Assessment of groundwater quality in Bamenda–Cameroon for suitable applications

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Abstract

Groundwater quality of the Bamenda metropolis (Northwest Region—Cameroon) was assessed for its suitability for possible uses. A total of 22 groundwater samples were collected from dug wells and boreholes within the Bamenda town during the wet and dry seasons. Hydrodynamics and physicochemical parameters were measured. Other parameters including, major ions, sodium percentage (Na %), sodium adsorption ratio (SAR), and water quality index (WQI) were deduced from chemical analysis, and their distributions were demonstrated using spatial distribution contour maps. Durov's plot, Gibbs diagram, and chloro-alkaline indices were used to deduce the source and detect the groundwater samples for different applications. The findings indicate that groundwater flows in the study area from shallow to deep aquifers. Piper's plot shows Ca–Mg–CO₃–HCO₃ and Ca–Mg–Cl–SO₄ as the main water types. WQI and World Health Organization (WHO) guidelines show that all the groundwater samples have excellent water quality for drinking purpose. Electrical conductivity (EC), Na %, and SAR values indicate that all wet season water samples are of low-salinity class, whereas dry season samples are of low to medium salinity; hence, all the samples are suitable for irrigation. Though there is extensive use of agricultural fertilizers and intense urbanization in the metropolis, anthropogenic activities, for now, seem to have minimal impact on the quality of groundwater.

Keywords Groundwater · Bamenda–Cameroon · Physicochemical analysis · Water quality index · Suitability

1 Introduction

Groundwater is one of the natural resources available for humanities. Its exploitation and utilization have been noted in both developed and developing countries. It plays a vital role in sustainable and socioeconomic development as it is required for livelihood, industrial growth, public health, economic development, and food security [1]. Groundwater is historically considered the most reliable source of water regarding its quality [2]. However, increasing population, unplanned urbanization,

industrialization, and agricultural intensification globally pose potential threats to groundwater reserves by altering the consumption pattern and degrading the quality [3].

In many developing countries with deplorable housing and infrastructures as well as inadequate waste disposal facilities and pipe-borne water supply; pushes the population to depend mainly on groundwater resources as their main water supply for domestic, irrigation, and industrial purpose. The literature indicates that approximately 80% of the population in developing countries utilizes groundwater as their main source for drinking

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and domestic needs [4, 5]. Likewise, Siebert et al. [6] cited that groundwater accounts for 43% of the irrigation water use and is more suitable for irrigation purpose relative to surface water. While Cameroon has generally made substantial progress in the provision of safe and potable water, the country still faces problems in addressing water supply in rural and informal settlements as well as densely populated areas. Like many other developing countries, Cameroon depends on groundwater as a source for domestic, agricultural, and industrial water supply, especially the population residing in fast-growing industrialized and densely populated towns like Bamenda. Unfortunately, degradation of the quality of groundwater is one of the major challenges encountered in such a metropolis.

Bamenda, being the capital of the North West Region of Cameroon, is inhabited by people of diverse cultures whose major activities are agriculture and animal husbandry. The daily activities of the inhabitants are highly aided by the use of groundwater, due to the inadequate piped water supply. With the problem of scarce pipe-borne water supply and limited surface water resources, the demands of the population are met only by the exploitation of groundwater from open dug wells and springs which is comparatively cleaner and free from pollution relative to surface water. Nevertheless, the ever-increasing population, poor sanitation, excessive use of fertilizers and pesticides in agriculture, poor sewerage system, and improper effluent disposal facilities within the metropolis pose potential threats to the groundwater reserves, resulting in health problems.

Even though the groundwater resources in the Bamenda metropolis are serving the population domestically, agriculturally, and industrially, there are still no water quality monitoring systems, no aquifer, and well-head protection zones for groundwater quality protection. This, therefore, remains a threat both to the aquifer and to the population. Hence, proper monitoring and analysis of groundwater within the metropolis are of paramount importance to ensure a sustainable supply of the resource. Lack of data for groundwater quality in the study area makes investigating the aforementioned groundwater chemistry extremely important to determine its health impact on the population. Likewise, producing spatial variation maps of the major physicochemical parameters for groundwater in Bamenda is essential for sustainable development and managing of groundwater resources. In an attempt to address these voids, a baseline study was conducted in Bamenda–Cameroon to determine the physicochemical properties of groundwater for suitable uses. Piper's plot, Gibbs diagram, spatial variation maps of major physicochemical parameters, water quality index (WQI), extended Durov plot, as well as seasonal groundwater contour maps and flow models, were employed

to characterize the water based on their wide usage and general acceptability [2, 6]. Findings from this study will not only contribute in improving the understanding of the factors controlling groundwater quality in Bamenda but will also provide groundwater quality data in the study area with emphasis on parameters that have not been addressed before, thus contributing to sustainable development and management of groundwater resources within Bamenda metropolis. The findings will also provide safer information to the population on the quality of drinking and irrigation water from the wells and springs.

2 Description of the study area

2.1 Location and climate of the study area

The study area (Bamenda) is situated in Mezam Division in the North West Region of Cameroon, precisely at the central part of the Cameroon Volcanic Line (CVL) and is implanted below the high lava plateau, at an altitude of about 1100–1500 m above sea level [7]. The climate is mainly of the equatorial monsoonal type characterized by high rainfall and relative humidity with two main seasons: a long rainy (wet) season lasting for 7.5 months from mid-March to early November, with approximately > 45% chance of a given day being wet, while the dry season lasts for 4.5 months from early November to mid-March. The annual average precipitation ranges from 1700 to 2824 mm and exhibits fluctuations [8, 9].

2.2 Geology and hydrogeology of the study area

The geology of the study area has been described in detail by Morin [10]. The scholar indicated that Bamenda belongs to the West Cameroon Highlands, the most important geomorphologic system in the region. The study area constitutes part of the Bamenda Mountains which is made up of a basement rock comprised mainly of leucogranite of Precambrian age, with the basement rock overlain by volcanic materials composed of mafic and felsic lavas [11]. The mafic lavas comprise of basalts which outcrop as lava flows and pyroclastic deposits, while the felsic lavas include trachytes, phonolites, and rhyolites [12]. These felsic lavas originate through fractional crystallization from mafic magmas, with crustal contamination. Chemical weathering of the basement and the resulting volcanic rocks (from felsic and mafic lavas) produced thick unconsolidated sediments consisting mainly of clay to sand-sized particles [13] with the major clay minerals being montmorillonite (smectite), while cristobalite, feldspars, ilmenite, and heulandite constitute the accessory minerals [14]. The

Fig. 1 Map of Bamenda with sample sites indicated

Online Resource shows the geological map of Bamenda with the major lithologies.

The study area is characterized by fractured phreatic aquiferous formations found within the hard rock system, and the aquifer types are defined as being superimposed or isolated [15]. The weathered basement (regolith) and alkali-rich fluvial sediments constitute the aquiferous materials in the area. Percolation of water through the unconsolidated sediments forms the groundwater aquifer system with depths < 30 m below the surface [16].

3 Field and experimental program

3.1 Fieldwork

3.1.1 Water sample collection

The fieldwork was conducted in two campaigns (wet and dry seasons), to have a better understanding of the variations of the groundwater quality during both seasons. A total of 22 sites (18 hand-dug wells and 4 boreholes) were sampled for both campaigns. Permission to conduct the study at the selected locations was sought from relevant authorities. The sampling technique employed was the stratified grid sampling method based on access and rate of utilization of the wells, boreholes, and springs. Water sample collection constituted water being drawn from the open dug wells using a bucket tied to a rope, while boreholes were pumped for 10–20 min before sampling

to prevent non-representative samples and polluted water. Three (3) sets of water samples were obtained from each water source. The first set was untreated sample for the determination of the pH, electrical conductivity (EC), and temperature with the use of a pH and EC meters as well as a thermometer, respectively. The second set was filtered untreated for the determination of anionic concentrations, and the last set was acidified (1:1 dilute nitric acid) for cationic concentrations.

The sample containers (0.35-liter plastic bottles) were cleaned with hydrochloric acid and then washed with tap water to render it free of acid, and later washed with distilled water and finally rinsed with the sampled water. Field filtration was carried out through acetate cellulose filter papers with a pore size of 0.45 μm to remove any suspended solids before being transferred into the containers and tightly closed in order to avoid evaporation. The samples were then sealed, labeled, and transported to the laboratory of the Agronomical Institute of Research and Development (IRAD) Ekona–Cameroon for chemical analysis. Prior to analysis, the samples were kept in a refrigerator at an operating temperature range of 7–10 $^{\circ}\text{C}$. This procedure was adopted to prevent or minimize any chemical and biochemical reactions. Figure 1 depicts the sample site within the study area.

3.1.2 Determination of physical parameters

The design of the dug wells varied from one site to another. They were characterized by varied collars,

aprons, lids, and angles of inclination. The wells had been developed over 2–15 years. In all cases, the tested wells were characterized by radii ranging from 0.3 to 0.55 m and depths ranging from 1.51 to 9.76 m. At each well site, coordinates of the site were recorded with the aid of a GPS, and the in situ physical parameters (EC, pH, and temperature) of the well and borehole waters were measured.

3.2 Laboratory work

The laboratory work involved the determination of the major cations and anions present in the water samples. The analyses were done at the Agronomical Institute of Research and Development (IRAD) laboratory Ekona–Cameroon. Sodium ions (Na^+), potassium ions (K^+), calcium ions (Ca^{2+}), magnesium ion (Mg^{2+}), and ammonium ion (NH_4^+) were the major cations determined. Sodium ions (Na^+) and potassium ions (K^+) were determined using the flame photometry technique, according to standard procedures outlined in Chikhale and Pratibha [18]. Calcium ions (Ca^{2+}) were determined by titration with a 0.02 M standardized solution of Ca – EDTA which combines with 1 ml of TEA and 1 ml of 5% KCN. Magnesium ions (Mg^{2+}) and ammonium ions (NH_4^+) were analyzed using the calorimetric method. Major anions such as bicarbonate ion (HCO_3^-) and chloride ion (Cl^-) were determined by titration. The nitrate ion (NO_3^-) and phosphate ions (PO_4) were determined by calorimetry, and the sulfate ion (SO_4^{2-}) was analyzed by turbidimetry.

3.3 Data synthesis

Analysis of data was done with the use of geological and statistical software packages including AQUA-CHEM 2012.1, Surfer 12, Global mapper 15, and Microsoft Excel 2016. Detailed discussion on the process and math mechanisms of these software packages can be found on their user guides. AQUA-CHEM was employed to construct ternary diagrams (Piper, extended Durov, Gibbs diagrams, and USSL diagrams) to determine the water types. The sampling locations and spatial distribution maps were prepared using Surfer 12. Global mapper was employed for georeferencing the base map. Microsoft Excel 2016 was used to statistically analyze the data, including the means, ranges, and standard deviations of the water quality data.

3.3.1 Water quality for drinking

In order to assess the water samples for drinking, World Health Organization (WHO) 2004 [19] guidelines and water

quality index (WQI) as described by Ravikumar [20] were used.

3.3.1.1 Water quality index The WQI was determined using Eq. (1):

$$\text{WQI} = \sum_{i=1}^n W_i q_i / \sum_{i=1}^n W_i \quad (1)$$

where

$$W_i = K / S_n \quad (2)$$

W_i = weightage factor of the i th parameter.

$$K = \left[\sum_{i=1}^n S_n^{-1} \right]^{-1} \quad (3)$$

K = constant of proportionality, n = number of parameters, S_n = sum of the standard permissible value of the i th parameter.

$$q_i = [(V_{\text{actual}} - V_{\text{ideal}}) / (V_{\text{standard}} - V_{\text{ideal}})] \times 100 \quad (4)$$

q_i = quality rating based on the concentration of i th parameter, V_{actual} = estimated value of the i th parameter from laboratory analysis, V_{standard} = WHO (2004), prescribed guideline permissible value of the i th parameter in mg/l except for conductivity ($\mu\text{S}/\text{cm}$) and pH. V_{ideal} = ideal value of the i th parameter in pure water (pH = 7 and for the other parameters it is equivalent to zero).

3.3.2 Water for irrigation purpose

To evaluate the suitability of groundwater for irrigation purpose, sodium adsorption ratio (SAR), sodium percentage (Na %), and EC measurements were obtained. The aforementioned parameters are defined by Eqs. (5) and (6).

$$\text{SAR}(\text{meq}/\text{l}) = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})^{0.5}} \quad (5)$$

$$\text{Na}\% = \frac{(\text{Na}^+ + \text{K}^+)}{(\text{K}^+ + \text{Mg}^{2+} + \text{Ca}^{2+} + \text{Na}^+)} \quad (6)$$

4 Results and discussion

4.1 Groundwater level and aquifer flow paths

The measured depths to water level in the wells varied from 1.12 to 9.27 m with higher water levels in the center and northeastern parts of the study area. The measured well depths varied from 1.52 to 9.76 m with deeper wells

Fig. 2 Water level and flow direction maps within the study area **a** wet season; **b** dry season

observed in areas with higher water levels. From the measured depths to water levels and well depths, groundwater level contour and flow maps of the study area were incorporated to ascertain the flow direction. Locations with higher altitude showed high water elevation relative to the surrounding low-altitude locations.

The groundwater level and aquifer flow path maps for both wet and dry seasons in the study area are presented in Fig. 2a, b, respectively. Both maps indicate that the flow of groundwater in the study area is generally from shallow aquifers (northwestern part) toward the deeper aquifers (center and northeastern parts) with higher elevations relative to their surrounding areas. Groundwater flow is, therefore, a function of the groundwater table and elevation since water flows from higher to lower water levels above mean sea level. This flow direction agrees with the drainage pattern of the main river and streams in the study area, as depicted in Fig. 1. Based on this, it is evident that the centre and northeastern parts of the study area experience large exploitation of groundwater for drinking, domestic, and irrigation uses evidenced by the high density of dug wells in these areas which are characterized by high urbanization and industrial activities.

According to Wirmvem et al. [21], areas with higher water levels are associated with higher elevations as a result of groundwater discharge at such high elevations through joints from some likely perched aquifer systems. Ako et al. [22] further cited that the use of altitudes and water levels from wells gives a better flow path and direction of groundwater flow. Ako et al. [22] showed that contaminant exposure pathways generally follow the

groundwater route, and they also indicated that topography plays a major role in groundwater flow.

4.2 Physical properties

Water temperatures were slightly lower during the wet season relative to the dry season for almost all sampled points (see Tables 1, 2). The pH of the groundwater ranged between 4.8 and 7.6, with a mean value of 5.71 in the wet season (see Table 3). Similarly, in the dry season, the pH ranged between 5.20 and 9.50 with a mean value of 7.40 (see Table 3).

The electrical conductivity values were lower in the wet season with a maximum value of 240 $\mu\text{S}/\text{cm}$, minimum value of 6 $\mu\text{S}/\text{cm}$, and a mean value of 78 $\mu\text{S}/\text{cm}$ and generally higher in the dry season with a maximum value of 490 $\mu\text{S}/\text{cm}$, minimum value of 9.8 $\mu\text{S}/\text{cm}$, and a mean value of 111.8 $\mu\text{S}/\text{cm}$.

4.2.1 pH of the groundwater

Figure 3a, b depicts the pH spatial variation map of groundwater in the wet and dry seasons of the study area, respectively. Various minerals and organic matter interact with each other, resulting in an increase or decrease in pH values [23]. The spatial variation map of the pH indicates that the groundwater of the study area is slightly acidic to basic in both wet and dry seasons, however, with higher alkalinity in the dry season. The highest pH values were recorded in the center and southeastern parts of the study area in the wet season; likewise, in the dry season

Table 1 Variations of physicochemical parameters and ions in the wet season for each sample location

Sample locations	Temp	pH	EC	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NH ₄ ⁺	HCO ₃ ⁻	NO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	HPO ₄ ²⁻	TH
Nitob IV	22.4	5	90	0.28	2.28	10.88	4	0.43	10.98	0	0.32	18	0.02	43.60
Alamatson	23.2	5.6	10	0.18	1.56	4.36	0.51	0.65	19.52	2.43	0	6	0.02	12.99
Mile 7 Mankon	23.4	5.5	20	0.14	1.72	4.36	0.39	0.61	43.92	0	0.33	2	0	12.50
Mile 6 Mankon	22.6	5.7	60	0.14	1.17	4.36	0.51	0.42	15.86	0	0.31	2	0	12.99
Foncha Street 1	23.8	6.2	20	0.23	2.57	6.52	0.65	1.47	91.50	0	0.34	2	0.01	18.97
Foncha Street 2	25.6	5.6	40	0.18	1.17	6.52	0.61	0.65	18.30	0	1.20	0	0.01	18.80
Mile 4 Nkwen	24.2	5.7	100	0.51	5.46	17.40	2.06	0.2	32.94	0.23	0.63	6	0.01	51.95
Mile 6 Nkwen	22.9	6.1	160	0.28	2.89	13.04	5.64	0.34	36.60	0.21	0	1	0.02	55.72
Mile 3 Nkwen	22.5	6.3	110	0.18	1.72	6.52	2.71	0.39	62.22	0	0	4	0.01	27.41
Mile 2 Nkwen	23.8	6.1	240	0.37	4.06	13.04	4.21	0.1	100.04	4.11	2.12	14	0	49.86
Nitob III	24.3	5.1	180	0.64	8.19	21.76	7.95	0.53	17.08	1.23	0.68	16	0.02	87.00
Travelers	22.8	5	110	0.46	3.51	10.88	3.01	0	2.44	0	0	12	0	39.54
Mile 7 Nkwen	22.4	6.3	30	0.18	1.87	8.68	2.84	0.43	40.26	0	0	2	0.01	33.34
Church Center	23	6	60	0.23	1.56	8.68	4.48	0.41	14.64	0.10	0	8	0.01	40.07
Oldtown	23.1	5.6	6	0.23	2.73	10.88	6.21	0.41	12.20	0.10	0	1	0.03	52.66
Atuakom	23.2	5.1	190	0.46	4.45	17.40	7.32	0	0	0	1.45	12	0.02	73.51
Ntarinkon Br.	24.1	4.9	110	0.41	4.91	15.24	3.84	0.4	14.64	0	0	1	0	53.84
Ntarinkon KG	22.3	4.9	80	0.23	1.87	15.24	3.25	0	1.22	0	0	1	0	51.43
Alakuma	22.7	4.8	40	0.37	3.51	8.68	3.33	0.32	9.76	4.21	1.42	6	0	35.35
Mbinfebei	21.9	5.2	10	0.18	1.17	17.36	2.95	0.34	39.04	0.23	0.65	4	0.02	55.50
Upstation	26.1	7.4	10	0.30	3.2	14.80	4.10	0.24	42.90	0.90	0.70	5	0.01	53.81
Finance junction	25.8	7.6	40	0.25	2.86	13.26	2.74	0.2	40.05	0.55	0.71	6	0.01	44.38

All ions concentration and total hardness (TH) in mg/l

the highest pH values were observed in the north and northeastern parts of the study area. The slightly acidic nature of the groundwater may be due to the formation and dissolution of minerals as well as the influenced of biochemical processes in solution [24]. On the other hand, the high pH values may be due to waste discharge and microbial decomposition of organic matter in the water body [25]. Ako et al. [22] obtained a similar range of pH values in groundwater sources along the Cameroon volcanic line, and they attributed the acidic nature of the waters to the presence of dissolved CO₂ from root respiration, decay of organic matter in soils, or dissolution of carbonate minerals.

Majority of the groundwater samples in the wet season failed to meet the permissible range (6.5–8.5) of pH for drinking water proposed by WHO [19], except for samples from Upstation and Finance junction. Conversely, the majority of the groundwater samples in the dry season are within the permissible range prescribed by WHO [19] for drinking water except for samples from Nitob III, Ntarinkon KG, and travelers.

4.2.2 Electrical conductivity of the groundwater

EC is a measure of the groundwater capacity to convey electric current. It indicates the amount of total dissolved salts in the groundwater, and it is a vital parameter for evaluating the purity of water. The spatial variation map of the groundwater EC for both wet and dry seasons in the study area is shown in Fig. 4a, b, respectively. It can be deduced that the conductance of the groundwater in both wet and dry seasons is a function of Ca²⁺ and Mg²⁺ cations as well as HCO₃⁻ and Cl⁻ anions concentrations. Thus, Ca²⁺, Mg²⁺, HCO₃⁻, and Cl⁻ are the ions dominating among salts constituting total dissolved salt amount. The EC values were lower in the wet season and generally higher in the dry season, thus indicating the presence of a high amount of dissolved inorganic substances in ionized form in the groundwater during the dry season relative to the wet season. The lowest EC was recorded at Oldtown in the wet season and Foncha Street 2 in the dry season, while the highest EC was recorded at Mile 2 Nkwen in the wet season and Church center in the dry season.

The spatial variation maps of the EC in both wet and dry seasons show that low elevations of the study area recorded high groundwater EC. High ECs were recorded in

Table 2 Variations of physio-chemical parameters and ions in the dry season for each sample location

Sample locations	Temp	pH	EC	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NH ₄ ⁺	HCO ₃ ⁻	NO ₃ ⁻	SO ₄ ²⁻	CL ⁻	HPO ₄ ²⁻	TH
Nitob IV	23.9	8.3	100	0.35	3.71	14.36	6.15	0.81	8.54	0.31	0.14	16	0.02	61.12
Alamatson	24.9	7.2	10	0.18	2.05	10.76	4.53	0.3	18.3	0.4	1.69	2	0.02	45.47
Mile 7 Mankon	24.1	6.7	20	0.37	3.28	14.36	10.91	0.3	32.33	0	0.61	24	0	84.63
Mile 6 Mankon	23	6.8	40	0.16	1.64	10.77	9.81	0.2	16.47	0.01	0.55	2	0	67.15
Foncha Street 1	24	7.5	180	0.27	2.89	7.18	10.11	0.74	42.7	0.08	8.31	1	0.01	59.40
Foncha Street 2	26.2	7.4	9.8	0.16	1.25	10.78	3.73	2.02	14.64	0.59	10.17	1	0.02	42.24
Mile 4 Nkwen	25	9.5	170	0.32	3.28	17.94	5.43	4.21	18.3	0.81	7.17	4	0.05	67.11
Mile 6 Nkwen	23	8.1	70	0.46	2.89	14.36	4.06	0.84	6.1	0.92	0.24	22	0.03	52.55
Mile 3 Nkwen	26.8	8.3	110	0.14	1.64	3.68	5.21	0	53.64	0.21	5.88	9	0.03	30.56
Mile 2 Nkwen	23	8.4	200	0.25	1.64	10.78	5.04	0.66	26.23	0.63	0.11	17	0.04	47.61
Nitob III	24.7	6.4	140	0.51	6.98	14.36	4.06	0.84	7.93	0.92	0.24	1	0.03	52.55
Travelers	23.6	5.2	110	0.14	1.25	3.58	2.25	0.3	9.76	0.23	0.39	0	0.02	18.18
Mile 7 Nkwen	22.0	8	110	0.3	1.64	7.18	4.54	0.31	17.08	0.43	1.68	24	0.02	36.56
Church Center	23	6.9	490	0.76	6.55	28.72	4.87	0.21	0	0	0.21	64	0	91.77
Oldtown	24	8.3	30	0.12	1.64	7.18	1.33	0.31	1.22	0	0.11	4	0	23.40
Atuakom	23	7.4	370	0.51	6.16	14.36	2.81	2.7	0	0	0.2	30	0.01	47.42
Ntarinkon Br	25	6.5	110	0.74	8.62	25.12	2.7	0.41	0	0.31	1	20	0.01	73.87
Ntarinkon KG	23	5.8	60	0.14	1.64	7.18	4.35	0.45	0	0	0.23	8	0	35.79
Alakuma	22.5	7.5	70	0.25	3.38	14.36	2.68	0.35	0	0	0.23	4	0.01	46.89
Mbinfebei	22.4	7.3	10	0.16	2.07	10.78	4.21	0.65	53.68	2.87	0.63	6	0.02	44.21
Upstation	26.4	7.8	10	0.16	2.46	10.78	4.51	0.31	17.08	0.41	1.66	2	0.02	45.44
Finance junction	26.6	7.5	40	0.83	10.69	32.3	8.68	0	104.92	0	3.6	20	0.01	116.34

All ions concentration and total hardness (TH) in mg/l

the center, north, and southern parts of the study area in the wet season. Similarly, in the dry season, high groundwater ECs were observed in the center and southern parts of the study area. The high ECs recorded in these areas may be due to the surface–groundwater interaction based on hydraulic conductance and groundwater level as well as the possible leaching of river water in the groundwater. Nonetheless, all the analyzed groundwater samples for both the wet and dry seasons in the study area are within the EC permissible limit ($< 750 \mu\text{S}/\text{cm}$) for drinking water prescribed by WHO [19].

4.2.3 Temperature of the groundwater

Temperature is one of the most vital properties of an aquatic system affecting the dissolved oxygen levels. Figure 5a, b depicts the interpolated spatial variation temperature map of the groundwater in both wet and dry seasons for the study area, respectively. Groundwater temperatures ranged between 21.90 and 26.10 °C in the wet season and 22.0–26.80 °C in the dry season. These low-temperature values suggest quick infiltration and shallow flow path [22]. Furthermore, it refutes any possibility of magmatic heating, as suggested in other volcanic areas [26]. Groundwater temperatures were generally higher

during the dry season and lower in the wet season for all sampled locations with mean temperatures of 23.46 °C in the wet season and 24.10 °C in the dry season. The slightly high temperatures recorded in the dry season relative to the wet season might be due to overheating by the sun. Similar findings were reported by Magha et al. [27], when they investigated the physicochemical properties of some springs and well waters in Bamenda III–Cameroon.

The low mean groundwater temperatures relative to the air temperature (28.4 °C) suggest that the depth of circulation is short as in local systems and near recharge areas with quick infiltration [28]. Studies carried out by Gnazou et al. [29] in coastal aquifers in Togo (along the Gulf of Benin) indicated higher groundwater temperatures (29–34 °C) relative to lower air temperature (27 °C). The authors associated the behavior to the presence of confined aquifers with depths of 50 to ≥ 200 m. Following this, the lower mean groundwater temperatures relative to the mean air temperatures as observed can be associated with the unconfined nature of the aquiferous formation. This fact is supported by field observations where aquifers are typically shallow, unconfined, and characterized by depths of 1.52–9.76 m.

Table 3 Summary of the physicochemical and water quality parameters for the sampled groundwater in both wet and dry seasons

Parameter	Wet season					Dry season				
	Max. value	Min. value	Mean value	Median. value	SD	Max. value	Min. value	Mean value	Median. value	SD
Temp	26.10	21.90	23.46	23.15	1.16	26.80	22.00	24.10	23.95	1.44
pH	7.60	4.80	5.71	5.60	0.76	9.50	5.20	7.40	7.45	0.96
EC	240.00	6.00	78.00	60.00	66.44	490.00	10.00	111.82	85.00	119.43
TDS	156.00	3.90	50.70	39.00	43.18	318.50	6.50	72.68	55.25	77.63
Na ⁺	0.64	0.14	0.29	0.24	0.13	0.83	0.12	0.33	0.26	0.22
K ⁺	8.19	1.17	2.93	2.65	1.71	10.69	1.25	3.52	2.68	2.61
Ca ²⁺	21.76	4.36	11.36	10.88	4.92	32.30	3.58	13.22	10.78	7.37
Mg ²⁺	7.95	0.39	3.33	3.13	2.14	10.91	1.33	5.09	4.52	2.59
NH ₄ ⁺	1.47	0.00	0.39	0.40	0.31	4.21	0.00	0.77	0.38	0.99
HCO ₃ ⁻	100.04	0.00	30.28	18.91	26.80	104.92	0.00	20.41	15.56	25.04
NO ₃ ⁻	4.21	0.00	0.65	0.05	1.27	2.87	0.00	0.42	0.27	0.63
SO ₄ ²⁻	2.12	0.00	0.49	0.33	0.59	10.17	0.11	2.05	0.58	3.01
CL ⁻	18.00	0.00	5.86	4.50	5.31	64.00	0.00	12.77	7.00	18.02
HPO ₄ ²⁻	0.03	0.00	0.01	0.01	0.01	0.05	0.00	0.02	0.02	0.01
TH	87.00	12.50	42.06	43.99	19.52	116.34	18.18	53.92	47.52	22.64
Na %	28.14	6.23	18.54	16.82	5.79	28.91	8.04	16.42	15.42	5.51
SAR	0.02	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.00
CAI 1	17.86	-4.32	5.02	4.30	6.08	63.89	-6.49	11.84	6.70	15.50
CAI 2	4.89	-0.90	0.43	0.04	1.27	269.95	-0.71	19.57	0.34	61.28
RSC	84.33	-24.72	15.59	12.33	28.89	63.94	-33.59	2.09	-1.99	23.37
Na/Cl	0.41	0.02	0.10	0.06	0.10	0.51	0.01	0.08	0.03	0.12
WQI	15.06	0.41	3.40	1.58	3.75	13.26	0.36	4.44	4.37	2.91

Temperature in °C; EC in $\mu\text{S}/\text{cm}$; ions concentration, TDS, RSC, and total hardness (TH) in mg/l

Fig. 3 Spatial variation map of pH for groundwater: **a** wet season; **b** dry season

Fig. 4 Spatial variation map of EC for groundwater **a** wet season; **b** dry season

Fig. 5 Spatial variation map of temperature for groundwater: **a** wet season; **b** dry season

4.2.4 Total hardness (TH)

Hardness is a very significant property of water for domestic applications. Hardness of water is caused by the presence of alkaline earth metals, i.e., calcium and magnesium, and by a variety of other metals. It represents the total concentration of Ca^{2+} and Mg^{2+} , indicated as calcium carbonate. That is, the amount of dissolved calcium and magnesium in water determines its

hardness. The groundwater spatial variation maps of TH for both wet and dry seasons are presented in Fig. 6a, b, respectively. Likewise, the maximum, minimum, and mean concentrations of TH in groundwater from the study area are presented in Table 3.

Although hardness of water is not considered a health risk, there is some suggestive evidence that long-term consumption of very hard water might lead to an increased incidence of urolithiasis, anencephaly,

Fig. 6 Spatial variation map of TH for groundwater: **a** wet season; **b** dry season

Table 4 Hardness of groundwaters in the study area

Hardness (mg/l CaCO ₃)	Water classification	Wet season		Dry season	
		Number of samples	%	Number of samples	%
0–75	Soft	21	95.45	19	86.36
75–150	Moderately hard	1	4.55	3	13.64
150–300	Hard	0	0	0	0
> 300	Very hard	0	0	0	0
Totals		22		22	

parental mortality, some types of cancer, and cardiovascular disorders [30]. Hardness of water is generally considered as total hardness (TH) and expressed by Eq. (7) after Todd [31].

$$TH = 2.5Ca + 4.1Mg \quad (7)$$

where TH is the total hardness as CaCO₃ in mg/l; Ca is the Ca²⁺ concentration in mg/l; and Mg is the Mg²⁺ concentration in mg/l.

Table 4 classifies the groundwater samples in the study area according to their hardness based on Dumfor and Becker [32] classification. The [19] guideline value for water for drinking purpose is 100 mg/l CaCO₃, and all the groundwater samples of the study area in the wet season comply with this limit.

4.3 Chemical properties

4.3.1 Cations

A summary of the chemical analysis of the 22 water samples indicating their highest, mean, and lowest cationic and anionic concentrations in both wet and dry seasons is presented in Table 3. Likewise, the individual concentrations of the cations and anions at each sampled location in both wet and dry seasons are presented in Tables 1 and 2, respectively. The dominant cation in the wet season in about 91% of the water samples is Ca²⁺, followed by Mg²⁺ and then by K⁺ and NH₄⁺ (Table 3).

Likewise, in the dry season, the dominant cation was Ca²⁺ followed by Mg²⁺ and then by K⁺ and NH₄⁺. Na⁺ was the least abundant cation in the water samples during both wet and dry seasons (see Table 1, 2).

4.3.2 Anions

HCO₃⁻ is the most abundant anion present in about 86% of the groundwater samples in the wet season (see Table 1). The next abundant anion is Cl⁻ followed by NO₃⁻ and HPO₄²⁻ the least abundant anion in the water samples during the wet season.

HPO₄²⁻ and NO₃⁻ are barely detectable in the dry season (see Table 2). HCO₃⁻ and Cl⁻ are the most abundant anions detected in the dry season (see Table 2). The highest concentrations of HCO₃⁻ in the wet and dry seasons were recorded at Mile 2 Nkwen and Finance junction, respectively.

Fig. 7 Piper's plot for groundwater samples during: **a** wet season; **b** dry season. The major hydrogeochemical facies are Ca–Mg–CO₃–HCO₃ and Ca–Mg–Cl–SO₄ (after Piper [34])

4.4 Hydrochemical facies

To understand the chemical facies of the groundwater in the study area, Piper's plot (Fig. 7a, b) for the groundwater chemistry in both wet and dry seasons was generated. In both seasons, the major cations and anions in the groundwater samples presented similar facies of Ca–Mg–CO₃–HCO₃ and Ca–Mg–Cl–SO₄. The similar facies indicate that there are no significant differences in the hydrochemical processes occurring within the aquifer during the dry and wet seasons, implying the mineralization processes occurring in both seasons are homogenous.

Rock–water interactions, solution kinetics, geology, and contamination sources are the factors that determine hydrochemical facies [33]

Gibbs diagrams were employed to reveal the main mechanism responsible for the chemistry of the groundwater. According to the Gibbs plot (Fig. 8a, b), the dominant mechanisms appear to be rock weathering followed by atmospheric precipitation with no dominance of evaporation and crystallization process. Moreover, it was found that mixed water types prevail in the study area as depicted in Durov diagram (Fig. 9a, b) in which 50% and 18% of the samples in the wet and dry seasons,

Fig. 8 Mechanisms controlling the chemistry of groundwater: **a** wet season and **b** for dry season (modified after Gibbs [38]). Red dots for cation ratio and green dots for anion ratio

respectively, plot along the dissolution or mixing line. Based on the classification of Lloyd and Heathcote [35], this trend can be attributed to recent fresh recharge water exhibiting simple dissolution or mixing. Also, a couple of samples (about 14% for the wet season and 36% for dry season) indicate that the groundwater is related to reverse ion exchange of Na–Cl waters. The remaining samples (about 36% for the wet season and 45% for dry season) are plotted in the ion-exchange field.

[36] used Na/Cl molar ratios to study silicate weathering reactions and showed that Na/Cl molar ratio > 1 reflects Na^+ released from silicate (feldspar) weathering in the process of exchange of magnesium and calcium in water with sodium and potassium in rock (cation–anion

exchange reaction). The molar ratios of Na/Cl for groundwater sources ranged from 0.02 to 0.41 for the wet season and 0.01–0.55 for the dry season (Fig. 10a, b). The values being < 1 imply that another source is contributing the chloride to the groundwater other than silicate, most likely anthropogenic sources [37].

4.4.1 Chloro-alkaline Indices

Two chloro-alkaline indices (CAI 1 and CAI 2) proposed by Schoeller [40] were computed to constrain the possible ion-exchange reactions between groundwater and the host aquifers. CAI 1 and CAI 2 were computed using Eqs. (8) and (9), respectively.

$$CAI\ 1 = Cl - (Na + K)/Cl \quad (8)$$

Fig. 9 Extended Durov's diagram with the various samples plotted at respective fields: **a** wet season and **b** dry season (after Durov [39])

$$CAI\ 2 = Cl - (Na + K) / (SO_4 + HCO_3 + CO_3 + NO_3) \quad (9)$$

18% and 32% of the samples in the wet season recorded negative values for CAI 1 and CAI 2 indices, respectively, whereas 82% and 68% showed positive indices for CAI 1 and CAI 2, respectively, in the wet season. About 14% and 27% of the samples in the dry season recorded negative values of CAI 1 and CAI 2 indices, respectively, while about 86% and 73% showed positive CAI 1 and CAI 2 values, respectively (Fig. 11a–d). The predominance of CAI 1 and CAI 2 values being positive suggests that Mg^{2+} and Ca^{2+} from water are exchanged with Na^+ and K^+ in rock favoring cation–anion exchange reactions [41]. The CAI ratio is

negative when Na^+ and K^+ contents are high. This situation occurs when groundwater has strongly been in contact with minerals able to yield these interchangeable cations easily [42]. This exchange is common with aluminosilicated clays formed by layers whose cohesion is ensured by the existence of interlayer cations and water. The surface of the layers is negatively charged, thus promoting the possibility of cation exchange with those of groundwater.

On the other hand, if the exchange occurs between Ca^{2+} and Mg^{2+} in the groundwater with Na^+ or K^+ in the aquifer material, the index will result to a negative, indicating ion exchange [40, 43]. The values of CAI 1 and CAI 2 as mentioned earlier are positive in majority of the

Fig. 10 Spatial variation map of Na/Cl for groundwater: **a** wet season; **b** dry season

Fig. 11 Spatial variation of CAI 1, CAI 2; **a** CAI 1 wet season; **b** CAI 1 dry season; **c** CAI 2 wet season; **d** CAI 2 dry season

Table 5 Groundwater quality parameters range within Bamenda in compliance with WHO [19] drinking water guidelines

Parameters	Range within Bamenda wet season	Range within Bamenda dry season	WHO limits	% Acceptability
pH	4.8–7.6	5.2–9.5*	6.5–8.5	90.9 and 13.6 unacceptable, respectively
EC	6–240	10–490	750	100% acceptable
TDS	3.9–156	6.5–319.5	500	100% acceptable
Na ⁺	0.14–0.64	0.83	200	100% acceptable
K ⁺	1.17–8.19	0.12–0.83	100	100% acceptable
Ca ⁺	4.36–21.76	1.25–10.69	75	100% acceptable
Mg ²⁺	0.39–7.95	3.58–32.3	30	100% acceptable
HCO ₃ ⁻	0–100.04	1.33–10.91	200	100% acceptable
NO ₃ ⁻	0–4.21	0–2.87	10	100% acceptable
SO ₄ ²⁻	0–2.12	0.11–10.17	250	100% acceptable
CL ⁻	0–18	0–64	250	100% acceptable
TH	12.49–86.99	18.18–116.34*	100	4.5% unacceptable for wet season

*Parameters out of WHO-recommended limit

Fig. 12 Spatial variation map of WQI for groundwater **a** wet season; **b** dry season

investigated water samples, thus suggesting an inverse reverse ion-exchange processes due to direct exchange of Ca²⁺ and Mg²⁺ from the aquifer matrix with Na⁺ and K⁺ from groundwater [43]. Hence, supports the fact that alkali earth elements are the most abundant.

4.5 Suitability for drinking purpose

The analytical results were evaluated to ascertain the suitability of groundwater in the study area for drinking purpose based on [19] recommendation as well as the calculated water quality index (WQI). Table 5 shows

the range of parameters in the study in compliance with WHO guidelines. WQI is defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water. It indicates the quality of an index number, which represents the overall quality of water for any intended use [44]. Spatial distribution of WQI values plotted as an infinite element map (Fig. 12a, b) for both wet and dry seasons reveal values in the range of 0.41–15.06 for the wet season samples and 0.36–13.26 for the dry season samples. According to Ravikumar's [20] classification, these values fall within the excellent quality class as the values

Fig. 13 Spatial variation map of SAR for groundwater: **a** wet season; **b** dry season

are less than 25. Therefore, all water samples based on this criterion are considered excellent for human consumption. However, the pH and TH of the groundwater samples in some locations failed to meet the recommended limits prescribed by the WHO [19]. Notwithstanding, the authors are of the view that the high value of the TH in some locations should not be used as a basis to reject the groundwater in those locations for drinking purpose since hardness is not considered as a serious health risk.

4.6 Suitability for irrigation use

In the current study, groundwater suitability for irrigation purpose was assessed based on EC, SAR, Na %, and USSSL.

4.6.1 EC and SAR

According to Richard's [45] classification, SAR and EC values for irrigation water are classified into four groups: low ($EC < 250 \mu S/cm$, $SAR < 10$), medium ($250-750 \mu S/cm$, $SAR, 10-18$), high ($750-2250 \mu S/cm$, $SAR, 18-26$), and very high ($2250-5000 \mu S/cm$, $SAR > 26$). While a high salt concentration in water leads to the formation of saline soil, a high sodium concentration leads to the development of alkaline soil [22]. The sampled groundwater in the study area recorded EC values in the range $6-240 \mu S/cm$ and SAR values in the range $0.004-0.02$ for the wet season; likewise for the dry season EC values were recorded in the range $10-490 \mu S/cm$ and SAR values in the range $0.03-0.01$. Figures 4a, b and 13a, b depict the spatial variation maps for the EC and SAR, respectively. Thus, all wet season samples

are of the low-salinity class, whereas dry season samples are of low to medium salinity according to Richard's classification. As such, the groundwater is generally suitable for irrigation purpose based on their EC and SAR.

4.6.2 Na%

In all natural waters, Na % is a common parameter used to assess its suitability for agricultural purpose [46]. A high Na % causes deflocculation and impairment of the tilt and permeability of soils [22, 47]. For agriculture use, Na % of water should not exceed 60% [22]. Based on this criterion, all investigated groundwater samples for both wet and dry seasons in the study area are excellent for irrigation purpose as their Na % are less than 60%. Figure 14a, b, depicts the spatial variation map of Na % of the groundwater samples in both wet and dry seasons, respectively.

4.6.3 United States Salinity Laboratory (USSSL) classification scheme

With respect to the United States Salinity Laboratory [48] classification. All the investigated samples plot in the C1S1 (low salinity and low sodium hazard) field for wet season (Fig. 15a). Likewise, for the dry season, 90.9% plots in the C1S1 field and 9.1% plots in the C2S1 (medium salinity and low alkalinity) field (Fig. 15b). Thus, all the investigated groundwater samples are suitable for irrigation application.

Fig. 14 Spatial variation map of Na % for groundwater: **a** wet season; **b** dry season

5 Summary and conclusions

Efforts have been made in the current study to evaluate the suitability of groundwater in the Bamenda metropolis for suitable applications. Twenty-two groundwater samples were collected from existing dug wells and boreholes, and their physicochemical properties were analyzed. Spatial variation maps of the physicochemical properties, as well as other water quality parameters, were generated. Assessment of the physicochemical properties of the groundwater samples led to an excellent understanding of groundwater quality within Bamenda for various applications. Based on the main findings, the following conclusions can be established:

- Ca^{2+} and Mg^{2+} were the dominant cations in groundwater of the study area, while HCO_3^- and Cl^- were the dominant anions in the groundwater. Piper plot showed that $\text{Ca-Mg-CO}_3\text{-HCO}_3$ and Ca-Mg-Cl-SO_4 are the main water types found in the study area. Gibb's diagram indicates that rock weathering followed by

atmospheric precipitation were the main water quality controlling factor.

- The computed SAR, Na %, USSL, and EC values reveal that all the groundwater samples were suitable for irrigation purpose
- The groundwater samples were generally suitable for drinking purpose according to WHO guidelines, though some few locations recorded pH and total hardness values out of boundary limits. The computed WQI showed that groundwater within the Bamenda metropolis is of excellent quality for drinking.

In general, although the effects of geogenic process, urban sewage, extensive use of agricultural fertilizers, and intense urbanization are not yet felt on the groundwater quality within the study area, their effects are inevitable in the nearest future. It is, however, recommended that other equally important water quality parameters of health concern such as arsenic (As), iodine (I), lead (Pb), mercury (Hg), as well as bacteriological parameters should be investigated in future studies.

Fig. 15 Wilcox plot and USSL classification plot for irrigation suitability of groundwater within Bamenda: **a** wet season samples; **b** dry season (modified after Wilcox [46])

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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