Hydrogeochemical Assessment of Surface Water in the Central Part of Ekiti-State, Southwestern Nigeria

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Abstract Surface water is an important water resource for drinking and irrigation purposes in the central part of Ekiti-State. The water bodies are used with little attention to their quality status in addition to increased threat of anthropogenic contamination in view of rapid growth in population. The objectives of this study were to determine the physico-chemical characteristics of surface water, its hydrochemical controls and suitability for drinking and irrigation. Forty surface water samples were investigated. Field measurements of physical parameters were preceded by chemical analyses of the samples for major ions concentrations and bacteriological content. The surface water has pH ranging from 8.3 – 9.6 implying that the water was barely alkaline. Electrical conductivity [<205 µS/cm] and total dissolved solids [<154 mg/l] were low suggesting low-mineralised freshwater. The relative abundance of major ions [mg/L] was $Na^+>Ca^{2+}>Mg^{2+}>K^+$ for cations and $Cl^->SO_4^{2-}>HCO_3^->NO_3^-$ for anions. Major ion concentrations were low and within the WHO guidelines for drinking water indicating chemical suitability of surface water. The water samples tested positive to total bacterial count and E – coli with median values of 31.50 and 8.00 (cfu/100ml) respectively. Main water types and proportions were [70 %] mixed $Ca^{2+}-Mg^{2+}-Cl^-$, [20%] Na^+-Cl^- and [10%] $Ca^{2+}-Cl^-$. Predominant processes influencing water chemistry were incongruent dissolution/weathering of silicate minerals and cation-exchange of Na^+ in rocks for Ca^{2+} in water. The low major ion concentrations indicated low water-rock interactions and short residence time. Irrigation quality indices [Sodium absorption ratio, salinity hazard, Kelly ratio and permeability index] revealed that the analysed water was suitable for irrigation.

Keywords: *freshwater, total bacterial count, E – coli, water chemistry cation-exchange*

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1. Introduction

The central part of Ekiti-State which is predominantly basement terrain is characterized with occurrence of numerous surface water bodies. Groundwater occurrence in the area is erratic and wells failures have been on the increase. These factors prompt the inhabitants to harness the surface water for drinking and domestic uses including agricultural activities. These surface water bodies are prone to impacts from anthropogenic activities apart from geogenic solute inputs from dissolved minerals. Major ion composition of surface water bodies are controlled by the interaction of precipitation with surficial geological and biological materials [1]. Therefore, knowledge of dissolved salts in such water bodies is a pre-requisite for making any decision on their proposed or potential use for any specific industrial, irrigational or domestic purposes.

A lot of studies abound in literature on hydrochemistry of surface waters. Such works include [2,3,4,5,6]. In most of these studies, water-rock interaction contributed significantly to hydrochemical evolution of the water bodies. [7] reported that about 40% or even more disease outbreaks are waterborne in nature. In the present study, the peasant farmers that constitute about 80% of the workforce of the study area rely mostly on surface water [replenish through annual rainfall] availability for yearly maintenance of farming activities paying little or no attention to the quality status of the water bodies which are prone to anthropogenic contamination.

This study aimed at evaluating the hydrogeochemistry of surface water in the central part of Ekiti-State in terms of domestic and irrigational quality assessments as well as to reveal the factors controlling the distribution and concentration of elements in the water bodies.

2. Study Area

The study area is within the basement complex terrain of southwestern Nigeria. It lies within latitudes 7° 30' to 7° 45' N and longitudes 5° 00' to 5° 30' E [Figure 1]. The area is a hummocky environment with average elevation of 250m above sea level [8]. It is drained by many rivers/streams flowing dendritically towards the major

rivers [Ose and Ogbese].The area has tropical climate characterized by high humidity [60 – 80%] and mean annual rainfall (1500mm) [8]. Two prominent seasons occur in the area with a long rainy season of March to November and short dry season commencing towards ending of November and terminating in early March. The effects of climate change are becoming apparent with exact periods of rainfall activities becoming unpredictable.

Geologically, the area is an Archean to early Proterozoic terrain underlain mainly by Precambrian rock units comprising of migmatite–gneiss, quartzite, granite and charnockite. [Figure 1]. The rocks in many places are covered with sediments resulting from the weathering of the basement rocks. These weathered regoliths along with fractured saprolite constitute the major aquifers in the study area.

3. Materials and Methods

Sampling exercise was carried out in January 2013. The samples' locations were noted and recorded in the field using Magellan eXplorist Hand held GPS. Forty rivers/streams samples were picked in the study area [Figure 1]. The sampling operation was conducted in a manner that allowed four samples per designated river or stream with a view to obtain an average value per river. At each location, water sample was put into polyethylene bottles [in triplicate] that have been previously properly rinsed with distilled water and air dried in the laboratory [to avoid contamination]. The water samples were collected as far as possible from the edges of the water bodies and as deep as possible from the flow paths of the rivers. Water samples for cations determination were acidified with concentrated nitric acid to prevent reactions with the container. All samples were stored in an ice packed large rubber container and transported to the Laboratory where they were kept in refrigerator at 4ºC before analysis. The first two sets of samples were used for cations and anions determinations respectively while the third set was for bacteriological analyses. In-situ parameters including water temperature, pH and electrical conductivity [EC] were measured immediately samples were collected using a multiparameter portable meter [model Testr-35]. Chemical and bacteriological analyses were carried out at the Federal Ministry of Water Resources Laboratoy, Akure in Ondo State, Nigeria. Anions and cations were analysed using colorimetric and atomic absorption spectrometry methods respectively.

The set of samples for bacteriological analysis were subjected to total bacteria count and coliform count. Nutrient agar medium was used to obtain plate count of living bacteria [viable cell count]. The procedure involved mixing 1 ml of water sample with liquefied agar at 40 °C in a Petri dish. The agar sets to a jelly, thus fixing the bacteria cell in position. The plate was then incubated under appropriate condition [24 hours at 37 ºC for bacteria organism from animal or man]. At the end of the incubation, the individual bacteria would have produced colonies visible to the naked eyes and the number of colonies was assumed to be a function of the viable cells in the original sample. Coliform count was achieved using a lactose medium inoculated with serial dilution of the sample. The appearance of acid and gas after 24 hours at 37 °C was taken as positive indication of the presence of coliform bacteria; results were expressed as number of colonies per 100 ml.

Chemical data were subjected to statistical evaluation using SPSS 17 while Chloro-Alkaline Indices [CAI-1 and CAI-2] were calculated [expressed as meq/l] using equation 1 and 2 to find out the ion exchange processes responsible for the concentration of ions in groundwater [9,10].

$$CAI\text{-}1 = [Cl^- - Na^+ + k^+]/[Cl^-] \qquad (1)$$

$$CAI\text{-}2 = (Cl^- - Na^+ + k^+)/(SO_4^{2-} + HCO_3^- + CO_3^{2-} + NO_3^-) \ (2)$$

Irrigation quality was assessed using estimated irrigation quality indices including salinity hazard, Sodium Absorption Ratio [SAR], Magnesium Absorption Ratio [MAR], Kelly's Ratio [KR] and Permeability Index [PI].

4. Results and Discussion

4.1. Physico-chemical Composition of the Surface Water

Table 1 and Table 2 present the physical and chemical parameters of surface water in the study area respectively while the statistical summary of the physico-chemical data is as presented in Table 3. The average temperature of the water was closer to the mean atmospheric temperature of 28°C, suggesting present day climatic influence and recharge. The pH of the water samples ranged between 8.3 and 9.6 signifying alkaline water. The EC and TDS values of the surface water bodies were low with range values of 84 – 205[av. 142.10] μS/cm and 63 – 153.75[av.106.58] mg/L respectively suggesting low-mineralised freshwater. Similarly, major ion concentrations were low [Table 2] and the order of ionic concentrations in [mg/L] for the cations is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and for the anions, $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^-$ [Figure 2]. All ionic concentrations are within approved [11] standard for drinking water indicating chemically potable water. The dissolve ionic species in the surface water are the resultant product of weathering of rock forming minerals with minor contribution from atmospheric precipitation and anthropogenic activities [12]. The contribution of atmospheric sources to the dissolved salts in the water bodies can be assessed by considering the rain water chemistry or by taking the ratios of elements to Cl [13, 14]. The average Na/Cl and K/Cl ratios of the surface water in the area come out to be 0.71 and 0.30 respectively which are lower than the marine aerosol [Na/Cl = 0.85] and higher than that for [K/Cl = 0.0176] [15]. This suggests that the ionic contribution from the atmospheric precipitation is limited in the area. The ionic contribution in the area is from rock water interaction. This observation was further confirmed by [16] diagram [Figure 3]. The Gibb's diagrams represent the plot of the ratios of $Na^+/[Na^+ + Ca^{2+}]$ and $Cl^-/[Cl^- + HCO_3^-]$ against TDS. The diagrams are widely utilized to assess the functional source of dissolved chemical constituents, such as precipitation dominance, rock dominance and evaporation dominance [16]. In this study, Gibb's diagram plot of analytical data of the water samples cluster in the regions

of rock and precipitation dominance indicating chemical weathering piloted by precipitation as the major factor controlling the chemistry of surface water.

The lack/weak correlations among most ionic parameters [Table 4] are indicative that varied hydrochemical processes account for the ionic concentrations in solution. However, the likely source of Cl^- is atmospheric inputs given the positive correlation with Na^+ [r = 0.92] and surface anthropogenic activities. A plot of Na^+ vs Cl^- [Figure 4] indicates most of water samples lie below the aquiline, implying that evaporation may be the cause of addition of Cl^-, due to more salt dissolution from soil as the water interacts with the rocks/soil in the area. Na^+ concentration is also being reduced by ion exchange. Hence Na^+ and Cl^- do not increase simultaneously. A Na^+/Cl^- ratio approximately equal to one [1] is usually attributed to halite dissolution whereas the ratio greater than one [1] indicates that sodium is released from silicate weathering [13]. In this study majority of the sample have Na^+/Cl^- ratio close to one [1] indicating that halite dissolution arising from precipitation interaction with the soil is responsible for the Cl^- in the water bodies of the study area.

4.2. Chloro-Alkaline Indices [CAI]

In the study area, the value of the chloro-alkaline indices; CAI-1 and CAI-2 vary from -0.38 to 0.23 and -0.11 to 0.17 respectively [Figure 5]. Whenever, the indices are positive, it is indicating ion exchange of Na^+ or K^+ in the surface water with the Ca^{2+} or Mg^{2+} in the aquifer weathered material that infers chloro-alkaline equilibrium [9]. However, in reverse exchange, indices are negative indicating exchange of Ca^{2+} and Mg^{2+} in the water bodies with Na^+ or K^+ of the rocks signifying chloro-alkaline disequilibrium. There is no systematic variation in the values of indices. So the ion exchange reactions seem to occur in both the negative and positive directions depending on the rivers flow path and the mixing of water process. The observed chloro-alkaline process indicated that the cation-anion exchange process is one of the important geochemical processes that control the water chemistry of the area.

4.3. Hardness of the Surface Water

Hardness is caused by compounds of calcium and magnesium and by a variety of other metals. General guidelines for classification of waters are: 0 to 60 mg/L as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard [17]. Surface water hardness in the study area ranged between 52 and 100 with 20% in the soft water category while the remaining 80% were in the moderately hard class. There is no health risk attached to the hardness depicted by the surface water as only water in hard and very hard categories might lead to pre-natal mortality, cardio-vascular diseases [18].
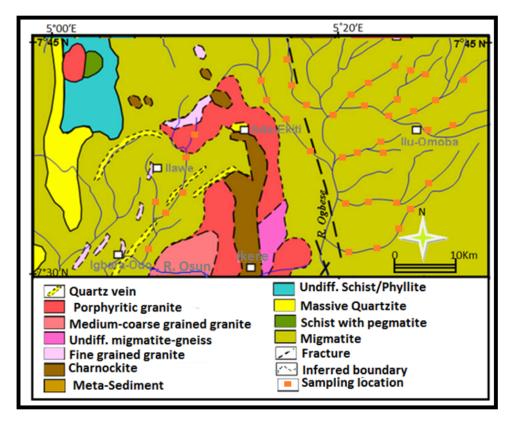

Figure 1. Location and Geologic map indicating sampling locations [Modified after 8]

4.4. Geochemical Classification of the Surface Water

The surface water samples were plotted on the Piper trilinear which permits the cations and anions compositions of the samples to be represented on a single graph in which major groupings or trends in the data can be discerned visually [19]. Water types are often used in the characterization of waters as a diagnostic tool [20]. Piper trilinear diagram [Figure 6] for the study area shows that mixed Ca^{2+}-Mg^{2+}-Cl^- representing 70% of the surface water as dominant with Na^+-Cl^- and Ca^{2+}-Cl^- representing

20% and 10% respectively as minor water types. In addition to the Piper trilinear diagram an overall characterization of hydrochemical facies of the surface water was carried out by using [21] plot where the rectangular field was divided into eight sub-fields, each of which represents a water type and hardness domain [Figure 7]. Majority of water samples in this study fall in domain six [6] which signifies water with permanent hardness i.e. alkaline earths and strong acidic anions exceeded both alkali metals and weak acidic anions. Water in this category represents Ca^{2+}-Mg^{2+}-Cl water with minor facies represented by Na^+-Cl^- and Ca^{2+}-Cl^- as indicated by the Piper diagram [22].

5. Bacteriological Analysis

Results of the bacteriological analysis of the water samples are presented in Table 2. All sampled water tested positive to bacteria counts, necessitating treatment of water before consumption. The Total Bacterial Count [TBC] ranged from 16 – 43 [av. 30.50] cfu/100ml while the E-Coli are from 4 – 11 [av. 7.6] cfu/100ml. The total bacterial counts for all the water samples were within the limit of $1.0X10^2$ cfu/ml which is the standard limit of heterotrophic count for drinking water [23]. However, the total coliform count for all samples were higher than the EPA maximum contamination level [MCL] for coliform bacteria in drinking water of zero total coliform per 100ml of water [24]. The high coliform count obtained in the samples may be an indication that the water sources were faecally contaminated [25]. None of the water samples complied with EPA standard for coliform in water. The primary sources of these bacteria in water are animal and human wastes introduced into surface runoff, pasture and other land areas where animal wastes were deposited. Seepage or discharge from septic tanks, sewage treatment facilities and natural soil/plant bacteria may also contribute to bacterial contamination of water [23].

Table 1. Results of average values of physical parameters of surface water in the study area [no of samples = 4]

Locality	Code	Temp.[°C]	pH	EC[μS/cm]	TDS [mg/L]	TH [mg/L]
Agbojoa	RI	28.2	9.2	201	150.75	66
Ero	R2	25.5	8.9	115	86.25	52
Ele	R3	25.7	8.9	177	132.75	64
Omo	R4	26.6	9.1	109	81.75	66
Awererin	R5	25	9.2	95	71.25	58
Ayegun	R6	25.8	8.3	205	153.75	70
Ureje	R7	28.1	9.2	191	143.25	98
Ogbese	R8	26.9	9.3	122	91.5	78
Isesi	R9	25.9	9.6	122	91.5	64
Osun	R10	26.7	9	84	63	100

Table 2. Mean values of chemical/bacteriological parameters of surface water in the study area (no of samples = 4)

Parameters	Min	Max	Mean	Median	Stdev
Temp.(˚C)	25.00	28.20	26.44	26.25	1.07
pH	8.30	9.60	9.07	9.15	0.34
EC(μS/cm)	84.00	205.00	142.10	122.00	46.27
TDS (mg/L)	63.00	153.75	106.58	91.50	34.70
TH (mg/L)	52.00	100.00	71.60	66.00	15.97
Ca^{2+} (mg/L)	8.60	31.00	17.14	15.30	6.87
Mg^{2+} (mg/L)	5.90	24.00	11.60	10.60	5.46
Na^+ (mg/L)	8.10	38.60	22.53	21.90	10.77
K^+ (mg/L)	5.30	10.20	7.37	6.70	1.69
HCO_3^-(mg/L)	22.00	49.00	33.25	33.50	8.81
SO_4^{2-}(Mg/L)	11.00	51.00	30.20	28.50	14.93
Cl^- (mg/L)	12.00	59.40	32.12	28.35	15.86
NO_3^-(Mg/L)	3.20	9.00	6.00	5.90	1.86
CA-1	-0.38	0.23	-0.01	-0.01	0.22
CA-2	-0.11	0.17	0.03	0.01	0.11
TBC (cfu/100ml)	16.00	43.00	30.50	31.50	10.15
E-Coli (cfu/100ml)	4.00	11.00	7.60	8.00	2.01

Table 3. Summary statistics of measured parameters of surface water in the study area

Locality	Code	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	HCO_3^- (mg/L)	SO_4^{2-} (Mg/L)	Cl^- (mg/L)	NO_3^- (Mg/L)	CA-1	CA-2	TBC (cfu/100ml)	E-Coli (cfu/100ml)
Agbojoa	RI	23.2	24	29.2	5.8	35	25	44.9	6.3	0.22	0.15	37	4
Ero	R2	10.4	6.3	8.1	8.4	23	32	12	5.7	-0.38	-0.07	43	5
Ele	R3	13.6	7.8	38.6	10.2	33	43	59.4	3.6	0.18	0.13	20	7
Omo	R4	8.6	16.7	13.5	8.9	44.5	48	20.8	3.2	-0.08	-0.02	31	8
Awererin	R5	12	8.8	30.9	6.3	35	42	47.6	4.8	0.22	0.13	42	9
Ayegun	R6	21.6	10.5	11.4	9.3	24	51	17.8	5.8	-0.16	-0.04	21	11
Ureje	R7	16.2	11.7	15.7	6.1	34	15	18.5	9	-0.18	-0.06	16	8
Ogbese	R8	20.4	10.7	34.1	6.6	49	17	32.6	6	-0.25	-0.11	32	9
Isesi	R9	31	5.9	28.1	5.3	33	18	43.5	7.4	0.23	0.17	22	8
Osun	R10	14.4	13.6	15.7	6.8	22	11	24.1	8.2	0.07	0.04	41	7

Table 4. Correlations of measured parameters in the study area

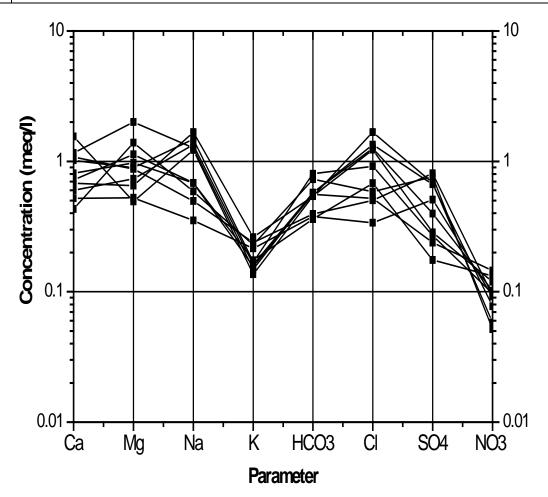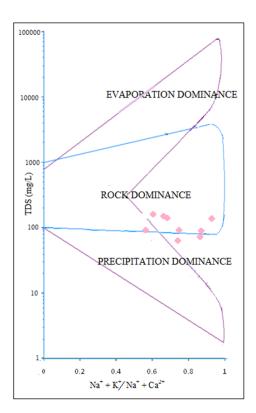|	Ca	Mg	Na	K	HCO3	Cl	SO4	NO3	EC	TDS	TH	TBC	ECOLI
Ca	1												
Mg	.008	1											
Na	.308	-.030	1										
K	-.517	-.190	-.196	1									
HCO₃	.022	.241	.496	-.170	1								
Cl	.269	-.008	.924	-.113	.269	1							
SO₄	-.383	-.063	-.093	.736*	-.002	.068	1						
NO₃	.453	.005	-.236	-.671*	-.342	-.310	-.825	1					
EC	.346	.289	.060	.182	-.078	.084	.183	.090	1				
TDS	.346	.289	.060	.182	-.078	.084	.183	.090	1.000	1			
TH	.049	.219	-.171	-.285	-.060	-.298	-.622	.696	.049	.049	1	-.244	
TBC	-.385	.204	-.113	-.182	-.129	-.089	-.070	-.131	-.629	-.629	-.244	1	
E-COLI	.111	-.393	-.031	.160	.157	-.129	.306	-.057	-.011	-.011	.167	-.430	1

Figure 2. Schoeller diagram indicating ionic concentrations of surface water in the study area

6. Irrigation Quality Assessment

The control of salt and alkali in the soil is as important as the supplying of irrigation water for the development and maintenance of successful irrigation projects [26]. In this study, salinity, sodium absorption ratio [SAR], residual sodium bicarbonate [RSBC], and permeability index [PI] were important irrigation quality parameters employed for determining the suitability of the surface water for agricultural uses.

6.1. Salinity Hazard

Electrical conductivity is a good measure of salinity hazard to crops as it reflects the TDS in water bodies. The EC value of surface water of the study area ranged from 84 to 205 μS/cm with an average value of 142.10μS/cm, which signified 'excellent to good' irrigation water [27]. In terms of the 'degree of restriction on use', EC value of < 700 μS/cm refers the water to 'none'; 700-3000 μS/cm 'slight to moderate' and above 3000 μS/cm 'severe' [28].

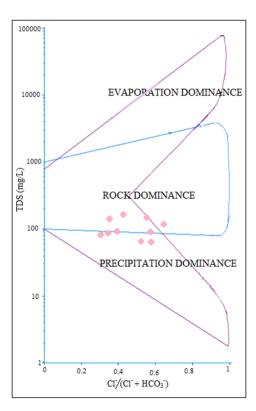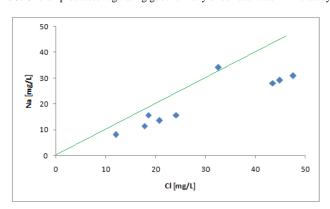**Figure 3.** Overall processes regulating geochemistry of surface water in the study area

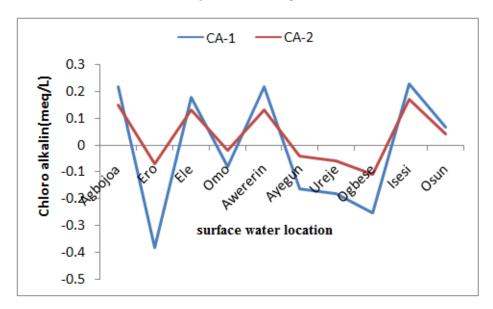

Figure 4. Na versus Cl plot

Figure 5. Chloro-Alkaline Indices of water samples from the study area

6.2. Salinity Hazard

It is easily deduced that the surface water from the study area in terms of EC values, was suitable for irrigation purpose as it fell under category 'none' [28]. High Na^+ concentration in water can lead to displacement of exchangeable cations Ca^{2+} and Mg^{2+} from the clay minerals of the soil and such soil becomes impermeable leading to low fertility and cultivation ability [29]. SAR is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkali/sodium hazard to crops [30]. Salinity and Toxicity problems of irrigation water are attributed to SAR [31]. It is defined by [32], that sodium – rich water may deteriorate the physical structure of the soil [pore Clogging]. The SAR was calculated by the following equation given by [33] as:

$$SAR = Na / \sqrt{Ca + Mg / 2} \qquad (3)$$

where, all the ions are expressed in meq/L. The values of SAR of the collected surface water samples ranged from 0.34 to 1.46 with an average value of 0.74 [Table 5]. Salinity classification was done using a quality diagram [Figure 8] given by the U. S. Salinity Laboratory [33]. The diagram has 16 classes, with reference to SAR as an index of sodium hazard and EC as an index of salinity hazard .

By plotting the obtained results in the diagram [Figure 5], all the sampled surface water was categorized into "C_1-S_1" an indication that such water can be safely used for irrigation purposes [33].

6.3. The Residual Sodium Bicarbonate

The RSBC was estimated according to [34] using;

$$RSBC = HCO_3^- - [Ca^{2+} + Mg^{2+}] \qquad (4)$$

Where, the concentrations of the constituents are expressed in meq/L. According to the US Department of Agriculture, water having more than 2.5 epm of RSBC is not suitable for irrigation purposes. All surface water samples of the study area had RSBC less than 2.5epm indicating that the water bodies are safe for irrigation purposes.

6.4. Kelly's Ratio

Kelly's ratio entails measuring Na^+ against Ca^{2+} and Mg^{2+} [35] and was calculated using:

$$KR = \frac{Na}{Ca + Mg} \qquad (5)$$

where, all the ionic concentrations are expressed in meq/L. The KR values computed for the surface water in the study area ranged from 0.25 to 1.26meq/L with mean of 0.57meq/L. Ninety percent [90%] of the surface water have values less than one and as such suitable for irrigational uses.

6.5. Magnesium Absorption Ratio

Generally, calcium and magnesium maintain a state of equilibrium in most waters. More magnesium in water will adversely affect crop yields as the soils become more saline [36]. The values of the magnesium adsorption ratio of surface water in this present study ranged from 24.08 to 76.40% with 50% of the water samples within the acceptable limit of 50% [37]. Fifty percent of the water was therefore considered unsuitable for irrigation since their magnesium adsorption ratio were higher than 50% and as such produce harmful effect to soil.

Table 5. Irrigation indices of water samples from the study area

Parameters	SAR	PI	MAR	KR	RSC
	0.71	45.76	63.29	0.40	-0.58
	0.34	69.16	50.24	0.34	-0.14
	1.46	80.24	48.87	1.26	-0.14
	0.43	59.83	76.40	0.32	0.30
	1.16	78.49	55.00	1.01	-0.03
	0.35	45.82	44.76	0.25	-0.68
	0.51	57.92	54.62	0.38	-0.25
	1.07	70.08	46.64	0.78	-0.21
	0.86	59.98	24.08	0.60	-1.01
	0.50	50.60	61.15	0.37	-0.36
min	0.34	45.76	24.08	0.25	-1.01
max	1.46	80.24	76.40	1.26	0.30
mean	0.74	61.79	52.51	0.57	-0.31
stdev	0.38	12.48	13.72	0.34	0.37

6.6. Permeability Index

The permeability of soil is influenced by sodium, calcium, and magnesium and bicarbonate contents in the soil as well as by long-term use of irrigation water [38]. [39] evolved a criterion for evaluating the suitability of water for irrigation based on PI. PI is calculated using the following equation:

$$PI = \left[\left(Na^+ + \sqrt{HCO_3^-} \right) / \left(Ca^{2+} + Mg^{2+} + Na^+ \right) \right] 100 \quad (6)$$

where, all ions are expressed in meq/l. The PI values computed for the area ranged from 45.76 to 80.24% with mean of 61.79%. Table 5 indicated that 20% of the samples fell under class II while 80% fell under class III of the Doneen chart. According to [40], waters can be classified into class I, II and III based on PI values. Class I and class II waters are categorized as good for irrigation with 75% or more maximum permeability while class III waters are unsuitable with 25% of maximum permeability. Majority of water in the study area fell in good irrigation class.
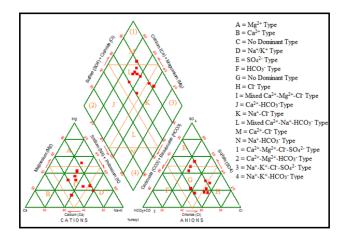
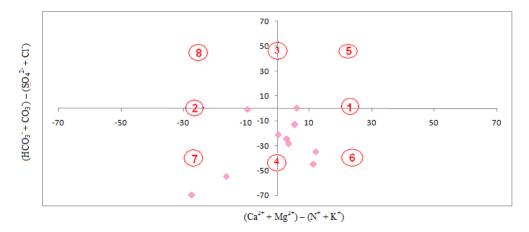**Figure 6.** Piper Diagram [modified after 41]

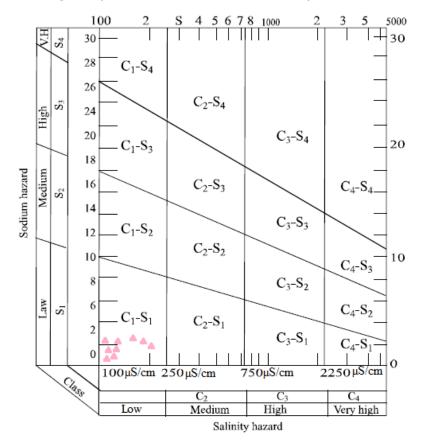**Figure 7.** Hydrochemical Facies of surface water in the study area [after 21]

Figure 8. Salinity classification of irrigation water [33]

7. Conclusion

This study has assessed the hydrochemistry, quality and suitability of surface waters in the central part of Ekiti state, southwestern, Nigeria. The physico-chemical parameters of the surface waters fell within the [11] Guidelines for drinking water and depict that the waters are chemically potable. Evaluation of the results showed that the waters are fresh ($63 \leq TDS \leq 154$ mg/ L), soft to moderately hard $52 \leq TH \leq 100$ mg/ L) and alkaline ($8.3 \leq pH \leq 9.6$) with low residence time and low water-rock interaction. All the surface water tested positive to total bacterial count and e-coli and need to be dis-infected before consumption. Mixed Ca^{2+}-Mg^{2+}-Cl^- was the dominant water type in the study area while Na^+-Cl^- and Ca^{2+}-Cl^- were the minority water facies. Irrigation assessment using SAR, RSC, PI and KR indicated that the surface waters from the area were within excellent to good irrigation water class with low salinity hazard and are suitable for most crops on most soils. The Gibbs plot depicted that the chemistry of waters were modified by chemical weathering piloted by precipitation as the major factor controlling the chemistry of the surface waters.

References

[1]   Raymond, G. S., Dean S. J. and Thomas A. C, Hydrochemical Methods and Relationships for Study of Stream Output from Small Catchments *Biogeochemistry of Small Catchments: A Tool for Environmental Research* Edited by B. Moldan and J.Cerny @ 1994 Scope Published by John Wiley & Sons Ltd.

[2]   Offiong, O. E. and Edet, A. E, Surface water quality evaluation in Odukpani, Calabar Flank, southeastern Nigeria Environ. Geol., 1998b, 36 (3/4): 343-348.

[3]   Udosen, E. D. and Benson, N. U, Spatio-temporal distribution of heavy metals sediments and surface water in Stubbs Creek, Nigeria. *Trends in Applied Sciences Research,* 2006, 1(3): 292-300.

[4]   Wakawa, R. J., Uzairu, A., Kagbu, J. A. and Balarabe, M. L, Impact assessment of effluent discharge on physico-chemical parameters and some heavy metal concentrations in surface water of River Challawa Kano, Nigeria. African *Journal of Pure and Applied Chemistry*, 2008, 2(9): 100-106.

[5]   Abdalla, F. A. and Scheytt, T, Hydrochemistry of surface water and groundwater from a fractured carbonate aquifer in the Helwan area, Egypt. *J. of Earth syst. Sci.* 2012, 121(1): 109-124.

[6]   Wirmvem, M. J., Ohba, T., Fantong, W. Y., Ayonghe, S. N., Suila, J. Y., Asaah, A. N. E., Tanyileke, G. and Hell, J. V, Hydrochemistry of shallow groundwater and surface water in the Ndop plain, North West Cameroon. *African Journal of Environmental Technology,* 2013, 7 (6): 518-530.

[7]   Iqbal, M. A. and Gupta, S. G, Studies on Heavy Metal Ion Pollution of Ground Water Sources as an Effect of Municipal Solid Waste Dumping. Afr. J. Basic Appl. Sci., 2009, 1(5-6): 117-122.

[8]   Talabi, A. O. and Tijani, M. N, Assessment of groundwater quality in parts of the basement complex terrain of southwestern Nigeria. *GQ10: Groundwater Quality Management in a Rapidly Changing World* (Proc. 7th International Groundwater Quality Conference held in Zurich, Switzerland, 13-18 June (2010). *IAHS Publ* , 2011, 342: 503-506.

[9]   Schoeller, H, 1965 Qualitative evaluation of groundwa-ter resources. In Methods and techniques of ground-water investigations and development.*UNESCO, 1965,* 54-83.

[10] Rajmohan, N. and Elango, L, Identification and evolution of hydrogeochemical processes of groundwater environment in an area of the Palar and Cheyyar River Basins, Southern India, *Journal of Environmental Geology,* 2004, 46: 47-61.

[11] World Health Organization (WHO), Guidelines for drinking water quality criteria, 2 Ed, *World Health Organization, Geneva*, 2006, 2: 281-308.

[12] Berner, E. K. and Berner, R. A, *The global water cycle,* Prentice Hall, Eaglewood Cliffs, 1981, NJ; 397.

[13] Stellard, R. F. and Edmond, J. M, Geochemistry of the Amazon 2: The influence of geology and weathering environment on dissolve load. *Jour. Geophys. Res.,* 1983, 88 (14): 967-968.

[14] Sarin, M. M., Krishnawamy, S., Dilli, K., Somayajulu, B.L.K. and Moore, W.S, Major in chemistry of Ganga-Brahmaputra river system: weathering processes and fluxes to the bay of Bengal, *Geochim Cosmochim Acta,* 1989, 53: 997-1009.

[15] Zhang, J., Huang, W. W., Letolle, R. and Jusserand, C, Major element chemistry of Husanghe (Yellow river), Chine-weathering processes and chemical fluxes, *Journal hydrology,* 1995,168: 173-203.

[16] Gibbs, R. J, Mechanism Controlling World Water Chemistry, *Science,* 1970, 170: 1088- 1090.

[17] McGowan, W, Water processing: residential, commercial, light-industrial, *Water Quality Association.*2000, 3rd ed. Lisle, IL.

[18] Agarwal V, Jagetai M, Hydrochemical assessment of groundwater quality in Udaipur city, Rajasthan, India. In: *proceedings of national conference on dimensions of environmental stress in India.* Department of geology, MS University, Baroda, India, 1997, 151-154.

[19] Freeze R. A. and Cherry J. A, Groundwater, Prentice-Hall Inc. Englewood Cliffs, 1979, N.J.

[20] Pitkanen P., Kaija J., Blomqvist R., Smellie J.A.T., Frape S.K., Laaksoharju M., Negral, P.H., Casanova, J. and Karhu J, Hydro geochemical interpretation of groundwater at Palmottu, Paper EUR 19118 EN, European Commission, Brussels, 2002, 155-167.

[21] Chadha, D. K, A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. *Hydrogeology Journa,l* 1999, (5), 431-439.

[22] Piper, A. M, A graphic procedure in the geochemical interpretation of water analyses. *Am. Geoph. Union Trans.*, 1944, 25, 914-923.

[23] EPA, US Environment Protection Agency, Safe Drinking Water Act Ammendment http:// www. epa. gov/safe water /mcl. Html, 2002.

[24] EPA, US Environmental Protection Agency Safe Drinking Water Act. EPA, 2003, 816-F-03-016.

[25] Osuinde, M. I. and Eneuzie, N. R,"Bacteriological analysis of ground water."*Nigeria Journal of Microbiology* 1999, 13:47-54.

[26] Haritash, A. K., Kaushik, C. P., Kaushik, A., Kansal, A. and Kumar, Y. A, Suitability assessment of groundwater for drinking, irrigation and industrial use in some North Indian villages. Environ Monit Assess., 2008, 145: 397-406.

[27] Wilcox, L. V, Classification and Use of Irrigation Waters. US Department of Agriculture, Washington D.C. USA, 1955, Cire. 969: 19.

[28] UCCC (University of California Committee of Consultants). Guidelines for Interpretations of water Quality for Irrigation. Technical Bulletin, University of California Committee of Consultants, California, USA, 1974, 20-28.

[29] Matthess, G, The Properties of Ground Water, John Wiley and Sons, New York, U.S.A., 1982, 397.

[30] Subramani, T., Elango, L. and Damodarasamy, S, Groundwater quality and its suitability for drinking and agricultural use in Chithar river basin, Tamil Nadu, India. *Envir. Geol.,* 2005, 47: 1099-1110.

[31] Raihan, F. and Alam, J. B, Assessment of groundwater quality in Sunamganj of Banglidesh. Iran *J. Environ. Health. Sci. Eng*., 2008, 5 (3): 155-156.

[32] US Salinity Laboratory Staff, Diagnosis and Improvement of Saline and Alkali Soils Handbook No. 60, US Government Printing Office, US Department of Agriculture,Washington DC, 1954, 160.

[33] Richards, L. A, *Diagnosis and improvement of Saline and Alkali Soils.* Agricultural Handbook 60, USDA and IBH Publishing Co. Ltd. New Delhi, India, 1954, 98-99.

[34] Gupta, S. K. and Gupta, I. C, Management of Saline Soil and Water. *Oxford and IBH Publication. Co.* New Delhi, India, 1987, 399.

[35] Kelly, W. P, Use of Saline Irrigation Water. *Soil Sci.* 1963, 95(4): 355-391.

[36] Joshi, D.M., Kumar, A. and Agrawal, N, Assessment of the irrigation water quality of River Ganga in Haridwar District India. *J. Chem.,* 2009, 2(2): 285-292.

[37] Ayers, R.S. and Westcot, D.W, Water quality for agriculture FAO irrigation and drain. 1985, Paper No 29(1): 1-109

[38] Vasanthavigar, M., Srinivasamoorthy, K., Rajiv Gantha, R., Vijayaraghavan, K. and Sarma, V.S, Characterization and quality assessment of groundwater with special emphasis on irrigation utility: Tirumanimuttar sub-basin, Tamil Nadu, India. *Arab. Geosci. J,* 2010.

[39] Doneen, I. D, The influence of crop and soil on percolating water. *Proc 1961 Biannual Conference on Groundwater Recharge* 1961, 156-163.

[40] Nagaraju, A., Suresh, S., Killham, K. and Hudson-Edwards, K, Hydrogeochemistry of Waters of Mangampeta Barite Mining Area, Cuddapah Basin, Andhra Pradesh, India. *Turkish Journal of Engineering and Environment Sciences,* 2006, 30: 203-219.

[41] Ravikumar, P., Venkatesharaju, K. and Somashekar, R. K, Major ion chemistry and hydrochemical studies of groundwater of Bangalore South Taluk, India, Environ Monit Assess., 2010, 163(1-4): 643-653.