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Physico-chemical and Bacteriological Characterization of Groundwater for Domestic and Irrigation Purposes in Santchou (Cameroon Western Highlands)

Magha Alice Mufur[1, *], Margaret Tita Awah[2], Primus Azinwi Tamfuh[3, 4], Aduck Jovens Nyangang[5], Agien Gilbert Njei[1], Kamgang Kabeyene Veronique Beyela[6]

[1]Department of Geology, Higher Teacher Training College, The University of Bamenda, Bambili-Bamenda, Cameroon

[2]Department of Biology, Higher Teacher Training College, The University of Bamenda, Bambili-Bamenda, Cameroon

[3]Department of Soil Science, Faculty of Agronomy and Agricultural Sciences, University of Dschang, Dschang, Cameroon

[4]Department of Mining and Mineral Engineering, National Higher Polytechnic Institute, The University of Bamenda, Bambili-Bamenda, Cameroon

[5]Deparment of Agricultural and Environmental Engineering, College of Technology, The University of Bamenda, Bambili-Bamenda, Cameroon

[6]Department of Earth Sciences, Ecole Normale Supéreiure Bertoua, University of Ngoundére, Bertoua, Cameroon

Email address:

amufur@yahoo.com (M. A. Mufur)

[*]Corresponding author

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Abstract: Groundwater quality is a function of the enclosing aquifer materials and/or human influences. Therefore, frequent water quality surveillance is essential as the subsurface resource is a main source of water supply in Santchou, Cameroon Western Highlands. In order to carry out the inquiries, 24 groundwater samples were collected during the wet period (July 2020) as well as during the dry season (February 2021) from springs, a borehole and hand-dug wells. The water samples were tested in the field for pH, electrical conductivity and turbidity, while two separate water samples were obtained from each sampling point for chemical and bacteriological parameters in the laboratory. The main results revealed that the studied groundwater samples are weakly mineralised, with a slightly acidic pH. The major ionic constituents of the sampled sources were within acceptable limits prescribed by the World Health Organisation except for Mg^{2+} and Cl^- that were noted in excess of the recommended values at some sites. Piper plot indicated that the water is essentially of Na-K-Cl-SO_4 type while the Gibbs diagram showed that hydrochemistry was predominantly due to rock-weathering. SAR (sodium absorption ratio) values, Na % (sodium percentage) and TH (total hardness) revealed that the water is suitable for irrigational practices. Microbiological pollutants such as *Enterobacteria, E. coli, Streptococcus spp, Salmonella spp, Shigella spp, Vibrio spp and Staphylococcus spp* were noticed in the water samples, and hence consumers' health may be compromised if basic treatment methods like boiling and filtration are not performed before the water is used for drinking.

Keywords: Groundwater Quality, Physicochemical, Santchou, Drinking Water Supply, Irrigation Water Quality

1. Introduction

World-wide accessibility to substantial amount and status of potable water remains influential to life quality [1]. In this regard, World Health Organization [2] accentuated on safe drinking water as a fundamental right to all humans since contaminated drinking water may lead to diseases like cholera, diarrhea, dysentery and poliomyelitis. As such, groundwater, often perceived in many communities as a reliable source of provision for irrigation as well as industries, is increasingly being withdrawn to meet up the demands [3-5]. Groundwater quality is influenced by geology, atmospheric inputs, bank infiltration and hydrogeochemical processes within the aquifer system and also various anthropogenic activities [6-9]. Naturally occurring groundwater however, usually contains acceptable concentrations of metals that are vital for the human body and which, in high quantities, can cause deleterious effects to humans [10]. The Earth comprises about 37 million km^3 of freshwater, of which nearly 22% is found in the subsurface, constituting practically 97% of freshwater potentially available for human usage [11].

As a result of urban expansion, industrial development and agricultural intensification, the quality of the subsurface resource has been compromised due to inadequate waste disposal and treatment facilities [12, 13]. Thus, increasing water demand for various usages (such as irrigation, transportation, waste disposal) equally contributes to contaminating existing water sources greatly [14-16].

Vetrimurugan et al. [10] has lamented on the fact that the subsurface resource is pumped from private wells in several parts of developing countries, and directly used for domestic purposes, including drinking, which could result in serious health challenges. Disproportionately, sub-Saharan Africa contributes to approximately 50% of the population that lacks access to improved drinking water sources [17]. Besides, rural areas of Cameroon are not indifferent from this practice, thus it is essential to continuously evaluate the status of the subsurface resource so as to ensure adequate provision of potable water. In fact, in most urban fringes of Cameroon, the major challenge is not inadequate quantity of the resource but rather the status of accessible freshwater [18, 19], the non extension of existing water production facilities and lack of spare parts to replace obsolete devices [20].

These challenges have therefore propelled many peri-urban inhabitants to rely principally on groundwater for various applications. It is therefore against this background that this study was designed to appraise the status of the subsurface resource in Santchou because the inhabitants use well, borehole and spring waters for domestic purposes. In addition, lack of groundwater quality data on this area warrants the necessity of this research. This study will therefore serve as a benchmark for other researchers in the area.

2. Materials and Methods

2.1. Study Area Description

The area of study is found in Santchou, Menoua Division, West Region of Cameroon. It covers a total surface of about 350 km^2 and is found between latitudes 5°12'5" – 5°20'0"N and longitudes 9°50'10"– 10°9'0" E (Figure 1). The study area is characterized by an equatorial climate of Guinea type, marked by alternating wet period (April to October) and dry period (November to March) [21, 22]. Rainfall patterns are more or less irregular as there is a decline in rainy days, with an average annual precipitation of approximately 2648 mm [23]. The temperature fluctuates between 22°C and 24.8°C. The relief is much diversified and characterized by numerous mountains, the highest point being at Mount Manengouba (about 2268 m) and a vast plain at an elevation of about 1250 m.

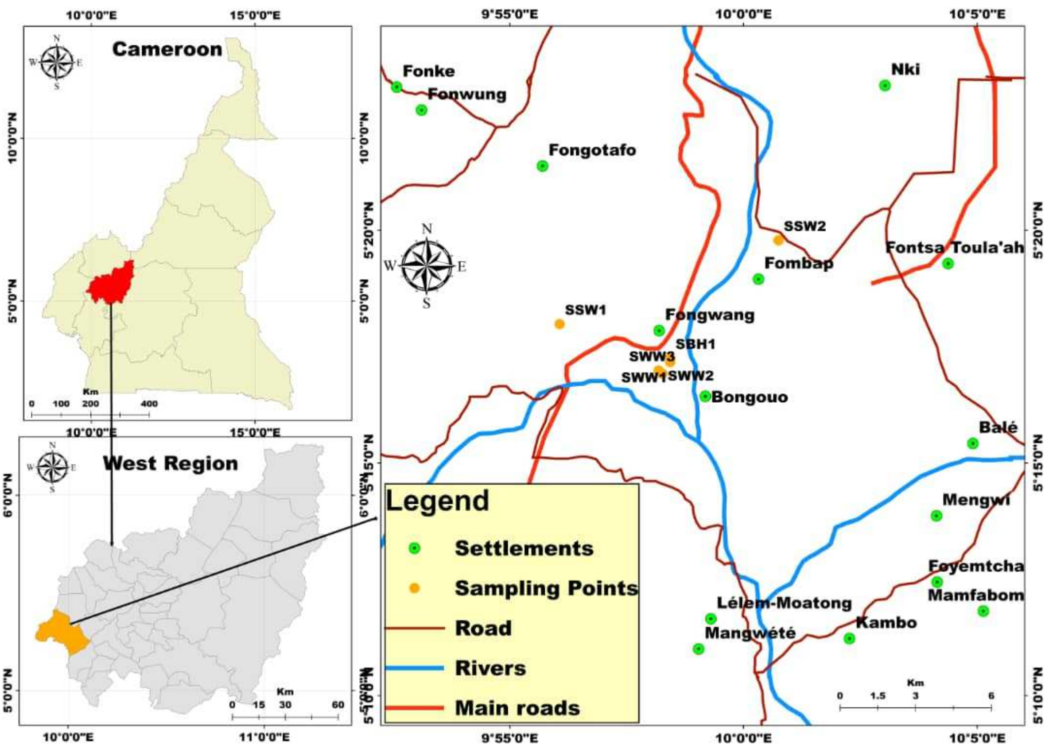


Figure 1. Location map of the study area, indicating groundwater sampling points.

The drainage of Santchou is a function of its relief, with the main river, the meandering River Nkam flowing through the town and depositing lots of materials which is evident from sand mining. Other streams and rivers that drain the area include River Alouno, River Metché and River Alouo, which join River Nkam to form a dendritic pattern. Flash floods are a common phenomenon in the town [24]. The fertile volcanic soils of the study area are gradually evolving into ferralsols due to continuous cultivation. The low-lying areas are characterized by hydromorphic soils due to poor drainage conditions [24]. The primary vegetation is both savannah and forest that has been cut down to obtain space for habitation and agriculture due to rich potentials of the volcanic soils.

Geologically, the study area forms part of Mount Manengouba which is about 2268 m, and is one of the major features of the Cameroon Volcanic Line (CVL) that is composed of a chain of highlands made of two stratovolcanoes that has suffered from a double subsidence and subsequently led to the development of two calderas: Eboga and Elengoum [25, 26]. Previous studies by Sato et al. [27] have revealed that the Manengouba Mountain is a polygenic volcano with characteristics of Ocean Island Basalts (OIB). Similarly, studies on the geochemistry of basaltic lavas from the Manengouba Mountain [28] have shown that the lava contains sodic and alkaline tendencies.

2.2. Methods

Groundwater samples were collected from wells, borehole and springs for analyses. Sampling was carried out during the dry season (February) and the rainy season (July). The sampling points were selected on the basis of the residents that depend on the water sources for drinking and domestic use. Representative samples were collected from 6 different points (3 wells, 1 borehole and 2 springs) in 1 litre polythene bottles. The samples were obtained as per the directives of APHA [29]. Two samples were collected at each sampling point for physico–chemical and bacteriological analyses. In situ measurement of physico-chemical parameters was performed in the field using a PCS tester 35 instrument.

Total dissolved solids (TDS) in the water samples were obtained according to equation (1) of Lloyd and Heathcote [30]:

$$\text{TDS mg/l} = \text{EC } (\mu\text{S/cm}) * 0.64. \quad (1)$$

After collection, the samples were immediately transported in a cooler box to the laboratory of Soil and Environmental Chemistry of the University of Dschang (Cameroon) while the microbiological characteristics were determined in the Laboratory of Animal Physiology and Microbiology of the same university.

2.2.1. Physico-Chemical Properties

Water physical properties like pH, EC and turbidity were determined in the field using a multi parameter probe. Water chemical parameters were determined at the Faculty of Agronomy and Agricultural Sciences (FASA) of the University of Dschang, Cameroon. Major ions of sodium, potassium, calcium, magnesium, chloride, bicarbonate, sulphate and nitrate were determined using standard techniques that have been approved by the American Public Health Association [29]. The following laboratory techniques were employed; flame photometry method for Na^+ and K^+, colorimetry method for Ca^{2+} and Mg^{2+} [31]. Volumetric methods were employed in the determination of the bicarbonate (HCO_3^-), chloride (Cl^-) and sulphate (SO_4^{2-}) while nitrate ions were determined with the use of the colorimetric method.

Total hardness (TH) as $CaCO_3$ was determined following equation 2 of Todd [32].

$$\text{TH} = 2.5\text{ Ca} + 4.1\text{ Mg} \quad (2)$$

2.2.2. Bacteriological Analysis

Subsurface water samples, obtained during the dry and rainy periods were as well subjected to investigation of bacteria indicator of pollution such as *Enterobacteria, E. coli, Streptococcus, Salmonella, Shigella, Staphylococcus, Vibrio* and total coliform in the membrane filtration procedure [29]. In the membrane filtration method, to 1 ml of the sampled water was added 9 ml of distilled water and each sample was diluted thrice. In order to impede interferences, the membrane was laid on a sterilized Wheaton Filtration funnel. Several diluted water samples were then prepared so as to obtain the required range of colonies. The prepared filter plates were then incubated at 44°C for *E. coli* and total coliform, 35°C for *Streptococcus* and faecal coliform [31].

To determine the suitability of the studied groundwater for irrigational use equations 3 and 4 were employed to compute for the values of Na% and SAR [33].

$$\text{Sodium percentage (Na \%)} = \frac{Na+K}{Ca+Mg+Na+K} \times 100 \quad (3)$$

$$\text{Sodium adsorption ratio (SAR)} = \frac{Na}{\sqrt{(Ca+Mg)}/_2} \times 100 \quad (4)$$

3. Results and Discussion

3.1. Physical Properties

The summary statistics of the studied groundwater samples is presented in Table 1. The pH levels of the groundwater samples oscillated between 6.1 and 6.6 with an average value of 6.32 and a standard deviation of 0.17 in the wet period, and between 5.5 and 7.0 with an average value of 6.07 and a standard deviation of 0.67 in the dry period. Just sampling site SSW2 recorded pH values (6.6 and 6.9) which were within recommended limits of the WHO during the study period. The rest of the sampling points presented pH values that were out of the WHO permissible limits. The pH variations of groundwater are probably associated with the lithology of the aquifer system as well as hydrogeochemical processes operating in the aquifer [34, 35]. The action of microorganisms, the proximity of latrines and other anthropogenic factors may also influence the pH of water [36]. The pH levels corroborated with values documented in Melong by Mufur et al. [13] and in Bamenda by Akoanung et al. [4] but were very low compared to those obtained by Ketchemen-Tandia et al. [37] in Douala (Littoral Cameroon) and Mukhopadhyay et al. [38] in West Bengal. Electrical Conductivity values for all the water samples ranged from 0.05 to 0.25 during the rainy period whereas during the dry period it varied between 0.08 and 0.38 µS/cm. The highest EC values of 0.38 µS/cm was noted at SSW2 during the dry season and the lowest (0.05 µS/cm) was recorded during the rainy period. The low mineralization of the sampled water clinches with studies by Mufur et al. [13] and Temgoua et al. [39] who equally observed low EC values in hand-dug wells and borehole water in Melong and Dschang (West Cameroon), respectively. The values obtained during the study period are far below the recommended limit of 1000 µS/cm [2]. This is an indication that the groundwater is fresh and is a reflection of the total amount of dissolved substance in the studied water [11, 40]. On the contrary, EC values as high as 1646 µS/cm and 2326.83 µS/cm have been reported in the works of Ketchemen-Tandia et al. [37], Ahada and Suthar [41] and Akakuru et al. [42].

Turbidity values of the water samples oscillated between 0.9 and 56.2 NTU in the wet period and 0.9 and 13.1 NTU in the dry period. The lowest turbidity values of 0.9 NTU and 1.4 NTU were recorded at SSW1 for both wet and dry periods, and the highest (56.2 and 13.1 NTU) were recorded at SBH during the wet and dry seasons respectively. Elevated turbidity values above the recommended limits of the WHO were measured at SBH (56.2 and 13.1 NTU), SSW1 (7.5 NTU) and SSW2 (21.6 NTU).

The TDS loads (mg/L) in the studied water oscillated between 0.03 and 0.16 (average of 0.08) in the wet period and 0.05 and 0.24 (average of 0.09) in the dry season. These values are far lower than the WHO recommended values for drinking water of 500 mg/L [2]. The TDS gives an overall idea on dissolved salts in water [43]. TDS values up to 65.1 mg/L have been measured by Akakuru et al. [42] in Southeastern Nigeria.

3.2. Chemical Properties

3.2.1. Concentrations of Major Cations

The major ion concentrations of the studied groundwater sources are illustrated in Figure 2 (rainy season) and Figure 3 (dry season).

(i). Na^+ and K^+

The Na^+ concentrations (mg/L) of the sampled water oscillated from 0.05 to 0.08 with a mean value of 0.06 and a standard deviation of 0.01 in the rainy period whereas during the dry period, Na^+ oscillated from 0.03 to 0.21 with a mean value of 0.08 and a standard deviation of 0.85. The measured values are within the desirable limits of 200 mg/L recommended by the WHO [2]. Studies carried out by Mohsin et al. [44] have shown that low sodium quantity in water may negatively affect the health of consumers while sufficient quantity of sodium in the human body may prevent many fatal diseases like kidney damage, hypertension and headache. Potassium levels (mg/L) in the studied water samples ranged from 32.55 to 246.5 with an average of 88.81 and a standard deviation of 80.18 in the rainy period meanwhile during the dry period it fluctuated from 0.0 to 256.6 with a mean value of 113.53 and a standard deviation of 105.93. High levels exceeding the WHO limits of 20 mg/L occurred at all the sampling sites except for SWW2 (0.0 mg/L) in the dry season. The probable origin of K^+ in subsurface water has been reported by Mohsin et al [44] as coming from the disintegration of silicate minerals like orthoclase, microcline, albite and muscovite and may also be associated with wrongful application of fertilizers and improper sewage disposal [41]. It is worth mentioning that the results obtained in this study are similar to studies by earlier researchers along the CVL such as Temgoua et al. [39] in Dschang; Akoanung et al. [4] in Bamenda and Mufur et al. [13] in Melong.

(ii). $Ca^{2+}$and Mg^{2+}

Calcium loads (mg/L) ranged from 7.2 to 32 with a mean value of 20.13 and a standard deviation of 9.86 in the wet period and 8.2 to 34 with an average of 21.8 and a standard deviation of 10.40 in the dry period. The concentrations of Ca^{2+} in wells were high compared to the borehole and spring water samples although the values were far below the recommended values of 75 mg/l for drinking water by the WHO. This is in accordance with the work of Nkansah et al. [45] who observed low concentrations of calcium in similar groundwater samples (wells, boreholes and springs) analysed. It has been shown that calcium insufficiency in the human body would lead to rickets, reduced blood clotting and weak bones.

Magnesium (Mg^{2+}) concentrations (mg/L) on the other hand fluctuated from 6.31 to 16.01 with a mean value of 9.70 and a standard deviation of 3.39 in the rainy period whereas dry period values fluctuated from 68.9 to 262.5 with a mean value of 132.63 and a standard deviation of 67.96. Magnesium concentration during the study period exceeded the recommended limits of the WHO of 200 mg/L at SWW2 (262.5 mg/L). The results obtained in this current study are in conformity with the findings of Ako et al. [46]. The WHO [47] had articulated that insufficient magnesium in humans may lead to some health effects like decrease insulin sensitivity, hypertension, coronary heart disease and metabolic syndrome. Total hardness of the studied water varied from 43.81 to 113.8 with an average of 90.12 in the rainy season and 363.49 to 1161.25 with an average of 598.3 in the dry season.

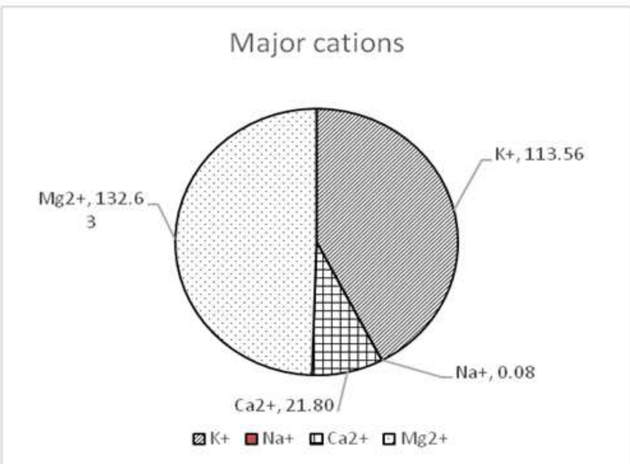
3.2.2. Major Anion Concentrations

Bicarbonate levels (mg/L) varied from 26 to 60 with a mean value of 43.66 and a standard deviation of 12.48 during the wet period whereas during in the dry period it fluctuated from 32 to 64 with an average value of 45.33 and a standard deviation of 12.11 (Table 1). Concentrations measured during the study period are in conformity with the permissible levels recommended for water supply by the World Health Organisation of 125 to 350 mg/L. Bicarbonate ions could stem partially from the atmosphere and also through organic matter oxidation, as well as plant and soil organisms' respiration [48]. Chloride ion levels (mg/L) ranged from 63.9 to 259.2 with a mean of 129.6 and a standard deviation of 67.89 in the wet period and 68.9 to 262.5 with an average value of 132.63 and a standard deviation of 67.96 in the dry season. During the study period Cl^- ions at some sites were registered in excess of the maximum allowable concentration of 200 mg/L prescribed by the World Health Organisation [47]. Studies have revealed that Cl^- in water sources may stem from natural sources like salt water encroachment, water-rock interactions and water from precipitation while anthropogenic origin may include fertilizers, industrial effluents, road salt, pollutants from diverse sources and municipal landfills leachates [49]. Nitrate concentrations (mg/L) varied from 0 to 24, having a mean of 1.03 and a standard deviation of 1.48 in the rainy season and 0 to 4.21 with an average of 1.50 and a standard deviation of 1.77 in the dry season. Nitrate concentrations measured during the study period are lower than the WHO recommended limits of 50 mg/L. Nitrate in subsurface water could result from natural sources such as oxidation by nitrogenous bacteria and play a central role to plant nourishment [50, 51]. Sulphate concentration (mg/L) fluctuated from 96.76 to 275.5, having a mean of 176.6 and a standard deviation of 77.35 in the rainy season and 91.4 to 265.2 with a mean value of 184.63 and a standard deviation of 64.62 in the dry season. Sulphate concentrations were generally low in the sampled groundwater and below the desirable limit of WHO of 250 mg/L except for SSW1 (275.5 and 265.2 mg/L) during the rainy and dry period. The concentration of the major anions measured in this study are less than values obtained by Ahada and Suthar [41] in Malwa region Punjab, India; Akakuru et al. [42] in Southeastern Nigeria. Ionic composition revealed low mineralisation of the sampled sources, which is in line with the study of Ako et al. [46] in the Banana Plain.

Table 1. *Summary Statistics of physico-chemical variables of the sampled groundwater sources.*

	Rainy Season					**Dry Season**					**WHO guideline**
	Min	**Max**	**Mean**	**STDEV**	**CV**	**Min**	**Max**	**Mean**	**STDEV**	**CV**	
pH	6.1	6.6	6.32	0.17	0.03	5.5	7	6.07	0.67	0.11	6.5-8.5
Turbidity	0.09	56.2	15	21.63	1.44	0.9	13.1	3.43	4.78	1.39	5
EC	0.05	0.25	0.13	0.09	1.02	0.08	0.38	0.14	0.12	0.84	1000
TDS	0.03	0.16	0.08	0.06	0.65	0.05	0.24	0.09	0.08	0.54	
TH	43.89	113.8	90.12	26.72	0.3	27.29	92.82	47.47	23.35	0.49	
Ca^{2+}	7.2	32	20.13	9.86	0.49	8.2	34	21.8	10.4	0.48	75
Mg^{2+}	6.31	16.01	9.7	3.39	0.35	68.9	262.5	132.63	67.96	0.51	200
Na^+	0.05	0.08	0.06	0.01	0.22	0.03	0.21	0.08	0.07	0.85	200
K^+	32.55	246.5	88.81	80.18	0.9	55.14	256.6	113.56	105.93	0.93	20
Cl^-	63.9	259.2	129.6	67.89	0.52	68.9	262.5	132.63	67.96	0.51	5
SO_4^{2-}	96.76	275.5	176.6	77.35	0.44	91.4	265.2	184.63	64.62	0.35	250
HCO_3^-	26	60	43.66	12.48	0.29	32	64	45.33	12.11	0.27	125-350
NO_3^-	0	24	1.03	1.45	1.4	0	4.21	1.5	1.77	1.18	50

3.2.3. Major ions Concentrations Are in mg/L; Turbidity (NTU); EC (µS/cm)



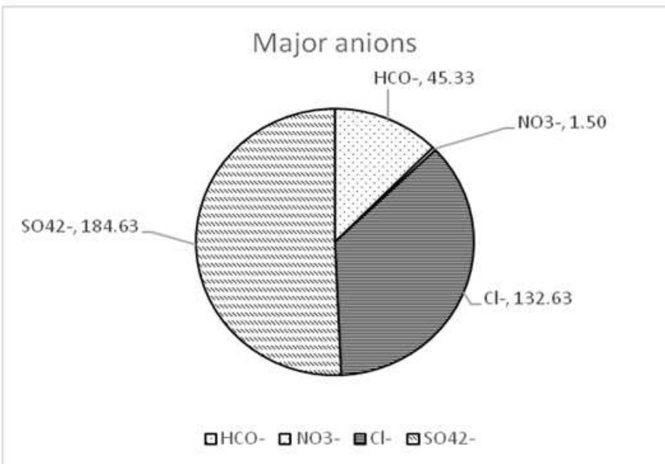


Figure 2. *Average values of major ion concentrations in the studied water sources in Santchou in the rainy season, (major ion concentrations are in mg/L).*

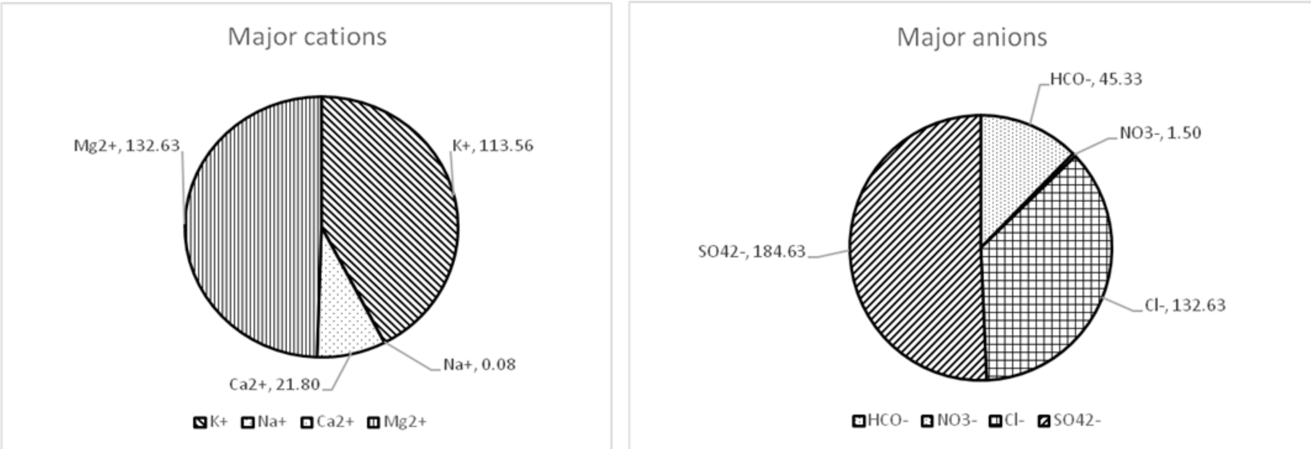


Figure 3. *Average values of major ion concentrations in the studied water sources in Santchou in the dry season, (major ion concentrations are in mg/L).*

3.3. Bacteriological Quality

The results of various specific microbes in the water samples are shown in (Table 2).

Enterobacteria was generally high in all samples and also in all seasons with the highest value recorded during the dry period (1200 CFU/100ml) at SSW1 than in the wet period (80 CFU/100ml) at SWW2.

E. coli had higher values during the dry period (500 CFU/100ml) at SBH and SSW1 and lower during the wet period (30 CFU/100ml) at SWW2. Elevated values of *Streptococcus spp* were noted during the dry period (400 CFU/100ml) at SSW1 and low during the wet period (15 CFU/100ml) at SWW2. Higher values of *Salmonella spp* were registered in the dry period (400 CFU/100ml) at SSW1 than in the wet season (05 CFU/100ml) at SWW2. *Shigella spp* was not seen at SSW2 in the wet season and also at SSW2 and SWW3 in the dry season. The highest value (50 CFU/100ml) was measured at SSW1 in the dry period and (02 CFU/100ml) at SWW2 in the rainy season. *Vibrio spp* was absent in the rainy season at SWW2 and in the dry season at SWW2, SSW1, SSW2 and SWW3 but the rainy season had a higher value (150 CFU/100ml) at SSW1 than the dry season (20 CFU/100ml). *Staphylococcus spp* value was higher (300 CFU/100ml) at SSW1 in the dry season than (80 CFU/100ml) at SWW3 in the rainy season.

All bacteria species were present in all the samples except *Shigella spp* and *Vibrio spp* that were absent in some samples in both the rainy and dry seasons. *Enterobacteria* had the highest counts of 1200 CFU/100ml at SSW1 in the dry season. The dry season in general had the highest bacteria counts than the rainy season except for *Vibrio spp* that had a higher value (150 CFU/100ml) in the rainy season at SSW1 than the dry season (20 CFU/100ml).

The results of bacteriological analysis of the studied groundwater revealed that the sampling point SSW1 has the highest concentrations for almost all bacteria species during the dry period and SWW2 has the lowest during the rainy period. This implies that SSW1 is the most contaminated sampling point which could probably result from unsustainable practices around the source and their proximity to pit latrines and septic tanks.

Table 2. *Specific microbes isolated in the studied water samples during the wet and dry periods (CFU/100ml).*

Sampling points	RAINY SEASON						DRY SEASON					
Baterial	**SWW1**	**SSW1**	**SWW2**	**SSW2**	**SWW3**	**SBH**	**SWW1**	**SSW1**	**SWW2**	**SSW2**	**SWW3**	**SBH**
Enterobacteria	260	500	80	600	230	400	100	1200	700	200	300	950
E. coli	90	100	30	300	150	100	40	500	150	20	60	500
Streptococcus spp	40	200	15	150	75	60	20	400	50	00	60	350
Salmonella spp	150	175	05	150	100	30	20	400	03	15	200	300
Shigellaspp	10	30	02	00	05	10	03	50	01	00	00	40
Vibriospp	22	150	00	03	30	02	00	20	00	00	00	50
Staphylococcus spp	200	250	100	150	80	150	40	300	240	30	20	250

Table 3. *Pearson Correlation Matrix of the studied Santchou groundwater.*

	EC	TDS	Tur	pH	K^+	Na^+	TH	Ca^{2+}	Mg^{2+}	HCO_3^-	NO_3^-	NH_4^+	Cl^-	SO_4^{2-}	PO_4^{3}-
EC	1														
TDS	0.88	1.00													
Tur	-0.36	-0.33	1.00												
pH	-0.55	-0.51	0.65	1.00											
K^+	0.98	0.87	-0.46	-0.59	1.00										
Na^+	0.51	0.83	-0.48	-0.44	0.51	1.00									
TH	0.05	0.51	-0.05	-0.05	0.03	0.83	1.00								
Ca^{2+}	0.79	0.94	-0.36	-0.43	0.83	0.77	0.51	1.00							

	EC	TDS	Tur	pH	K^+	Na^+	TH	Ca^{2+}	Mg^{2+}	HCO_3^-	NO_3^-	NH_4^+	Cl^-	SO_4^{2-}	PO_4^{3-}
Mg^{2+}	-0.09	0.38	0.00	0.03	-0.11	0.76	0.99	0.37	1.00						
HCO_3^-	-0.50	-0.61	0.52	0.31	-0.43	-0.76	-0.46	-0.39	-0.43	1.00					
NO_3^-	0.65	0.27	-0.35	-0.38	0.60	-0.07	-0.57	0.07	-0.62	-0.40	1.00				
NH_4^+	-0.52	-0.69	0.22	-0.02	-0.58	-0.59	-0.48	-0.86	-0.37	0.23	0.15	1.00			
Cl^-	-0.10	0.37	-0.12	-0.07	-0.10	0.78	0.98	0.38	0.99	-0.45	-0.61	-0.35	1.00		
SO_4^{2-}	0.47	0.24	0.25	-0.45	0.39	-0.17	-0.37	0.04	-0.40	0.07	0.56	0.37	-0.44	1.00	
PO_4^{3-}	-0.59	-0.75	-0.20	0.39	-0.57	-0.50	-0.46	-0.73	-0.37	0.06	0.08	0.45	-0.31	-0.50	1.00

3.4. Correlation Matrix

Correlation has been shown to provide vital information on associations and relationships between several hydrogeochemical variables. From Table 3, elevated correlation can be observed between EC and TDS (0.88), K^+ (0.98), Ca^{2+} (0.79); between TDS and K^+ (0.87), Na^+ (0.83), Ca^{2+} (0.94); between K^+ and Ca^{2+} (0.83); between Na^+ and TH (0.83), Ca^{2+} (0.77), Mg^{2+} (0.76), Cl^- (0.78); between TH and Mg^{2+} (0.99), Cl^- (0.98), between Mg^{2+} and Cl^- (0.99) meanwhile moderate correlation is noted between CE and Na^+ (0.51), NO_3^- (0.65); between TDS and TH (0.51); between turbidity and pH (0.65), HCO_3^- (0.52); K^+ and Na^+ (0.51); TH and Ca^{2+} (0.51); NO_3^- and SO_4^{2-} (0.56). Very strong correlation amid ionic groups suggests that they stem probably from a common provenance. Weak correlation between ionic constituents may denote that mixing did not occur between groundwater and salt water, an indication that the studied groundwater is principally recharged from freshwater systems [40]. Strong correlation observed between TDS and K^+, Na^+ and Ca^{2+} may signify that TDS is influenced by these ions [46].

3.5. Hydrogeochemical Facies

In order to have insight into the geochemical evolution of the studied groundwater, Piper's diagram [52] and Durov's plot [53] were plotted. The Piper diagram is useful in bringing out the different hydrochemical facies found in an aquifer system. Analytical data showed that cationic and anionic species are in the order of $K^+ > Ca^{2+} > Mg^{2+} > Na^+$ and $SO_4^{2-} > Cl^- > HCO_3^- > NO_3^-$ respectively. This order is further affirmed by Figure 4 in which most of the samples concentrated in the Na-K-Cl-SO_4 zones, except for one sample (SSW2) that plotted in the Ca-Mg-Cl-SO_4, thus, depicting the dominance of alkali metals over alkaline earth metals and strong acidic anions (Cl+ SO_4) over weak acid (CO_3+ HCO_3).

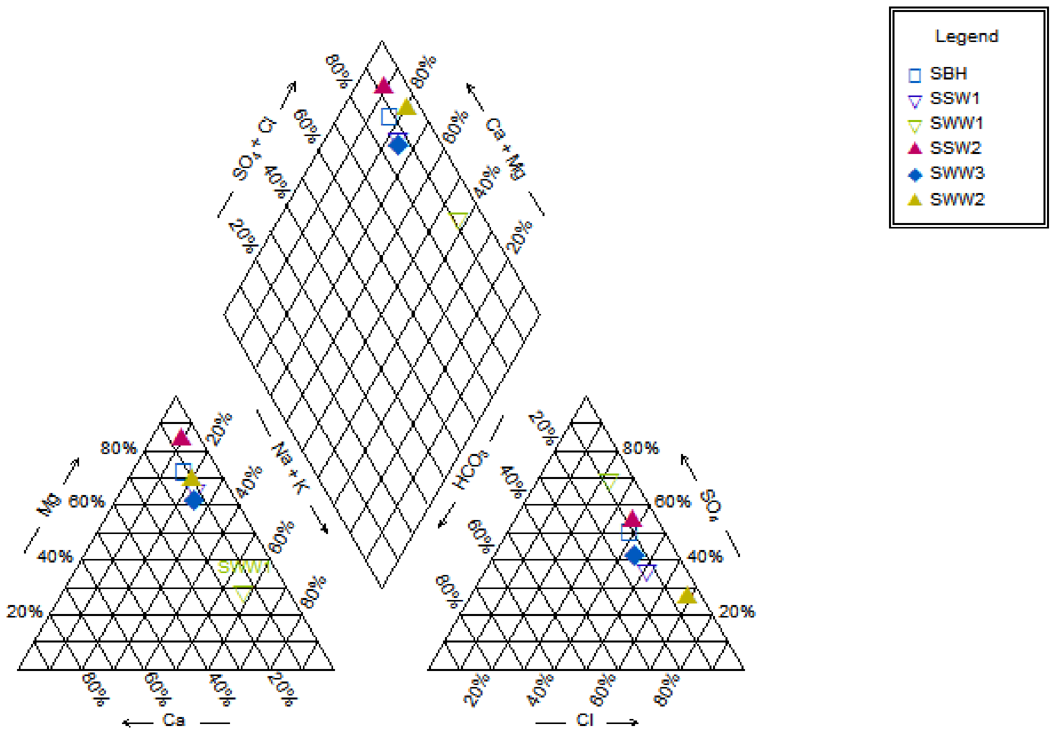


Figure 4. Piper diagram for Hydrochemical facies of the Santchou studied groundwater.

3.6. Durov Diagram

Similarly, Durov diagram [53] helps in interpreting the evolutionary trends and furnishes additional understanding about hydrogeochemical processes that occur within aquifer systems, which may denote mingling of dissimilar water types, substitution of ion and reverse ion exchange processes [54]. The diagram is a fused plot comprising of two ternary diagrams in which major cationic species (Na^++ K^+, Ca^{2+}, Mg^{2+}) are plotted against major anionic (Cl^-, HCO_3^-, SO_4^{2-})

sides to create a binary plot of major cations as opposed to major anionic contents; extended form includes total dissolved solids (mg/L) and pH data attached to the edges of the binary plot to permit additional evaluations [55]. Durov diagram was used to appraise the hydrogeochemical process in the studied subsurface water (Figure 5). It can be observed that most of the sampling points fell along the dissolution or mixing and ion exchange fields of Durov's diagram. This trend could be accredited to freshly recharged water displaying simple dissolution or mixing without any predominant major anionic or cationic species [30]. It can be noticed that rock weathering and the process of ion exchange are the main mechanisms influencing the chemistry of the sampled groundwater.

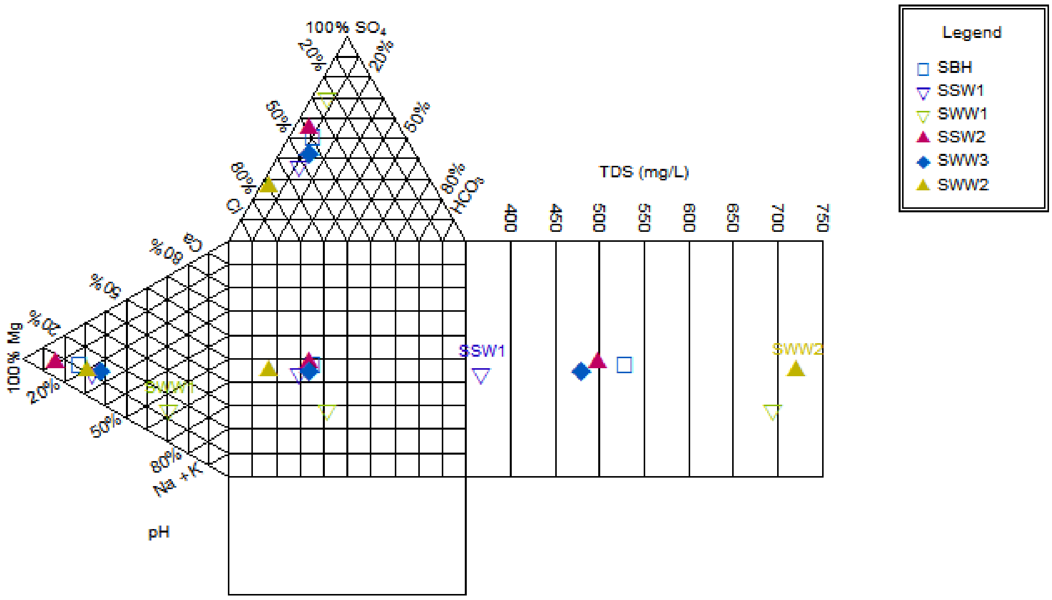


Figure 5. *Durov diagrams of Santchou groundwater.*

3.7. Control Mechanisms of Groundwater Chemistry

Investigating the control on groundwater chemistry, Gibbs's plot [56] was employed. Figure 6 illustrates a clustering out of the major ions in the rock weathering field, which implies that chemical decay of minerals is the dominant process that determines the hydrochemistry of the sampled groundwater during the study period.

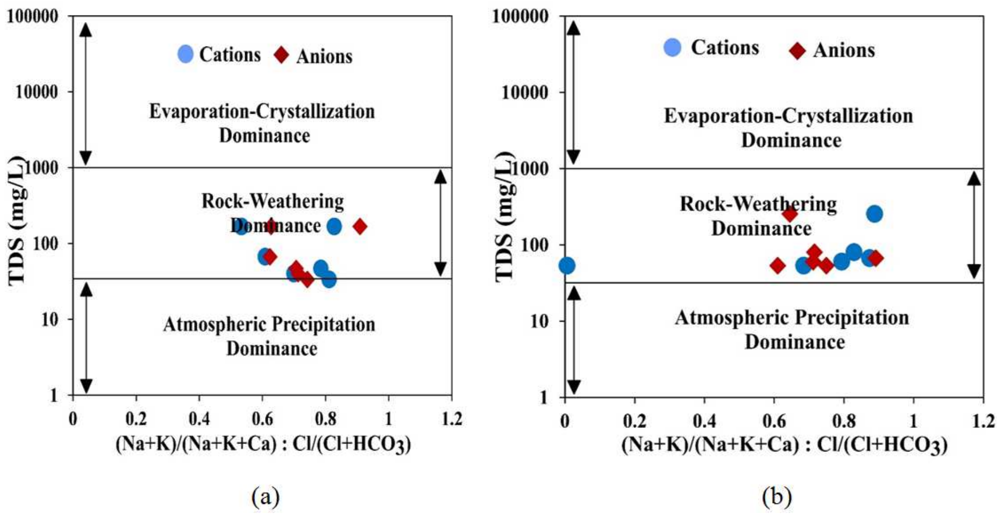


Figure 6. *Gibb's plot indicating rock weathering as the major process regulating the chemistry of the studied sources: (a) Wet season, (b) dry season.*

3.8. Suitability Assessment of the Studied Under Groundwater for Drinking Purpose

The analysed subsurface water samples were evaluated to determine their fitness for water supply in comparison with World Health Organisation [47] guidelines for drinking water standards. Physicochemical properties of the samples were within acceptable limits apart from pH that fluctuated from

6.1 to 6.6 with a mean of 6.32 and from 5.5 to 7.0 with an average of 6.06 in the rainy and dry periods respectively and thus slightly acidic. Bacteriologically, bacteria indicators of pollution were registered at all the sampling sites which suggest that the studied subsurface water does not conform to norms for domestic purposes.

3.9. Assessment of the Studied Water Sources for Irrigational Practices

Classifying water quality for irrigation is paramount because poor status of water may obliterate the soil structure, closing up soil pores which may in turn retard the flow of water into the subsurface, thus, crusting the soil which may be associated with negative consequences on the plant growth [51, 57]. The suitability of the studied groundwater sources for irrigational practices was performed using sodium adsorption ratio (SAR), sodium percentage (Na %), electrical conductivity (EC) and total hardness (TH). SAR values in mg/L of the studied water varied from 1.77 to 2.72 with a mean of 2.19 in the wet period and from 0.81 to 1.59 with an average of 0.98 in the dry season. The sampled sources can be categorised as being of excellent quality when intended for irrigational use [38]. The SAR values in this study were lower at some sites than values obtained by Mukhopadbyay et al. [38] who registered SAR values as high as 12.22 mg/L in West Bengal.

Elevated concentrations of Na % in water may unite with carbonates to create alkaline soils. Equally, when surplus Na^+ combines with Cl^-, saline soils result which have the tendency of reducing soil permeability [38]. In this study all the sampling sites registered Na % between 45.39 to 76.20% with an average of 56.97% in the rainy season and are thus considered as permissible for irrigational practices. In the dry period, Na % fluctuated from 0.02 to 47.42% with an average of 18.27% (Table 4). Thus 33.33% of the study sites are good while 66.67% are of excellent quality regarding water status for irrigational purpose.

Table 4. *Classification of irrigational water based on Na % [58].*

Sodium %	Status of water	% of sample in the rainy season	% of sample in the rainy season
<20	Excellent	-	16.67
20-40	Good	-	50
40-60	Permissible	16.67	16.67
60-80	Doubtful	66.67	16.67
>80	Unsuitable	16.67	-

High EC values of irrigation water have the tendency of lowering the soil's osmotic pressure thereby reducing the general assimilation of nutriments by crops which may result in stunted growth [59]. EC values in mg/L of the studied water varied between 0.05 to 0.25 with a mean of 0.13 in the wet period and from 0.08 to 0.38 with a mean of 0.14 in the dry period which is within permissible limits and will not cause salinity hazards in the area.

Total hardness (TH) (mg/L) of the studied groundwater samples varied between 43.89 and 113.80 with a mean of 90.12 in the rainy season and from 27.29 to 92.82 with a mean of 47.47 in the dry season. Analytical results indicated that 33.33% of the sampled water sources being soft and 66.67% was moderately hard during the wet season. Whereas, during the dry period, 83.33% of the samples were soft and 16.67% was moderately hard. Thus, the analysed samples are soft to moderately hard (Table 5) and thereby, would not affect an irrigated crop land. Similar results have been documented by Magha et al. [17] in Northern Bamenda.

Table 5. *Hardness classification of the Santchou studied groundwater according to Sawyer. and McCarty [60].*

Hardness	Classification	Rainy season		Dry season	
		No of samples	% of samples	No of samples	% of samples
0 – 75	Soft	2	33.33	5	83.33
75 – 150	Moderately hard	4	66.67	1	16.67
150 – 300	Hard	0	0	0	0
> 300	Very hard	0	0		0

4. Conclusion

This present study set out to scrutinize the status of subsurface water for domestic water supply and irrigational uses in Santchou as it is a prominent water source in the area. Thus, physicochemical and bacteriological characteristics of the water were assessed. Analytical results revealed that the groundwater is suitable physicochemically as most ionic concentrations were below the WHO acceptable limits except for pH that was slightly acidic in both seasons. On the other hand, the sampled water sources were not suitable bacteriologically as indicator bacteria of pollution were registered in all the analysed samples, implying that the studied water sources are not suitable with respect to bacteriological affinities. The values of SAR, Na %, EC and TH denoted that the studied sources are suitable for irrigational practices. Piper plot revealed that the groundwater in Santchou is of Na-K-Cl-SO_4 types and the Gibbs diagram revealed that the main mechanism responsible for groundwater chemistry is rock weathering. Sufficient quantity of potable water cannot be ensured without protection of water sources. Therefore, efforts should be made to protect the groundwater sources against man-made pollution of various forms.

Conflict of Interests

The authors declare that they have no competing interests.

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References

[1] Alabi, A. A., Popoola, O. I., Olurin, O. T., Ogungbe, A. S., Ogunkoya, O. A. and Okediji, S. O. (2020) Assessment of groundwater potential and quality using geophysical and physicochemical methods in the basement terrain of Southwestern, Nigeria. Environmental Earth Sciences, 79, 1-13. https://doi.org/10.1007/s12665-020-09107-y

[2] World Health Organization (2017) Guidelines for drinking–water quality: 4th edition incorporating the first addendum, Geneva. CC BY–NC–SA 3.0 IGO.

[3] World Bank (2012) Rural water supply design manual, vol 1. Water Partnership Program, Manila, Philippine.

[4] Akoanung, A., Endene, E., Enoh, J. F. and Akoachere, R. A. (2019) Assessment of groundwater quality in Bamenda–Cameroon for suitable applications. SN Applied Sciences, 1, 1 21. https://doi.org/10.1007/s42452-019-1351-1.

[5] Gurmeet, S., Sanjoy, G., Dwarikanath, R., Bholu, R, Y. and Amit, D. (2021) Monitoring groundwater quality status using geo-spatial technique: a case study on Malwa region Punjab, India. Int J Energ Water Res., https://doi.org/10.1007/s42108-021-00134-4

[6] Krishna, K. S., Chandrasekar, N., Seralathan, P., Godson Prince, S. and Magesh, N. S. (2011) Hydrogeochemical study of shallow carbonate aquifers, Rameshwaram Island, India. Environ MonitAssess, 184, 4127–4139.

[7] Saravanan, K., Srinivasamoorthy, K., Prakash, R., Gopinath, S. and Suma, C. (2015) An Evaluation of hydrogeochemistry of groundwater in upper vellar sub-basin using mineral stability and solute transport modelling. Aquat. Procedia, 4, 1119–1125.

[8] Tajinder, K., Renu, B. and Saroj, A. (2016) Assessment of groundwater quality for drinking and irrigation purposes using hydrochemical studies in Malwa region, southwestern part of Punjab, India. Appl Water Sci, 1-16. DOI 10.1007/s13201-016-0476-2.

[9] Shwan, S. (2020) Hydrochemical assessment and groundwater quality of Koysinjaq area in Kurdistan Region-Iraq. Arab J Geosci, 13, 1-13. https://doi.org/10.1007/s12517-020-05410-x

[10] Vetrimurugan, E., Brindha, K., Elango, L. and Ndwandwe, O. M. (2017) Human exposure risk to heavy metals through groundwater used for drinking in an intensively irrigated river delta. Appl Water Sci, 7, 3267–3280. DOI 10.1007/s13201-016-0472-6.

[11] Sarath Prasanth, S. V., Magesh, N. S., Jitheshlal, K. V., Chandrasekar, N. and Gangadhar, K. (2012) Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. Appl Water Sci, 2, 165–175. DOI 10.1007/s13201-012-0042-5.

[12] Shrikant, K., Shridhar, K. and Prajkta, J. (2020) Water Quality Analysis of Urun-Islampur City, Maharashtra, India. Appl. Water Sci, 10, 1-8. https://doi.org/10.1007/s13201-020-1178-3

[13] Mufur, A. M., Tita, M. A., Azinwi, P. T., Asaba, M. A., Afanwie, N. A. and Kamgang, V. K. (2021a). Groundwater resources for domestic and irrigation purposes in Melong (Littoral Region, Cameroon): Hydrogeochemical constraints. Afr. J. Environ. Sci. Technol., 15, 270-281. DOI: 10.5897/AJEST2021.3027.

[14] Zoi, D., Nektarios, N. K. and Karatzas, G. P. (2015) Assessing groundwater quality in Greece based on spatial and temporal analysis. Environmental Monitoring and Assessment, 1-34. https://www.researchgate.net/publication/284727805

[15] Guo, H., Li, M., Wang, L., Wang, Y., Zang, X., Zhao, X., Wang, H. and Zhu, J. (2021) Evaluation of Groundwater Suitability for Irrigation and Drinking Purposes in an Agricultural Region of the North China Plain. Water, 13, 1-22. https://doi.org/10.3390/w13233426

[16] Mufur, A. M., Tita, M. A., Nono, G. D. K., Tamfuh, P. A., Wotchoko, P. and Kamgang V. K. (2021b). Physico-chemical and bacteriological characterisation of surface water in Bamenda (North West Cameroon). Appl Water Sc, 11, 1-13. https://doi.org/10.1007/s13201-021-01512-3

[17] Magha, A., Awah, M. T., Nono, G. D. K., Tamfuh, P. A., Wotchoko, P., Adoh, M. and Kabeyene, V. B. K. (2021) Assessment of Groundwater Quality for Domestic and Irrigation Purposes in Northern Bamenda (Cameroon). Journal of Water Resource and Protection, 13, 1-19. https://doi.org/10.4236/jwarp.2021.131001

[18] Magha, A., Tita, M. A., Kouankap, N. G. D., Wotchoko, P., Ayuk, M. T., Kamgang, V. K. (2015) Physico-Chemical and Bacteriological Characterization of Spring and Well Water in Bameneda III (NW Region Cameroon). American Journal of Environmental Protection, 4, 163-173.

[19] Ali, H. N., Njilah, I. K., Yene, A. J. Q., Magha, A., Arkhat, K., Poh, M., Prasad, M., Henry, M. D., Agbogun, Mbida, Atekwana E. (2020). Water everywhere but how much is there to drink? A geophysical investigations and water quality assessment in a rural community: Nkoteng, Cameroon. Seg Library. 1-4. https://doi.org/10.1190/segam2020-3423261.1

[20] Saidou, B. O. and Josue, M. (2013) An Assessment of the Performance of the Cameroon Water Corporation for the Period 1967 to 2013. Economic Research Southern Africa (ERSA) working paper 413.

[21] Valet, S. (1985) Notice explicative des cartes du climat des paysages agro géologiques et des propositions d'aptitude à la mise en valeur des paysages agro géologiques de l'ouest – Cameroun au 1/20 000 [Explanatory note of the climate maps of the agro-geological landscapes and proposals for the suitability for the development of agro-geological landscape in west Cameroon at 1/20 000]. CIRADT – IRA T Montpellier.

[22] Olivry, J. C. (1986) Fleuves et rivières du Cameroun [Streams and Rivers of Cameroon]. MESRES-ORSTOM-ISBN2-7009-0844-2.

[23] Severin, M. M., Bill, V. B., Olivier, T. S., Lizzette, N. and Dieudonne, B. (2020) Assessment of Rainfall Variations in South Region, Cameroon. American Journal of Climate Change, 9, 410-422. https://doi.org/10.4236/ajcc.2020.94026

[24] Meli, F. R. and Meli, M. V. (2015) Modelling Drivers of Forest Cover Change in the Santchou Wildlife Reserve, West Cameroon using Remote Sensing and Land Use Dynamic Degree Indexes. Canadian Journal of Tropical Geography, 2, 29-42.

[25] Itiga, Z., Chakam Tagheum, P. J., Wotchoko, P., Wandji, P., Bardintzeff, J. M., and Bellon, H., (2004) La ligne du Cameroun: Volcanologie et geochronologie de trois regions (Mont Manengouba, du Noun et Tchabal Gangdaba) [The Cameroon Line: volcanology and geochronology of the three regions (Mount Manengouba, Noun and Tchabal Gangdaba)]. Geochronique, 91, 13-16.

[26] Zangmo, T. G., Román, A. Q. and Umaña, P. D. (2020) Geomorphosites inventory in the Eboga Volcano (Cameroon): contribution for geotourism promotion. Géomorphologie Relief Processus Environnement, 1-16.

[27] Sato, H., Aramaki, S., Kusakabe, M., Hirabayashi, J. I., Sano, Y., Nojiri, Y. and Tchoua, F. M. (1990) Geochemical difference of basalts between polygenetic and monogenetic volcanoes in the central part of the Cameroon Volcanic Line. Geochemical Journal, 6, 357-370.

[28] Kagou, D. T., Wandji, P. J., P., Pouclet, A., Vicat, J. P., Cheilletz, A., Nkouathio, D. G., Alexandrov, P., and Tchou, F. M. (2001) Evolution volcanologique du mont Manengouba (Ligne du Cameroon) nouvelles données pétrographiques, géochimiques et géochronologique [volcanological evolution of Mount Manengouba (Cameroon Line) new petrographic, geochemical and geochronological data]. C. R Acad. Sci., Terre et planètes, 333, 155-162.

[29] APHA (1995) Standard methods for the examination of water and wastewater 21st ed., Washington D.C, American Public Health Association.

[30] Lloyd, J. A. and Heathcote, J. A. (1985) Natural inorganic hydrochemistry in relation to groundwater: An introduction. Oxford Uni. Press, New York.

[31] Trivedy, R. K. and Geol, P. (1986) Chemical and biological method for water pollution studies. Environ Pub, Karad.

[32] Todd, D. K. (1980) Groundwater hydrology [M], 2nd ed. Wiley, New York.

[33] Soleimani, H., Nasri, O., Ojaghi, B., Pasalari, H., Hosseini, M., Hashemzadeh, B., Kavosi, A., Masoumi, S., Radfard, M., Adibzadeh, A. and Feizabadi, G. K. (2018) Data on drinking water quality using water quality index (WQI) and assessment of groundwater quality for irrigation purposes in Qorveh & Dehgolan, Kurdistan, Iran. Data in Brief, ELESEVIER, 20, 375-386.https://doi.org/10.1016/j.dib.2018.08.022

[34] Mkandawire, T. (2008) Quality of groundwater from shallow wells of selected villages in Blantyre District, Malawi. PhyChem Earth, 33, 807–811.

[35] Nouayti, N., Khattach, D. and Hilali, M. (2015) Evaluation de la qualité physicochimique des eaux souterraines des nappes du Jurassique du haut bassin de Ziz (Haut Atlas central, Maroc) [Evaluation of physicochemical quality of groundwater from the Jurassic aquifers of the upper Ziz basin (central High Atlas, Morocco)]. J. Mater. Environ. Sci., 6, 1068-1081.

[36] Djuikom, E., Njine, T., Nola, M., Sikati, V. and Jugnia L. B. (2006) Microbiological water quality of the Mfoundi River watershed at Yaoundé, Cameroon, as inferred from indicator bacteria of fecal contamination. Environ Monit Assess, 122, 171-183.

[37] Ketchemen-Tandia, B., Boum-Nkot, S. N., Ebondji, S. R., Nlend, B. Y., Emvoutou, H. and Nzegue, O. (2017) Factors Influencing the Shallow Groundwater Quality in Four Districts with Different Characteristics in Urban Area (Douala, Cameroon). Journal of Geoscience and Environment Protection, 5, 99-120. http://www.scirp.org/journal/gep

[38] Mukhopadhyay, B. P., Chakraborty, A., Bera, A. and Saha, R. (2022) Suitability assessment of groundwater quality for irrigational use in Sagardighi block, Murshidabad district, West Bengal. Appl Water Sc, 12, 1-17. https://doi.org/10.1007/s13201-021-01565-4

[39] Temgoua, E., Ngnikam, E. and Ndongson, B. (2009) "Drinking Water Quality: Stakes of Control and Sanitation in the Town of Dschang – Cameroon," International Journal of Biology and Chemical Sciences, 3, 441-447.

[40] Egbueri, J. C., Mgbenu, C. N. and Chukwu, C. N. (2019) Investigating the hydrogeochemical processes and quality of water resources in Ojoto and environs using integrated classical methods. Modeling Earth Systems and Environment, *5*, 1443-1461.https://doi.org/10.1007/s40808-019-00613-y

[41] Ahada, C. P. S. and Suthar, S. (2018) Assessing groundwater hydrochemistry of Malwa Punjab, India. Arabian Journal of Geosciences, 11, 1-14. https://doi.org/10.1007/s12517-017-3355-8

[42] Akakuru, O. C., Akudinobi, B., Opara, A, I., Onyekuru, S. O. and Akakuru, O. U. (2021) Hydrogeochemical facies and pollution status of groundwater resources of Owerri and environs, Southeastern Nigeria. Environ Monit Assess, 193, 1-26.https://doi.org/10.1007/s10661-021-09364-9

[43] Adimalla, N. and Venkatayogi, S. (2018) Geochemical characterization and evaluation ofgroundwater suitability for domestic and agricultural utility in the semi-arid region of Basara, Telangana State, South India. Appl. Water Sci., 8, 1-14. https://doi.org/10.1007/s13201-018-0682-1

[44] Mohsin, M., Safdar, S., Jamal, F. and Ashhgar, F. (2013) Assessment of Drinking Water Quality and its Impact on Residents Health in Bahawalpur City. International Journal of Humanities and Social Science, 3, 114-128. https://www.researchgate.net/publication/273724845

[45] Nkansah, M. A., Ofusuah, O. and Boakye, S. (2010) Quality of groundwater in the West district of Ghana, Environmental Research Journal, 1, 578-584. DOI: 10.3923/erj.2011.31.37.

[46] Ako, A. A., Shimada, J., Hosono, T., Ichiyanagi, K., Nkeng, G. E., Fantong, W. Y., Eyong G. E. T. and Roger, N. N. (2011) Evaluation of groundwater quality and its suitability for dinking, domestic, and agricultural uses in the Banana Plain (Mbanga, Njombe, Penja) of the Cameroon Volcanic Line. Environ. Geochem. Health, 33, 559-575.

[47] WHO (2004). Guidelines for drinking water quality. 3rd ed., World Health Organization, Geneva, Switzerland. http://www.who. int/water_ sanitation_ health/dwq/ GD WQ2004web.pdf.

[48] Nono, A., Likeng, J. D. H., Wabo, H., Tabue Youmbi, G. and. Biaya, S. (2009) Influence de la nature lithologique et des structures géologiques sur la qualité et la dynamique des eaux souterraines dans les hauts plateaux de l'Ouest-Cameroun [Influence of lithology and geologic structures on quality and dynamics of groundwater in Cameroon western highlands]. Int. J. Biol. Chem. Sci., 3, 218-239. ttp://www.ajol.info

[49] Ahmad, A., Mohammad, A. A., Majeda, K. and Nabil, Z. (2020) Hydrogeochemical characterization and quality evaluation of groundwater suitability for domestic and agricultural uses in the state of Qatar. Groundwater for Sustainable Development, 1-71 https://doi.org/10.1016/j.gsd.2020.100467

[50] Fouepe, A. T., Kuitcha, D., Fantong, W. Y., Ewodo, M. G., Khan, H., Issa and Takeshi, O. (2013) Assessing Groundwater Nitrate pollution in Yaounde Cameroon, Modeling Approach. World Applied Science. Journal, 23, 333-344. DOI: 10.5829/idosi.wasj.2013.23.03.321.

[51] Eyankware, M. O., Obasi, P. N., Omo-Irabor, O. O. and Akakuru, O. C. (2020) Hydrochemical characterization of an abandoned quarry and mine water for domestic and irrigation uses in Abakaliki, southeast Nigeria. Model. Earth Syst. Environ., https://doi.org/10.1007/s40808-020-00827-5

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

[53] Durov, S. A. (1948) Classification of natural waters and graphical representation of their composition. DokladyAkademiiNauk, 59, 87-90.

[54] Aly, A. A., Al-Omran, A. M. and Alharby, M. M. (2015) The water quality index and hydrochemical characterization of groundwater resources in Hafar Albatin, Saudi Arabia. Arab J Geosci, 8, 4177–4190.

[55] Verma, P., Singh, P. K., Sinha, R. R. and Tiwari, A. K. (2020) 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. Appl Water Sci, 10, 1-16 Doi: https://doi.org/10.1007/s13201-019-1088-4

[56] Gibbs, R. J. (1990) Mechanisms Controlling World's Water Chemistry. Science, 170, 1088-1090. https://doi.org/10.1126/science.170.3962.1088

[57] Mohammad, Z., Shabbir, A., Lee, H. (2018) Irrigation Water Quality. International Atomic Energy Agency, 113-131.https://doi.org/10.1007/978-3-319-96190-3_5

[58] Wilcox, L. V. (1955) Classification and use of irrigation waters. Washington, D.C., Circular No. 969.

[59] Keesari, T., Ramakumar, K. L., Chidambaram, S., Pethperumal, S. (2016) Understanding the hydrochemical behaviour of groundwater and its suitability for drinking and agricultural purposes in Pondicherry area, South India- a step towards sustainable development. Groundw Sustain Dev, 2, 143–215. https://doi.org/10.1016/j.gsd.2016.08.001

[60] Sawyer, C. N. and McCarty, P. L. (1967) Chemistry for Sanitary Engineers, 2nd ed., McGraw Hill, New York.