



# Physico-chemical and bacteriological characterisation of surface water in Bamenda (North West Cameroon)

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## Abstract

The Mezam River and its tributaries constitute a prominent water source for domestic use and vegetable irrigation in Bamenda Town (North West Cameroon). The river flows through the city and is thus vulnerable to impairment by substances from point and non-point sources. This current research aims to assess the degree of pollution of the Mezam River water to ascertain its suitability for various uses. A total of 24 water samples were collected from six segments of the Mezam River basin in the dry and rainy seasons during the years 2015 and 2016 in view of physico-chemical and bacteriological analyses. In situ measurement of physical parameters was taken in the field. The data were analysed by multivariate statistical techniques (principal component analysis and factor analysis). The results revealed that the river water is slightly acidic (pH = 5.45–6.47) and ion concentration is low (41.67–237.00  $\mu\text{S}/\text{cm}$ ). The water type is Ca-SO<sub>4</sub> and Ca-Mg-(Cl + NO<sub>3</sub>) in the dry season and Ca-Mg-SO<sub>4</sub> in the rainy season. High NO<sub>3</sub><sup>-</sup> values (50 mg/l) are recorded at Nkimefueh. The Mezam River water is heavily polluted with indicator bacteria (0–500 CFU/100 ml) whose concentrations steadily increase from the reference point (YB) through sampling points in the city centre, suggesting the influence of human-induced activities. The population is urged to adopt a responsible behaviour towards waste disposal and refrain from disposing waste in water courses in order to safeguard the aquatic environment and also protect the health of the population.

**Keywords** Mezam River water · Physico-chemical · Bacteriological analysis · Pollution · Bamenda Town

## Introduction

Water is crucial for the existence of all life forms, yet the precious liquid is overwhelmingly degraded as the world's population continuously skyrockets (Alabi et al. 2020). Ensuring environmental sustainability and promoting the

sustainable use of water resources is highlighted in the Millennium Development Goal in specific target 7 (UNEP/GEMS 2006). In addition, the sustainable management of freshwater ecosystems is primordial as these areas constitute the world's most diversified habitats that furnish varied products and services as stipulated in the Sustainable Development Goal (SDG) 6.6 (UN Water 2018). Social, economic and political development is largely related to the availability and distribution of fresh water contained in riverine systems (Simona 2012; Yıldız 2017; UN Water 2018). Major rivers worldwide serve as sources of water supply, irrigation, industrial and municipal use, waste disposal, navigation, hydroelectric plants, fishing, boating, recreation and aesthetics (Chapman 1998; UNESCO 2003; UN Water 2011; Shrikant et al. 2020). However, some of these water services (such as irrigation, waste disposal and industrial services) often lead to deterioration of water quality and quantity (UNEP/GEMS 2006; Fatema et al. 2014; UN Water 2018). In some parts of the world, many rivers are polluted to the point that they are becoming biologically dead (World Bank

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2012). The Mezam River system in Bamenda (Cameroon) lacks protective mechanisms and has been turned by many residents into refuse dumps which makes it unfit for various activities. In this community, like in most developing countries, most industrial, domestic and agricultural wastes flow untreated into the river and its tributaries, thereby posing a serious health threat as thousands of inhabitants continue to depend on the polluted river water for daily use (Ako et al. 2010; Nyenje 2014; Mary Banke et al. 2020). This necessitates an investigation of the river water quality to assess its suitability for various purposes. The works of Tita et al. (2009) in Foumbot, Tita et al. (2013) in Bamenda, Wirmvem et al. (2013) in the Ndop Plain and Rakotondrabe et al. (2017) in Betaré Oya (East Cameroon) have revealed a high level of surface water degradation in Cameroon. Similar works are quite rare in Bamenda, and available information (Kamgang et al. 2010; Nzenti et al. 2010; Nono et al. 2018) in this area is dedicated mostly to petrography. The present work aims to assess physico-chemical characteristics and bacteriological levels of the Mezam River water as well as to investigate their temporal and seasonal fluctuations. The results obtained will serve as a benchmark for various stakeholders in the sustainable management of surface water resources in Bamenda Town and beyond.

## Geographic and geologic setting

Bamenda Town extends from latitude 5°43' to 7°10' north and longitude 9°35' to 11°12' east and at an altitudinal range of 1200 m to 1865 m above sea level. It is characterised by very steep slopes, with slope angles ranging from 45° to 60° (Ndenecho and Eze 2004), with a surface area of about 3125 ha (Acho 1998). The climate is essentially the Cameroonian type equatorial domain characterised by two seasons: a rainy season of about 7 months (April to October) and a dry season of about 5 months (November to March). The mean annual rainfall is 2670 mm, and the average annual temperature is 25 °C. The vegetation is typically grassland savannah and has been greatly modified in many areas by the planting of secondary eucalyptus forest (Kometa 2013). The tributary streams (Yambot, Ayaba, Mougheb, Nkimefueh and Naaka) that culminate to form River Mezam originate from the base of the Bamenda Highlands and the Bamenda Escarpment (Molou and Lambi 2006). These water bodies flow through Bamenda city, draining residential areas and commercial centres and form a dense dendritic system. The town is located along the Cameroon Volcanic Line (Fig. 1) and exhibits two very distinct relief environments: the high lava plateau (upstation) with an altitude of about 1400 m and the lower plateau (downtown) with an average altitude of 1100 m. The upstation and downtown are separated by an escarpment of about 150 m whose slope steepness attains 35°. Geologically, Bamenda is underlain by

a Precambrian granite–gneiss basement which is overlain by volcanic rocks (basalts, trachyte, dolerite and ignimbrites) and sedimentary silty clays of the Mezam River flood plains (Ndenecho and Eze 2004). The dominant soils are ferralsols associated with lithosols and gleysols. Farming is the main activity carried out, and it is mostly crop-based farming, pure pastoral nomadism, mixed crop livestock, secondary and tertiary activities.

## Field and laboratory methods

Water samples were collected from six sampling points (Fig. 1) in the rainy and dry seasons. Two sets of samples were obtained from each station: one for the physico-chemical analysis and the other for the bacteriological analysis. The sampling bottles were initially rinsed with distilled water and, thereafter, with the water to be sampled. After collection the sampling bottles were tightly capped, labelled and placed in an ice-pack cooler to maintain the temperature below 4 °C. The sampling points and their corresponding codes are shown in Table 1. The water temperature, pH, electrical conductivity, turbidity and dissolved oxygen were measured in situ.

The chemical analysis of the water samples was conducted in the Research Unit 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. Major cations (Ca, Mg) were dosed by the flame atomic absorption spectrometry, while K and Na were analysed by the flame atomic emission spectrometry as specified by Atteia (2005). Chloride ions were determined by titration, bicarbonate ions by spectrophotometry and sulphate ions by photometry using barium iodate. Heavy metals were determined using the atomic absorption spectrometry and X-ray fluorescence. The water samples were equally analysed for indicators of faecal contamination such as *Escherichia coli* (*E. coli*), *Streptococci*, *Salmonella* and *Pseudomonas*. *E. coli* was determined by the Most Probable Number (MPN) method using sterile MacConkey broth as described by Cheesbrough (1991), *Salmonella* and *Streptococcus* were dosed from their respective agars according to Cheesbrough (1991), and *Proteus* was measured by the triple sugar iron (TSI) technique as described by MacFaddin (2000).

## Results

### Physical characteristics

The mean water temperature ranges from 18.3 °C at YB to 23.4 °C at LN. The lowest temperature values are recorded

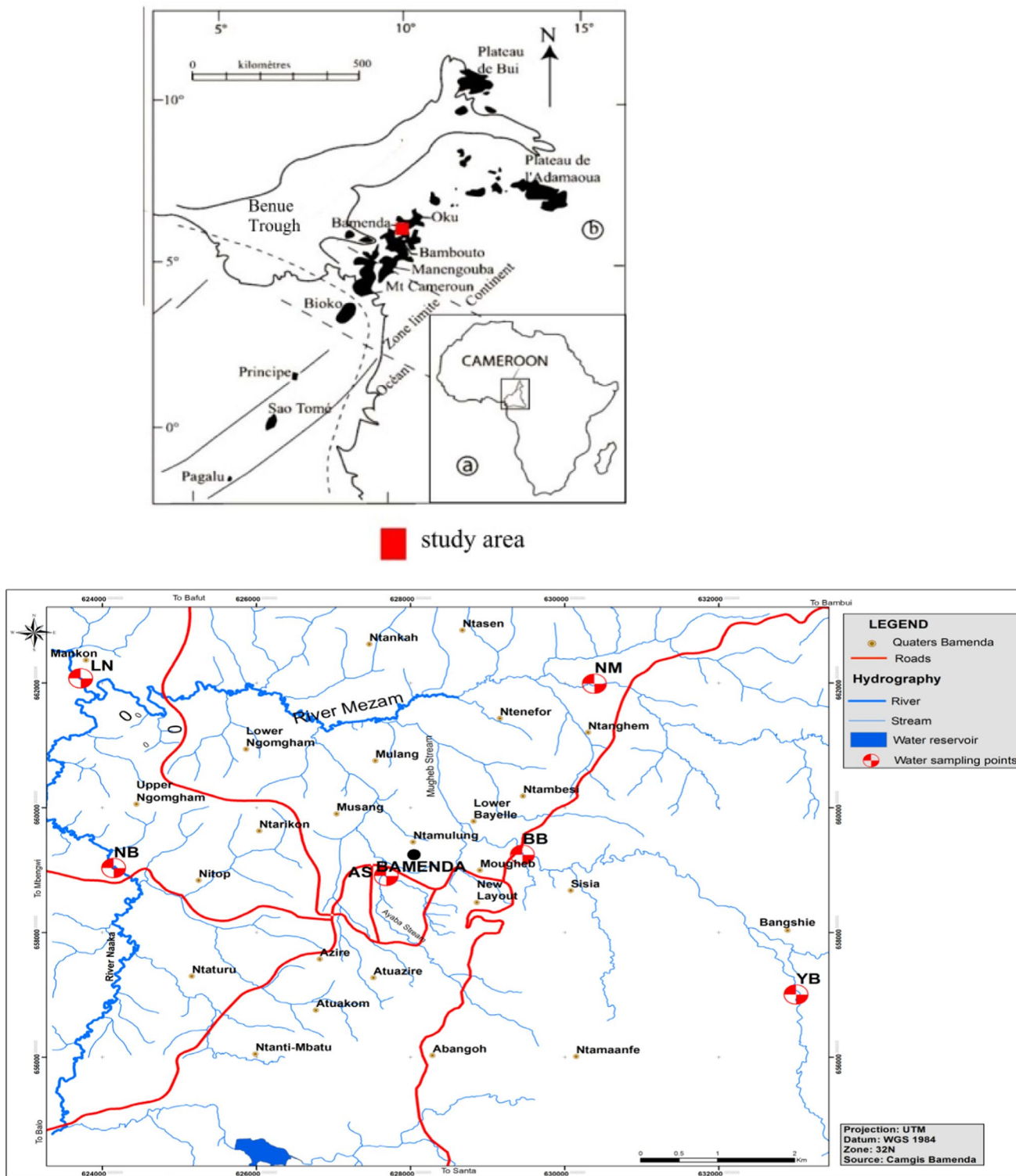


Fig. 1 Geology and location of sampling points in the study area

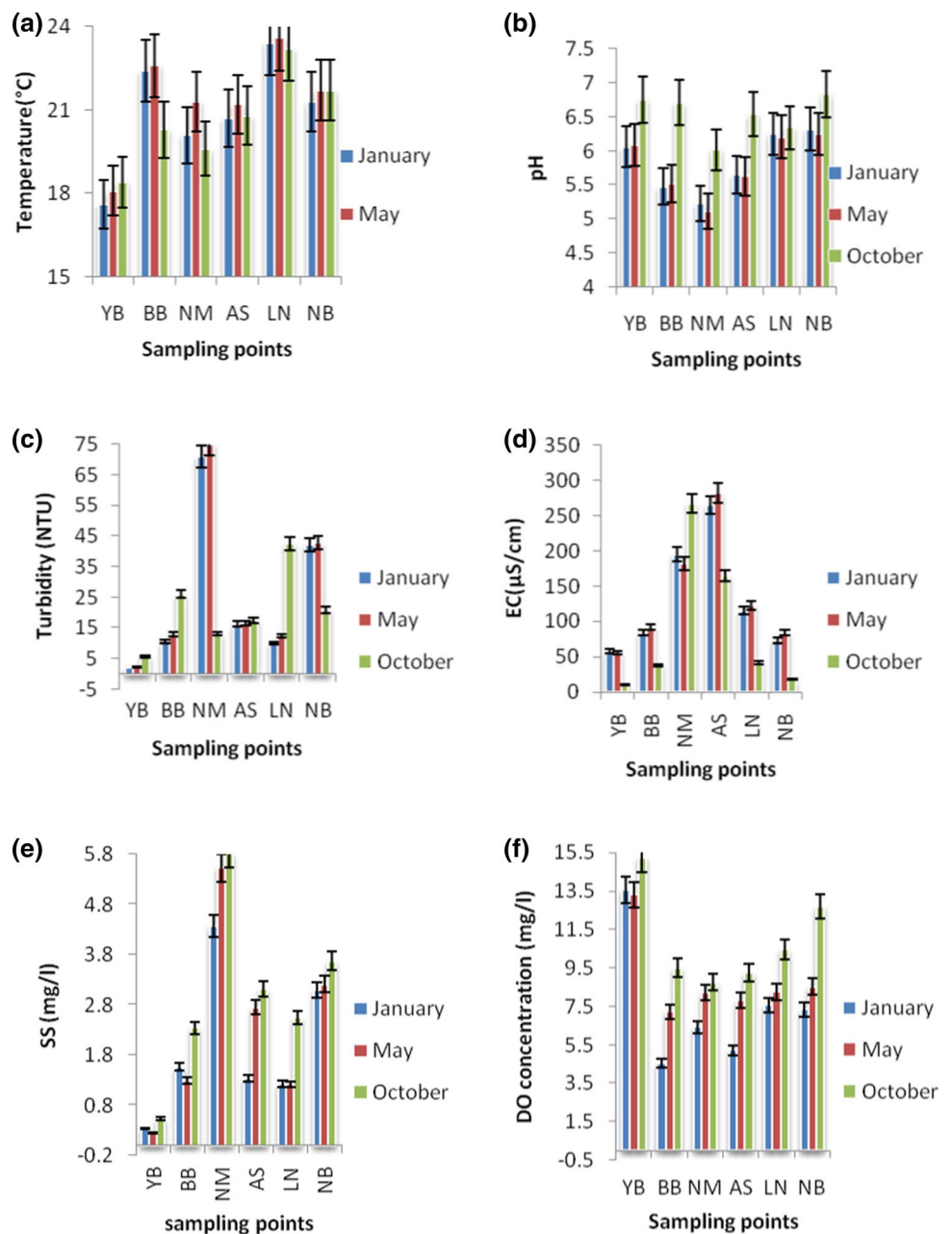
at YB and the highest values at LN (Fig. 2a). The mean pH values of the Mezam River water range from 5.85 in May to 6.53 in October (Table 2). Seasonal variations are not eminent, with highest values measured in October at NB and

lowest at NM during all sampling occasions (Fig. 2b). The mean values of turbidity range from 20.85 NTU in October to 26.93 NTU in the May sampling period. There is a marked seasonal variation at YB, BB, AS, LN and NB

**Table 1** Sampling points and their corresponding codes in the study area

Sampling point	Codes	Description of sampling points	Altitude (m)	Latitude	Longitude
Yambot (Mendankwe)	YB	Reference point	1652	N05°55'56"	E10°11'12"
Bayelle segment	BB	The river receives runoff from habitation, the Nkwen market, garages and agricultural land	1216	N05°57'58"	E10°09'49"
Nkimefueh segment (Mile 4)	NM	Receives wastewater from the Bamenda slaughterhouse	1234	N05°59'08"	E10°10'31"
Ayaba segment	AS	Receives runoff from the Old Town quarter, the Commercial Avenue	1237	N05°57'33"	E10°08'51"
Lower Ngomgham	LN	Exit of River Mezam from Bamenda municipality	1222	N05°59'07"	E10°07'40"
Naaka	NB	Located in a sparsely populated area where the dominant activity is agriculture	1221	N05°55'22"	E10°06'55"

**Fig. 2** Seasonal variations of physical parameters in the Mezam River water



**Table 2** Summary statistics of the Mezam water physico-chemical characteristics for the studied period

Variable	Minimum	Maximum	Mean	SD	CV (%)
<i>January (n = 6)</i>					
pH	5.23	6.65	6.00	0.53	8.83
EC	73	265	131.67	81.5	61.90
Turbidity	10	70.9	25.30	9.22	36.44
Ca <sup>2+</sup>	0.83	1.22	0.95	0.31	32.63
Mg <sup>2+</sup>	0.5	1.01	0.58	0.26	44.83
K <sup>+</sup>	0.35	0.99	0.48	0.31	64.58
Na <sup>+</sup>	0.04	0.14	0.08	0.04	50.00
SO <sub>4</sub> <sup>2-</sup>	0.3	0.33	0.26	0.05	19.23
NO <sub>3</sub> <sup>-</sup>	38	50	42.83	6.49	15.15
<i>May (n = 6)</i>					
pH	5.12	6.21	5.80	0.45	7.76
EC	56	282	136.50	83.23	60.97
Turbidity	2.2	74.9	26.93	13.16	48.87
Ca <sup>2+</sup>	0.38	1.36	1.03	0.35	33.98
Mg <sup>2+</sup>	0.26	1.04	0.61	0.27	44.26
K <sup>+</sup>	0.12	0.95	0.46	0.30	65.22
Na <sup>+</sup>	0.04	0.12	0.07	0.03	42.86
SO <sub>4</sub> <sup>2-</sup>	0.16	0.32	0.26	0.06	23.08
NO <sub>3</sub> <sup>-</sup>	0.04	0.12	0.07	0.03	42.86
<i>October (n = 6)</i>					
pH	6.02	6.84	6.53	0.31	4.75
EC	11	267	90.17	33.33	36.96
Turbidity	5.6	42.4	20.85	12.61	60.48
Ca <sup>2+</sup>	0.05	0.37	0.13	0.08	80.00
Mg <sup>2+</sup>	0	0	0.06	0.03	50.00
K <sup>+</sup>	0.02	0.07	0.07	0.03	42.86
Na <sup>+</sup>	0	0	0	0.00	0.00
SO <sub>4</sub> <sup>2-</sup>	10.17	62.15	22.92	11.09	49.22
NO <sub>3</sub> <sup>-</sup>	6.72	16.24	9.33	3.54	37.94
<i>January + May + October (n = 18)</i>					
pH	5.12	6.84	6.11	0.52	8.57
EC	11.00	282.00	119.44	87.12	72.90
Turbidity	2.00	74.90	24.36	21.75	89.28
Ca <sup>2+</sup>	0.05	1.36	0.70	0.49	70.00
Mg <sup>2+</sup>	0.00	1.04	0.42	0.33	79.62
K <sup>+</sup>	0.01	0.99	0.33	0.31	91.56
Na <sup>+</sup>	0.00	0.14	0.05	0.05	91.62
SO <sub>4</sub> <sup>2-</sup>	0.16	62.15	15.87	7.80	49.16
NO <sub>3</sub> <sup>-</sup>	0.04	50.00	19.32	17.44	90.26

SD: standard deviation; CV: coefficient of variation

with the lowest values observed in January and the highest values in October (Fig. 2c). The mean values of electrical conductivity (EC) vary in the Mezam River water with mean values ranging from 90.17  $\mu\text{S}/\text{cm}$  in October to 136.50  $\mu\text{S}/\text{cm}$  in May. With the exception of the NM sampling points, the highest values are scored in January, while the lowest

values are noted in October. The lowest EC value measured during the study period is at YB (Fig. 2d). The concentrations of dissolved oxygen (DO) range from 4.5 mg/l at BB to 15.24 mg/l at YB. The lowest DO values are measured in January and the highest recorded in October at all the sampling points. There is a high disparity in the DO concentrations from the reference point at YB through the sampling points in the city centre to those downstream as the water exits the city (Fig. 2e). The mean of suspended solids (SS) ranges from 0.37 mg/l at YB to 5.24 mg/l at NM. The highest value of this variable is obtained during the October sampling occasion; meanwhile, seasonal variations are not prominent between the January and May sampling periods. The lowest value of suspended solids is 0.24 mg/l measured at YB (reference point), while the highest value is 5.82 mg/l at NM (Fig. 2f).

### Chemical characteristics of surface water in Bamenda Town

The major cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup> and Na<sup>+</sup>) in the Mezam River water are in minute concentrations (0.00 to 1.36 mg/l) at all the sampling points (Tables 2, 3). The lowest values are observed at YB. All the major cations are present in water samples in the May sampling period (Fig. 3). The highest concentrations of the cations during the study period are observed for Ca<sup>2+</sup> (1.36 mg/l) at NM in May (Fig. 3a), and the least values are obtained during the October sampling occasion. Mg<sup>2+</sup>, on the other hand, is absent at the NB and YB sampling points (Fig. 3b). Low Na<sup>+</sup> and K<sup>+</sup> levels are observed at all the sites.

Major anions (Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>) appear in very low concentrations in the Mezam River water (0.00–3.2 mg/l). The chloride ion varies from 0.00 mg/l to 0.09 mg/l (Fig. 3a). Seasonal variations are not very perceptible except at BB, NM and LN (Fig. 4a). The highest mean concentration (0.09 mg/l) is recorded at NM in May and the lowest at YB. The bicarbonate ion ranges from 0.11 mg/l to 3.2 mg/l, and seasonal variations are observed with lowest levels recorded in October and about 95% of the highest concentration is noted in January (Fig. 4b). The lowest level of the bicarbonate ion is 0.86 mg/l at YB and the highest is 3.2 mg/l at NB. The mean concentrations of sulphate ions range from 0.18 mg/l to 0.31 mg/l (Fig. 4c). Low levels of sulphate ion (0.01 mg/l) are observed in May and October with no perceptible trend, while higher levels appear in January.

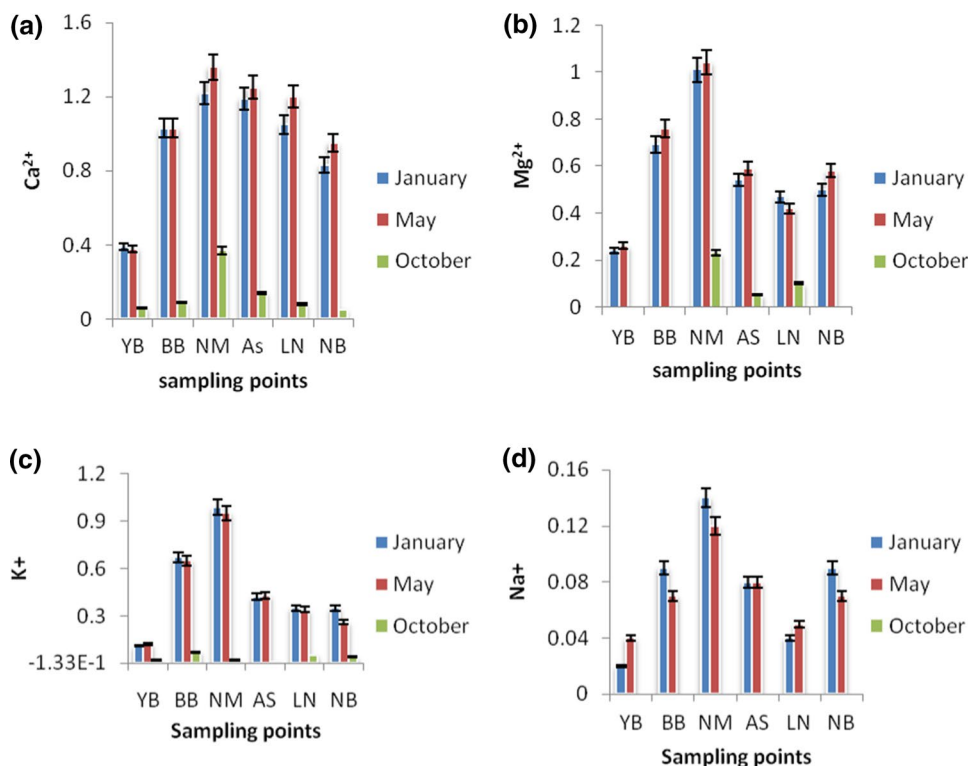
The concentrations of phosphate ions vary from 0.03 mg/l to 0.12 mg/l, with no significant variation between seasons and among the sampling points. The lowest mean concentration of the phosphate ion is 0.05 mg/l at YB, and the highest is 0.075 mg/l at NB (Fig. 5a). The mean concentration of nitrate ions varies from 13.25 mg/l to 19.77 mg/l in the Mezam River water. The lowest

**Table 3** Principal component analysis generated based on factor loading ( $n=18$ )

	PC1 (pH/Ca <sup>2+</sup> /Mg <sup>2+</sup> /K <sup>+</sup> /Na <sup>+</sup> )	PC 2 (Proteus)	PC 3 (Salmonella)	PC 4 (EC)
pH	<b>- 0.81</b>	0.40	0.07	0.10
EC	0.47	- 0.37	0.15	<b>0.75</b>
Turbidity	0.64	0.29	0.25	- 0.03
Ca <sup>2+</sup>	<b>0.89</b>	- 0.12	- 0.06	0.08
Mg <sup>2+</sup>	<b>0.98</b>	- 0.12	- 0.12	- 0.03
K <sup>+</sup>	<b>0.95</b>	- 0.14	- 0.19	- 0.02
Na <sup>+</sup>	<b>0.97</b>	0.04	- 0.05	- 0.06
SO <sub>4</sub> <sup>2-</sup>	- 0.47	- 0.23	0.00	0.65
NO <sub>3</sub> <sup>-</sup>	0.31	0.56	- 0.49	0.35
E.coli	0.11	0.61	0.46	0.33
Streptococcus	0.51	0.47	0.50	- 0.12
Salmonella	0.11	- 0.34	<b>0.80</b>	- 0.05
Proteus	0.13	<b>0.70</b>	- 0.08	0.07
Total loading <sup>A</sup>	5.49	1.98	1.49	1.26
% variance explained	42.27	15.23	11.51	9.700
Cumulative % variance explained	42.27	57.51	69.02	78.72

The very high factor loadings of some variables in bold imply that the chemistry of water is controlled mainly by those variables

**Fig. 3** Seasonal variations of major cations (mg/l) in the Mezam River water



concentration (0.04 mg/l) is obtained in May at YB and the highest (50 mg/l) in January at NM (Fig. 5b). The mean concentration of the ammonium ions ranges from 33.27 mg/l to 44.79 mg/l. Seasonal variations are noted with the lowest concentration (7.84 mg/l) measured in October (rainy season) and the highest (63 mg/l) in May, except at AS (Fig. 5c). The spatial variations are also noted

with the highest concentration (63 mg/l) recorded at LN in May and the lowest (7.8 mg/l) at NM in October.

The Piper’s ternary diagram (Piper 1953) enables the identification of three main hydrochemical water types (Fig. 6). In the dry season, two water types are noted, the Ca-SO<sub>4</sub><sup>2-</sup> type and the Ca- Mg- Cl+ NO<sub>3</sub><sup>-</sup> type. For the cations, some of the samples plot in the calcium domain and

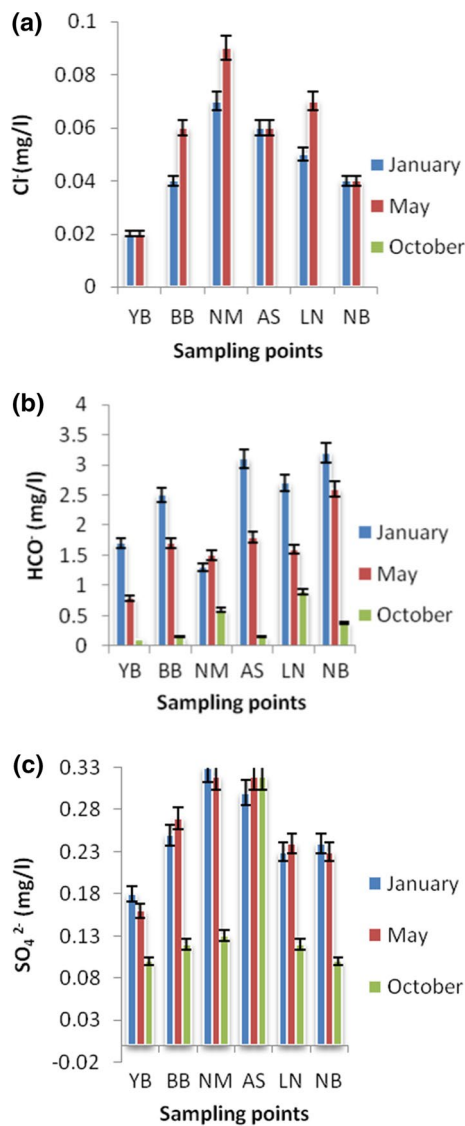


Fig. 4 Seasonal variations in major anions of the Mezam River water

others in the magnesium domain; meanwhile, for the anions, most of the samples plot in the sulphate and some in the Cl + NO<sub>3</sub><sup>-</sup> fields. In the rainy season, a Ca-Mg- SO<sub>4</sub><sup>2-</sup> water type is observed since some samples plot in the Ca and Mg fields for the cations and almost all samples plot in the SO<sub>4</sub><sup>2-</sup> fields.

### Variation of indicator bacteria in the Mezam River water

The *E. coli* occurs in all the sampling points, with mean concentrations ranging from 333.33 CFU/100 ml in May to 433.33 CFU/100 ml during the January sampling period (Table 4). Seasonal variations are not conspicuous (Fig. 7a). The lowest concentrations (100 CFU/100 ml) are observed at YB and AS in May, while the highest (500 CFU/100 ml)

occur at BB, NM and AS. The mean concentration of *Streptococcus* ranges from 208.33 CFU/100 ml in October to 275.50 CFU/100 ml in May. The highest concentrations (500 CFU/100 ml) appear at NM and NB in January, and the least (100 CFU/100 ml) is recorded at YB, BB, AS, LN and NB (Fig. 8b). *Salmonella* is detected once at YB (3 CFU/100 ml) in October and twice at BB, LN and NB, whereas it is present at the NM and AS throughout the sampling periods (Fig. 8c). The mean concentration of *Salmonella* ranges from 20.00 CFU/100 ml in January to 151.67 CFU/100 ml in May. *Proteus* species is not detected at the AS and BB sampling points. The mean value ranges from 50 CFU/100 ml in October to 196.63 CFU/100 ml in January, and there is no observable trend in seasonal variation (Fig. 8d). The lowest concentration (0.00 CFU/100 ml) of *Proteus* is measured at AS and BB and the highest (500 CFU/100 ml) at NM.

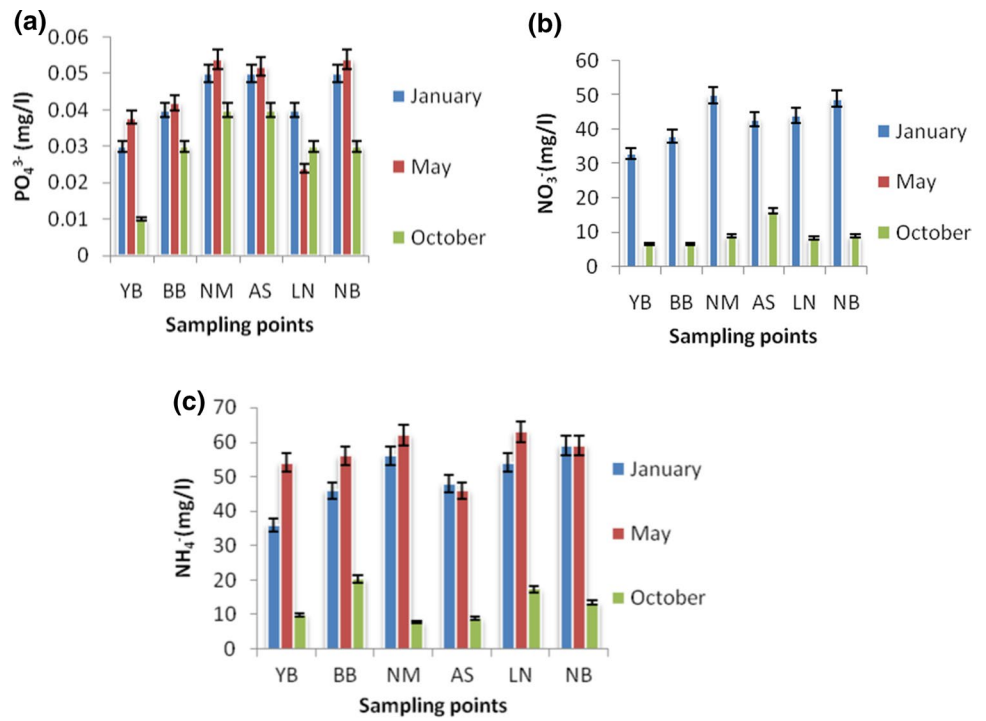
## Discussion

The Mezam River water in Bamenda is not used directly as a drinking water source, but is rather widely used to irrigate crops grown in the River’s floodplain during periods of drought. If the river water used is polluted, it may have a considerable impact on soil properties and plants grown because the contaminants may be absorbed by the crops and would have negative consequences on the population when consumed.

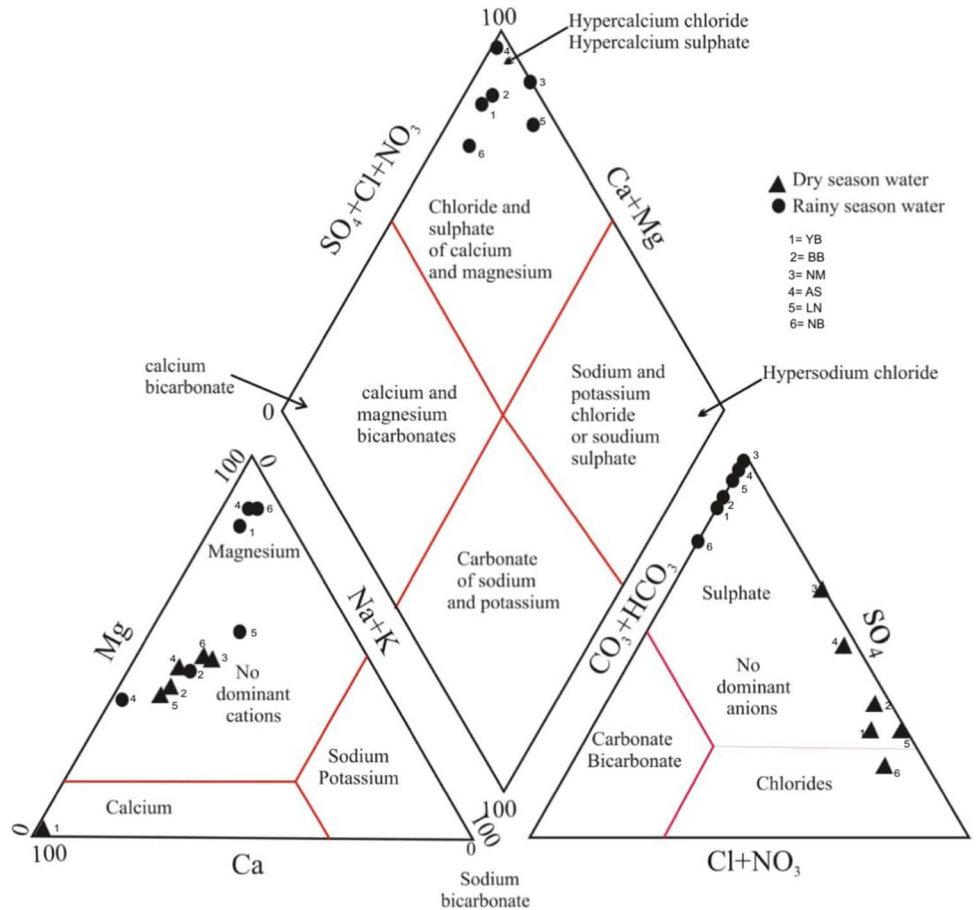
### Physico-chemical peculiarities and sources of ions in surface water in Bamenda Town

The spatial variation of physical characteristics is not very distinct, but variation is perceptible between seasons at some sampling points. The mean temperature of the Mezam River water, varying from 18.3 °C to 23.4 °C, is a reflection of the average ambient temperature. Temperature is a crucial parameter that controls the distribution, growth, survival and reproduction of organisms in an ecosystem (Vincy et al. 2012). Higher-temperature values within the range of 24.6 to 31 °C have been observed in the Foma River in Nigeria by Agbabiaka and Oyeyiola (2012). All the water samples show pH values below neutrality, ranging from 5.12 at Nkimefueh to 6.84 at the Naaka River. This pH range is compatible with aquatic life, particularly green plants that may serve to aerate and purify the water (Tita et al. 2007). Lower pH values of 4.7 to 4.9 have been observed by Boeglin et al. (2003) in the Nsimi catchment ( South Cameroon), while Akoanung et al. (2019) have recorded mean pH values of 5.71 from groundwater samples in Bamenda and Mufur et al. (2021) documented weakly acidic to neutral pH values of 5.3 to 7.1 in Melong. The EC values vary from 6.09 μS/cm at

**Fig. 5** Seasonal variations of nutrients in the Mezam River water



**Fig. 6** Piper diagram showing variation in ion composition of the Mezam River water

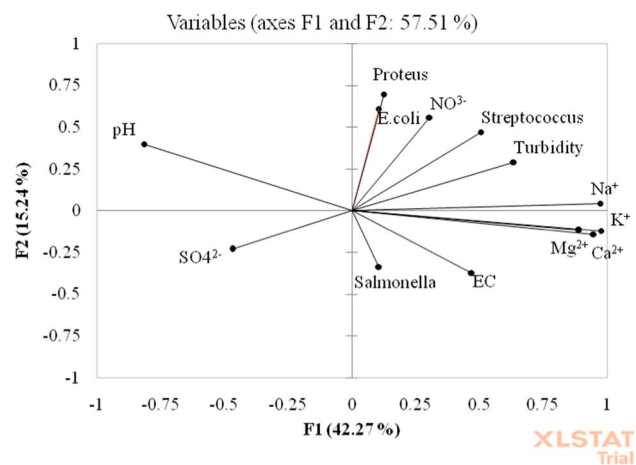




**Table 4** Summary statistics of the Mezam water bacteria count for the studied period (n = 18)

Variable	Minimum	Maximum	Mean	SD	CV (%)
<i>January (n = 6)</i>					
<i>E. coli</i>	300	500	433.33	103.28	23.80
Streptococcus	100	500	233.33	56.23	24.09
Salmonella	0	50	20.00	10.00	50.00
Proteus	0	500	196.63	52.43	26.66
<i>May (n = 6)</i>					
<i>E. coli</i>	100	500	333.33	96.63	28.99
Streptococcus	200	300	275.00	41.83	15.21
Salmonella	0	500	151.67	83.34	54.95
Proteus	0	100	53.33	16.76	31.42
<i>October (n = 6)</i>					
<i>E. coli</i>	160	500	393.33	165.73	42.13
Streptococcus	100	300	208.33	102.06	48.98
Salmonella	10	200	51.67	24.40	47.20
Proteus	0	150	50	18.32	36.64
<i>January + May + October (n = 18)</i>					
<i>E. coli</i>	100	500	386.66	156.13	40.37
Streptococcus	100	500	238.88	130.11	54.46
Salmonella	0	500	123.99	71.44	57.61
Proteus	0	500	121.51	78.89	64.92

SD: standard deviation; CV: coefficient of variation



**Fig. 7** Graphical representation of the first two principal components of the Mezam water characteristics, extraction method: principal component analysis (n = 18)

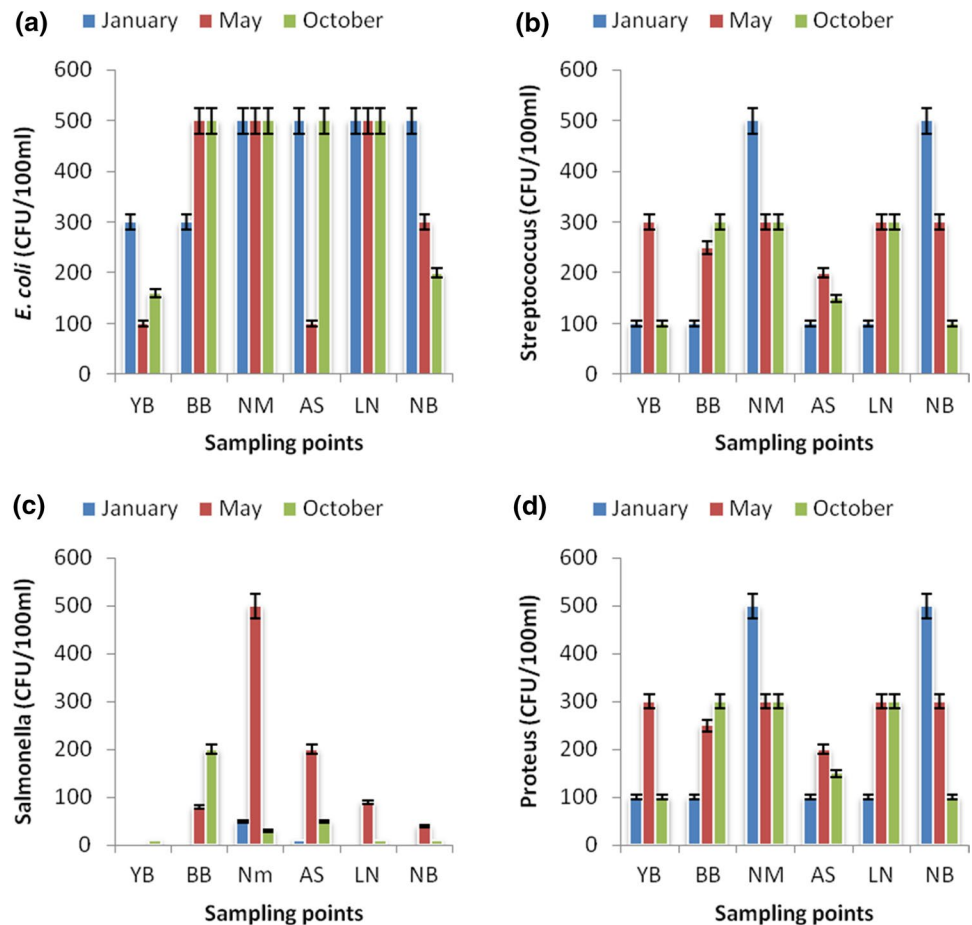
Yambot to 28.5 µS/cm at the Ayaba Segment. In fact, EC for the downstream sampling points at Nkimefueh, Ayaba and Lower Ngomgham always portrays excess values of 50 µS/cm, which could be an indication of anthropogenic sources of ions in water. A mean EC value of 421.54 µS/cm has been reported by Engome et al. (2013) in the Rio del Rey Basin (South West Cameroon).

Dissolved oxygen is generally low (< 10 mg/l) and the sampling points in the urban areas (BB and AS) most often maintain a substandard level (< 5 mg/l). The low values of DO are in agreement with results of Togue et al. (2017) in Nkam River. The amount of dissolved oxygen in water is a good indicator of water quality and the kind of aquatic life that can be supported. Organic wastes such as food processing waste, runoff from feedlots and piggery, stimulate oxygen consumption by decomposers (Bishop and Prosser 2002). When these microorganisms breakdown the organic materials, they use up oxygen (hence the name oxygen-demanding wastes) resulting to a decrease in oxygen content in water. The AS and BB sampling points (Figs. 9, 10) are characterised by huge quantities of refuse from commercial as well as residential areas of the town. Low DO levels have been observed by Fatema et al. (2014) in the Merbok estuary.

The cation concentration of the water during the study period followed the following trend:  $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ . From Table 3, it is noticed that the chemical constituents controlling surface water chemistry in the study area are the major cations which might stem from the weathering of silicate minerals in the surrounding rocks. The anion concentration is such that  $HCO_3^{-} > SO_4^{2-} > NO_3^{-} > Cl^{-}$ . The high  $HCO_3^{-}$  ion concentrations might result from dissolved  $CO_2$  in precipitation according to Tanyileke et al. (1996); this is a characteristic of natural waters along the CVL. However, the marked increase in their respective concentrations downstream lends credence to additional anthropogenic inputs. This is particularly so with heavy metal levels during the May sampling period at BB, NM, AS and NB river segments. Similarly, nitrate concentrations attained the FAO (1994) limits of 50 mg/l at NM in May. This is justifiable in Fig. 9 where the NM sampling point is highly variable from the other sampling points. Here, the water samples are less variable in terms of physico-chemical characteristics with a total variance weight of 41.70% relative to the higher variability of samples in terms of bacteria count with a variance expression of 69.22%.

**Sources of ionic constituents in the studied surface water**

The correlation matrix is useful in establishing relationships among variables. The Pearson correlation matrix (Table 5) showed that strong positive correlation exists between  $Ca^{2+}$  and  $Mg^{2+}$  (0.91),  $K^{+}$  (0.83) and  $Na^{+}$  (0.88).  $Mg^{2+}$  on the other hand is strongly positively correlated with  $K^{+}$  (0.96) and  $Na^{+}$  (0.95), while  $K^{+}$  is strongly positively correlated with  $Na^{+}$  (0.91). This may result from natural hydrogeochemical processes of weathering of the surrounding rocks to liberate the cations into the water. This corroborates with

**Fig. 8** Seasonal variations in **a** *E. coli*; **b** *Streptococcus*

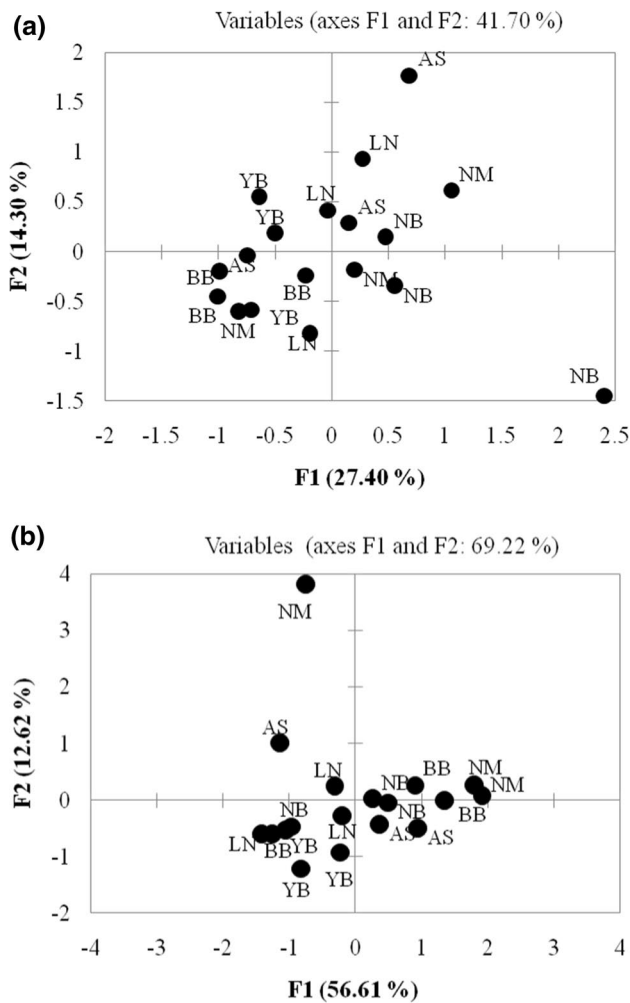
the study of Magha et al. (2021) in which Gibbs plot indicated that groundwater chemistry in Northern Bamenda is controlled principally by rock weathering. Moreover, the principal component analysis (PCA) was used to elucidate the provenance of major ions in the studied water. Among the dominant constituents, the distribution of the PCA variables in the factorial spread F1-F2 revealed two important groups (Fig. 7). The first group in the first quadrant is made up of turbidity,  $\text{Na}^+$ ,  $\text{NO}_3^-$ , *E. coli*, *Streptococcus* and *Proteus*, while the second quadrant is made up of EC,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{K}^+$  and *Salmonella*. The ionic components that determine water mineralisation may result from natural processes of mineral decomposition, atmospheric deposition or breakdown of organic matter or as well from human sources as is the case for the indicator bacteria (Rakotondrabe et al. 2018).

### Bacteriological levels and anomalies of surface water in Bamenda Town

The occurrence of faecal indicator bacteria in all the sampling points reflects the different human activities carried out in the neighbourhood as well as the population density. The

lowest concentration of indicator bacteria of pollution is gotten at the YB sampling point situated in an undeveloped area below the Bamenda Highlands where contributions from human influence are at a minimum. The occurrence of high bacteria counts indicates that the source is not necessarily human but rather other warm-blooded animals (Park 2001; Abednego et al. 2013). The highest concentrations of faecal indicator bacteria were measured at BB and NM. The BB sampling point is situated downstream at a densely populated area where a good number of households do not have adequate sanitary facilities, and in most cases, effluents are channelled directly into the waterway. In addition, there are small-scale piggeries and poultries in the back yards of many homes whose wastes constantly flow into the river channel. This result corroborates with the results of Kuitcha et al. (2010) in the Mfoundi watershed in Yaoundé, Cameroon. In particular, the NM sampling point is located downstream to the Bamenda slaughterhouse where the waste is conveyed into the river channel, possibly raising the concentrations of faecal bacteria.

The bacteria concentrations also show seasonal variations with comparatively higher levels in the dry season and onset of rains and lower levels in the rainy season. In the dry



**Fig. 9** Factor separation showing variability of water sampling points in terms of bacterial count **(a)** and physico-chemical analysis **(b)** of the Mezam

season, the volume of water in the river is greatly reduced rendering it more accessible to both humans and animals as already observed by Tita et al. (2013).

**Implications for surface water management**

Water pollution is an acute environmental problem that results from rapid population growth and can have many adverse effects on human health, aquatic environment, agricultural productivity, natural ecosystems and the cost of treatment of water for drinking. The pollution of the Mezam River water in Bamenda has greatly affected its usage, including the recreational value of the resource. A great multitude of diseases that affect humans is transmitted through polluted water, either directly through drinking contaminated water or indirectly through consumption of food stuffs, especially vegetables that are irrigated with polluted water. The health impact of water pollution in the Bamenda area can be aggravated as many residents do not understand the implications that could arise from using urban water bodies and continue to use the water to water vegetables (huckleberry) that are widely consumed in Bamenda and other towns of Cameroon.

**Conclusion**

This study aimed to investigate the physico-chemical and bacteriological characteristics of surface water in Bamenda Town (North West Cameroon). The main results reveal that the surface water in Bamenda Town is slightly acidic with pH values varying from 5.12 to 6.84. The implication of the acidic water when it comes in contact with geologic materials of the surroundings is that it may dissolve some minerals and incorporate them into

**Fig. 10** Refuse dumped at some sampling points in the Mezam River water



**Table 5** Correlation among selected Mezam water characteristics for the studied period (n = 18)

Variables	pH	EC	Turbidity	Ca <sup>2+</sup>	Mg <sup>2+</sup>	K <sup>+</sup>	Na <sup>+</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sup>3-</sup>
pH	1.00								
EC	- 0.39	1.00							
Turbidity	- 0.43	0.16	1.00						
Ca <sup>2+</sup>	- <b>0.67**</b>	<b>0.55*</b>	0.33	1.00					
Mg <sup>2+</sup>	- <b>0.85**</b>	<b>0.46*</b>	<b>0.55*</b>	<b>0.91**</b>	1.00				
K <sup>+</sup>	- <b>0.86**</b>	0.44	<b>0.58*</b>	<b>0.83**</b>	<b>0.96**</b>	1.00			
Na <sup>+</sup>	- <b>0.74**</b>	0.41	<b>0.57*</b>	<b>0.88**</b>	<b>0.95**</b>	<b>0.91**</b>	1.00		
SO <sub>4</sub> <sup>2-</sup>	0.21	0.29	- 0.15	- <b>0.49*</b>	- 0.44	- 0.37	- <b>0.55*</b>	1.00	
NO <sup>3-</sup>	- 0.04	0.12	0.10	0.24	0.25	0.28	0.35	- 0.19	1.00
E.coli	0.29	0.12	0.23	0.13	- 0.03	- 0.07	0.09	- 0.15	0.32
Streptococcus	- 0.29	0.03	<b>0.67**</b>	0.23	0.38	0.35	<b>0.48*</b>	- 0.21	0.07
Salmonella	- 0.18	0.29	- 0.02	0.13	0.03	- 0.05	0.08	- 0.15	- 0.41
Proteus	0.10	- 0.11	0.18	0.08	0.06	- 0.01	0.14	- 0.08	0.36

\*Correlation is significant at the 0.05 level; \*\*correlation is significant at the 0.01 level

The very high factor loadings of some variables in bold imply that the chemistry of water is controlled mainly by those variables

the water, thereby enriching the chemical content of the water. The cation concentration of the studied water is such that  $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ . The high  $Ca^{2+}$  content might be derived from the weathering of feldspar and hornblende present in the country rocks. Heavy metals were detected in the water in very low concentrations at some sampling points and were completely absent in most samples. The Mezam River water is polluted with different faecal bacteria, with high levels attaining 500 CFU/100 ml mainly in the city centre. Some physical and bacteriological parameters show great variations from the reference point and various sampling points, increasing from the reference point through sampling points in the urban centre. Remarkable seasonal variations are perceived in the physical, chemical and bacteriological parameters in the studied surface water samples in Bamenda Town. The major cations and anions in the studied water in Bamenda Town result mainly from the alteration of various country rocks within the water shed of the Mezam River system. The high pollutant loads degrade the quality of surface water in Bamenda Town. The population is therefore urged to adopt a responsible behaviour towards waste disposal and refrain from disposing wastes into the river channel in order to safeguard the aquatic environment and also protect the health of the population.

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#### Declaration

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

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