



SUITABILITY OF GROUNDWATER FROM BASEMENT AND SEDIMENTARY TERRAINS FOR THEIR USE IN IRRIGATION ACTIVITIES



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Abstract: The needs for sustainable food supply have made assessment of groundwater resources for irrigation a mandatory act. The present study evaluates the possible use of Ogun State groundwater for irrigation in Southwest Nigeria. One hundred (100) water samples were evaluated for trace elements using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP/OES) while physicochemical parameters (pH, Electrical Conductivity EC, Redox potential Eh, Bicarbonates, Chlorides, Nitrates, Ammonium, Phosphates and Sulphates) were determined using standard methods. Piper's plot showed that the order of dominating cations from both basement and sedimentary area are $\text{Na}^+ > \text{Ca}^{2+} > \text{K}^+ > \text{Mg}^{2+}$, however, the order of anion concentration in basement groundwater are $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$ while in sedimentary area are $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$. The Kerlin Ratio (KR) showed that 62% of basement and 82.5% of sedimentary groundwater are not suitable for irrigation. Government support is needed for treatment in order for farmers to be able to use it for irrigation and enhance sustainable food production.

Keywords: Groundwater, index, irrigation, Kerlin ratio, metals, permeability

Introduction

Increase in human population makes the demand for fresh water increases. The scarcity of natural fresh water and its unequitable distribution on the Earth makes pursuance of groundwater as an optional source inevitable. Groundwater is characterized by its quality, good for human consumption without treatment in most cases, and presence of trace elements at very low concentrations as a result of aquifer rocks decomposition (Fernando *et al.*, 2015). Groundwater contamination may occur due to domestic sewage, animal wastes, pesticides and fertilizer residue's infiltration (Justen *et al.*, 2012). The vulnerability of groundwater to contamination by heavy metals due to human activities has been reported (Borba *et al.*, 2003; Lopes *et al.* 2012).

The geochemical information of groundwater provides evidence to the nature of rocks, recharge, storage and movement of water beneath the soil (Thilagavathi, 2014; Arveti, 2016). The hard rock terrains make water required for household, agriculture and industrial activities to be challenging (Chae, 2004; Dragon, 2006). The knowledge of hydrochemistry is needed to determine the acceptability of water for drinking, agricultural and industrial use. Studies on hydrogeochemical characteristics and water contamination of different locations have been carried out (Bouzourra *et al.*, 2015; Wu *et al.*, 2015; Wu and Sun, 2015; Sajil - Kumar *et al.*, 2014; Li *et al.*, 2013; Marghade *et al.*, 2012; Schoeller, 1965). The Chemistry of groundwater consists of rock, cation exchange, dissolution and precipitation (Li *et al.*, 2016). The hydrochemical characteristics of groundwater were assessed and halite dissolution was found to be correlated with increase in sodium and chloride (Sarikhani *et al.*, 2015).

Irrigation is very important for agricultural production, which guarantee food availability across seasons. Climate change and over dependence on rainfall constitutes major constraints on crop production (Akinbile *et al.*, 2016; Venot *et al.*, 2010). In Nigeria, irrigation has the capability of aiding the achievement of sustainable food security goals through increased food production (Adeoti, 2006). Exploitation of aquifers for this purpose requires knowledge of water quality and hydrogeochemistry. Published work on hydrogeochemistry of groundwater in Ogun States of Nigeria based on geological terrain are few, there is need for this information because Ogun State has large expanse of land for agriculture coupled with incessant climate change which resulted in irregular rainfall events. The present study aimed at providing information on the suitability of groundwater resources in Ogun State for irrigation purposes to enhance sustainable food production.

Materials and Methods

The study area

Ogun State lies on Latitude $6^{\circ} 20' \text{N} - 7^{\circ} 55' \text{N}$ and Longitude $2^{\circ} 45' \text{E} - 4^{\circ} 45' \text{E}$ (Fig. 1).

The area covered include Abeokuta (B_1), Ijebu-Igbo (B_2), Ago-Iwoye (B_3), Ayetoro (S_1) and Ilaro (S_2). The sedimentary areas of Ogun State consist of Oshosun, Ilaro and Ewekoro formations. The Basement Complex rocks consists of Abeokuta formation (Kehinde - Phillips, 1990).

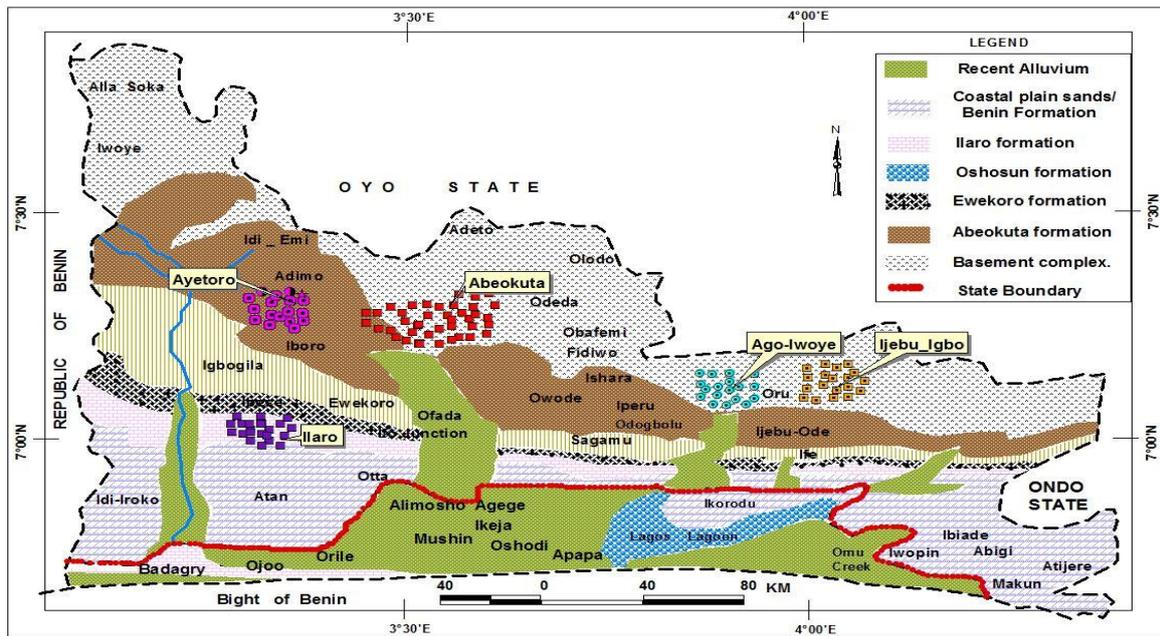


Fig. 1: The study area showing the geology and the sampling area

Sample collection

Groundwater samples were collected from 100 locations across Ogun States, Southwest Nigeria. Water samples from Seventy (70) wells and Thirty (30) boreholes were collected into a cleaned polythene bottles of one litre capacity which were rinsed with water to be sampled before collection.

Sample analysis

The physico-chemical parameters such as pH, Temperature, Electrical Conductivity (EC), Redox Potential (RP) and position of the wells were measured on the field using the following instruments. Hand-held 2000VWR Scientific meter for pH and redox potential, Thermo Orion model conductivity meter (USA made) was used to measure the conductivity of the water while TDS was measured using Horiba-U-51 model Multimeter. Five (5) mL concentrated nitric acid were added to one liter of water samples meant for metal analysis as preservatives. Samples for anions were kept in ice, transferred to the laboratory and analyzed within five days. Geographical Positioning System (GPS) Extrex legend model (made in USA) was used to measure the co-ordinates of individual location of wells and boreholes.

Chemicals and reagents

All glass wares and polyethylene bottles were soaked separately in 10% HCl for 72 h, washed, rinsed thoroughly in de-ionized water and dried. The samples were preserved with HNO₃ (supra pure, Merk). The concentrations of anions were determined using standard methods (APHA, 2005). Colorimetric methods were used for nitrates, sulphates, phosphates and ammonium ions determination using Cecil UV-Visible Spectrometer. However, Mohr’s method and titration methods were used for chloride and alkalinity determination, respectively.

The concentrations of elements were measured using ICP/OES (Perkin Elmer model). The NIST1643 water standard was run at the beginning and the end of each batch as control materials. The results of the quality control samples showed a good agreement with the certified value of NIST1643 water reference material. The % recovery for Mg, Ca, K, and Na are 96, 106, 105 and 106%, respectively.

Calculations

The parameters such as, percentage Sodium (%Na), Sodium Adsorption Ratio (SAR), Total Hardness (TH), Magnesium Hardness (MH), Permeability Index and Ion Exchange (Li *et al.*, 2015; Marghade *et al.*, 2012; Schoeller, 1965) were calculated using the equations listed below. The SAR values for each water sample were calculated according to Richard (1954). The SAR is used to predict the Na hazard of high carbonate waters to establish the presence of excess residual alkali (Kassa *et al.*, 2005).

$$i \ % \ Na = \frac{Na + K}{Ca + Mg + Na + K} \times 100 \quad \text{-----} (1)$$

$$ii \ SAR = \frac{Na}{\sqrt{Ca + Mg} / 2} \quad \text{-----} (2)$$

$$iii \ TH = 2.5 \ Ca + 4.1 \ Mg \quad \text{-----} (3)$$

$$iv \ MH = \frac{Mg}{Ca + Mg} \quad \text{-----} (4)$$

$$v \ PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg} \quad \text{-----} (5)$$

$$vi \ Cation \ Exchange \ CAI \ 1 = \frac{Cl - (K + Na)}{Cl} \quad \text{-----} (6)$$

$$CAI \ 2 = \frac{Cl - (K + Na)}{(HCO_3^{2-} + CO_3^{2-} + SO_4^{2-} + NO_3^-)} \quad \text{-----} (7)$$

Data analysis

SPSS 18.0 was used for data analysis while Duncan Multiple Range Test (DMRT) was used for mean values separation. Pearson correlation was used to determine association between base elements and physicochemical parameters.

Results and Discussion

Physicochemical parameters and major elements

The pH of basement groundwater ranged between 4.61 and 7.03 with the mean value of 5.69±0.01 while in sedimentary groundwater, the pH ranged between 3.60 and 6.31 with the mean value of 5.12±0.21. Thirteen percent (13%) of the water from basement has pH within the range of WHO recommended limit, this percentage were found within B₁ and B₃ (Table 1). However, in groundwater from sedimentary environments, all the water samples have pH values less than WHO limit.

Table 1: Range and mean of physicochemical parameters of groundwater from basement and sedimentary area of Ogun State

Parameters	Basement		Sedimentary		
	Range	Mean ± SD	Range	Mean ± SD	WHO (2011)
pH	4.61 – 7.03	5.69±0.01	3.60 – 6.31	5.12±0.21	6.5 – 8.5
EC(µScm ⁻¹)	10.0 – 1400.0	407±120	10.00 – 800.0	238±127	NA
Eh(mV)	2.00 – 150.00	72.4±15.1	34.00 – 180	101±25.1	NA
TDS (mgL ⁻¹)	60.0 – 840.0	247.7±105	6.00 – 480.00	143±80	250
Cl ⁻ (mgL ⁻¹)	28.79 – 413.1	119.4±30	23.03 – 165.5	74.4±41	250
HCO ₃ ²⁻ (mgCaCO ₃ L ⁻¹)	60.00 – 520.0	232±110	260.0 – 820.0	414±132	400
NO ₃ ⁻ (mgL ⁻¹)	0.290 – 6.33	1.92±0.03	0.14 – 12.11	2.34±0.02	50
NH ₄ ⁺ (mgL ⁻¹)	0.01 – 1.28	0.181±0.01	0.01 – 0.20	0.025±0.001	1.5
PO ₄ ²⁻ (mgL ⁻¹)	0.68 – 104.0	32.8±15.1	24.80 – 31.20	27.7±3.2	NA
SO ₄ ²⁻ (mgL ⁻¹)	13.66 – 495.4	158±32.5	7.29 – 51.91	21.04± 11.1	250
Ca ²⁺ (µgL ⁻¹)	3300 – 83300	23073±1006	1800 – 35900	9685±798	250000
Mg ²⁺ (µgL ⁻¹)	100.00 – 28700	7126±564	300.0 – 7000	2620±632	150 000
Na ⁺ (µgL ⁻¹)	2590 – 138000	39710±2025	4700 -122000	39895±15800	200000
K ⁺ (µgL ⁻¹)	2700 – 62900	9853±822	300.00 – 57500	8970±655	NA

Table 2: Duncan multiple range test of physicochemical parameters of groundwater from basement and sedimentary area of Ogun State

	pH	EC	Eh	TDS	Cl	HCO ₃ ²⁻	NO ₃ ⁻
B ₁	5.860±0.226a	420.0±53.33c	48.40±9.576a	252.0±32.00c	100.2±13.20b	212.0±31.01ab	3.220±0.614a
B ₂	5.405±0.148a	281.0 ± 69.16b	94.10 ±9.545b	179.0±38.14b	116.6±35.06b	292.0±46.39ab	0.340±0.112b
B ₃	5.819±0.184a	520.0±117.2c	74.60±12.84ab	312.0±70.31c	141.34±22.24b	192.0±18.18a	2.202±0.633a
S ₁	5.046±0.2333a	37.00±13.75a	104.1±13.21b	22.20±8.249a	80.89±13.64a	418.0±48.94b	2.112±1.122a
S ₂	5.194±0.207a	440.0±79.16c	98.30±10.99b	264.0± 47.49c	67.93±5.66a	410.0±28.94b	2.575±0.944a
	NH ₄ ⁺	PO ₄ ²⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
B ₁	0.340±0.112b	73.04±6.780c	133.8±12.69b	26510±4715ab	6850±1412b	32400±8400a	9390±2405b
B ₂	0.1682±0.124b	4.21±2.344a	130.9±43.63b	12100±2725a	3990±728.1ab	41960±11316ab	8210±2809b
B ₃	0.036±0.009a	21.03±5.806b	209.5±44.4c	30610±7640c	10540±2111c	44770±11112ab	11960±5705b
S ₁	0.0285±0.019a	29.22±0.511b	29.14±5.07a	9070±3309a	2250±656.9a	48220±10308ab	7550±3123a
S ₂	0.0206±0.004a	26.24±0.629b	12.93±1.022a	10300±2711a	2990±662.1a	31570±5010a	10390±5435b

B₁-Abeokuta; B₂- Ijebu Igbo; B₃- Ago Iwoye; S₁-Ayetoro; S₂-Ilaro

Note: Mean values with the same letter are not significantly different down the group using Duncan Multiple Range Test

The Electrical Conductivity (EC) in basement groundwater ranged between 10 to 1400 µScm⁻¹ with the mean value of 407±120 µScm⁻¹ in basement groundwater while in sedimentary groundwater the range are 10 to 800 µScm⁻¹ with the mean value of 238±127 µScm⁻¹. Higher values of EC indicate the presence of inorganic ions released from weathering of rocks (Alam *et al.*, 2020). The TDS measured in groundwater of basement ranged between 60.0 and 840.0 mgL⁻¹ with the mean value of 247.7±105 mgL⁻¹ while that of sedimentary groundwater ranged between 6.00 and 480.00 mgL⁻¹ with the mean value of 143±80 mgL⁻¹. Twenty-three percent (23%) of TDS values from basement groundwater were higher than WHO limit while 13% of sedimentary groundwater samples exceeded WHO recommended limit. Plot of TDS against (Ca + Cl⁻) for data obtained from groundwater of basement area showed a negative correlation with r = -0.155 while that of sedimentary showed r = -1.69. This implies that TDS is not responsible for effect of Ca in combination with Cl⁻ concentration in the groundwater of the study area (Appendices i and ii). Chloride content of basement groundwater ranged from 28.79 to 413.1 mgL⁻¹ with the mean value of 119.4±30 mgL⁻¹ while that of sedimentary groundwater ranged between 23.03 and 165.5 mgL⁻¹ with the mean value of 74.4±41 mgL⁻¹. Thirty percent (30%) of Cl⁻ values from basement (B₁, B₂ and B₃) groundwater were significantly P < 0.05 higher than those from sedimentary area

(Table 2). However, none of the sedimentary groundwater samples has Cl⁻ above WHO recommended limit. The NH₄⁺ concentration ranged between 0.01 – 1.28 mgL⁻¹ with the mean value of 0.181±0.01 mgL⁻¹ in basement groundwater while in sedimentary groundwater the range was 0.01 – 0.20 mgL⁻¹ with the mean value of 0.025 ± 0.001 mgL⁻¹. The results showed that 1% of the total number of samples is higher than WHO limit mainly found in basement groundwater. The SO₄²⁻ concentration in basement groundwater ranged between 13.66 and 495.4 mgL⁻¹ with the mean value of 158±32.5 mgL⁻¹ while in the sedimentary groundwater the range are 7.29 – 51.91 mgL⁻¹ with the mean value of 21.04 ± 11.1 mgL⁻¹. Two percent (2%) of the basement (B₁ and B₂) groundwater samples showed significantly (P < 0.05) high SO₄²⁻ concentration (Table 2). The Ca²⁺ concentration in basement groundwater ranged between 3300 and 83300 µgL⁻¹ with the mean value of 23073±1006 µgL⁻¹ while in the sedimentary groundwater the range are 1800 – 35900 µgL⁻¹ with the mean value of 9685 ± 798 µgL⁻¹. The significantly (P < 0.05) high Ca²⁺ concentration was recorded from location B₃. The Na⁺ concentration in basement groundwater ranged between 2590 and 138000 µgL⁻¹ with the mean value of 39710±2025 µgL⁻¹ while in the sedimentary groundwater the range are 4700 –

122000 μgL^{-1} with the mean value of $39895 \pm 15800 \mu\text{gL}^{-1}$. The function of sodium for the characterization of groundwater in water system is based on the way sodium responds to dirt which reduces penetrability (Todd, 1980). The high level of sodium disperses the dirt formation and decreases crop yield (Domenico, 1990). The K^+ concentration in basement groundwater ranged between 2700 and 629000 μgL^{-1} with the mean value of $9853 \pm 822 \mu\text{gL}^{-1}$ while in the sedimentary groundwater the range are 300 – 57500 μgL^{-1} with the mean value of $8970 \pm 655 \mu\text{gL}^{-1}$.

Correlation

Significant correlation ($p < 0.01$) was recorded in basement groundwater between Eh and pH with $r = -0.755$; TDS and EC with $r = 0.994$, between Ca^{2+} and pH with $r = 0.523$, between Ca^{2+} and Eh with $r = -0.466$, between Mg^{2+} and Ca^{2+} with $r = 0.830$, between Na^+ and Ca^{2+} with $r = 0.528$, between Na^+ and Mg^{2+} with $r = 0.583$, between K^+ and Ca^{2+} with $r = 0.675$, between K^+ and Mg^{2+} with $r = 0.665$, between K^+ and Na^+ with $r = 0.623$ (Table 2). At ($p < 0.05$) level of significance, correlation was found between PO_4^{2-} and Eh with $r = -0.397$, between Mg^{2+} and pH with $r = 0.385$ (Table 3).

However, in sedimentary groundwater, significant correlation ($p < 0.01$) was recorded between Eh and pH with $r = -0.868$;

TDS and EC with $r = 1.0$, between HCO_3^{2-} and Eh with $r = 0.670$, between SO_4^{2-} and HCO_3^{2-} with $r = -0.643$. Significant correlation ($p < 0.05$) was recorded between HCO_3^{2-} and pH with $r = -0.543$, between HCO_3^{2-} and EC with $r = 0.494$, between HCO_3^{2-} and TDS with $r = 0.494$, between NO_3^- and EC with $r = 0.541$, between NO_3^- and TDS with $r = 0.541$, between PO_4^{2-} and Cl^- with $r = 0.523$, between SO_4^{2-} and Eh with $r = -0.523$, between SO_4^{2-} and PO_4^{2-} with $r = 0.558$, between Mg^{2+} and NH_4^+ with $r = 0.478$, between Mg^{2+} and PO_4^{2-} with $r = 0.518$, between Mg^{2+} and Ca^{2+} with $r = 0.518$, between Na^+ and pH with $r = -0.456$, between Na^+ and Eh with $r = 0.493$ (Table 4).

Table 3: Pearson correlation between physicochemical parameters and base metals in groundwater of the basement area

Parameter	pH	EC	Eh	TDS	Cl^-	HCO_3^{2-}	NO_3^-	NH_4^+	PO_4^{2-}	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
pH	1													
EC	.140	1												
Eh	-.755**	-.352	1											
TDS	.141	.994**	-.361	1										
Cl^-	-.270	.218	.335	.204	1									
HCO_3^{2-}	-.012	.109	-.020	.113	.206	1								
NO_3^-	.027	.047	-.301	.039	-.166	-.067	1							
NH_4^+	.214	.226	-.328	.226	-.221	.128	.238	1						
PO_4^{2-}	.126	-.012	-.397*	-.033	-.204	-.232	.302	.310	1					
SO_4^{2-}	.203	.293	-.130	.288	-.011	.054	.242	.334	-.133	1				
Ca^{2+}	.523**	.226	-.466**	.208	-.207	-.017	-.033	.184	.205	-.004	1			
Mg^{2+}	.385*	.206	-.313	.185	-.086	.035	-.120	.074	.050	.132	.830**	1		
Na^+	.140	.247	-.191	.253	-.107	.245	.106	.288	-.108	.218	.528**	.583**	1	
K^+	.232	.201	-.245	.193	-.161	-.048	-.167	.263	-.087	.191	.675**	.665**	.623**	1

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Table 4: Pearson correlation between physicochemical parameters and base metals in groundwater of the sedimentary area

Parameter	pH	EC	Eh	TDS	Cl ⁻	HCO ₃ ²⁻	NO ₃ ⁻	NH ₄ ⁺	PO ₄ ²⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
pH	1													
EC	-.381	1												
Eh	-.868**	.346	1											
TDS	-.381	1.000**	.346	1										
Cl ⁻	-.309	.001	.185	.001	1									
HCO ₃ ²⁻	-.543*	.494*	.670**	.494*	-.076	1								
NO ₃ ⁻	-.294	.541*	.282	.541*	.091	.092	1							
NH ₄ ⁺	.049	-.109	-.160	-.109	.075	-.368	.005	1						
PO ₄ ²⁻	-.012	-.059	-.205	-.059	.523*	-.403	.110	.434	1					
SO ₄ ²⁻	.311	-.153	-.557*	-.153	.319	-.643**	-.128	.314	.558*	1				
Ca ²⁺	.366	-.299	-.442	-.299	.058	-.532*	-.199	.116	.129	.446*	1			
Mg ²⁺	.223	-.122	-.182	-.122	.165	-.258	-.150	.478*	.518*	.170	.518*	1		
Na ⁺	-.456*	-.099	.493*	-.099	.111	.276	.079	-.319	.220	-.207	-.295	-.055	1	
K ⁺	.122	-.098	.102	-.098	.072	.169	-.193	-.129	-.061	-.107	.439	.379	.122	1

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Table 5: Classification of groundwater based on irrigation indices

Parameters	Range	Water Class	Basement (%)	Sedimentary (%)
EC (Richard, 1954)	<250	Excellent	27	55
	250 - 750	Good	63	35
	750 - 2000	Permissible	10	10
	2000 - 3000	Doubtful	Nil	Nil
%Na (Wilcox, 1955)	<20	Excellent	3	45
	20 - 40	Good	10	50
	40 - 60	Permissible	34	05
	60 - 80	Doubtful	40	Nil
	>80	Unsuitable	13	Nil
SAR (Bouwer, 1978)	<6	No problem	Nil	Nil
	6 - 9	Increasing problem	Nil	Nil
	>9	Severe Problem	100	100
MH	<50	Suitable	100	100
	>50	Unsuitable	Nil	Nil
TH	<75	Soft	0	0
	75 - 150	Moderately hard	0	0
	150 - 300	Hard	0	0
	>300	Very hard	100	100
KR	<1	Suitable	20	2.5
	1 - 2	Marginal	18	15
	>2	Unsuitable	62	82.5
PI	>75	Class I	30	Nil
	25-75	Class II	65	80
	<25	Class III	05	20

% Sodium: The % Na from basement groundwater ranged between 29 – 91.27% with more than half of the total samples from the terrain has % Na greater than 60% which classify the water as unsafe for irrigation purposes according to Wilcox (1955). Forty-two (42%) of the samples from basement area are suitable for irrigation. However, the % Na from sedimentary environment ranged between 5.83 – 43.16%. All water samples from sedimentary area has % Na < 60% which classify them as safe for irrigation purposes (Table 5).

Bhat *et al.* (2016) reported results similar to the one obtained from the basement area of the present study. The higher % Na recorded from the basement groundwater may be linked with dissolution of minerals from lithological composition, prolong retention time of water, and presence of chemical fertilizers in waters (Subba *et al.*, 2002). A high intake of Na may cause hypertension and kidney problems. Sodium ions tends to be

absorbed by clay particles when the concentration of sodium is high in irrigation water, which causes displacement of Mg²⁺ and Ca²⁺ ions (Ravikumar *et al.*, 2011). This exchange process of Na⁺ in water for Ca²⁺ and Mg²⁺ in soil reduces the permeability and eventually results in soil with poor internal drainage. As a results of this, the soil become hard when dry (Salem *et al.*, 2015).

Sodium adsorption ratio (SAR): The rainfall pattern of the study area was higher than other parts of the country, however, during dry season, groundwater is still the main source of irrigation in the area. The quality and quantity of water is very essential for proper growth of plants. Therefore, the quality of water used for irrigation purposes should be within recommended range (Aher, 2012). The SAR in groundwater from basement and sedimentary area are both 100% not suitable for irrigation. Higher SAR values similar to

the present results were obtained in water meant for irrigation in previous studies (Sigh *et al.* 2011). This can cause soil crusting, poor seedling and poor aeration.

Magnesium hazard: The Mg^{2+} concentration in basement groundwater ranged between 100 and 28700 μgL^{-1} with the mean value of $7126 \pm 564 \mu gL^{-1}$ while in the sedimentary groundwater the range are 300 – 7000 μgL^{-1} with the mean value of $2620 \pm 632 \mu gL^{-1}$. The significantly ($P < 0.05$) high value of Mg^{2+} $10540 \pm 2111 \mu gL^{-1}$ was recorded from B₃ (Ago Iwoye). The magnesium hardness (MH) from both basement and sedimentary area less than 50 which can be classified as suitable for irrigation (Table 5). Tofaya *et al.* (2019), reported higher value in groundwater of Shagordari, Jashore, Bangladesh. Most of the calcium and magnesium concentrations in natural water might be due to the chemical weathering and the erosion of rocks and minerals (Al-Qawati *et al.*, 2018).

Total hardness (TH): TH is generally caused by the presence of calcium and magnesium (Sappa *et al.*, 2014). The results from the present study indicate that all the groundwater from the study area are very hard. Raju *et al.* (2011) reported that 53% of groundwater TH exceeded safe limits in Uttar Pradesh India. TH in groundwater is produced by dissolution of Ca and a smaller amount of Mg (Singh, 2002). It is regarded as the equivalent amount of $CaCO_3$ and reflection of the biological environment with which exchange of ions occur (Singh *et al.*, 2011). Water hardness causes more consumption of detergents during cleaning, encrustation on metallic water supply distribution and some cardiovascular disorder.

Kelly's ratio (KR): The KR ranged between 0.05 to 9.7 in basement groundwater while in sedimentary groundwater the range are 0.57 to 14.9. Bhats *et al.* (2016), reported range >1. Twenty percent (20) % of the basement groundwater are suitable, 18 % are marginally suitable while 62% are unsuitable. However, in sedimentary groundwater, 2.5% are suitable, 15% are marginally suitable while 82.5% are unsuitable for irrigation. Variations of parameters in basement and sedimentary groundwater are available in Appendices I – v of additional information.

Permeability index (PI): Thirty percent (30%) of calculated PI for basement groundwater can be categorize as Class I in line with Doneen (1964) classification, 65% are classified as Class II while 5% are classified as Class III. However, none of the sedimentary groundwater can be classified as Class I, 80% are Class II while 20% are Class III. The Class I and II water are categorized as good for irrigation with 75% or more of maximum permeability while the Class III water is unsuitable with 25% of maximum permeability (Bhat *et al.*, 2016). This implies that only 5% of basement groundwater and 20% of the sedimentary groundwater are not suitable for irrigation purposes. Nagaraju (2016) reported that majority of the groundwater samples collected from Rapur area, Andhra Pradesh, South India fall under class-I which indicates its suitability for irrigation.

Cation exchange: The two chloro-alkaline indices CAI1 and CAI 2 values from basement groundwater ranged from -19151 to -59.37 and -730.27 to -17.99, respectively. However, in sedimentary groundwater, the range are -317.98 to -6.66 (CAI1) and -3047 to -109.3 (CAI 2). The cation exchange is an important indicator of groundwater chemistry and evolution processes (Schoeller, 1965). The negative values of the two indices were obtained which indicates reverse cation exchange occur in most of the groundwater in the basement and sedimentary area of Ogun State (Appendices iii and iv). In cases of this nature, the ion exchange process increases the Na^+ ion content, and decreases the Ca^{2+} ion content (Li *et al.*, 2016).

Hydrochemical facies

The trilinear diagram defined the composition class based on subdivisions which represent hydro - chemical facies (Back and Hanshaw, 1965). The diagram explains the variations of cation and anion concentrations (Ravikumar *et al.*, 2011). The piper diagram facies of groundwater from basement area were dominated Na, K and averagely by Cl ions (Fig. 2).

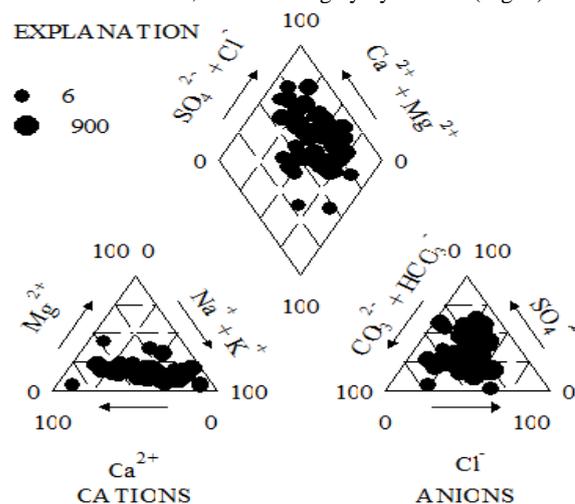


Fig. 2: Piper's plot for basement groundwater of Ogun State

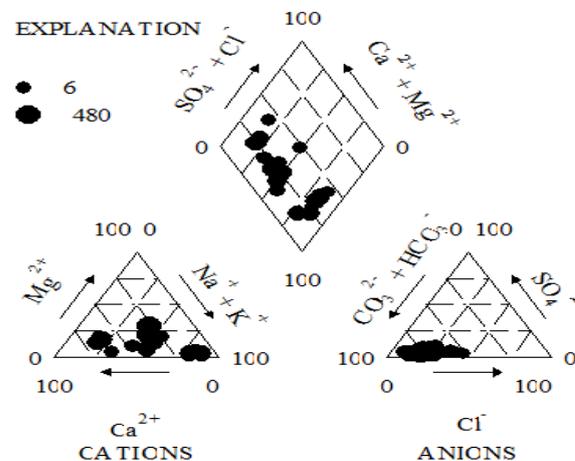


Fig. 3: Piper's plot for sedimentary groundwater of Ogun State

There is a substantial enrichment of Ca Mg ions and CO_3 and HCO_3 ions. This is more possibly a mixture of Ca and Mg carbonates (De - Cariate *et al.*, 2019). Many of the samples lies in alkaline earth (Ca + Mg) demonstrating water contaminated with gypsum (Kumaravel, 2019). The piper diagram facies for groundwater in sedimentary area were dominated by Na, K and CO_3 and HCO_3 ions (Fig. 3). In sedimentary areas few (Ca + Mg) was recorded which showed that amounts of mineral issues is a direct result of the overall insolubility of the rock composition.

The water samples can be categorized into three distinct types with two end members: (Ca + Mg)-rich and (Na + K)-rich waters. The ionic dominance for water bodies according to Stumm and Morgan (1981) are: $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_3^- > SO_4^{2-} > Cl^-$ for fresh waters, and $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and $Cl^- > SO_4^{2-} > HCO_3^-$ for waters of marine origin. The order of dominating cations from the both basement and

sedimentary area are $\text{Na}^+ > \text{Ca}^{2+} > \text{K}^+ > \text{Mg}^{2+}$. The average concentration of Na^+ and K^+ are almost the same from both terrains while the average Ca^{2+} and Mg^{2+} concentration in basement groundwater doubled that of sedimentary area. The order of anion concentration in basement was $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$ while in sedimentary area the order was $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$. Hydrochemical zonation of various water types occur in sedimentary area which are mainly controlled by migration and mixing of saline water with groundwater, however, the pattern of sedimentary anions and cations in the present study is in agreement with previous study (Alam *et al.*, 2020; Khan *et al.*, 2021). Major cation and anion concentrations dominance pattern in the order of $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ and $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$ and thus indicating partial cationic and anionic characteristics of fresh water was reported (Yankey *et al.*, 2011). The results showed an enrichment of Na^+ from both terrain and depletion of Ca^{2+} from the sedimentary area. The observed ionic dominance pattern may have resulted from ion exchange reactions in which sodium displaces calcium and magnesium in the groundwater (Edmunds *et al.*, 2003). Natural softening of groundwater could also involve ion exchange and be a possible cause of the observed trend.

Conclusion

Groundwater from basement area of Ogun state are more enriched with Ca, Mg than those from sedimentary area. However, groundwater from sedimentary area of Ogun State are less enriched with Ca and Mg. The order of dominating cations from the both basement and sedimentary area are $\text{Na}^+ > \text{Ca}^{2+} > \text{K}^+ > \text{Mg}^{2+}$. The results of SAR and KR showed that groundwater from the two major geological terrains of Ogun State are not suitable for irrigation without treatment. Synergy between government and the farmers is very important in order to make the groundwater amenable to use for irrigation, enhance food supply and facilitate sustainable development.

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Conflict of Interest

I hereby declare that this manuscript submitted for publication is free of conflict of interest.

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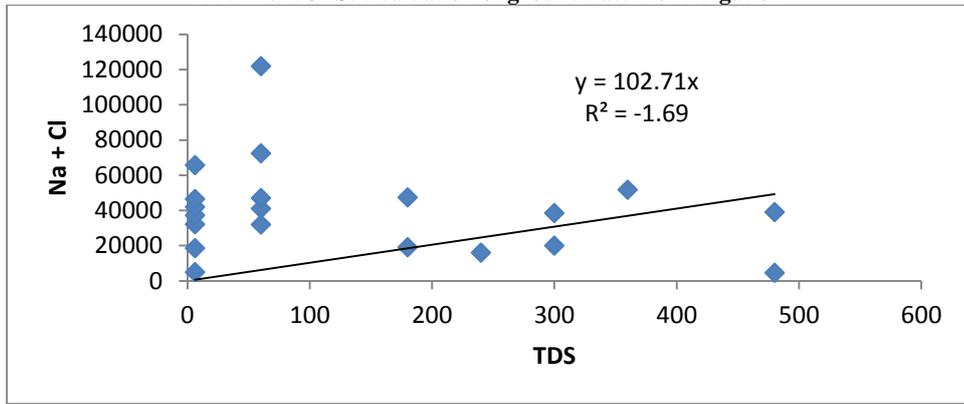
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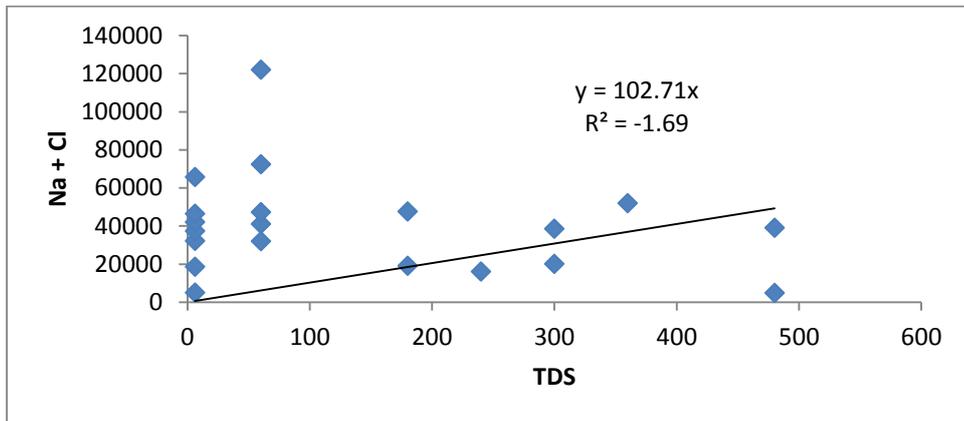
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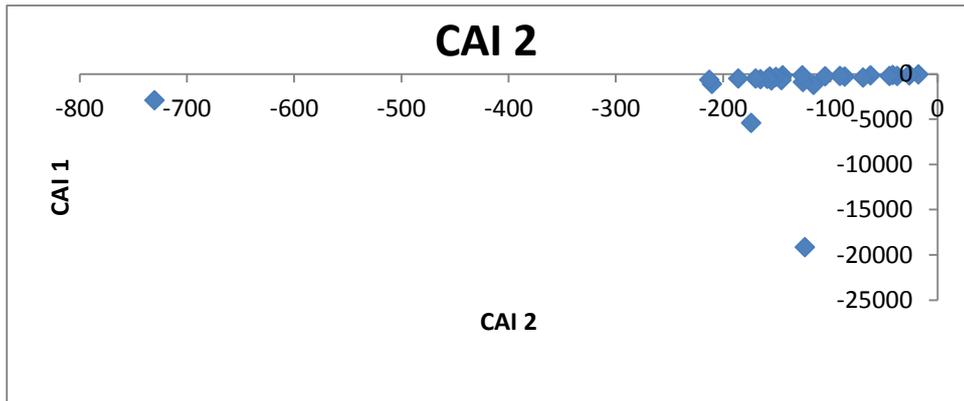
APPENDICES: Evaluation of groundwater for irrigation



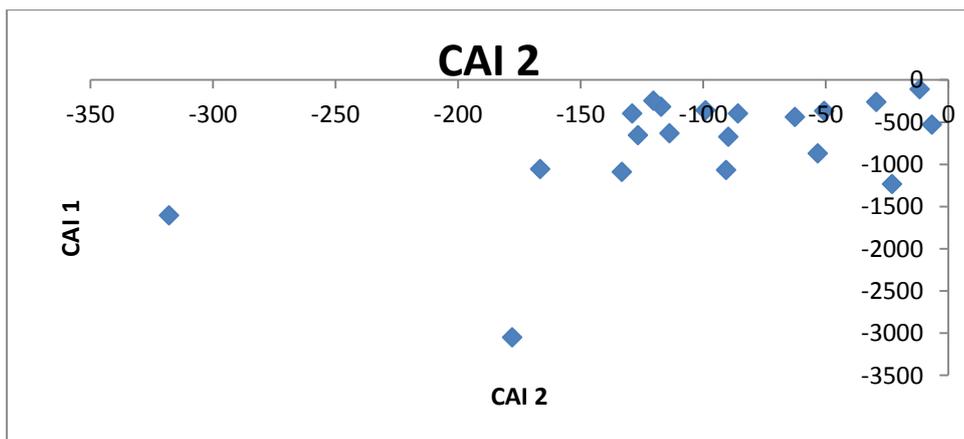
Appendix i: Plot of total dissolve solid (TDS) against (Na + Ca) for basement groundwater



Appendix ii: Plot of total dissolve solid (TDS) against (Na + Cl) for sedimentary groundwater



Appendix iii: Plot of chloro alkaline index 1(CAI 1) against CAI 2 for basement groundwater



Appendix iv: Plot of chloro alkaline index 1(CAI 1) against CAI 2 for sedimentary groundwater