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Physico-Chemical Assessment of Water Quality in the Gidan Gulbi Shallow Floodplain Aquifer, Northwestern Nigeria

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Abstract Water quality of shallow floodplain aquifers in the Gidan Gulbi Fadama area of Gada, Sokoto State, Nigeria was assessed using water quality pollution indices for both irrigation and domestic use. Drinking water quality was assessed using pollution indices including concentration factor (CF), contamination degree (CD) and heavy metal pollution index (HPI), while irrigation water quality parameters such as sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), soluble sodium percentage (SSP), Kelly ratio (KR), residual sodium carbonate (RSC), permeability index (PI) and total hardness (TH) were used to evaluate the suitability of the water for irrigation purposes. Five heavy metals (Fe, Zn, Mn, Cr, and Cd) were selected to be assessed alongside other inorganic elements. The CF shows low intensities of contamination for Mn, Cr, and Zn while Fe and Cd have high and very high contamination intensities respectively. The results of CD and HPI indicate moderate to high contamination in the study area. The Fe most likely originates from the surrounding rocks of Taloka Formation, during fluid-rock interaction while the high degree of Cd contamination suggests an anthropogenic source. Given the land use pattern in the study area, the most likely source of the anthropogenic Cd is from pesticides, herbicides and fertilizers utilized for agricultural purposes. The areas with highest intensity of contamination (GW2, GW4 and GW7) are within or proximal to farmlands, consistent with the earlier inferred anthropogenic (agriculture) source for the major heavy metal pollutant (Cd). Furthermore, all of the water in the study area falls within the Ca-Mg/HCO_3 type as revealed by the piper diagram and Schoeller plots, moreover, except for the total hardness (with a mean level of 253.13 mg/l), all other irrigation quality parameters suggest that the water is suitable for irrigation.

Keywords: *water quality, shallow floodplain aquifers, pollution indices, heavy metals, irrigation, drinking water*

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1. Introduction

Shallow flood plain aquifers constitute one of the most important water sources for both irrigation and domestic purposes [1]. The potential of such aquifers was evaluated within the Sokoto basin of Nigeria and were ascertained to hold high groundwater potentials [2]. However, shallow floodplain aquifers are more vulnerable to contamination than deeply-seated confined aquifers [3]. Moreover, agricultural activities are a very common practice within these floodplains, which are locally referred to as Fadamas [4,5], with half of the total irrigation farming in Nigeria taking place within Fadama areas [6]. Application of fertilizers, herbicides and pesticides, contribute to heavy metals’ contamination within these areas. Heavy metals of both geogenic and anthropogenic sources pose great health risks and affect water quality especially in high concentrations [7]. However, some other metals such as Lead and Cadmium are harmful even at very low concentrations [8,9].

The major source of drinking water within the study area is the shallow floodplain aquifer, as obtained in many other rural parts of northern Nigeria, due to the seasonal nature of surface water bodies in these areas [10]. Generally, the water quality is not assessed before use; thereby exposing these communities to potentially contaminated water. The health effect of these contaminants is unfortunately under reported due to the absence of proper health care facilities in these rural areas and the lack of trained personnel that can recognize and document such health effects. Heavy metal toxicity can result in damaged or reduced mental and central nervous function, damaged reproductive system, lower energy levels, damage to blood composition, lungs, kidneys, liver, and other vital organs [11]. Some of these heavy metals have been reported to be carcinogens [12]. Heavy metals have resulted to death of adults and children as it was the case in some rural villages in Zamfara State in the year 2010 [13].

This study was undertaken to assess the heavy metal contamination levels of the shallow aquifer of the Gidan Gulbi Fadama area and also assess the suitability of the groundwater in the area for irrigation purposes. Based on preliminary testing, five heavy metals (Fe, Zn, Mn, Cr, and Cd) were selected to be assessed alongside other inorganic elements.

2. Geology of the Study Area

The study area covers about 60 Km^2 and is bounded by latitudes N 13° 35' 00" to N 13° 39' 00" and longitudes E005° 43' 30" to E005° 46' 00" and it lies within the Nigerian sector of the Iullemmeden basin. The sediments of the Iullemmeden Basin were accumulated during four main phases of deposition. Overlying the Pre-Cambrian Basement unconformably, is the Illo/ Gundumi Formation, made up of grits and clays and constitutes the Pre-Maastrichtian "Continental Intercalaire" of West Africa. They are overlain unconformably by the Maastrichtian Rima Group, consisting of mudstones and friable sandstones (Taloka and Wurno Formations), separated by the fossiliferous, shelly Dukamaje Formation. The Dange and Gamba Formations (mainly shales) separated by the calcareous Kalambaina Formation, constitutes the Palaeocene Sokoto Group. The overlying continental Gwandu Formation forms the Post-Palaeocene Continental Terminal. These sediments dip gently and thicken gradually towards the northwest, with a maximum thickness of over 1,200m near the frontier with Niger Republic [14]. The topography is a gently undulating plain with an average elevation varying from 250 to 400 m above sea-level. This plain is occasionally interrupted by low hills with flat top.

The rocks encountered in the study areas fall within the Taloka and Dukamaje Formations (Figure 1). Taloka Formation is mostly made up of siltstone with thin intercalations of shale towards the top, sedimentary structures observed on the Taloka Formation include load cast, bioturbation structures, and cross-bedding. The Dukamaje Formation overlies the Taloka Formation and it is majorly dark grey shale which is gypsiferous in most locations. The Dukamaje Formation has about 2 meters of limestone towards the top [15], although only a thin layer (30cm) of the limestone was observed in the study area (Figure 2). Both Formations have ferruginized capping and thin iron rich strata were observed on the Taloka Formation. The Fe rich strata could be representing intra-formational unconformities.

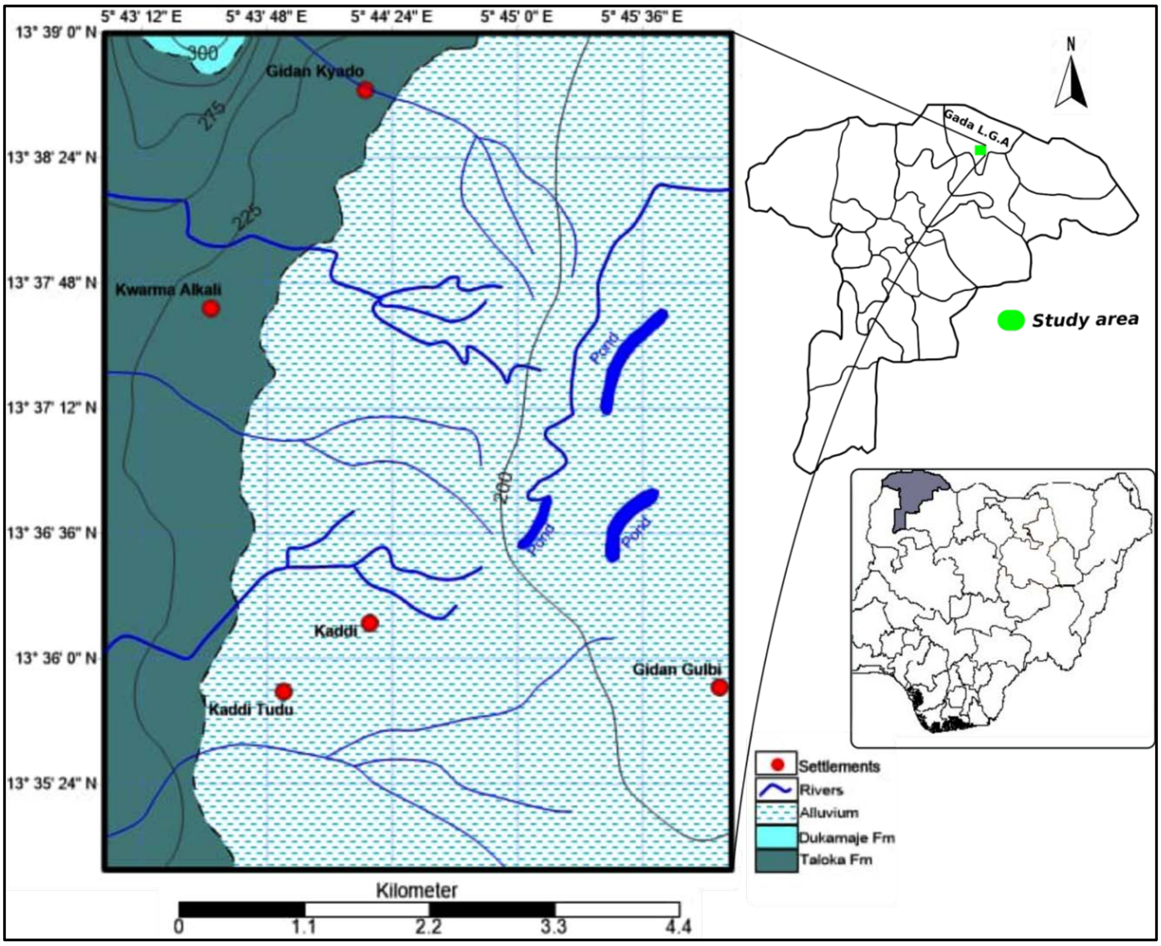

Figure 1. Geologic map of the study area

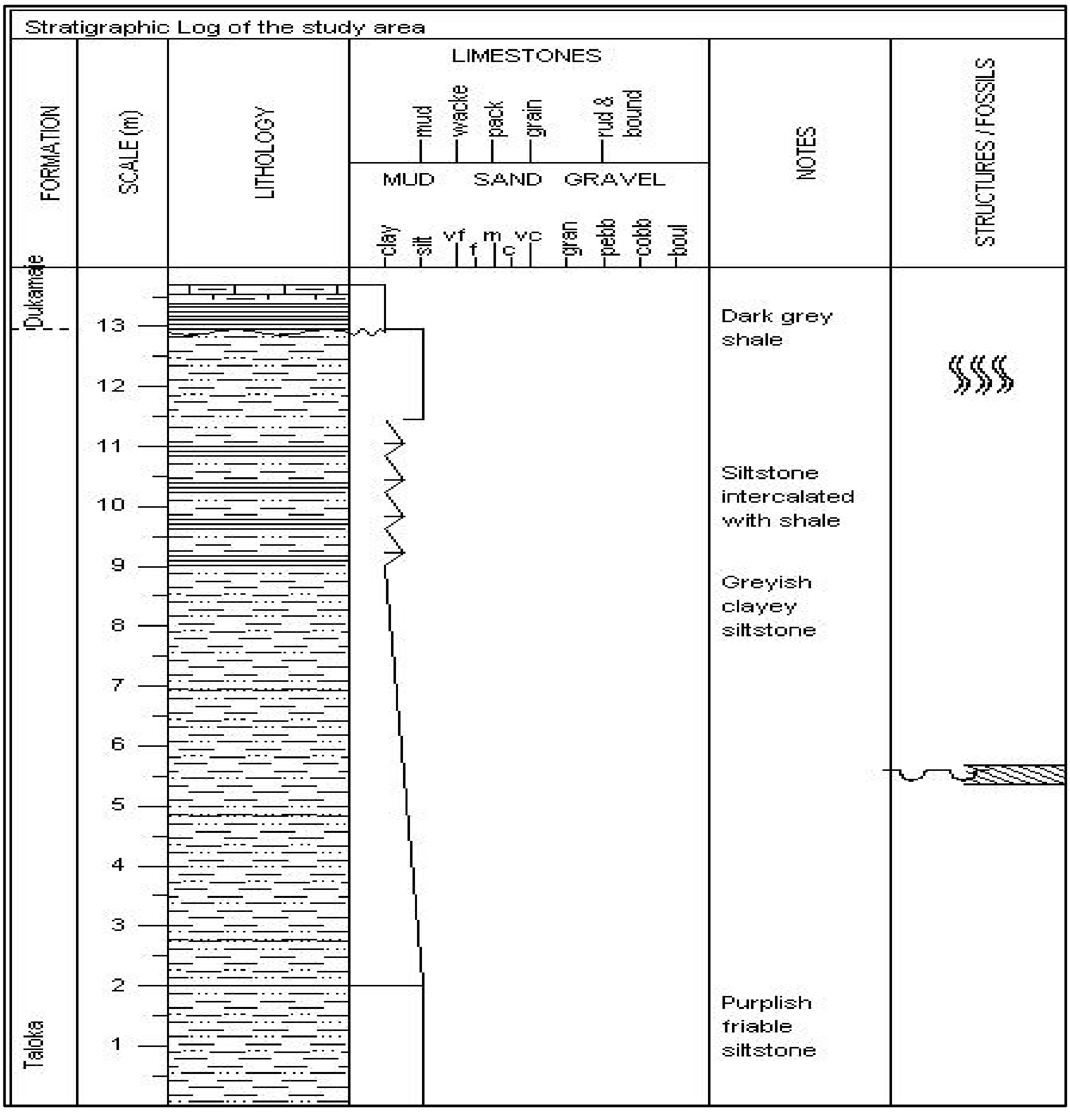

Figure 2. Stratigraphic log of Taloka and Dukamaje Formations as observed in the study area

3. Methodology

Field mapping and sample collection: Water samples were obtained in **duplicates** from 11 hand-dug and tube wells that currently serve as sources of drinking and irrigation water in the study area. A clean and chemically inert container was used to draw out water from the wells in a controlled fashion. The samples for heavy metal analysis were acidified with concentrated HNO_3 according to the guidelines of the American Public Health Association [16]. Critical parameters such as pH, EC, TDS and Temperature were taken on site with the aid of a multi meter. Obtained water samples were taken to the laboratory and stored in a refrigerator until all analyses were completed within seven days.

Multi-elemental Analysis: Major ions were determined using photo-titrimetry and titration while trace element concentration was measured using the Atomic Adsorption Spectrometer (AAS).The samples were filtered (< 45 µm syringe/filter paper) and diluted to volume prior to sample aspiration to avoid clogging the sample introduction system. The obtained result was compared to relevant water quality standards.

Pollution indices for drinking water quality: Heavy metal pollution indices such as Concentration Factor (CF), Contamination degree (CD) and Heavy metal Pollution Index (HPI) were used to assess the drinking water quality in terms of heavy metal pollution.

- *Contamination Factor* (CF)

The contamination factor (CF) was used to determine the contamination status of the well water in the study area. The C*f* value was postulated by [17] and used to describe intensity of contamination. The C*f* was calculated using the equation;

$$Cf = C_{metal} / C_{Background\ value} \qquad (1)$$

Where CF = Contamination Factor, C_{metal} = metal concentration in water and $C_{Background\ value}$ = background value of metal

- *Contamination Degree* (CD)

Contamination degree is defined as the summation of all contamination factors; it provides information on the intensity contamination caused by the combined effect of all metals present in the groundwater.

$$Mathematically\ Cd = \sum Cf \qquad (2)$$

Where CD = Contamination degree and CF = Contamination factor.

• *Heavy metal Pollution Index* (HPI)

HPI provides a holistic depiction of water quality based on heavy metal content, HPI is calculated in two steps and it utilizes the weighted arithmetic quality mean method. The first step in HPI evaluation is to establish a rating scale for each parameter of interest thus assigning a weightage to it. Secondly, a pollution parameter on which the index is to be based is selected. The value inversely proportional to the recommended standard for each corresponding parameter is mostly used for the rating system and is adopted in this study [18]

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (3)$$

where *Wi* is the unit weightage (1/Si), *Si* is the highest permitted value for drinking water, *n* is the number of parameters considered and *Qi* is the sub-index of the i-th parameter, and calculated by;

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{S_i - I_i} \times 100 \quad (4)$$

where *Mi* is the monitored value of heavy metal and *Ii* is the desirable maximum value.

It should be noted that the negative sign between *Mi* and *Ii* indicates the numerical difference between the two values only and thus the algebraic sign is ignored.

Pollution indices for irrigation water quality: Irrigation water quality parameters such as Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Soluble Sodium Percentage (SSP), Kelly Ratio (KR), Residual Sodium Carbonate (RSC),Permeability Index (PI) and Total Hardness (TH) were used to assess the suitability of the water for irrigation purposes. The parameters were calculated using the formulas stated below.

The laboratory results obtained in mg/l were converted to meq/l before being applied in the under listed formulas:

$$\mathbf{SAR} = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad (5)$$

(equation was postulated by [19])

$$\mathbf{MAR} = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100 \quad (6)$$

(equation was given by [20]).

$$\mathbf{SSP} = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} * 100 \quad (7)$$

(equation was given by [21]).

$$\mathbf{KR} = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (8)$$

(equation was postulated by [22]).

$$\mathbf{RSC} = (HCO_3^- + CO_3^{2-}) - Ca^{2+} \quad (9)$$

(equation was given by [23]).

$$\mathbf{PI} = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} * 100 \quad (10)$$

(equation was postulated by [24])

$$\mathbf{TH} = (Ca^{2+} + Mg^{2+}) * 50 \quad (11)$$

(equation was by [25]).

Aqua Chem computer software was used to plot Piper diagram and Schoeller plots which were used to classify the groundwater into facies according to their geochemistry.

4. Result and Discussion

The result of the chemical analysis revealed that the level of Fe, Cd and PO_4^{2-} in most of the sampling locations exceeded the safe limits stipulated by the Nigerian Standard for Drinking Water Quality [8] and the Food and Agriculture Organization standard for irrigation [26]. All other monitored parameters appear to largely fall within the safe limits of both standards (Figure 3).

Table 1. Physico-chemical parameters of groundwater of the study area

	Ph	EC µs/cm	TDS mg/l	Na^+ mg/l	K^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^- mg/l	HCO_3^- mg/l	SO_4^{2-} mg/l	PO_4^{2-} mg/l	Fe mg/l	Mn mg/l	Zn mg/l	Cr mg/l	Cd mg/l
GW 1	6.7	418	205	0.4	2.2	68	29	1.8	20	0.23	0.09	0.987	0.046	0.184	0.042	0.016
GW 2	6.4	540	265	0.5	2.5	66	30	1.4	28	0.21	0.16	1.956	0.018	0.157	0.034	0.039
GW 3	6.5	516	258	0.6	2.4	66	32	1.5	26	0.21	0.12	0.832	0.023	0.17	0.052	0.013
GW 4	6.5	519	255	0.4	0.9	16	20	2.0	20	0.08	0.14	1.890	0.041	0.13	0.043	0.038
GW 5	6.7	515	252	0.5	0.6	17	21	2.2	20	0.07	0.13	0.673	0.009	0.17	0.033	0.021
GW 6	6.6	200	100	0.6	1.0	14	19	2.2	21	0.06	0.15	0.883	0.142	0.25	0.038	0.011
GW 7	6.6	192	100	0.5	1.3	66	32.4	2.0	20	0.12	0.15	1.886	0.041	0.15	0.071	0.036
GW 8	6.5	190	97	0.4	3.4	66	33.5	2.5	22	0.14	0.15	0.554	0.172	0.56	0.062	0.017
GW 9	6.8	193	90	0.7	3.3	69	30.8	3.0	31	0.17	0.18	0.921	0.183	0.71	0.029	0.016
GW 10	6.2	300	148	0.6	3.5	72	34	2.8	30	0.17	0.14	0.945	0.074	0.75	0.037	0.021
GW 11	6.9	303	150	0.5	3.3	72	36	2.9	29	0.15	0.18	0.936	0.035	0.66	0.043	0.014

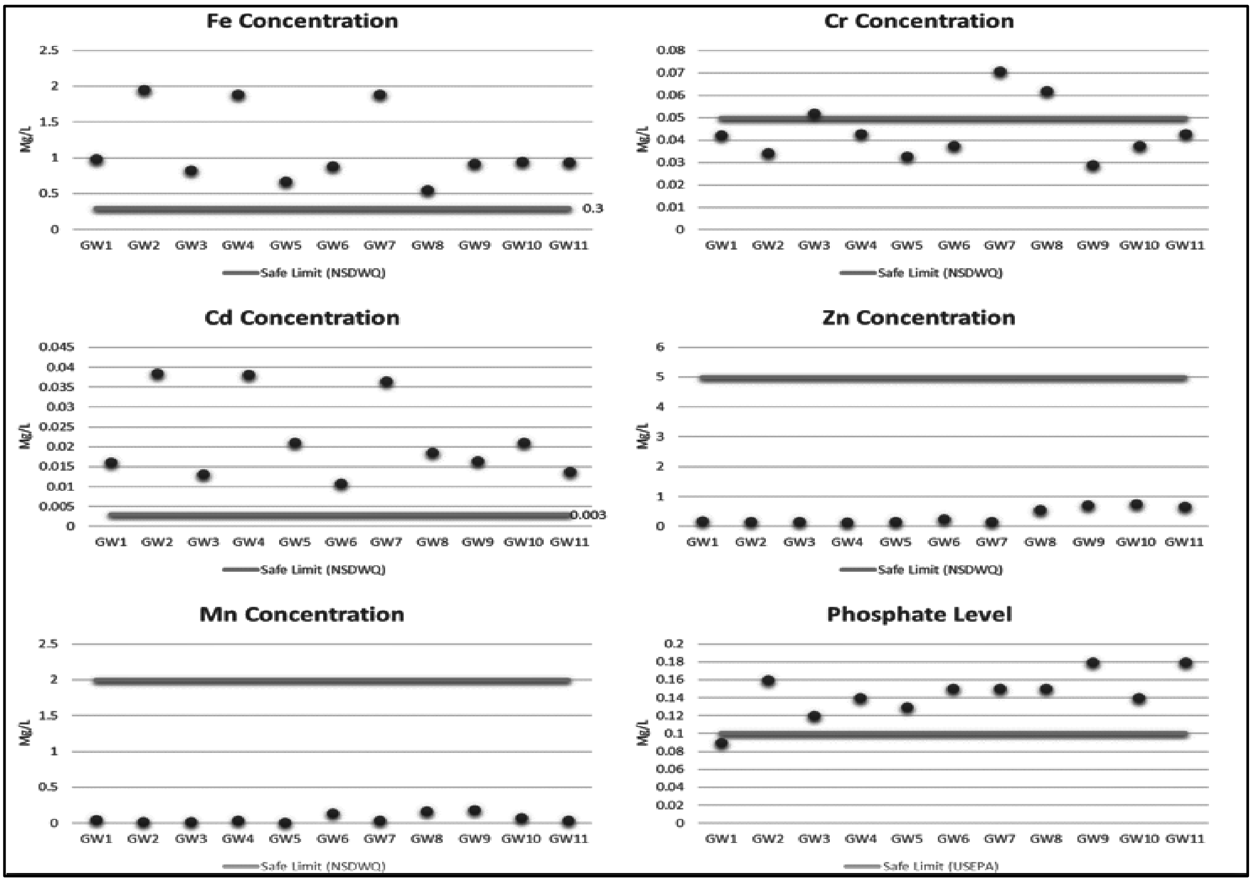

Figure 3. Graphical presentation of some selected physico-chemical parameters

However, to further ascertain the level of contamination, some ecological pollution indices were employed.

4.1. Drinking Water Pollution Indices

Contamination Factor: The calculated contamination factor revealed low intensities of contamination for Mn, Cr, and Zn. Fe has high contamination intensity, while Cd has very high contamination intensity (Table 2). CF less than 1 is considered low, a range of 1 to 3 is considered moderate, 3 to 6 is high, while above 6 is considered very high [17]. In terms of heavy metal contamination, Cd and Fe appear to be the major contaminants in the study area. The Fe is most likely sourced from the geology of the area (Taloka Formation) during rock-water interaction while the high degree of Cd contamination suggests anthropogenic source. Given the land use pattern in the study area, the most likely source of the anthropogenic Cd is from pesticides, herbicides and fertilizers utilized for agricultural purposes.

Table 2. Mean concentration factors of heavy metals in groundwater of the study area

Contaminant	Mean Cf	Remark
Fe	3.78	High contamination
Mn	0.36	Low contamination
Zn	0.12	Low contamination
Cr	0.88	Low contamination
Cd	7.41	Very High contamination

Contamination Degree: The calculated contamination degree suggests moderate to high degree heavy metal contamination in all of the sampling locations, with GW2, GW4 and GW7 being the most contaminated (Table 3). C*d* less than 6 is considered low, a range of 6 to 12 is considered moderate, 12 to 24 is high, while above 24 is considered very high [17].

Table 3. C*d* and HPI at each sampling point in the study area

Sample ID	CD	Remark	HPI	Remark
GW1	9.83	Moderate	506.95	High
GW2	20.18	High	1195.57	High
GW3	8.38	Moderate	415.52	High
GW4	20.11	High	1183.62	High
GW5	10.04	Moderate	655.42	High
GW6	8.12	Moderate	343.07	High
GW7	20.13	High	1137.57	High
GW8	10.34	Moderate	585.68	High
GW9	10.30	Moderate	514.79	High
GW10	11.55	Moderate	656.26	High
GW11	8.97	Moderate	433.24	High

Heavy metal Pollution Index (HPI): The HPI calculated for each sample location is presented in Table 3. Even though the HPI result suggests high contamination in all of the sampling locations, GW2, GW4 and GW7 are distinctively the most contaminated sample points. The HPI for the whole study area was also calculated and presented in Table 4. The result confirms the high contamination level calculated for each sampling point. The critical pollution index for drinking water is stipulated as 100 [18], although this will depend on purpose, i.e. the critical pollution index for drinking water will differ from that of irrigation water.

Table 4. Calculation for HPI of 11 groundwater samples of the study area

Contaminant	(M) Mean Concentration (ppb)	(Si) Standard (ppb) (NSDWQ, 2015)	(Wi) Weightage 1/S	(I) Ideal (ppb) (Prasad and Bose, 2001)	(Qi) Sub index	(Wi*Qi)
Fe	13465.7	300	0.0033	100	6,682.5	22.05
Mn	784	200	0.005	100	684	3.42
Zn	3891	5000	0.0002	3000	44.55	0.0089
Cr	484.1	50	0.02	-	968.2	19.36
Cd	244.5	3	0.3333	-	8,150	2716.40
			0.3616			**2761.24**

HPI = 2761.24/0.3616 = 7636.

The result for both Cd and HPI suggested moderate to high level of heavy metal contamination of groundwater in the study area. Interestingly, the areas with highest intensity of contamination (GW2, GW4 and GW7) are on or proximal to farmlands, this is consistent with the earlier inferred anthropogenic (agriculture) source for the major heavy metal pollutant (Cd) in the study area.

4.2. Irrigation Water Pollution Indices

Total Hardness (TH): The total hardness of all water samples varied from 113.12 mg/l to 327.78 mg/l with a mean level of 253.13 mg/l (Table 5). According to [27], the ideal water TH required for irrigation purpose ranges between 50mg/l to 150mg/l, thus water with total hardness above 150mg/l is considered unsuitable for irrigation. Eight of the obtained water samples have TH values that are unsuitable for irrigation. The TH is a function of the concentration of Ca and Mg in the water samples and presence of high calcium and magnesium ions could be related to the geology of the study area (Limestone of the Dukamaje Formation). Irrigating farmlands with water with high TH affect the ability of plant to extract nutrients, increase the salinity of soil and clogs irrigation pipes

Sodium Adsorption Ratio (SAR): The calculated SAR values ranged from 0.01 to 0.02 meq/l (Table 5). SAR is utilized to evaluate the concentration of Sodium in relation to the concentrations of Magnesium and Calcium. It accesses the potential of the water to cause damages in the soil structure and permeability over a long period of time. According to FAO standards [26], irrigation water should have SAR value below three. All of the groundwater samples have SAR values that are far below three, thus suitable for irrigation.

The SAR values together with the EC values was used to plot a salinity hazard diagram [19], which shows that most of the water samples fall under the C2-S1 category, signifying low sodium hazard and medium salinity hazard (Figure 4).

Magnesium Adsorption Ratio (MAR): The calculated MAR values ranged from 41.29% to 69.12% with a mean value of 50.35% (Table 5). MAR measures the concentration of magnesium in relation to calcium. Usually the concentration of calcium and magnesium are expected to be in some form of equilibrium. However, when the concentration of magnesium in irrigation water is significantly higher than that of calcium, the soil becomes more saline and adversely affect crop yield [11]. The FAO standard for irrigation water suggests that MAR value of less than 60% is most suitable for irrigation. Only three water samples have MAR values slightly above 60%, thus the groundwater of the study area can be categorized as suitable for irrigation in terms of MAR.

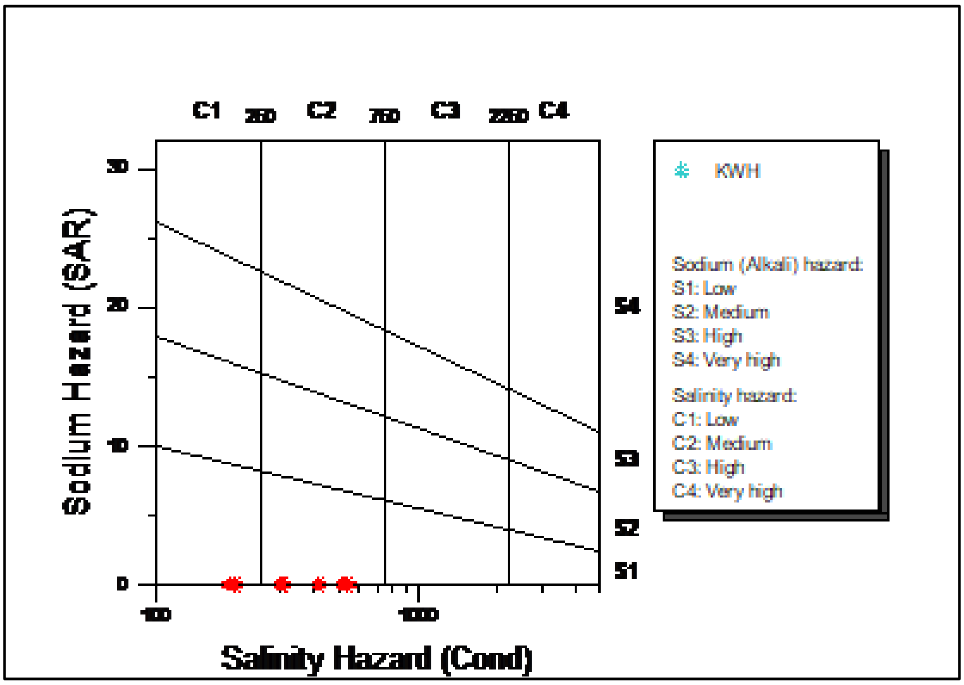

Figure 4. Salinity Hazard Diagram

Table 5. Irrigation water quality parameters for each sampling location

SAMPLE ID	SAR meq/l	MAR %	PI meq/l	RSC meq/l	SSP %	KR meq/l	TH mg/l	pH	EC **µs/cm**	TDS mg/l
GW1	0.01	41.29	0.99	-5.45	1.26	0.00	289.00	6.70	418.00	205.00
GW2	0.01	42.85	1.18	-5.30	1.47	0.00	288.12	6.40	540.00	265.00
GW3	0.02	44.43	1.10	-5.50	1.46	0.00	296.35	6.50	516.00	258.00
GW4	0.02	67.34	2.33	-2.12	1.63	0.01	122.22	6.50	519.00	255.00
GW5	0.02	67.08	2.21	-2.25	1.42	0.01	128.83	6.70	515.00	252.00
GW6	0.02	69.12	2.58	-1.92	2.23	0.01	113.12	6.60	200.00	100.00
GW7	0.01	44.74	0.96	-5.63	0.91	0.00	298.00	6.60	192.00	100.00
GW8	0.01	45.57	0.99	-5.69	1.70	0.00	302.52	6.50	190.00	97.00
GW9	0.02	42.40	1.19	-5.47	1.89	0.01	298.90	6.80	193.00	90.00
GW10	0.01	43.78	1.10	-5.90	1.78	0.00	319.55	6.20	300.00	148.00
GW11	0.01	45.19	1.05	-6.08	1.59	0.00	327.78	6.90	303.00	150.00
MIN	0.01	41.29	0.96	-6.08	0.91	0.00	113.12	6.20	190.00	90.00
MAX	0.02	69.12	2.58	-1.92	2.23	0.01	327.78	6.90	540.00	265.00
MEAN	0.01	50.35	1.43	-4.66	1.58	0.01	253.13	6.58	353.27	174.55
FAO Standard	3	<60	<60	<2.5	<60	<1	50-150	6.5-8.4	<700	<450

Permeability Index (PI): The calculated permeability index range from 0.96 to 2.58% with a mean value of 1.43% (Table 5). Permeability index evaluates the potential of the irrigation water to over a long period of time affect the permeability of the soil. It is generally accepted that a permeability index of less than 60% is suitable for irrigation. All water samples have PI values below 60% and are thus suitable for irrigation.

Residual Sodium Carbonate (RSC): Calculated RSC values varied from -6.08meq/l to -1.92meq/l with an average value of -4.66 (Table 1). High RSC values in irrigation water significantly increase the soil, pH, EC and SAR which significantly reduce crop yield [11]. RSC value greater than 2.5 meq/l is considered unsuitable for irrigation. All water samples have RSC values significantly lower than 2.5meq/l thus the samples were categorized as suitable for irrigation purposes.

Soluble Sodium Percentage: Calculated SSP values ranged from 0.91% to 2.23%, with a mean value of 1.58 (Table 5). SSP and SAR serve similar purpose, they are both used to assess sodium hazard and are often strongly correlated [28]. Irrigation water with 60% SSP is considered unsuitable for irrigation according to FAO standards. All groundwater samples obtained from the study area has SSP value far below 60% and are thus categorized as suitable for irrigation.

Kelly Ratio (KR): Calculated KR values range from 0.00meq/l to 0.01meq/l (Table 5). KR also assess sodium hazard. KR values greater than one is generally considered unsuitable for irrigation [22], thus all sampled water are categorized as suitable for irrigation because of their low KR values (less than 1).

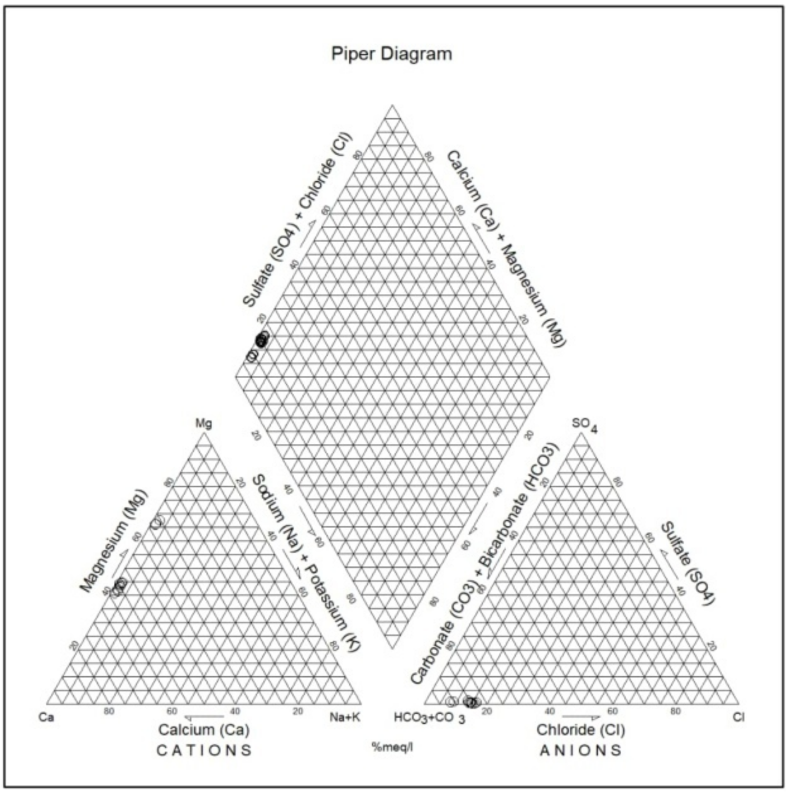

Figure 5. Piper trilinear diagram showing dominant water type

4.3. Hydrogeochemical Facie Characterization

Piper Diagram: Piper diagram [29] shows the concentration and relationship of eight major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^-, HCO_3^-, and SO_4^{2-}) on the Piper diagram. The relative concentration of the cations and anions are plotted in the lower triangles, and the resulting two points are extended into the central field to represent the total ion concentration. The Piper trilinear diagram was used to classify the hydrochemical facies of the groundwater according to the dominant ions listed above. The water type in the study area is mainly Ca-Mg/CO3-HCO3 type (Figure 5).

Schoeller plot: Schoeller plot [30] is a semi-logarithm diagram representing the water chemistry and concentration in meq/l of major ion in the water. A Schoeller plot of the groundwater (Figure 6) shows the dominant ions in the groundwater to be Ca^+, $Mg^{2+}$and HCO_3^-.

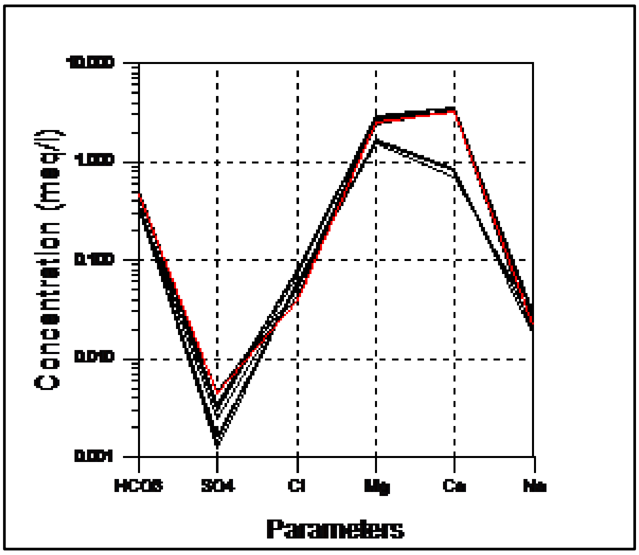

Figure 6. Schoeller plot showing dominant water type

5. Conclusion

The calculated contamination factor (CF) revealed low intensities of contamination for Mn, Cr, and Zn while Fe and Cd have high and very high contamination intensities respectively. The results of the contamination degree (CD*)* and heavy metal pollution index(HPI) show moderate to high contamination in the study area with GW2, GW4 and GW7 having the highest contaminations. Aside from total hardness (TH), all the irrigation quality parameters assessed suggest that the water is suitable for irrigation. Considering the geology of the study area, the high Fe content is most likely geogenic, however the high Cd concentration is most likely from anthropogenic source specifically application of agrochemicals. The high TH is a result of high Ca and Mg in the water that could have been derived from the limestone of Dukamaje Formation during rock water interaction. All of the water in the study area falls within the Ca-Mg/HCO3 type as revealed by the piper diagram and Schoeller plots.

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