



# Evaluation of the Variability of Drinking Water Quality within Bamenda Metropolis, North West Region, Cameroon

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. Author GBNA perform the statistical analysis wrote the protocol, and wrote the first draft of the manuscript. Authors NMN and SNA read through the manuscript and made corrections. All authors read and approved the final manuscript.*

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## **ABSTRACT**

**Aims:** The quality of drinking water within Bamenda metropolis was evaluated for its variability and suitability.

**Place and Duration of Study:** Twenty-two (22) samples were collected (11 in the dry season and 11 in the wet season) from 4 main drinking water networks in Bamenda (public, community, non-distributed and private network).

**Methodology:** The samples were tested for physico-chemical and bacteriological parameters. American Society for Testing and Materials (ASTM) and Norme Française (NF) were the methods used to determine the organoleptic, natural structure, undesirable, toxic and bacteriological parameters of the different samples. Water Quality Index (WQI), Na/Cl ratio and hydrochemical facies were deduced from the physicochemical parameters.

**Results:** The findings indicate that water quality in Bamenda varies with seasons, location and sources. The pH of the study area was acidic with a higher dry season mean percentage of 52.6% against 47.4% for wet season. Turbidity showed a mean percentage of 75: 25% for wet and dry season respectively. Wet season cations, showed abundance  $\text{Ca}_2^+$  and  $\text{Mg}_2^+$  while dry season showed  $\text{Ca}_2^+$  and  $\text{Na}^+$ . Bicarbonate and Chloride were the most abundant anions in both seasons but varied with seasonal concentrations. Bacteriological analysis identified faecal coliform in 3 dry season samples. Hydrochemical facies showed dominant of magnesium and bicarbonate for wet season samples while Sodium and Chlorine were dominant for dry season samples. Water Quality Index (WQI) ranged from 72 to 94 for the wet season and 84 to 100 for dry season.

**Conclusion:** Though the results for WQI were within the acceptable standard for drinking water, pH for 21 samples and turbidity of 6 samples were not within the Cameroon nor World Health Organisation (WHO) Standard for drinking water. It is important that drinking water be tested seasonally to ascertain the quality being consumed.

**Keywords:** *Drinking water quality; variability; physicochemical and bacteriological parameter of water; Bamenda-Cameroon.*

## 1. INTRODUCTION

The United Nation 2015 Sustainable Development Goals (SDG-6) is to increase the proportion of the world's population that have access to safe drinking water and basic sanitation. More and more countries are experiencing water stress and it is projected that by 2050 at least one in four people will suffer recurring water stress [1]. According to [2], water crisis is life threatening, it can halt economic activities and even destroy the ecosystem. Water is essential for good health and should be safe, reliable, affordable, and easily accessible [1,3,4].

Freshwater sources are in high demand and water quality is fast deteriorating [5]. Changes in water quality and quantity are influenced by urbanization and climate change [6]. Water resources are subjected to hydro-climatic variability over space and time, this is a key constraint to economic and social development [7]. Water resources are influenced by anthropogenic and natural conditions leading to variation in water quality and quantity [4,8]. Clean water and adequate sanitation would be one of humanity's best investment to achieve development and sustainability [9]. According to [10], several factors can create diversity in water types, amongst which are: temporal and spatial changes like mineralogy of watershed, agricultural activities, composition of precipitation, anthropogenic influence, rock water interaction, climate and topography. These factors affect the chemical composition of surface and ground water [10,11].

The city of Bamenda located along the Cameroon volcanic line (CVL) is endowed with

watershed [12] [13] and characterized by unplanned urbanization, rapid population increase which has brought intense settlement, agricultural exploration and drinking water crisis [12,14,15]. The drinking water situation in Bamenda has been researched by several authors. [13] studied the physico-chemical and bacteriological characterization of springs and well water in Bamenda III Council. [15] assessed groundwater quality in Bamenda for suitable application and [16] assess ground water quality for domestic and irrigation purpose in Northern Bamenda. These studies were geared toward analyzing ground water quality. The aforementioned research did not take into account the physio-chemical and bacteriological variability of the different drinking water sources within Bamenda metropolis which does not limit to ground water. Bamenda does not have a general drinking water monitoring system so the water is liable to variation and hence possibility of a proportion of the population consuming water of doubtful quality. Drinking water in Bamenda seems to be of doubtful quality since it sometimes in some areas flows with light brown colouration. It is therefore, important to look at the physico-chemical and bacteriological variability and suitability of drinking water within Bamenda metropolis. Hence, this paper was aimed at evaluating the variability of drinking water quality within Bamenda metropolis with attention on the suitability. This was achieved by:

1. Assessing the spatial and seasonal variability of physico-chemical and bacteriological parameters of drinking water.
2. Examining the hydrochemical facies of drinking water.

3. Evaluating the suitability of drinking water.

This research will provide a deeper understanding of drinking water quality in Bamenda metropolis. The findings will contribute towards proper management of drinking water for sustainable development within Bamenda metropolis.

2. MATERIALS AND METHODS

2.1 Site Description

Bamenda is the headquarter and biggest metropolitan city in the North West Region of Cameroon. This city is made up of three council

areas which are: Bamenda I, Bamenda II and Bamenda III [17]. Bamenda topography constitute the High Lava Plateau and the Lower Plateau sandwiched by an escarpment and found along the Cameroon Volcanic Line [17]. The high lava plateau, with altitude of about 1,400m above sea level, constitute the greater part of Bamenda I Council areas. The lower Plateau which is about 1,100 m above sea level covers mainly Bamenda II and Bamenda III council areas [17]. Bamenda is found between latitudes 5°55"N and 6°05"N and longitude 10°2"E and 10°13"E (Fig. 1), with a population of about 536922 and a surface area of 391 km<sup>2</sup> [17,18,19].

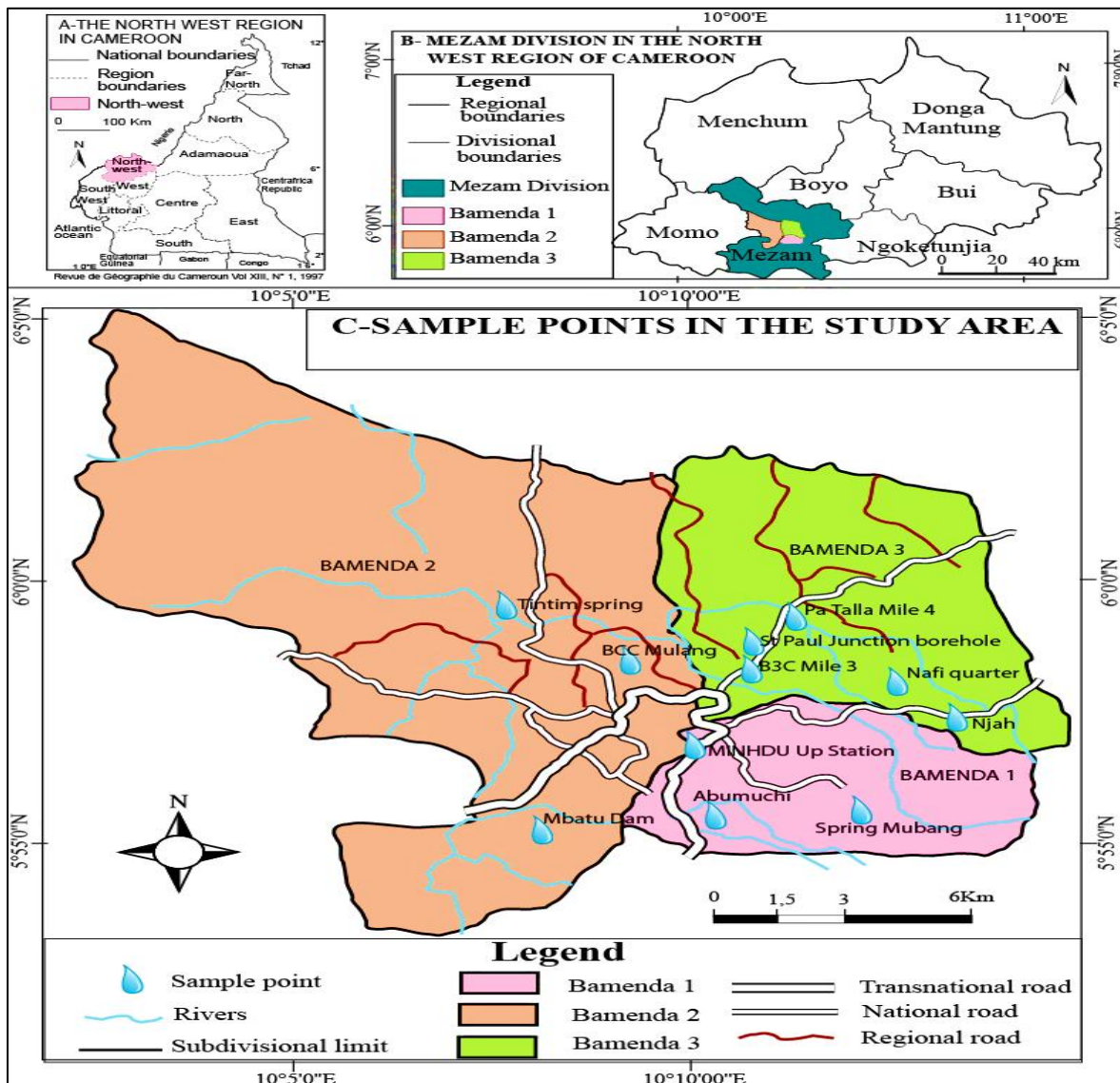


Fig. 1. Location of the study area  
Source: Administrative map of Cameroon, INC 2015

**Table 1. Description of the different water samples in the study area**

<b>Network (NSCPS)</b>	<b>Management Body</b>	<b>Collection point</b>	<b>Sample name</b>	<b>Sample code</b>	<b>Origin of sample</b>	<b>Area supplied</b>
Public (4)	CAMWATER	Source	Bda I CAMWATER	PSDS1	Stream Mubang	Bamenda I Council
			Bda II CAMWATER	PSDS2	Mbatu Dam	Bamenda II and III Councils
Community (4)	BdaIII Council water Committee	Source	Bda I CAMWATER	PSDT1	Stream Mubang	Bamenda I Council
			Bda II CAMWATER	PSDT2	Mbatu Dam	Bamenda II and III
	Bda III Council	CSDS1	Stream Ntafi	Bamenda III Council		
	Nkwen Community water Committee		Nkwen Community	CSDS2	Spring Njah	Bamenda III Council
	BdaIII Council water Committee	Tap	Bda III Council	CSDT1	Stream Ntafi	Bamenda III Council
	Nkwen Community Water Committee		Nkwen Community	CSDT2	Spring Njah	Bamenda III Council
Non-distribution (2)	Abumuchui Spring Bda I	Spring	Bda I General	GSDS1	Spring	Bamenda I Council
	Timtim spring Bda II		Bda II General	GSDS2	Spring	Bamenda II Council
Private (1)	Borehole BdaIII	Borehole	Bda III General	GSDS3	Borehole	Bamenda III Council

*Bda I: Bamenda I, Bda II: Bamenda II, Bda III: Bamenda III, NSCPS.: Number of Sample(s) collected per season*

Bamenda has two main seasons; the dry season characterized by sunshine during the day and wet (rainy) season that last from mid-March to mid-October with an annual average precipitation that ranges from 1,700-2,824mm [20]. River Mezam is the main river that flows from the upper plateau through the city center towards Mankon rural area in Bamenda II Sub-Division [20]. Water consumed within Bamenda Metropolis is mainly from: Public network (CAMWATER: Cameroon Water Utilities Company), community network (Councils or local authorities), non-distributed network (like springs) and private network (boreholes and Protected wells). The study area has rocks that are mainly leucogranite of Precambrian age, overlain by felsic lavas and mafic [21]. Montmorillonite (smectite), cristobalite, feldspars, ilmenite and heulandites are some of the minerals found within the study area [22]. The main activity of the area is subsistence agriculture and the dominant soil type is the reddish coloured lateritic soils [21,22].

## 2.2 Data Collection

Water samples, within Bamenda metropolis, were collected both in the dry (March 2020) and wet (August 2020) seasons. A total of 22 samples were collected with 11 in the dry season and 11 in the wet season. The technique used for sampling was the stratified grid sampling method based on access and utilization rate as carried out by [15]. Water samples collected per season was based on the different types of drinking water network in Bamenda (Table 1). For the Public Network, four samples were collected: two from sources (Untreated water samples) and two from taps (treated water samples). For Community Network, four samples were equally collected: two from sources and two from taps. For non-distributed network, two water sources were sampled: one from Bamenda I and one from Bamenda II. The private network had a sample collected from Bamenda III council area (Table 1). For the 11 samples collected per season, 6 were from surface water while 5 from ground water. Before carrying out the research, the local administrators of the study area were contacted and they happily granted verbal consent. Permission was granted by the councils of Bamenda I, Bamenda II and Bamenda III.

Each sample was collected in 500 ml clean plastic bottles after rinsing three times with the respective water. Samples were collected from 11 different sites as shown in Table 1 and Fig. 1. The water samples were transported in a cooler

to PAC-LAB (Petroleum Water Analysis and Control Laboratory) Limbe-Cameroon for analysis. At every site where samples were collected, the geographical coordinates were taken using a Geographical Positioning System (GPS), model Garmin GPS map 62s from Olathe, Kansas, United State of America.

## 2.3 Laboratory Analyses

Laboratory analyses involved the determination of physico-chemical and bacteriological properties of the water samples. The analyses were carried out in PAC-LAB.NF (Norme Française) and ASTM (American Society for Testing and Materials) methods for water testing were used to determine the organoleptic, natural structure, undesirable, toxic and bacteriological parameters of the different samples (Table 2). The analyses were carried out least than 24 hours after samples were collection. This is in line with the work of [23].

## 2.4 Data Analysis

The laboratory results were analyzed based on the World Health Organisation guideline for drinking water quality [24]. Maps were produced using MAPINFO 10.0 and GW chart calibration plot version 1.30.0.0 software were used to produce Pipers plots for examining the hydrochemical facies of potable water [25].

### 2.4.1 Suitability of water quality

In a bid to evaluate the suitability of drinking water quality, the Canadian Water Quality Index (WQI) as described by [26] was used. The WQI is a calculated number that describes the overall water quality from a combine influenced of different water quality parameters. It evaluated the influence of natural and anthropogenic activities based on several key parameters of groundwater chemistry. To calculate the WQI, weight has been assigned for the physico-chemical parameters according to the parameters relative importance in the overall quality of water for drinking purposes, equation 1 [26,27].

$$WQI = 100 - \left( \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (1)$$

Where:

$F_1$  = Scope. The percentage of parameters that exceed the guideline

$$F_1 = \left( \frac{\text{Number of failed parameters}}{\text{Total number of parameters}} \right) \times 100 \quad (2)$$

F<sub>2</sub> = Frequency: The percentage of individual test within each parameter that exceeded the guideline

$$F_2 = \left( \frac{\text{Number of failed Test}}{\text{Total number of Test}} \right) \times 100 \quad (3)$$

F<sub>3</sub> = Amplitude. The extent to which the fail test exceeds the guideline.

F<sub>3</sub> is calculated using the formula that scales the nse to range between 1 and 100

$$F_3 = \left( \frac{nse}{0.01nse+0.01} \right) \times 100 \quad (4)$$

$$\text{Excursion} = \left( \frac{\text{failed Test value}}{\text{Guideline values}} \right) - 1 \quad (5)$$

$$nse = \left( \frac{\sum \text{Excursion}}{\text{Total number of tests}} \right) \quad (6)$$

The index equation generates number between 0 and 100. The generated numbers have been designated to classify water quality as poor, marginal, fair, good or excellent [26], presented in Table 3.

**Table 2. Water parameters testing methods and units used for each sample**

	<b>Parameters</b>	<b>Methods</b>	<b>Unit</b>	
Organoleptic	<b>Appearance</b>	Visual		
	<b>Colour</b>	NF T 90-034	mgPtCo/l	
	<b>Odour/Taste</b>	NF T 90-035		
Natural structure	<b>Turbidity</b>	ASTM D 1889/NF T 90-033	NTU	
	<b>Temperature</b>	ASTM 4196	°C	
	<b>pH</b>	ASTM D 1293		
	<b>Conductivity at 20°C</b>	ASTM D 1125	us/cm	
	<b>Sulphate</b>	ASTM D 516	mg/l	
	<b>Chloride</b>	ASTM D 512	mg/l	
	<b>Calcium</b>	ASTM D 511 / NF T 90-016	mg/l	
	<b>Carbonate</b>	ASTM D 3875	mg/l	
	<b>Bicarbonate</b>	ASTM D 1067	mg/l	
	<b>Magnesium</b>	ASTM D 3561	mg/l	
	<b>Potassium</b>	NF T 90-020	mg/l	
	<b>Sodium</b>	ASTM D 020	mg/l	
	<b>Aluminium Total</b>	ASTM D 857	mg/l	
	Undesirable	<b>Nitrates</b>	NF T 90-012	mg/l
<b>Nitrites</b>		NF T 90-003	mg/l	
<b>Floride</b>		ASTM D 1179	mg/l	
<b>Phosphorus</b>		NF T 90-018	mg/l	
<b>Silver</b>		NF T 90-015	mg/l	
<b>Iron</b>		ASTM D 1068	mg/l	
<b>Free Chlorine</b>		NF T 90-037	mg/l	
<b>Silica</b>		ASTM D 859 / NF T 90-007	mg/l	
<b>Copper</b>		ASTM D 857	mg/l	
<b>Manganese</b>		ASTM D 858	mg/l	
<b>Ammonia</b>		ASTM D 511	mg/l	
Toxic		<b>Arsenic</b>	NF T 90-027	mg/l
		<b>Cadmium</b>	NF T 90-119	mg/l
		<b>Total Chromium</b>	ASTM D 1687	mg/l
	<b>Nickel</b>	ASTM D 1886	mg/l	
	<b>Selenium</b>	NF T 90-119	mg/l	
	<b>Cyanide</b>	NF T 90-026	mg/l	
	<b>Mercury</b>	NF T 90-028	mg/l	
Bacteriological	<b>Aerobic bacteria at 37°C</b>	NF T 90-413	cfu/100ml	
	<b>Total Coliform at 37°C</b>	NF T 90-413	cfu/100ml	
	<b>Feacal Coliform</b>	NF T 90- 416	cfu/100ml	
	<b>Feacal Streptococcus</b>	NF T 90-413	cfu/100ml	
	<b>Salmonella</b>	NF T 90-414	cfu/100ml	
	<b>Staphylococcus</b>	NF T 90-416	cfu/50ml	
	<b>FeacalBacteriopha</b>	NF T 90-413	cfu/100ml	
	<b>Pseudomonas sp</b>	ASTM D 5246	cfu/100ml	

Source: PAC-LAB, 2020. (Petroleum Water Analysis and Control Laboratory)

**Table 3. Water Quality Index (WQI) designations**

Designation	Index Values	Description
<b>Excellent</b>	95 - 100	All measurements are within objectives virtually all of the time
<b>Good</b>	80 – 94	Conditions rarely depart from natural or desirable levels
<b>Fair</b>	65 – 79	Conditions sometimes depart from natural or desirable levels
<b>Marginal</b>	45 – 64	Conditions often depart from natural or desirable levels
<b>Poor</b>	0 – 44	Conditions usually depart from natural or desirable levels

Source: [26]

### 3. RESULTS AND DISCUSSION

#### 3.1 Physicochemical and Bacteriological Parameters of Water Samples

##### 3.1.1 Organoleptic parameters

Laboratory results for appearance, colour and taste/odour for both wet and dry season samples were in accordance with the Cameroon and WHO standards for drinking water but for turbidity that showed variation especially for some wet season samples. The water colour ranged from 4 to 11mgPtCo/l for the wet season and from 5 to 12 mgPtCo/l for the dry season samples (Table 4). Generally, the public network had the highest value for water colour (from 6 to 12) while non-distributed network has the lowest (2 to 6).

Turbidity in drinking water samples was higher in the wet season with values ranging from 0.2 to 10.9 while the dry season ranged from 0.3 to 6.3. The wet season had a higher mean percentage of turbidity than the dry season, 75% and 25% respectively (Table 4). The results indicated that wet season samples for Public network (PSS1, PSS2, PST1 and PST2) and Bamenda III Council source (CSS1) had turbidity values greater than the Cameroon standard for drinking water (Fig. 2). According to the WHO standards, turbidity should not be more than 5NTU and should ideally be below 1NUT. Most of the dry season samples were below 5 NTU, for both treated and untreated water sample. The sample from Mbatu dam (PSS2), with value 6.3 NTU,

was the only dry season sample with value above 5 NTU.

Turbidity in water is often attributed to the presence of organic and inorganic materials including bacterial growth leading to the production of unpleasant by-products of metabolites [28]. Ground water hardly contain higher values of turbidity but surface water is more susceptible to be influenced by runoff and vegetable decay [29]. The results of Public network (PSS1, PSS2, PST1 and PST2) and the Bamenda III Council source (CSS1), which constitute the untreated water samples with source form stream might have been influenced by runoff and/or vegetable decay causing cloudiness. Organoleptic parameters especially turbidity were associated with other water quality concerns like trihalomethane that is carcinogenic and a source of other reproductive disorder in the human system [29,30].

##### 3.1.2 Natural structure parameters of water

The analyses of the natural structure parameters for water in the study area are presented on Table 5 for the wet and dry seasons. The mean values for the different water parameters shows seasonal variation. Looking at variability in terms of mean values, conductivity varied the most followed by bicarbonate while carbonate manifested the least seasonal variability (Table 5). Dry season samples showed absence in Carbonate and Total Aluminium meanwhile these parameters were present in some wet season samples.

**Table 4. Seasonal analysis for Organoleptic parameters**

Parameters	Wet season				Dry season				Cameroon Limit
	Mean	min	max	%mean	Mean	min	max	% mean	
Colour	6.9	4	11	47.8	7.5	5	12	52.2	15
Turbidity	4.8	0.2	10.9	75	1.6	0.3	6.3	25	5

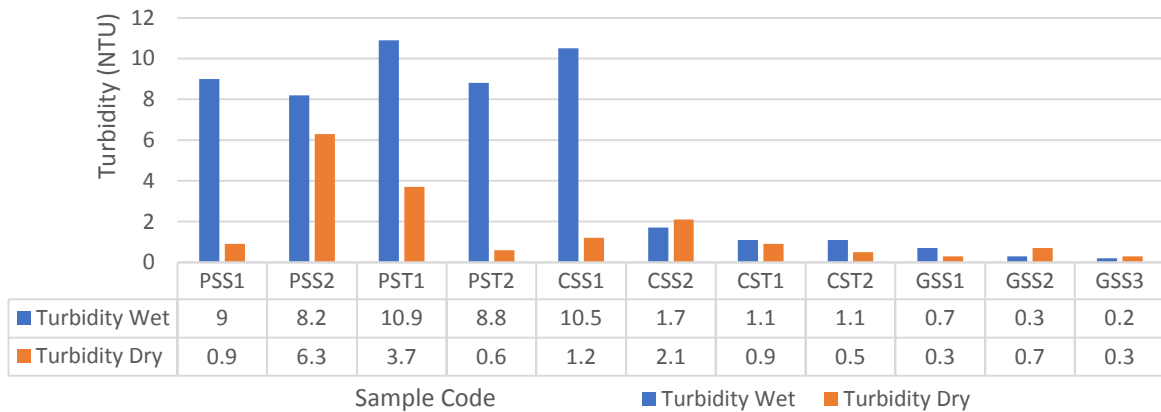


Fig. 2. Variation of turbidity for the wet and dry season in the study area

Table 5. Analysis for Natural structure parameters of water for both wet and dry season

Parameters	Wet season				Dry season				Cameroon Limits
	Mean	min	max	Mean %	Mean	min	max	Mean %	
pH	5.45	4.70	6.00	47.4	6.05	4.90	6.70	52.6	6.5-9.0
Conductivity	21.33	2.80	80.00	38.2	34.55	10.00	80.00	61.8	1000 Max
Sulphate	3.09	0.00	10.00	57.6	2.27	0.00	10.00	42.4	250Max
Chloride	5.97	2.20	11.40	46.9	6.75	1.50	10.60	53.1	200 Max
Calcium	2.55	0.30	5.60	52.8	2.28	0.04	8.20	47.2	100 Max
Carbonate	0.03	0.00	0.30	100.0	0.00	0.00	0.00	0.0	50 Max
Bicarbonate	10.86	0.10	35.40	48.1	11.74	0.10	56.10	51.9	305 Max
Magnesium	1.36	0.03	2.80	52.9	1.21	0.00	5.40	47.1	50 Max
Potassium	0.54	0.00	1.60	50.9	0.52	0.00	1.50	49.1	12 Max
Sodium	0.85	0.10	2.00	32.9	1.73	0.20	5.40	67.1	150 Max
Aluminium Total	0.01	0.00	0.10	100.0	0.00	0.00	0.00	0.0	0.2 Max

### 3.1.2.1 pH

From the results obtained, the pH in the study area was generally acidic and ranged from 4.7 to 6.7 for both seasons (Table 5). The dry season registered a slightly higher mean pH value with a percentage of 52.6% against 47.4% in the wet season (Table 5). The Abumuchui spring with pH 4.7 recorded the lowest pH value while the Nkwen Community water sources with pH 6.0 had the highest value for the wet season samples. For the dry season samples, the borehole at St Paul Junction (GSS3) registered the lowest pH value of 4.9 while Nkwen Community water tap (CST2) with pH 6.7, had the highest and only pH value within the Cameroon standard (6.5 -9) and WHO Standard for drinking water (6.5 – 8.5) (Fig. 3). The non-distributed network showed a relatively low pH values especially the wet season samples.

According to [29], when pH of water is less than 6, it is not suitable for domestic use and can corrode metal pipes used for its distribution. Acidic

pH could probably be due to pollution resulting from anthropogenic activities [29,30]. This is possibly caused by released and deposition of gases and the combination of CO<sub>2</sub> with water to form carbonic acid, which affects the pH of the water [31]. The acidic nature of water in the study area may also be as a result of the formation of dissolution of minerals, influenced by biochemical processes in solution [32]. Acidic pH can cause health challenges like diarrhea, nausea, vomiting and dental health challenges [31,32]. Acidic pH can also affect solubility of trace elements like Copper and manganese which have immunomodulatory effects that can cause a variety of viral infection [33].

### 3.1.2.2 Conductivity

The conductivity of the different samples showed a higher value in the dry season with a mean percentage of 61.8 % against 38.2% in the wet season (Table 5). Conductivity ranges from 2.8 to 80.0 us/cm for wet season and 10 to 80.0 us/cm for dry season samples (Table 5). All 22



samples had value for conductivity within the Cameroon and WHO standard for drinking water. According to [34,35], conductivity values are used as a guide to overall salinity and are influenced by calcium, sodium, chlorine and sulphate. Thus the high conductivity values in the dry season is possibly as a result of spreading of saline into fresh water aquifers of the study area. From the results obtained, samples from St Paul Junction and the Nkwen Community water had salt water intrusion (SWI) into fresh water resources more than other areas meanwhile, the dry season generally experiences a salt water intrusion more than the wet season.

### 3.1.2.3 Cations (Ca, Mg, K and Na)

Laboratory results showed variation in the cations concentration. Calcium was the dominant cation in the wet season samples with mean percentage of 48.08% followed by magnesium (25.65%), Sodium (16.14%) and Potassium (10.13%) Fig. 4a. In the dry season, while calcium remains dominant with a mean percentage of 39.75%, it was rather followed by Sodium (30.11%), then magnesium (21.11%) and finally Potassium (9.03%), Fig. 4b. The

quantity of cations found in the water samples are within the standards for drinking water, however, the concentration of the cation in the water samples are generally low.

Cation in fresh water comes from the weathered rocks, sewage and breakdown of organic matters producing hard water [36,37]. Water hardness is expressed by the concentration of cations in water [36]. Although hardness of water is not considered as a serious health risk, studies have shown that long-term consumption of hard water might lead to an increased incidence of urolithiasis, and anencephaly [28]. Hardness causes precipitation of fatty acid leading to formation of scums and making it difficult to lather soap [37,38]. On the other hand, cation in drinking water has an important physiological role in humans as they contribute to biological processes like hormonal response, DNA synthesis, cell maturation, vascular contraction and oxygen transport [36]. These elements can be provided to the body through water and food intake; when meat intake is low, water is the most abundant source [39]. With low cation concentration, there are possibilities of long term health effects [36].

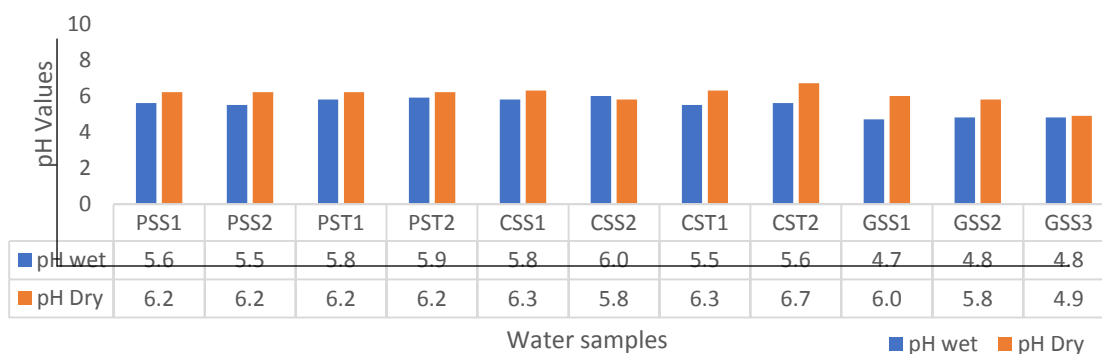


Fig. 3. Variation of pH for wet and dry season in the study area

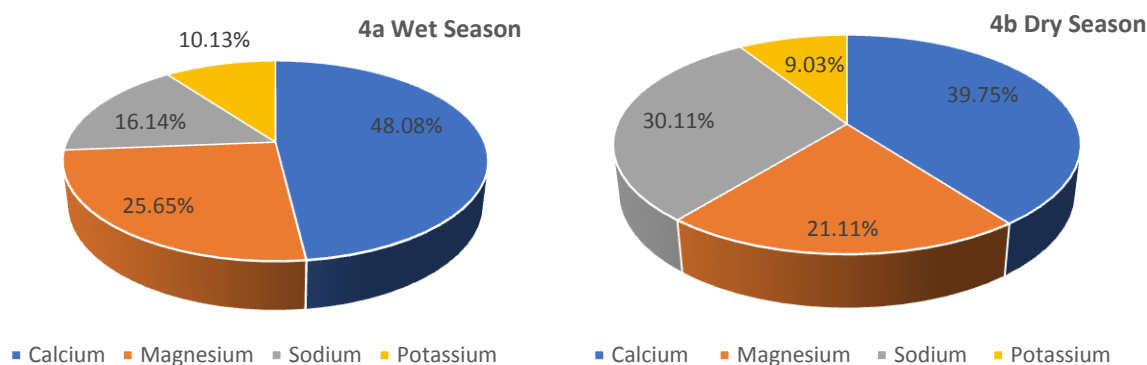
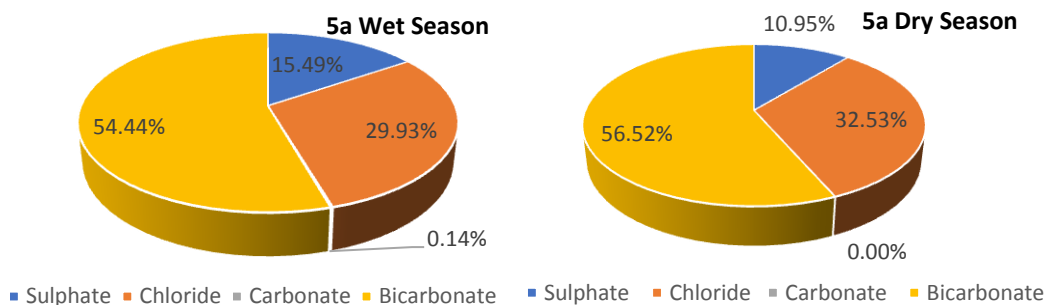


Fig. 4a and 4b. Mean percentage distribution of cation for wet Season and dry Season



**Fig. 5a and 5b. Mean percentage distribution of anion for wet Season and Dry Season**

**3.1.2.4 Anions (Bicarbonate, Chloride, sulphate and Carbonate)**

Results from analyses showed that, bicarbonate was the dominant anion for wet and dry season with a percentage of 54.44 % and 56.52% respectively (Fig. 5a and 5b). Chloride was the second most abundant anion with a mean percentage of 29.93% for wet season and 32.55% for dry season (Fig. 5a). Sulphate was next with a wet season mean anion percentage abundant of 15.49% and 10.95% for dry season. Carbonate registered 0.14% for wet season and 0.00% for dry season (Table 6, Fig. 5b). The anion concentrations were within the standard for drinking water. The concentration of anion varied with seasons.

Bicarbonates are very vital in buffering acids in water, it equally acts as a refresher in drinking water [39,40,41]. Chlorine in drinking water can cause corrosion of metallic pipes, however, it can play the role of a disinfectant [40]. Magnesium chloride can cause the production of hydrochloric acid [39]. Sulphate and chloride have laxative effect that can lead to dehydration and alter the taste of fresh water [29,41]. Sulphur is commonly

found in drinking water as sulphate and Hydrogen Sulfide. Sulfide can be present in surface water as a result of bacteria decomposition under anaerobic conditions [29]. Sulphate can also get into fresh water through dissolution of minerals from rocks over time while Hydrogen Sulfide in water is produced by sulphur reducing bacteria [42]. Bicarbonates ( $\text{HCO}_3^-$ ), which is the main contributor of carbonates ( $\text{CO}_3^{2-}$ ) in water, causes alkalinity which is measured by the presence of the  $\text{OH}^-$  [42]. Generally anions in water comes from sewage, dissolved agricultural fertilizers and natural breakdown or organic matter [36,42].

**3.1.3 Undesirable parameter**

The analyses of the undesirable parameter for the water samples are presented in Table 6. The results showed that silver, free chlorine, copper, manganese and ammonia were completely absent from the wet and dry season samples. Nitrate, nitrites, fluoride, phosphorus and silica showed a higher mean percentage in the dry season while iron had a higher mean percentage in the wet season (Table 6).

**Table 6. Season analysis for Undesirable parameter of water**

Parameters	Wet Season				Dry Season				Limits
	Mean	Min	Max	Mean%	Mean	Min	Max	Mean%	
Nitrates	0.77	0.00	4.20	41.62	1.08	0.00	3.60	58.38	50
Nitrites	0.00	0.00	0.03	0	0.01	0.00	0.03	100	0.1
Fluoride	0.19	0.00	0.40	44.19	0.24	0.04	0.40	55.81	0.7
Phosphorus	0.09	0.00	0.30	45	0.11	0.01	0.58	55	5
Silver	0.00	0.00	0.00	-	0.00	0.00	0.00	-	0.01
Iron	0.05	0.00	0.15	71.43	0.02	0.00	0.10	28.57	0.2
Free Chlorine	0.00	0.00	0.00	-	0.00	0.00	0.00	-	0.2
Silica	7.09	2.70	8.70	48.2	7.62	6.40	8.50	51.8	5-25
Copper	0.00	0.00	0.00	-	0.00	0.00	0.00	-	1
Manganese	0.00	0.00	0.00	-	0.00	0.00	0.00	-	0.05
Ammonia	0.00	0.00	0.00	-	0.00	0.00	0.00	-	0.5

Silica was the most abundant undesirable element in terms of their mean values with a percentage of 86.65 % for wet season and 83.92% for dry season samples. The second abundant undesirable element was Nitrates with 9.35% for the wet season and 11.86% for the dry season samples. Next was fluoride with 2.29% for dry season and 2.66% for wet season, while phosphorus had 1.06% for wet season and 1.23% for dry season. The other parameters had percentages below 1 (Fig. 6a and 6b).

Nitrate in water is mostly from urine and elevated concentration can cause Blue-baby [43]. Iron is very important in normal body functioning, for example, oxygen transportation and metabolism of neurotransmitter [44]. Copper in human system is responsible for bone strengthening, red and white cell maturation and brain development [44]. Phosphorus is very important in cell membrane and essential for energy production and storage [45]. Fluoride is necessary in the prevention of dental cavity leading to more resistance enamel [46]. The concentrations of undesirable parameter were within the standards, nevertheless, some parameters like Nitrate, iron and Phosphorus could be considered to be of low concentration since they are often need by the body to supplement metabolic processes [24,45].

### 3.1.4 Toxic and Bacteriological parameter

Toxic substances like Cadmium, Mercury, Nickel Cyanide, when found in water, can be detrimental to the human system and the

environment [43,44]. Test results showed a complete absent of toxic substance; this is in accordance with the standards.

Bacteriological analysis showed that Aerobic bacteria were present in all the water samples (Table 7). However, though the values were within the standards for drinking water (2 000 cfu/100ml maximum), the seasonal mean percentage values were different: 60% in the wet season and 40% in the dry season (Table 7).

Dry season samples for Nkwen Community Source (CSDS2), Nkwen Community Tap (CSDT2) and Abumuchui spring (GSDS1) indicated the presence of Total Coliform and Faecal Coliform, which according to Cameroon and WHO standard, these bacteria should be absent. From Fig. 7, Abumuchui spring was most contaminated with total coliform of 24cfu/100ml and Faecal coliform of 12cfu/100ml. Nkwen Community source was the second most contaminated source with Total Coliform 10 and Faecal Coliform 5 cfu/100ml while Nkwen Community Tap was the least contaminated with Total Coliform 6 and Faecal Coliform 3 cfu/100ml. The presence of these bacteria in drinking water could possibly come from anthropogenic activities most especially from animal and/or human faeces that somehow leaked into drinking water supply [47]. This is the case of Abumuchiu source that is close to human habitation and animals. Total Coliform and Faecal Coliform in drinking water can lead to health challenges like diarrhoea, jaundice and nausea [43,48].

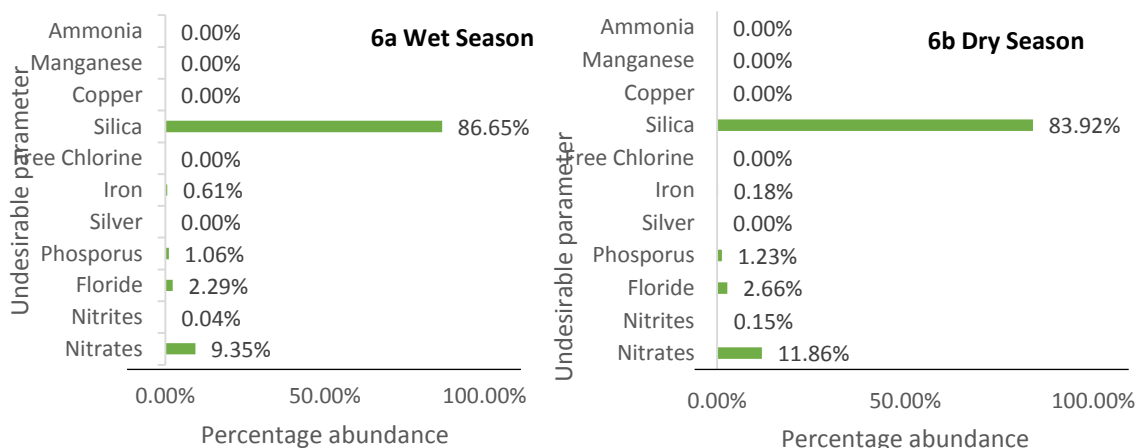
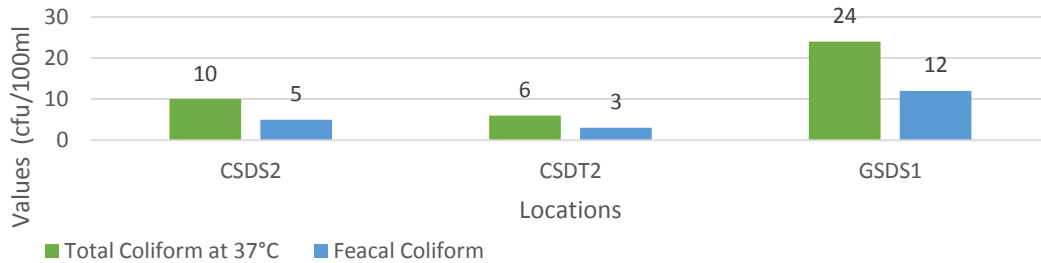


Fig. 6a and 6b. Wet and dry season mean percentage abundances of undesirable elements

**Table 7. Variation of the Aerobic Bacteria in wet and dry season samples**

Sample code	PSRS1	PSRS2	PSRT1	PSRT2	CSRS1	CSRS2	CSRT1	CSRT2	GSRs1	GSRs2	GSRs3%	mean
Wet season	1400	1490	1600	1500	1600	1200	1200	1300	1660	1500	1380	60.0%
Dry Season	860	1500	820	400	1620	850	520	850	1200	1200	750	40.0%



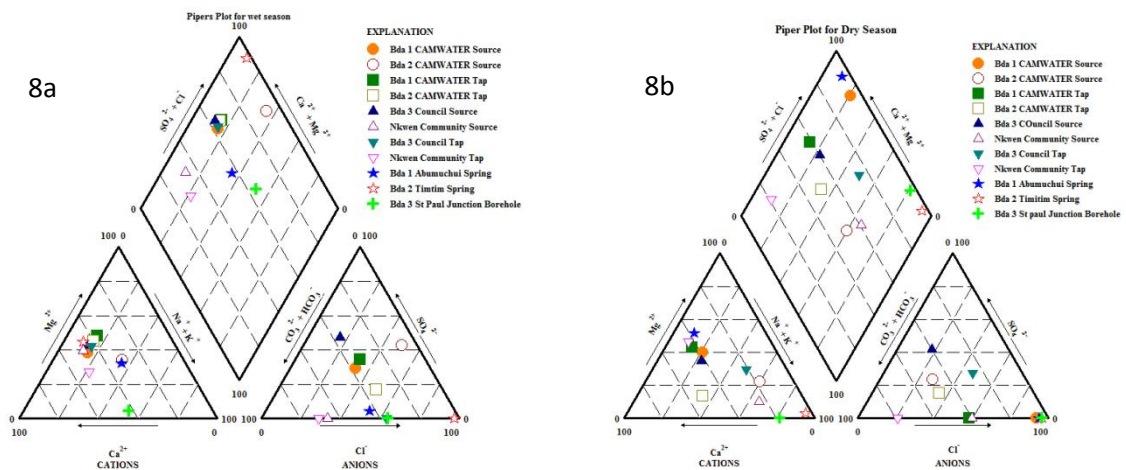
**Fig. 7. Variation of Total Coliform and Feecal coliform for dry season infected samples**

### 3.2 Hydrochemical Facies of Drinking Water

Piper’s plot was used to express the hydrochemical facies for drinking water samples in Bamenda metropolis (Fig. 8a, b). The major cations and anions of the water samples showed some similarity and variation for both wet and dry season. The two seasons showed more of the Calcium Chloride facies with few samples of the magnesium bicarbonate facies.

From the piper’s plot, alkaline earth metals were more in the wet season, while the dry season had more of the alkaline metals. Bamenda II

CAMWATER source varied from calcium chloride facies in the wet season to magnesium bicarbonate facies in the dry season. The Bamenda II Tintim spring wet season sample depicted the calcium chloride facie while dry season is rather of the sodium chloride facie. Nkwen Community source also showed prominent seasonal variation with wet season sample being of the magnesium bicarbonate facie while the dry season samples were of Sodium Chloride facie. Generally, the dry season samples presented more of sodium chloride facie making it different from the wet season samples which presented more of the magnesium bicarbonate facies (Fig. 8a and 8b).



**Fig. 8a and 8b. Piper’s Plot for Drinking water samples for the wet and dry season**

### 3.3 Na/Cl ratio

The Na/Cl ratio ranges from 0.02 to 0.40 mg/l for the wet season samples and 0.02 to 1.02 mg/l for the dry season samples. Dry season samples had Na/Cl ratio higher than wet season ratio with a few exceptions being the samples from Mbatu Dam, Abumuchui spring and the borehole at St Paul Junction. Generally, all the samples had values less than 1 except Nkwen Community source (CSS2) dry season sample with value greater than 1 (Fig. 9). This is in accordance with the work of [49], and an indicator that another source is contributing to the chloride other than silicate which could possibly be anthropogenic. Silicate weathering reactions is influenced by the Na/Cl molar ratio and when the ratio is greater than one then sodium ions are released from silicate [49]. The different water sources are closer to the population and anthropogenic influence on water sources is possible.

### 3.4 Water Suitability for Drinking Purpose Using Water Quality Index (WQI)

The suitability of drinking water in the study area were ascertain by calculating the WQI for the different water samples both for the wet and dry season (Table 8). The WQI values ranged from 72 to 94 for the wet season samples and from 84 to 100 for the dry season samples. According to the results presented on Table 8, the WQI values for the dry season samples were generally better than wet season values. The dry season sample of Nkwen Community Tap was the only sample with 'Excellent' while Bda II CAMWATER Source was the only dry season sample under the 'Fair' category the rest were of the good category. The wet season samples had 5 samples under the Fair Category and 6 with the good category. Low values were generally recorded from samples gotten from streams with a few samples from taps.

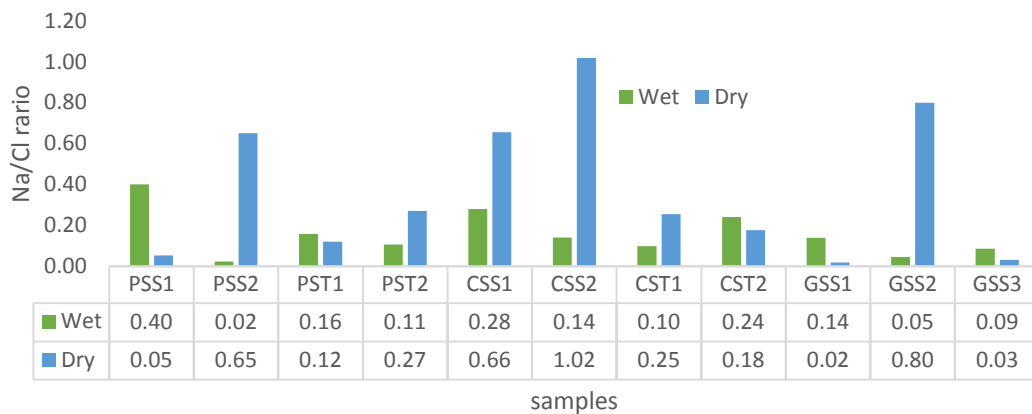


Fig. 9. Seasonal variation of Na/Cl ratio for wet and dry season sample

Table 8. Spatial variation of water quality Index (WQI) for wet and dry season

Sample Name	Sample Code	Wet Season		Dry Season	
		WQI value	Category	WQI value	Category
Bda I CAMWATER Source	PSS1	74	Fair	94	Good
Bda II CAMWATER Source	PSS2	76	Fair	79	Fair
Bda I CAMWATER Tap	PST1	72	Fair	84	Good
Bda II CAMWATER Tap	PST2	75	Fair	87	Good
Bda 3 Council Source	CSS1	72	Fair	87	Good
Nkwen Community Source	CSS2	87	Good	86	Good
Bda 3 Council Tap	CST1	87	Good	94	Good
Nkwen Community Tap	CST2	87	Good	100	Excellent
Bda 1 General Source	GSS1	94	Good	94	Good
Bda 2 General Source	GSS2	94	Good	91	Good
Bda 3 General Source	GSS3	94	Good	94	Good

Water quality index considers a result of the composite influence of the different water parameters [50]. Results from the calculations of WQI showed that direct spring sources (GSS, GSS2 and GSS3) were most reliable regardless of the season; this is similar to the work of Akoanung [15]. More attention, in terms of water treatment should be given to water from stream most especially during the wet season. The WQI provides an overview of the water quality but does not replace the need for a detail statistical analysis of water samples [26,27]. The veracity was proven by the fact that, despite the results obtained from WQI, the pH and turbidity of several water samples were a call for concern.

#### 4. CONCLUSIONS

From evaluation, drinking water quality within Bamenda metropolis is subjected spatial and seasonal variation. Analysis of the drinking water quality showed that pH poses a foremost challenge. Laboratory results of all water samples were acidic in nature with the water having low mineral content. Turbidity equally showed up as a challenge to water quality, but mainly wet season samples. Total Coliform and Faecal Coliform were found in 3 out of 11 dry season samples, an indication that anthropogenic activities have impact on drinking water quality. Variation in ions showed that cations varied with Calcium and Magnesium being more abundant in the wet season while calcium and sodium were abundant in the dry season. Bicarbonate and Chloride are the abundant anions that showed seasonal variation in concentration of the anions. Calculation of Water Quality Index indicates that all the water samples fall within the natural or desirable standard. Based on the findings, potable water quality in Bamenda metropolis, though suitable for drinking, it varies with location, water supplier and influenced by seasonal changes. From the above analysis, drinking water in Bamenda is a potential source of danger. The inhabitant of Bamenda are liable to serious health challenges if appropriate actions are not taken to prevent or mitigate the challenge especially of pH, turbidity, low mineral content total coliform and fecal coliform. It is imperative that those charge with water supply and management within Bamenda Metropolis be diligent in their activities and the water quality be tested every change of season. A drinking water management system could be set up to handle the exigency of potable water supply within Bamenda metropolis. It is recommended that further research be carried

out on the evolution of water quality in a bid to determine the trend of water quality and facilitate prediction to better avoid possible future drinking water challenges.

#### DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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