (Table 1). Excessive iron in water can impair the quality through colouration. Likely, sources of iron in water include weathered amphiboles, magnetites, biotites and garnets. Substantial amounts are also contributed by direct leaching of laterites, water from hand-dug well 2, 7, 10, 17 and possibly 22 are unsafe for consumption (Table 1).

The concentration of nitrate ion varies from 0 to 45.98 mgl^{-1}; with a mean value of 12.87 ± 11.61 mgl^{-1}. However, nitrate concentrations of the hand-dug wells exceeded the WHO highest desirable level (Table 2). The presence of nitrate ion in the analyzed samples might be attributed to pollutions from human waste and also from the fertilizers used by the farmers since the study area is an agricultural area. Excess nitrate in water can produce undesirable effect such as methemoglobinemia in infants, commonly known as blue baby. The chloride ion varies from 4 to 42 mgl^{-1}; with a mean value of 15.83 ± 9.87 mgl^{-1}. The analyzed values fall below the maximum permissible level of WHO [48] standard. The sources of chloride ion in water include magmatic rocks, fertilizers, human excretion and air. The chloride concentrations in the analyzed water could be linked to organic fertilizers since it is an agricultural area. Sources of chloride in the analyzed sample could also be attributed to leachates from Cl –rich minerals, which occurred as mineral constituents in the gneisses of the study area. The sulfate ions vary from 0 to 19 mgl^{-1}; with an average value of 6.42 ± 5.66 mgl^{-1}. These values are below the WHO acceptable limit. The water of the study area is not likely to have laxative effect on the users since the sulfate ion detected in water samples are not in excess. Phosphate ions in the study area vary between 0 and 1.90 mgl^{-1}; with an average of 0.44 ± 0.50 mgl^{-1}. Phosphate is a not natural constituent of water, it is formed during certain biological transformation to form phosphates and also found in fertilizers [48]. Phosphates belong to nutrient substances that limit the process of photosynthesis in plant. The phosphate ion concentration content is due to the runoff of fertilizer since farming is the major occupation in the study area. The Fluoride ions vary from 0 to 1.78 mgl^{-1}; with an average of 0.60 ± 0.50 mgl^{-1}. The mean concentration of the fluoride ion fall below the permissible level but wells 1, 2, and 19 exceed the recommended limit of WHO [48]. From Table 1, it was revealed that most of these wells will soon reach the maximum permissible level of WHO. Naturally, presence of fluoride in groundwater system as a result of fluoride containing rock minerals' dissolution like fluorite, cryolite, and rock phosphate (apatite) are adjudged to be the source of fluoride concentrations. In another words, elevated concentration of fluoride in groundwater system is possible through artificial source. This can be materialized by excessive application of phosphate fertilizers having fluoride as one of its constituents, sewage sludge, or pesticide. Excess of fluoride can cause fluorosis, and skeletal tissue (teeth and bone) morbidity.

Skewness measures the extent at which a distribution varies from normal. Skewness is used to estimate the level of relationship that occurs among the variables under consideration. Kurtosis measures the thickness of the distribution tails. It is a way to identify the level of proportionality of the datasets to the normal distribution. A high kurtosis has outliers while a relatively low kurtosis has no outliers. All parameters tested for showed positive skewness except pH, TH and Na (Table 2). Likewise, the kurtosis' coefficients were greater than zero (at 92% confidence) in fifteen parameters while the remaining four parameters (i.e. pH, TH, SO_4, and Na) showed negative kurtosis.

Table 1 Physicochemical constituents of groundwater in the study area

Sample	EC (mS/cm)	TDS (mg/l)	pH	TSS (mg/l)	TS (mg/l)	Turb. (FTU)	TH (mg/l $CaCO_3$)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	Alkali. (mg/l $CaCO_3$)	Cl^- (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Fe^{2+} (mg/l)	PO_4^{3-} (mg/l)	F^- (mg/l)
Well 1	0.11	71.5	7.26	0	71.5	2	90	2.09	1	52	6	12	2	32.8	1.96	0.12	0.32	1.09
Well 2	0.34	221	7.01	2	223	8	120	1.01	0	45	12	3	1	35.2	7.84	1.09	0.12	1.76
Well 3	0.22	143	7.55	0	143	4	100	0.32	6	34	8	5	0	24	4.9	0.72	0.67	0
Well 4	0.10	65	6.11	2	67	0	80	0.16	5	32	10	6	1	16.8	4.9	0.26	0.89	0
Well 5	0.09	58.5	6.23	0	58.5	2	82	0.17	7	38	20	7	2	40.8	12.25	0.38	0	0.67
Well 6	0.42	273	6.68	3	276	2	152	32.12	13	20	12	8	1	40	5.88	0.04	0	0.43
Well 7	0.40	260	7.00	0	260	0	124	30.19	19	15	10	10	2	40	5.39	1.23	0.1	0.76
Well 8	0.36	234	6.42	1	235	6	122	21.12	1	15	10	12	0	32	5.88	0	1.29	0.56
Well 9	0.11	71.5	7.57	1	72.5	2	120	10	18	90	34	12	2	60	19.6	1.67	0.07	0.90
Well 10	0.55	357.5	7.65	11	368.5	13	230	22.03	0	34	10	7	0	32.8	4.41	0.18	0.43	0.23
Well 11	0.23	149.5	6.09	2	151.5	0	100	13	1	15	20	2	2	48.8	19.11	0.27	1.9	0.32
Well 12	0.56	364	5.76	0	364	2	200	7.87	9	50	28	11	4	40	5.88	0.12	0.97	0.12
Well 13	0.24	156	7.16	0	156	0	124	1.65	8	25	42	9	1	75.2	17.15	0	0	0.63
Well 14	0.91	591.5	6.56	0	591.5	0	258	65.98	1	68	28	12	3	40	9.31	0.32	0.12	0
Well 15	0.41	266.5	6.99	0	266.5	2	138	12.99	1	60	26	13	4	39.2	7.84	0	0.93	0.43
Well 16	0.43	279.5	6.98	1	280.5	2	130	14	9	20	4	7	1	19.2	2.94	0	0	0.54
Well 17	0.05	32.5	8.12	0	32.5	2	60	10	10	20	12	5	1	31.2	7.35	1.5	0	0.90
Well 18	021	136.5	7.22	12	148.5	47	108	8.28	1	40	10	2	0	40.8	6.37	0.12	0.6	0
Well 19	0.32	208	6.89	0	208	0	128	18.9	1	20	4	8	2	24	4.9	0.37	0.43	0.65
Well 20	0.06	65	7.20	3	68	3	80	0	10	32	10	12	10	40	10.29	0.12	0.45	1.78
Well 21	0.18	117	7.79	0	117	0	142	10.91	9	98	12	18	10	39.2	5.88	0.1	0.02	0.90
Well 22	0.17	110.5	8.31	0	110.5	3	122	11.13	12	20	10	1	0	27.2	7.84	0.47	0	0.98
Well 23	0.43	279.5	7.65	4	283.5	3	182	17	2	80	20	12	8	37.6	21.56	0.1	0.26	0.17
Well 24	0.29	188.5	6.09	2	190.5	1	122	18.07	10	60	22	14	4	32	10.29	0	0.90	0.54

Table 2 Comparison of the present study with WHO [48] and USEPA [53] standards

Parameters	WHO	USEPA		Present study				Side effects
	Acceptable level for domestic uses	Domestic uses	Aquatic life	Range (n = 24)	Mean	Skewness	Kurtosis	
EC (mS/cm)	1.00	-	-	0.05-0.91	0.31 ±0.2	1.23	2.43	Laxative effects, salty taste in water
TDS (mg/l)	500-1000	500	-	32.5-591.5	195.81 ±127.95	1.28	2.55	Scaling in pipes and household appliances
pH	7-8.5	5.0-9.0	6.5-9.0	5.76-8.31	7.01 ±0.03	-0.03	-0.62	Skin irritation
TSS (mg/l)	10	-	-	0-12	1.83 ±3.21	2.52	6.06	Lowers the quality of water by absorbing light
TS (mg/l)	500	-	-	32.5-591.5	197.65 ±128.31	1.25	2.44	Scaling in pipes and domestic appliances
Total hardness (mg/l)	50	-	-	60-258	132.5 ±47.41	-1.87	-2.48	Scaling in pipes and heaters
Nitrate ion, NO_3^- (mg/l)	45	10	-	0-45.98	12.87 ±11.61	1.14	1.53	Injurious to pregnant women, children and adults
Sulfate ion, SO_4^{2-} (mg/l)	200	25	-	0-19	6.42 ±5.66	0.65	-0.34	Laxative effect
Chloride ion, Cl^- (mg/l)	200	250	-	4-42	15.83 ±9.87	1.12	0.71	Corrosivity
Sodium ion, Na^+ (mg/l)	150	-	-	1-18	8.67 ±4.33	-0.04	-0.48	Corrosivity
Potassium ion, K^+ (mg/l)	15	-	-	0-10	2.54 ±2.92	1.71	2.27	Hyperkalemia, nausea, chest tightness
Calcium ion, Ca^{2+} (mg/l)	75	-	-	16.80-75.20	37.03±12.32	1.26	3.32	Reproductive failure, growth retardation, cardiovascular disease
Magnesium ion, Mg^{2+} (mg/l)	50	-	-	1.96-21.56	8.74 ±5.42	1.27	0.66	Laxative effect, diarrhea
Iron ion,Fe^{2+} (mg/l)	1.0	300	1000	0.00-1.67	0.39 ±0.49	1.61	1.56	Stains laundry and utensils, forms rust-coloured sediments
Phosphate ion, PO_4^{3-} (mg/l)	250	-	-	0.00-1.90	0.44 ±0.50	1.35	1.75	Limiting nutrient for eutrophication, rapid plant growth and algal blooms
Fluoride ion, F^- (mg/l)	1.0	-	-	0.00-1.78	0.60 ±0.49	0.94	0.91	Dental and skeletal fluorosis
Turbidity	5.0	5.0	-	0.00-47.00	4.33 ±9.56	4.21	19.00	Creates medium for microbial growth
$CaCO_3$				60.00-258.00	129.75 ±47.20	1.26	1.68	Irritability and allergic reaction such as skin rash, hives, swelling of the face, lips, and tongue
Alkalinity				15.00-98.00	40.96 ±24.32	0.97	0.11	Corrosivity

4.2. Its Domestic, Industrial and Agricultural Quality and Usability

The principal justification of analyzing water constituents is to ascertain its worthiness for the intended use. Thus, the chemical character of any groundwater confirms its attributes and usefulness. The potability of any water is considered in the line of household, industrial, and agricultural purposes. The industrial use can further be subdivided into food, laundry and assorted industries. Water for each of these purposes is required to meet certain safety standard, which have been set by the professional health institutions such as WHO, USEPA, FEPA and many more.

4.2.1. Its Domestic Use

The potability of any water for household or domestic use in most cases depends on the geographical location. The inhabitants of low salinity water areas would probably find small amounts of salts distasteful while dwellers of more arid areas have higher tolerance limits. Elevated concentrations of some physical and chemical parameters tested for in the water samples revealed that the water needs treatment before consumption.

4.2.2. Industrial Use

Assessment of Iresa-Apa water for industrial use is paramount because the outcome of this study will sensitize the stakeholders about the quality of the water they intend to use in their factories especially bottled water industries and other processing food industries as the need arise for it in the future. Quality requirement for industrial waters vary widely according to potential use. Water used in boilers should be soft and non-corrosive. Laundry water should not be hard so as to form scum or waste soap. Water for food industries should be odourless, colorless, and free from suspended matter and of low iron and manganese content. Water is said to be soft if its hardness < 50 mgl^{-1} and vice versa [48]. As revealed from Table 3, the groundwater samples' hardness is higher than the standard of [54]. It is therefore inferred that the shallow wells in Iresa-Apa is unfit for industrial use without pretreatment as well. Sanitary requirement for water used in processing milk, canned goods, meat and beverages exceed even those used for domestic purposes.

Table 3 Water hardness classification comparison from [54]

Classification	Range	This study
Soft	0 – 75	
Moderately hard	75 – 150	
Hard	150 – 300	60 – 258
Very hard	> 300	

4.2.3. Agricultural Use

Water usability for agricultural purpose is in twofold: it is useful in livestock management and irrigation. The water quality for domestic uses is the same as that of livestock management [55]. However, the irrigation usability of the water in the study area is tested through four parameters; namely, Salt Index (SI), Total Hardness (TH), Magnesium Ratio (MR), and Sodium Absorption Ratio (SAR). The quality of water, types of soil as well as the agricultural practice systems play significant role in successful irrigation. Good-quality water permits maximum yields, consistent with proper soil and water management. Water with good quality for irrigation is distinguished by admissible compositions of TDS, sodium proportion to other cations (magnesium and calcium), nitrate concentration and salinity, and so on. The two principal effects of sodium are soil hardening and permeability reduction of soil. These effects are kindled by the substitution of magnesium and calcium by sodium ions. Dug wells for irrigation contain chemical constituents from geogenic and anthropogenic origins. The chemical constituents of irrigation water determine the fertility of the farm soils and productivity of the crops planted on it. Too much salt in the soil results to salinity and toxicity of soil to crops [56].

The water worthiness for irrigation depends on the effect that the salt concentration contained therein has on plant and soil [57]. The salt index is therefore adopted in the classification of water for irrigation purposes. It is given by Equation (1).

$$SI = (Na^{2+}) - 24.5 - 4.85(Ca^{2+}) \quad (1)$$

Water samples with negative values of SI are considered good for irrigation while those with positive values are considered unsuitable. The suitability of Iresa-Apa water for irrigation is confirmed in Table 4 with the estimated mean SI value of -195.45.

Water hardness (temporary or/and permanent) is as a result of soap in water. This is achievable by precipitation of Mg^{2+} and Ca^{2+} ions. Water is said to be permanently hard when Mg^{2+} and Ca^{2+} ions are removed by ion exchange processes, while temporary hardness occurs when $CaCO_3$ in water is removed by heating. Water hardness results to scaling in pipes (industrial and irrigation pipes), pots, and heaters (Table 2), which limits its usability for industrial and agricultural activities. A correlation study by [58] has related some of the heart diseases problems to too much of water hardness. The TH for industrial use has been estimated and presented in Table 3. For irrigation purpose, the most advisable limit is 80 – 100 mg $CaCO_3$/l [59]. For this study, the TH varied from 60 – 250, with an average of 130 $CaCO_3$/l. This categorizes the well in Iresa-Apa as Hard.

From a general perspective, Mg^{2+} and Ca^{2+} ions are almost equilibrium constituents in groundwater. The equilibrium composition of Mg^{2+} in groundwater increases the alkalinity of soil, which in turn reduces the yield of farm crops [59]. The effect of magnesium on water for irrigation could be detrmined through estimation of Magnesium Ratio (MR) as originally given by [60]. The MR of groundwater samples in Iresa-Apa was estimated based on Equation (2).

$$MR = \left(\frac{\left(Mg^{2+} \times 100\right)}{Ca^{2+} \times Mg^{2+}} \right) \quad (2)$$

The MR values as presented in Table 4 varied from 1.33 to 5.95, with an average of 2.99. Based on Paliwal's MR index, MR < 50 is suitable for irrigation, while MR > 50 is unsuitable for irrigation activities [59–60]. This reveals that the groundwater in the study area is suitable for irrigation activities.

SAR of the water samples were estimated based on Equation (3) as given by [61]. Toxicity and salinity problems in irrigation system are attributed to SAR.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (3)$$

The sodium hazard can be estimated from SAR. [55] posited that this is the simplest method to assess the risk of high concentration of sodium in water for irrigation system. If the magnesium and calcium concentrations supersede that of sodium, the risk is low but if it is vice versa, the alkali hazard will be high because alkali hazard is determined by the sodium level in water. US Salinity Laboratory Staff [62] defined SAR as sodium-rich water that causes deterioration through pore clogging in the subsurface. A SAR < 3.0, is described as safe water for irrigation while SAR > 12.0 causes sodicity. This leads to soil swelling and jeopardizes the survival of crops. It also causes soil permeability reduction [63]. The aggravating consequence of releasing high SAR water into the soil is that it makes soil unfit for agriculture and grazing.

It also creates societal risks such as damaging of stream channel's integrity and production of fugitive dust from wind [55, 63– 64]. The SAR fluctuated between 0.24 and 3.79 (Table 4), with the mean of 1.86. 91.7% of the analyzed groundwater showed SAR below 3.0 threshold, with the exeption of W21 and W24. The estimated mean of 1.86 justifies the suitability of Iresa-Apa groundwater system for irrigation. The mean calcium- magnesium dominancy over sodium is by the factor of 5.3 which further confirms its suitability for irrigation.

The relationship between SAR (alkalinity hazards) and EC (salinity hazards) was determined by adopting the proposed model by [62] and [65]. The model was used to evaluate the suitability of groundwater system of Iresa-Apa for irrigation. The alkalinity hazard axis was classified into low (S1: < 10); medium (S2: 10 – 18); high (S3: 18 – 26); very high (S4: > 26), while the salinity hazards axis was classified into low (C1: < 250 µs/cm); medium (C2: 250 – 750 µs/cm); high (C3: 750 – 2250 µs/cm); and very high (C4: > 2250 µs/cm) respectively. 62.5% of the groundwater samples fall under C1S1 block, 33.3% fall under C2S1 block, while 4.2% fall under C3S1 block (Figure 3). The C1S1 block signifies low conductivity and low salinity hazards, while C2S1 block signifies medium conductivity and low salinity hazards respectively. This showed that the water is suitable for irrigation. The third block that was represented from Figure 3 is C3S1 block. This implies that the conductivity of the water sample is high, while its alkalinity is low. Groundwater with this characteristic has been described as suitable water for irrigation in all the soil types, with minimal hazard of sodium exchange [59, 66].

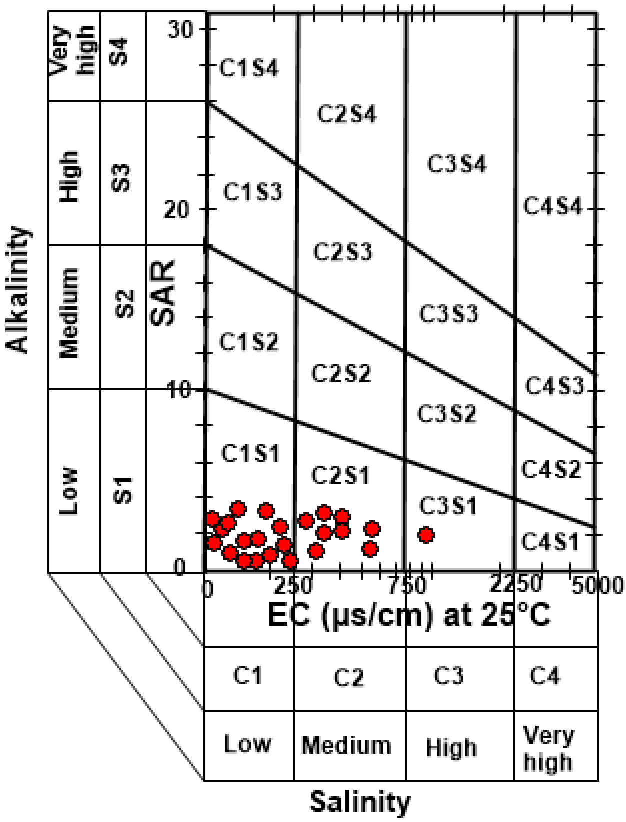

Figure 3 Graph of SAR against EC (based on US salinity laboratory staff index [62]).

Table 4 Irrigation indices for the water samples.

Sample ID	SI	MR	SAR
W1	-171.58	3.05	2.878435
W2	-192.22	2.84	0.646696
W3	-135.90	4.17	1.315334
W4	-99.98	5.95	1.821530
W5	-215.38	2.45	1.359159
W6	-210.50	2.50	1.670295
W7	-208.50	2.50	2.099109
W8	-167.70	3.13	2.757346
W9	-303.50	1.67	1.902128
W10	-176.58	3.05	1.622868
W11	-259.18	2.05	0.343224
W12	-207.50	2.50	2.296656
W13	-380.22	1.33	1.324461
W14	-206.50	2.50	2.416733
W15	-201.62	2.55	2.680555
W16	-110.62	5.21	2.103896
W17	-170.82	3.21	1.138866
W18	-220.38	2.45	0.411824
W19	-132.90	4.17	2.104535
W20	-206.50	2.50	2.393070
W21	-196.62	2.55	3.791365
W22	-155.42	3.68	0.238909
W23	-194.86	2.66	2.206389
W24	-165.70	3.13	3.044558
Mean	-195.45	2.99	1.86

5. CONCLUSION

The study area is predominantly distinguished by migmatite-gneiss with mineralogical conglomeration of feldspars, quartz, ferromagnesian minerals like biotite, and micas. Consequently, the abundance of calcium, magnesium and bicarbonates in the water samples seems to be explained by the mineralogy. Minute concentration of sodium ion in the analyzed water can be linked to the release of soluble products of weathered plagioclase. The magnesium ion can be attributed to the relative abundance of ferromagnesian minerals such as biotite. The high concentration of calcium ions can be associated with the dissolution of calcium rich feldspars such as anorthite. The presence of nitrate recorded can be attributed to the propinquity of some of the wells to raw sewage effluents. The major source of nitrate concentrations is believed to be from fertilizer leachates from neighboring farms. The presence of sulfate in water is unlikely to be as a result of geogenic contributions, as most rock forming minerals have low sulfate concentrations. Its presence in water in most cases is as a result of anthropogenic contributions (e.g. sulfates from burning fuels and automobiles waste). This is the reason it occurred below the permissible level in the area of study. The iron ions detected were not in much abundance. The few detected iron ions can be linked to the ferromagnesian minerals. The presence of calcium ion detected in the groundwater can be ascribed to the existence of plagioclase feldspars in the host location of the groundwater. Potassium in the earth's crust has a low mobility relative to sodium because it enters into the structure of certain clay-like materials during weathering. It has been established that the physicochemical properties of Iresa-Apa is fit for irrigation, but unfit for domestic, industrial, and livestock management without treatment. Boiling of water before drinking is hereby recommended to the dweller of the study area. This will reduce outbreak of waterborne diseases. Wells should be properly sited particularly far from the sewage pits. Water softening process for removal of hardness is recommended in the study area. We also employ governments at all tiers to assist rural dwellers to have access to a good water supply.

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