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EVALUATION OF WATER QUALITY FOR IRRIGATION PURPOSES IN ONIKITINBI VILLAGE, OGUN STATE, SOUTHWESTERN,NIGERIA.

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ABSTRACT
The evaluation of groundwater quality is crucial for sustainable agriculture, as it is a primary water source for irrigation. This study discusses the results of examining the groundwater quality and its appropriateness for irrigation in Onikitinbi village, located in the Ogun waterside area of Ogun State, southwestern Nigeria. This was carried out using the irrigation water quality indices (hydrogeochemical and physio-chemical parameters). The indicators considered include the Magnesium Absorption Ratio (MAR), Kelly Ratio (KR), pH, Total Hardness (TH), Total Dissolved Solid, Stiff and Piper's Diagram, and Kelly's ratio. The values obtained were MAR (19.25 to 28.85%, mean of 6.95%), Kelly Ratio (0.11 to.016, mean of 0.13), and pH (6.83 to 7.08, mean of 6.95). Total Hardness (98 mg/L to 266 mg/L, mean of 183 mg/L) and Total Dissolved Solid (40 mg/L to 375 mg/L, mean of 207 mg/L). The Ca-HCO_3^- and Ca-SO_4^{2-} water types from Stiff diagram and Piper's diagram shows that the water sample in the Onikitinbi are from freshwater and Industrial or agricultural sources respectively, while the Gibbs diagram suggests that the main factor controlling the water chemistry is the water-rock interaction. The calculated water indices indicate that the groundwater in the study area meets the required standards for agricultural purposes, specifically irrigation.

Keyword: Groundwater Suitability, Irrigation, Irrigation Water Indices, Onikitinbi village.

I. INTRODUCTION

Water is highly demanded in both urban and rural areas, being a fundamental necessity for human survival, as stated by [1]. It is the main element in the earth that sustains the life of all living organisms [2]. Water can be found in two main forms, either as surface water or as groundwater. Groundwater is the water present in the empty spaces of a geological layer [3]. It is viewed as the primary freshwater source, particularly for the dry and semi-dry areas, because of the minimal rainfall in those regions [4]. According to [5], groundwater is an important natural asset, and as stated by [6], it is a replenishable resource. It is a crucial matter in water resources management and a growing concern for urban areas worldwide [7, 8]. Groundwater plays a crucial role in supporting the lives of plants and animals worldwide, providing water for various uses such as household, agriculture, and industrial purposes [9, 10, 11]. It makes up 43% of irrigation water use worldwide, being viewed as more appropriate for irrigation than surface water [12]. Water has a certain amount of minerals dissolved in it [13]. The dissolved minerals break apart into ions positively charged cations and negatively charged anions [14]. This describes the makeup of chemicals in a water source. The composition of groundwater is influenced by the breakdown of rocks and decomposition and varies over time and location, as well as human activities, according to [15, 16, 17]. The quality of a water source is influenced by its chemical composition, and this impacts its suitability for various uses. Therefore, analyzing its quality is of the utmost significance [18]. The quality of irrigation water refers to water that is appropriate for agricultural use [19]. The mineral content of water used for irrigation is crucial, as an excess of salts in the water can negatively impact soil permeability, structure, and the growth and yield of crops. [20,21]. Given the information presented earlier, this research aims to assess the suitability of groundwater for irrigation in the specified area. This will give the needed information about water quality to implement the essential irrigation techniques for sustainable agriculture.

II. THE STUDY AREA

The study area of Onikitinbi village is situated at 06^{0}40'00''N and 06^{0}50'00''N latitude, and 04^{0}10'00''E and 04^{0}20'00''E longitude. It is located on the Equator and east of the Greenwich Meridian (Fig. 1). The research area is located in the eastern section of the Dahomey basin.

The Dahomey basin in Benin extends across the continental margin of the Gulf of Guinea, from the Volta- Delta in Ghana to the Okitipupa Ridge in Nigeria. It formed during the Mesozoic period because of the separation of the Africa and America plates. The state shares boundaries with Ekiti and

Kogi States to the north, Edo State to the east, Oyo and Ogun States to the west, and the Atlantic Ocean to the south.

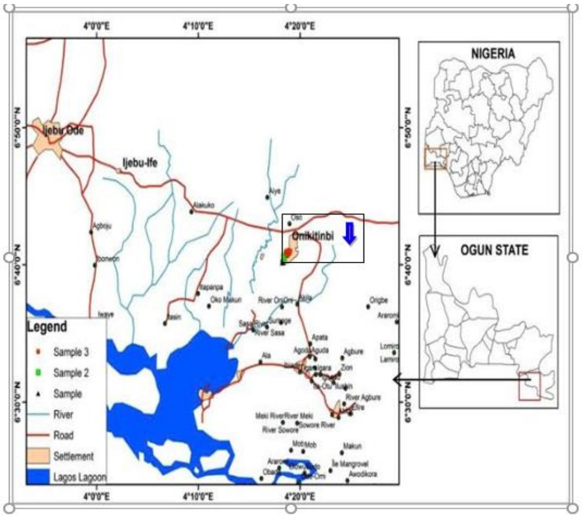

Fig.1. Map showing the location of the study area Onikitinbi

III. MATERIALS AND METHODS

3.1 Sample Collection

A grand total of 10 samples of groundwater (Table 1) were gathered in 500-ml containers made of acid-washed polyethylene throughout the study region, with appropriate preservatives added for storage until the quantitative chemical analysis was finished. In-situ measurements of pH, total hardness, and total dissolved solids were conducted using the HI9811-5 Portable pH/TH/TDS Meter by Hanna Instruments. The containers were filled to the top with water, making sure no air bubbles were caught in the sample. Next, the bottles were sealed with two plastic caps to prevent evaporation, and care was taken to prevent sample agitation during transport to the laboratory following [22]. The specimens were promptly taken to the lab.

3.2 Laboratory Analysis

The major ionic concentrations in the samples were analyzed in the laboratory using standard methods. Calcium and magnesium were determined titrimetrically using standard EDTA, chloride by standard $AgNO_3$ titration, bicarbonate by titration with HCl, and sodium and potassium were determined through flame photometry. Sulfate was determined by the spectrophotometer CL 22D, while nitrate was obtained using an ion-selective electrode. The analytical precision for the major ions was determined by the ionic balance calculated from 100*(cations - anions) ÷ (cations + anions), and the value obtained was ±3.5%, which falls within the acceptable limit of ±5% in accordance with [23].

3.3 Irrigation Quality Index

In order to achieve the objective of the research, the concentration of the major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and anions (CO_3^{-}, HCO_3^{-}, SO_4^{2-}, and Cl^{-}) was converted from milligrams per liter (mg/L) to milliequivalents per liter (meq/L) and used to compute the irrigation index parameters. Groundwater suitability for irrigation purposes in this study was assessed through the magnesium adsorption ratio (MAR), Piper's diagram, stiff diagram, Gibbs diagram, Kelly ratio (KR), total dissolved solids (TDS), total hardness (TH), and pH.

IV. RESULT AND DISCUSSION

4.1 Physiochemical Parameters

a) pH

The groundwater's pH levels ranged from 6.83 to 7.08, averaging 6.95, suggesting it had a fluctuation between mild acidity and mild alkalinity. According to the WHO, the ideal pH range for irrigation and human consumption is between 6.5 and 8.5. All samples within this range show that they are suitable for both irrigation and human consumption due to their low acidity levels (Fig. 2).

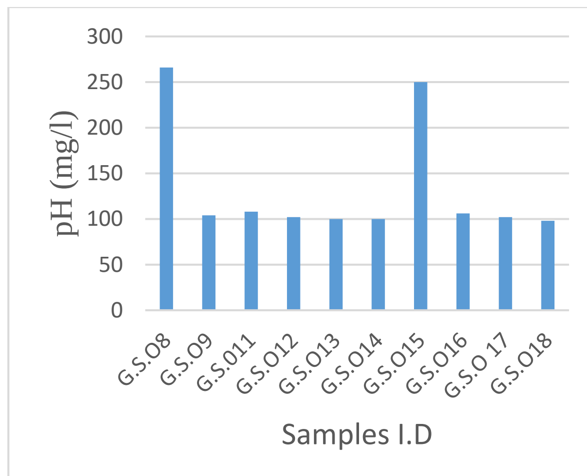

Fig 2. Column chart distribution of pH Values

b) Total Hardness

The level of water hardness is determined by the concentration of ions in the water that have lost two electrons. The composition of a stream or river can indicate the geological characteristics of the surrounding area as well as potential human influence. [24] Below is a graph displaying the total hardness plotted against the different samples. The groundwater samples in the study area have a total hardness ranging from 98 to 266 mg/L, with an average of 183 mg/L. Most locations in the area have TH levels below 150 mg/L, except for G.O.S. 8 and G.O.S. 15, which have levels of 266 mg/L and 250 mg/L, respectively. The elevated values in these areas are a result of the impact of underlying geological formations and human activities in those regions (Fig. 3). The level of calcium, magnesium, and iron in water determines its hardness, typically measured in milligrams of calcium carbonate equivalent per liter [24].

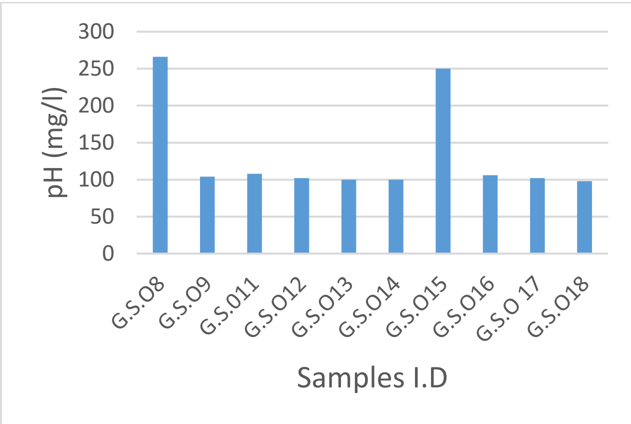

Fig 3. Bar chart of Total Hardness Values

c) *Total Dissolved Solid (TDS)*

This is another significant characteristic for irrigation, with TDS concentrations varying from 40 to 375 mg/L and an average of 207.5 mg/L (Table 1). It is a way to evaluate the total amount of inorganic and organic materials found in water. The TDS levels that are less than 1000 are considered good to excellent for watering plants and will not impact the soil solution's osmotic pressure [25]. This indicates that the samples of water in the study area are good to excellent for irrigation purposes (Fig. 4).

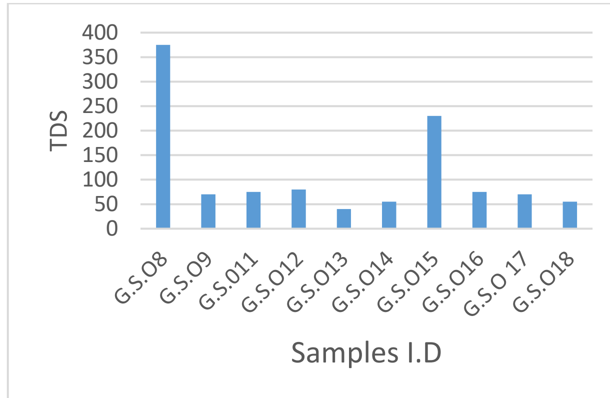

Fig 4. Bar Chart of Total Dissolved Solid

Table 1. Overall Physiochemical and Hydro-chemical Parameters of the Study Area

Sample I. D	pH	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	NO_3^{-}	SO_4^{2-}	Cl^{-}
G.S.O-8	7.02	375	266	78.4	20.02	11.91	8.01	266	0.69	34	39.92
G.S.O-9	6.84	70	104	29.6	9.72	6.42	3.83	104	0.24	28	19.92
G.S.0-11	6.87	75	108	30.4	9.72	6.6	3.57	108	0.28	32	19.96
G.S.O-12	6.85	80	102	29.58	9.16	6.19	3.53	102	0.28	36	21.89
G.S.O-13	6.83	40	100	28.8	8.58	6.11	3.01	100	0.16	34	19.94
G.S.O-14	6.86	55	100	28.01	8.57	6.17	3.86	100	0.25	32	22.9
G.S.O-15	7.08	230	250	79.88	15.44	10.22	6.64	250	0.21	26	29.84
G.S.O-16	6.97	75	106	28.79	9.72	6.51	3.62	106	0.39	30	20.95
G.S.O-17	6.85	70	102	28.01	8.58	6.61	3.81	102	0.41	28	21.05
G.S.O-18	6.84	55	98	28.01	9.15	6.53	3.59	98	0.32	28	19.77
WHO	6.5-8.5	500	150	-	-	200	-	-	50	200	250
Min	6.83	40	98	28.01	8.57	6.11	3.01	98	0.21	26	19.77
Max	7.08	375	266	79.88	20.02	11.91	8.01	266	0.69	36	39.92
Mean	6.95	207.5	182	53.94	14.3	9.01	5.51	182	0.45	31	29.85

Table 2. Results of the Hydrogeochemical of groundwater in the study area

Sample I. D	Cation	Mg/L	Meq/L	Anion	Mg/L	Meq/L
G.S.O-8	Ca^{2+}	78.4	3.92	Cl^-	39.92	1.12
	Mg^{2+}	20.02	1.66	SO_4^{2-}	34	0.71
	Na^++K^+	19.92	0.63	HCO_3^-	266	4.25
G.S.O-9	Ca^{2+}	29.6	1.48	Cl^-	19.92	0.55
	Mg^{2+}	9.72	0.86	SO_4^{2-}	28	0.59
	Na^++K^+	10.35	0.33	HCO_3^-	104	1.66
G.S.O-11	Ca^{2+}	30.4	1.52	Cl^-	19.96	0.55
	Mg^{2+}	9.72	0.81	SO_4^{2-}	32	0.67
	Na^++K^+	10.17	0.2	HCO_3^-	108	1.72
G.S.O-12	Ca^{2+}	29.58	2.4	Cl^-	21.89	0.156
	Mg^{2+}	9.16	0.95	SO_4^{2-}	36	0.168
	$Na^+ + K^+$	9.72	0.35	HCO_3^-	102	2.624
G.S.O-13	Ca^{2+}	28.8	1.44	Cl^-	19.94	0.55
	Mg^{2+}	8.58	0.71	SO_4^{2-}	34	0.71
	$Na^+ + K^+$	14.69	44	HCO_3^-	100	1.6
G.S.O-14	Ca^{2+}	28.01	1.4	C^{l-}	22.9	0.64
	Mg^{2+}	8.57	0.71	SO_4^{2-}	32	0.67
	$Na^+ + K^+$	10.03	0.32	HCO_3^-	100	1.6
G.S.O-15	Ca^{2+}	79.88	3.99	Cl-	29.84	0.83
	Mg^{2+}	15.44	1.28	SO_4^{2-}	26	0.55
	$Na^+ + K^+$	16.86	54	HCO_3^-	250	4
G.S.O-16	Ca^{2+}	28.79	2.4	Cl^-	20/95	0.156
	Mg^{2+}	9.72	0.95	SO_4^{2-}	30	0.168
	$Na^+ + K^+$	10.13	0.35	HCO_3^-	106	2.624
G.S.O-17	Ca^{2+}	28.01	1.4	Cl^-	21.05	0.59
	Mg^{2+}	8.58	0.71	SO_4^{2-}	28	0.58
	$Na^+ + K^+$	10.42	0.33	HCO_3^-	102	1.63
G.S.O-18	Ca^{2+}	28.01	1.4	Cl^-	19.77	0.55
	Mg^{2+}	9.15	0.75	SO_4^{2-}	28	0.588
	Na^++K^+	10.12	0.32	HCO_3^-	98	1.58

4.2 Hydrogeochemical Facies Characteristics

The findings of the groundwater hydrogeochemical measurements in the study area are displayed in Table 2.

a) Piper's Diagram

[26] stated that the Piper diagram is commonly employed for analyzing the geochemical evolution of groundwater. This illustration contains three separate areas: two triangular fields and a diamond-shaped field. Cations are represented as a percentage of total cations in meq/l as a single point on the left triangle, while anions are plotted in the right triangle [27]. The Piper's diagram can identify similarities and differences between surface water samples since water with comparable properties tends to plot together as groups. $Ca\text{-}SO_4^{2-}$ indicates water from industrial or agriculture sources. (Fig. 5).

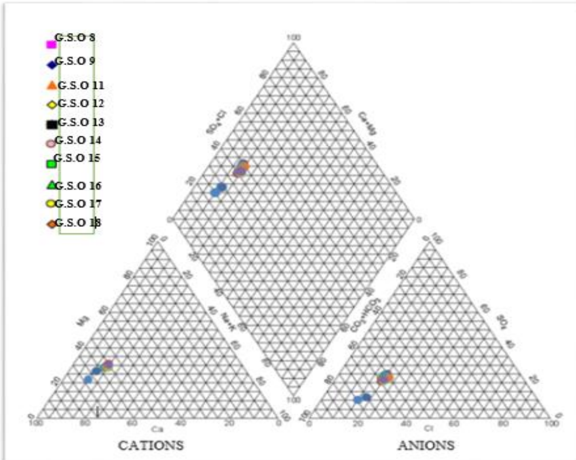

Fig 5. Piper's diagram

b) Stiff Diagram

A stiff diagram shows concentration ratios for separate samples. In 1951, the Stiff system was created by [28]. It is a unique approach to illustrating variations in water and alterations in chemical makeup. Rigid graphs illustrate differences in the levels of Ca^{2+}, Mg^{2+}, $Na^{+}+K^{+}$, Cl^{-}, SO_4^{2-}, and HCO_3^{-} among the eight samples examined in this research. Nevertheless, the rigid diagrams effectively show the average levels of both cations and anions. Meq/l concentrations are shown on the horizontal axis, with cations on the left and anions on the right. The points are connected to create a polygon, as illustrated in (Figs. 6 and 7). The stiff diagram also indicates the main anion and cation in each water sample, as well as a table of dominant anions and cations. The stiff diagram also supports the analysis of Piper's diagram. Stiff diagrams show that calcium and bicarbonate (HCO_3^{-}) are the two main ions present in all samples, located at the extreme ends of both the cation and anion sides.

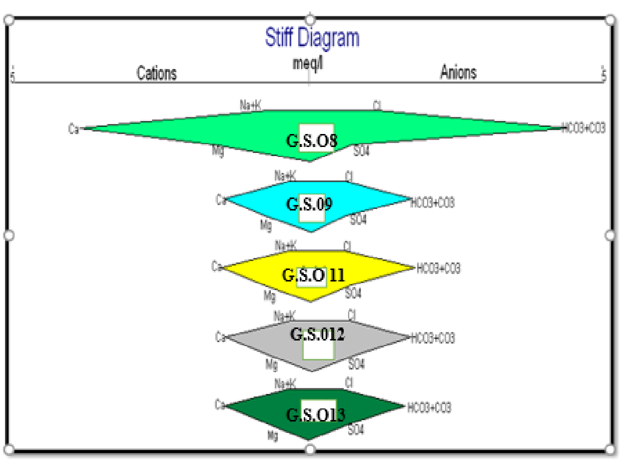

Fig 6. Stiff pattern for water samples G.S.O8 to G.S.O13

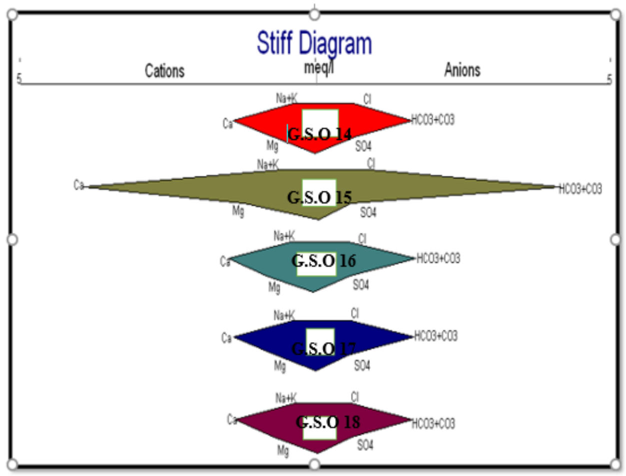

Fig 7. Stiff pattern for water samples G.S.O 14 to G.S.O 18

c) Gibb's Diagram

The quality of groundwater is altered substantially by both weathering and human activities. The Gibbs diagram is commonly employed to determine the connection between the water composition and the lithological properties of an aquifer [29]. The Gibbs diagram displays three separate fields representing dominance in precipitation, evaporation, and rock-water interaction. The three different areas on Gibb's plot are: precipitation dominance, evaporation dominance, and rock dominance. The diagram shows the correlation between TDS and Gibb's ratio for both anions and cations. Gibb's ratio is determined by $(Na^{+}+K^{+})$ / $(Na^{+}+K^{+}+Ca^{2+})$ for cations and $(Cl^{-})/(Cl^{-}+HCO_3^{-})$ for anions. The diagrams below display Gibb's diagram for anions and cations, represented by (Figs. 8 and 9). The data demonstrates that the cations and anions come from the water reacting with chemical elements found in the rocks of the region.

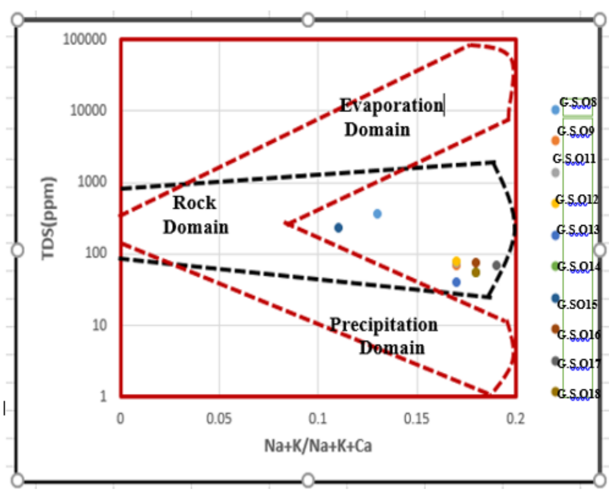

Fig 8. Gibb's Diagram for Cation

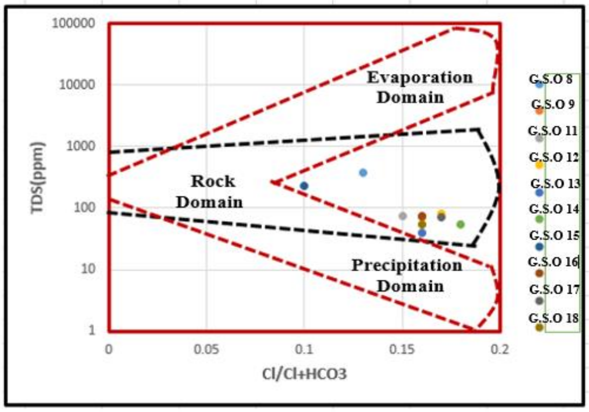

Fig 9. Gibb's Diagram for Anions

d) *Kelley's Ratio*

Kelley's ratio is another factor utilized in evaluating the quality of water and its appropriateness for irrigation [30]. Water samples with Kelley's greater than 1 are considered inappropriate for irrigation purposes. The Kelly ratio for each sample is shown in (Fig. 10). The water samples in the study area have a value less than 1, which means they are appropriate for irrigation use.

Table 3. Kelley's ratio distribution

Sample	Kelly's ratio
G.S.O-8	0.11
G.S.O-9	0.16
G.S.O-11	0.15
G.S.O-12	0.14
G.S.O-13	0.15
G.S.O-14	0.12
G.S.O-15	0.11
G.S.O-16	0.13
G.S.O-17	0.14
G.S.O-18	0.15

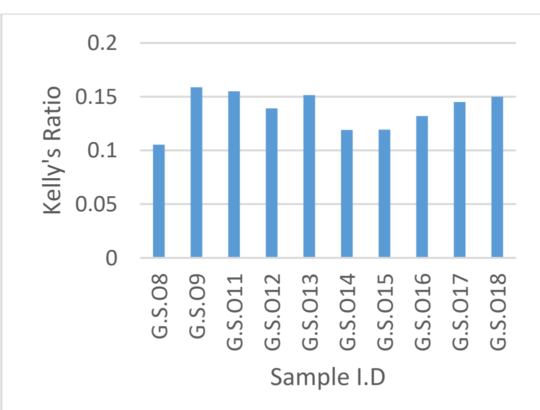

Fig 10. Column chart distribution of Kelley's Ratio Values.

e) *Magnesium Adsorption Ratio*

MAR is used in conjunction with Kelley's ratio, as both are parameters for irrigation. A magnesium level of over 50% is essential for irrigation to prevent a decrease in crop yield for planted crops. The data is illustrated in the diagrams shown in (Fig. 11). All samples have analyses indicating less than 50%, indicating that the water is appropriate for irrigation.

Table 4. Magnesium Adsorption Ratio

Sample	Magnesium Adsorption ratio (%)
G.S.O-8	19.25
G.S.O-9	22.81
G.S.0-11	22.58
G.S.O-12	25.02
G.S.O-13	21.57
G.S.O-14	22.24
G.S.O-15	21.25
G.S.O-16	25.85
G.S.O -17	25.77
G.S.O-18	25.65

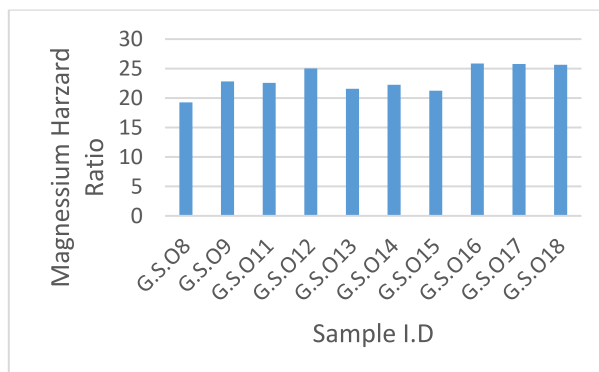

Fig 11. Bar Chart of Magnesium Adsorption Ratio

V. CONCLUSION

This study assesses the water quality for farming purposes (irrigation) in Onikitinbi village (study area), Ogun water-side area of Ogun State, Southwestern Nigeria, through examination of its water quality analysis and hydro-chemical characteristics. The water quality analysis (pH, TH, and TDS) shows that all the water samples that were taken from the study area are suitable for farming purposes (irrigation), except for the TH values for G.S.O. 8 and G.S.O. 15. The Ca-HCO_3^- and mixed Ca-Mg water types can be identified from the freshwater water by the piper diagram and stiff diagram. While Gibbs suggests that the main factor controlling the water chemistry is the water-rock interaction, which includes mineral dissolution and chemical weathering, The Kelly's ratio result shows that the water samples have a value less than 1, which means they are appropriate for irrigation use. The MAR results indicate that all the water samples have values less than 50%, indicating that the water is appropriate for irrigation. It is recommended that a routine check be done to assess the quality of the groundwater for effective monitoring and to ascertain the different methods to put in place to control the pollution of the water.

REFERENCES

[1] Gupta, S., & Gupta, S. K., A Critical Review on Water Quality Index Tool. Genesis, Evolution and Future directions. Ecological Informatics 63(2021). 101299. https: //doi.org/10.1016/j.ecoinf.2021.101299.

[2] Aouiti, S., Azaza, F. H., Melki, F. E., Hamdi, M., Celico, F., & Zammouri, M., Gorundwater Quality Assessment for Different uses using various Water Quality Indices in Semi-Arid Region of Central Tunisia. Environmental Science and Pollution Research, 28(2021). 46669-46691. https://doi.org/10.1007/s11356-020-11149-5.

[3] Todd, D. K., & Mays, L. W. (2005). Groundwater Hydrology (3rd, Ed.). John Wiley and Sons.

[4] Kayemah, N., Al-Ruzuoq, R., Shanableh, A., & Yilmaz, A. G. (2021). Evaluation of Groundwater Quality using Groundwater Quality Index (GWQI) in Sharjah UAE.E3S web of conferences, 241(2021) 01005.https://doi.org/10.1051/e3sconf/202124101005.

[5] Hossain, M., & Patra, P. K., Investigation of Groundwater Quality for Agricultural use in a Lateritic Soil Belt. Indian Journal of Environmental Protection, 41 (2021) 34-41.

[6] Mostaza-Colado, D., Carreno-Conde, F., Rasines-Ladero, R., & Lepure, S., Hydrogeochemical Characterisation of a shallow Alluvial Aquifer: 1 Baseline for Groundwater Quality Assessment and Resource Management. Science of the Total Environment., 639(2018)11101125.https://doi.org/10.1016/j.scitotenv.2018.05.236.

[7] Sutadian, A. D., Multil, N., Yilmaz, A., & Perera, C., Development of River Water Quality Indices – A Review. Environmental Monitoring and Assessment, 188(2016)58. https://doi.org/10.1007/s10661-015-5050-0.

[8] Verma, P., Singh, P. K., Sinha, R. R., &Tiwari, A. K., Assessment of Groundwater Quality Status by using Water Quality Index (WQI) and Geographic Information System (GIS) approaches: a Case Study of the Bokaro District, India. Applied Water Science, 10(2020). 27. https://doi.org/10.1007/s13201-019-1088-4.

[9] Jamshidzadeh, Z. (2020). An Integrated Approach of Hydrogeochemistry, Statistical Analysis and Drinking Water Quality Index for Groundwater Assessment. Environmental Processes. https://doi.org/10.1007/s40710-020-00450-7.

[10] Oinam, J. D., Ramanathan, A., & Singh, G., Geochemical and Statistical Evaluation of Groundwater in Imphal and Thoubal District of Manipur, India. Journal of Asian Earth Sciences, 48(2012)136-149. https://doi.org/10.1016/j.jseaes.2011.11.017.

[11] Ramakrishnaiah, C. R., Sadashivaiah, C., & Ranganna, G., Assessment of Water Quality Index for the Groundwater in Tumkur Taluk, Karnataka State, India. E-Journal of Chemistry, 6(2009), 523-530.

[12] Siebert, S., Burke, J., Faures, J., Frenken, K., Hoogeveen, J., P, P. D., & Portmann, F., Groundwater use for Irrigation-A Global Inventory. Hydrol. Earth Syst. Discuss.,7(2010), 3977-4201.

[13] Mirabbasi, R., Mazloumzadeh, S. M., & Rahnama, M. B., Evaluation of Irrigation water Quality using Fuzzy Logic. Research Journal of Environmental Sciences, 2(2008), 340-352.

[14] Rubini, S., Kumar, V. S. H., & Gowsick, T. (2020). Multivariate Statistical Technique in Water Quality Determination: A Critical Review and Assessment of Parameter Datas. TEST Engineering and Management., 83.

[15] Abimbola, A. F., Odukoya, A. M., & Olatunjia, A. S. , Influence of Bedrock on the Hydrogeochemical Characteristics of Bedrock of groundwater in Northern Part of Ibadan Metropolis. Journal of the Nigeria Association of Hydrogeologists, 13(2002)1-6.

[16] Drissa, S. T., Ernest, A. K., Marie-Solange, O. Y., Gbombee, S., & Nagnin, S., A multivariate Statistical Analysis of Groundwater Chemistry Data in the Highest Bandama Basin at Tortiya (Northern Cote D'Ivorie). Earth Resources, 1(2013), 72-77. https://doi.org/10.12966/er.09.03.2013.

[17] Raghunath, H. M. (2006). Groundwater (3rd ed.). New Age International (P) Limited Publishers.

[18] Beg, A. A. F., Awadh, S. M., Thamer, M. B., & Al-Sulttani, A. H., Assessment of Groundwater Quality for Drinking Purposes using Water Quality Index and Identifying the Affecting Mechanism in Rashdiya, Central

Iraq. Iraqi Geological Journal, 54(2021), 20-32. https://doi.org/10.46717/igj.54.1F.3ms-2021-06-23.

[19] Adegbola, G. A., Soyewo, L. T., Odey B. O., & Ajani, A. B., River Water Quality Assessment and it's Suitability for Irrigation Purpose. FUDMA Journal of Sciences, 5(2021)413-419. https//doi.org/10.33003/ fjs-2021-0503-770.

[20] Badmus, G. O., Akinyemi, O. D., Gbadebo, A. M., & Oyedepo, J. A. (2020). Hydrochemical Analysis of Groundwater Quality along the Coastal Aquifers in part of Ogun Waterside, Ogun State, Southwestern Nigeria.Heliyon,6,112.https://doi.org/10.1016/j.heliyon.2020.e05661.

[21] Murty, V. V. N., & Jha, M. K. (2011). Land and Water Management Engineering (6th ed.). KALYANI Publishers.

[22] AOAC (1990): Official Methods of Analysis of the Association of Analytical Chemists. Edited By Kenneth Helrich.

[23] APHA. (1995). Standard Methods for the Examination of Water and Wastewater. Washington, DC, USA.

[24] Sawyer, G. N and McCarthy, D. L., (1967). Chemistry of sanitary Engineers. McGraw Hill,New York, 518.

[25] NSDWQ (2017): Nigerian Standard for Drinking Water Quality. Nigerian Industrial Standard: Abuja, Nigeria. NIS: 554, 1-14.

[26] Krishna kumar, S., Logeshkumaran, A., Magesh, N.S., Gordon P.S. and Chandrasekar, N. "Hydro-geochemistry and application of water quality index for groundwater quality assessment, Anna Nagar, part of Chennai city, Tamil Nadu, India". Applied water science 5(2015) pp 335-343.

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

[28] Stiff Jr., H. A. "The interpretation of chemical water analysis by means of patterns". Journal of Petroleum Technology, 3(1951), pp 15-16.

[29] Gibbs R.J.,"Mechanism controlling world water chemistry". Journal of Sciences170(1970)795–840.

[30] Kelly, W. P. , Use of Saline Irrigation Water. Soil Sci., 94(1963), 355-359.