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A Comparative Assessment of the Spatio-Temporal Dynamics of Potable Water Delivery for Water Resource Management within Mount Cameroon and Mount Manengouba, Cameroon

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Abstract
Mountain regions, including Mount Fako and Mount Manengouba, are vital natural water catchments that supply freshwater to over half of the world's population. These areas play a critical role in delivering potable water through ecosystem services. Although water from the source is typically pure, its quality and quantity decline as it flows downstream, especially through human settlements, resulting in unreliable and intermittent water supply. This study assessed the spatial and seasonal dynamics of water quality in three streams from each mountain—Wolikakwo, Koke, and Ndongo (Mount Cameroon), and Shut, Chambre Noir, and Poladam (Mount Manengouba). Samples were collected at three points along each stream (source, upstream settlement, and downstream settlement) during both dry and rainy seasons. Ten parameters were analyzed using the Weighted Arithmetic Water Quality Index (WQI), with laboratory results compared to WHO drinking water standards. ANOVA and Independent Sample Tests were employed to detect spatial and temporal variations. Findings revealed significant spatial and/or seasonal variations in several streams. In Mount Manengouba, streams showed variations in pH, K^+, and coliform counts. Chambre Noir and Poladam exhibited significant seasonal changes in conductivity, calcium, sulfates, bicarbonates, and nitrates. In Mount Cameroon, streams like Wolikakwo, Koke, and Ndongo displayed similar patterns, particularly for EC, TDS, temperature, coliforms, and key ions. Overall, WQI results indicated that none of the water sources met WHO standards for potable use. To ensure sustainable water delivery, the study recommends establishing watershed management boards and enforcing water catchment protection laws to safeguard mountain water sources.

Keywords: Mount Cameroon; Mount Manengouba; Portable water delivery; Water quality parameters; Water quantity parameters; Water quality index

Introduction
Mountain ecosystems are among the planet's most important ecological assets, providing essential goods and services that are critical for human well-being both within mountain regions and far beyond their boundaries (MEA, 2005; TEEB, 2010). They serve as vital water towers, acting as natural catchments with exceptional water storage and release capacities due to their geological formations and vegetation cover. The water originating from mountain catchments is often of high purity at its source; however, as it travels downstream, its quality and quantity are subject to alteration due to both natural processes and human-induced pressures. Despite the fundamental role of freshwater in sustaining life, mountain water resources are increasingly threatened. Over recent decades, rapid population growth, intensified land use, and unregulated anthropogenic activities have accelerated the degradation of both the quality and availability of freshwater

(Haygarth & Jarvis, 2002). These impacts are particularly concerning in contexts where communities depend heavily on untreated gravity-fed water supply systems from mountain sources. Human occupation and activities—such as agriculture, domestic water abstraction, deforestation, and waste disposal—have been shown to alter the chemical, physical, and biological properties of mountain water systems. Seasonal variability in water quality and quantity is also pronounced, reflecting shifts in rainfall patterns and human activity throughout the year.

In many parts of the world, including sub-Saharan Africa, these pressures have resulted in severe water crises. Despite the abundance of water resources in some mountainous regions, the failure to adequately manage and conserve them has led to irregular, unreliable, and intermittent water supplies, sometimes with communities going for weeks or months without potable water. This situation is compounded by the lack of recognition and valuation of mountain ecosystems as providers of crucial water purification and supply services. For instance, Kolinjivadi (2014) notes that up to 70% of local communities are unaware of the significant role mountain ecosystems play in water provision. The lack of this awareness contributes to unsustainable practices that further erode the ecosystem's capacity to deliver clean water.

Globally, access to safe and reliable water remains a major challenge, but the problem is particularly acute in developing countries (Ivey et al., 2006), including Cameroon (Usongo & Briyan, 2021; Usongo et al., 2023). In such contexts, the sustainable management of mountain water resources is not only an environmental imperative but also a socio-economic necessity. Poor water governance, inadequate infrastructure, and weak enforcement of environmental regulations exacerbate water scarcity and contamination, threatening the attainment of international development targets such as the Sustainable Development Goals (SDGs), particularly SDG 6 on clean water and sanitation. Motivated by the growing crisis of inadequate and unreliable water supply in mountain regions, this study focuses on the Mount Cameroon and Manengouba watersheds—two critical highland ecosystems in Cameroon that are central to local and regional water supply. Recognizing that both water quality and quantity are closely linked to the integrity of the source environment, the research seeks to: identify and map human activities along stream courses within the study area; examine the spatio-temporal dynamics of key water quality parameters as a provisioning ecosystem service; compare the measured parameters with World Health Organization (WHO) drinking water standards; and evaluate the current capacity of these mountain ecosystems to sustain potable water supply.

By providing evidence-based insights, the findings of this study aim to guide policy recommendations and management strategies that will ensure the long-term provision of safe and reliable water from mountain ecosystems in Cameroon.

Material and methods

Study area

Mount Cameroon the highest uplift in West and Central Africa with a peak just about 20 km inland from the Atlantic coastline is located between 3°57'- 4°27' N and 8°58'-9°24'E (Fig. 1). It is an active volcano which lastly erupted in 2012. Climatically, the area has two seasons; the rainy and dry season. The mean annual rainfall decreases with altitude to approximately 4,000 mm at 1000 m and to less than 3,000 mm above 2,000 m (Payton, 1993). For each 100 m ascent, the average temperature drops by about 0.6°C.

The humidity is 75-85% due to the marine influence and the incidence of mist and orographic cloud formation. The Mt Fako area is characterized by a dense hydrological network with several rivers, seasonal and permanent streams, springs, lakes and waterfalls. No permanent rivers/streams are found at the upper slopes of the mountain. Most rivers and streams are found at the lower slopes at about 700m above sea level. Very few catchments are located within the forested region of the Mountain except for few brooks. (Ako *et al.*, 2012). Streams flow from some catchments and go underground thereafter they resurface some few km below the foot of the Mt as resurgent streams. Mount Manengouba is located 120km North-East of Mount Fako, between 09°42' to 10° 10'E and 4°49' to 5° 15'N, (Fig. 2). It is situated to the North-West of Nkongsamba, and the surrounding escarpments are very steep, except on the northwestern side. The largest expanse of forest, which is also denser, is found on the Southern and South-Eastern slopes, down to an altitude of 1,500m above sea level (Kagou Dongmo et al. 2005).The Manengouba massif is made up of a succession of mountains that culminate at 2.411m. There exist a crater lake at the top which is located at an altitude of 2,078m (Andre Pouclet et al., 2014). The area contains a fairly large network of watercourse, some of which flows into larger drainage beds that converge into rivers Moungo and Dibombari at the southern flank. These rivers frequently flow though seasonality affects the quality characteristics over space.

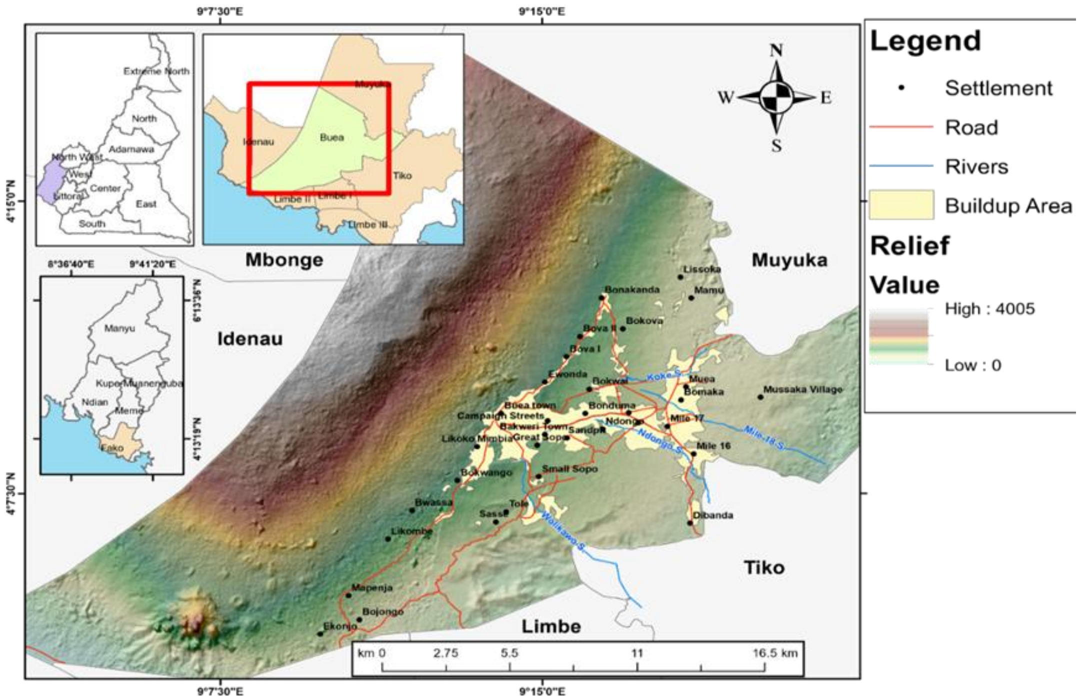


Fig. 1. Location of Mount Cameroon

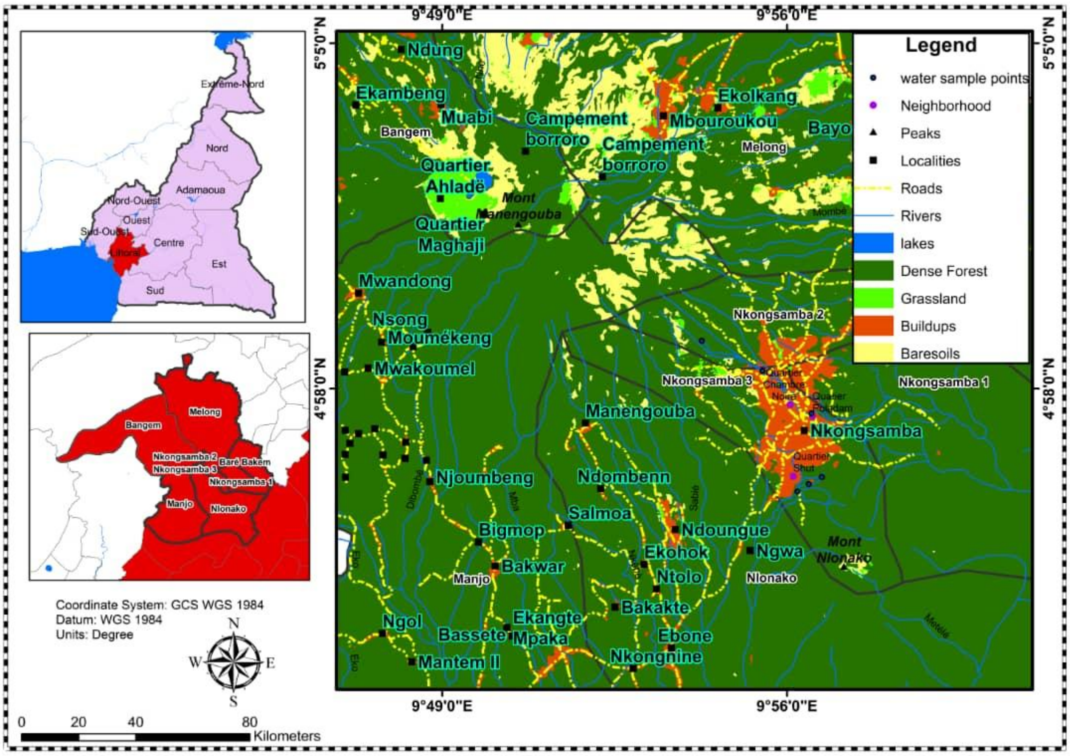


Fig. 2. Location of Mount Manengouba

Criteria for Site and Stream Selection

Mounts Cameroon and Manengouba were chosen because they are important watersheds not just for the Buea and Nkongsamba Municipalities but for other areas within the South West and Littoral Regions where most streams take their rise and flow into different communities. The criteria used for the selection of sampled sites were; proximity to human influences, population density, dependence on stream use and the flow pattern of the streams for easy monitoring. The streams selected for the study within Mt Fako were: Ndongo, Koke and Woklikawo while Shut, Chambre Noir and, Poladam were selected within Mt Manengouba region. All the streams selected flow on a permanent basis that is during both the rainy season and dry season. These streams also have the highest proximity to human influences, dense population around the streams and settlements are highly concentrated along these streams with increase dependence on the streams for domestic and agricultural uses in the area.

Collection of Water Samples

Water samples from the respective streams were collected from 3 different points: the source, at the point of encroachment of human activities and further downstream. A Global Positioning System (GPS) was used to take the location of the sampling sites. The source point acted as the control because there is little or no interference and the other two sites served as the treatments. Water samples were collected using sterilized 500 ml glass bottles rinsed with distilled water and dried thereafter. At the collection sites, these bottles were rinsed to eliminate foreign water in the containers. Each sample was coded and transported in an ice-cool container to the laboratory within 24 hours for analysis of parameters that could not be measured on the field. Four water samples were collected from each point for the 6 streams both during the rainy and dry seasons and analyzed for selected biological and physio-chemical parameters relevant to the study.

Calculation of Water Quality Index

WQI was used for the detection and evaluation of water pollution and defined as a reflection of the composite influence of different quality parameters on the overall quality of water (Horton, 1965). It is a summarization of all water quality parameters into a single value. The calculation was done based on the summarization of the parameters tested using the Horton's method as thus;

$$\mathbf{WQI = \sum q_n w_n / \sum W_n}$$

Where, qn = Quality rating of n^{th} water quality parameter.
W_n= Unit weight of n^{th} water quality parameter.
Quality rating (q_n)
The quality rating (q_n) is calculated using the expression given in
Equation (2).

$$\mathbf{q_n = [(Vn - V_{id}) / (Sn- V_{id})] \times 100}$$

Where,
V_n = Estimated value of n^{th} water quality parameter at a given sample location.
V_{id} = Ideal value for n^{th} parameter in pure water.
(V_{id} for pH = 7 and 0 for all other parameters)
S^n= Standard permissible value of n^{th} water quality parameter

Unit weight

The unit weight (W_n) is calculated using the expression given in the equation below;

$$\mathbf{W_n = k / S_n}$$

Where,
S_n = Standard permissible value of n^{th} water quality parameter.
k = Constant of proportionality and it is calculated by using the
Expression given in Equation

$$\mathbf{k = [1 / (\sum 1/ Sn=1, 2, _n)]}$$

The ranges and corresponding status of water quality and their possible uses are summarized on Table 1.

Table 1. Water Quality Index Table (Chatterji and Raziuddin, 2002)

S/N	WQI	Status	Possible Usage
1	0-25	Excellent	Drinking, Irrigation and industrial
2	25-50	Good	Domestic, Irrigation and Industrial
3	51-75	Fair	Irrigation and Industrial
4	76-100	Poor	Irrigation
5	101-150	Very poor	Restricted use for Irrigation
	Above 150	Unfit for Drinking	Proper treatment required before use

Statistical Analysis

Data collected were entered using the EpiData Version 3.1 and analyzed using the Statistical Package for Social Sciences (SPSS) Standard version, Release 21.0 (IBM Inc. 2012). One-way ANOVA and independent sample test were performed to investigate whether there are significant variations of water quality and quantity parameters tested between the various sampling points (spatial variations) and the seasons (temporal variations). This was followed by multiple comparisons to further separate significant levels if overall significant treatment differences exist. To carry out this analysis, a table showing the water quality parameters at different sampling points during both the dry and the rainy seasons was generated and verified at 0.05% level of significance. To test the difference between water parameters tested and the WHO water quality standard for drinking water, the WHO 2006 drinking water standard was used. The Standard deviation was used to compare the tested parameter and WHO Standard. The results were verified at 0.05% level of significance.

Results and discussion

Identification of human activities along stream courses

Man plays a vital role in ecosystem and land use changes and his actions will continue to have negative impacts on water quality at all scales. Water plays a great role in human development and the streams under study are used for drinking, farming and irrigation washing, cooling, car wash, construction, as well as for dump sites.

Farming and irrigation

Within these Mt regions, farming activities serve as a backup for food production for most homes. Within Wolikawo and the surrounding villages around Mt Cameroon the predominant economic activity is farming. Output from farming is mainly for subsistence though some may be channeled to the local market (Ako et al., 2012). Koke and Ndongo streams found at the center of the Buea Municipality are famous for market gardening practices (Fig.3A). Irrigation is a common practice. The farmers make use of furrow, sprinkler and manual irrigation (bucket watering) resulting to water quantity reduction.

Figure 3A. A: Market gardening along Ndongo **B:** Subsistence food crop production along Koke (4°9′8.058″ N 9°17′3.906″ E, 4°17′287″ N 9°27′847″ E)

Within Mt Manengouba, Nkongsamba is noted for both household and commercial agriculture. Farming is an important activity in the area and major crops cultivated include; plantain, banana, vegetable, tubers, maize. Chambre Noir and Poladam found at the center town of Nkongsamba are noted for market gardening (Fig. 3B). The expansion of agricultural activities along these watercourses has led to contamination from agrochemicals and organic waste, which negatively impact both water quality (Usongo et al., 2023).

Figure 3B. A: Subsistence food crop productions on both sides along Shut **B:** Vegetable cultivation along Chambre Noir

Domestic Activities

Domestic activities such as laundry, washing of dishes, bathing are common within the streams. Dirt, soap and other detergents from such activities are contagion to fresh water. According to research carried within Ndongo, Nkwelle (2010) stated that laundry constituted (13.77%) and bathing (06.09%). Even though livelihood is facilitated there is an impact on water quality and quantity. Chambra Noir and Poladam streams, at the center of the town in Nkomgsamba are noted for these domestic activities. However, the after effects of these activities are consequential to water quality and quantity parameters. Bartram and Balance (1996) reiterated that, water quality is a reflection of the chemical, physical, and biological constituents that are suspended or dissolved in the water from both natural processes and human activities.

Construction Activities

Construction activities along the streams is common in both areas and are major sources of pollution, particularly through sediment-laden runoff that affects nearby streams and lakes. These projects require large amounts of water, increasing the demand for residential areas near freshwater sources. As a result, construction impacts the quality of local water resources. The issue of sediment loading highlights the critical need for effective erosion and sediment control measures, as widely documented (Ray et al., 1992).

Dump Sites

Collection and management of solid waste is a major challenge in the study areas and streams are being used as dump sites (Fig. 4) thereby affecting water quality. The most common means of municipal solid waste disposal in these areas is by the use of landfills which are not well-constructed. Running streams and rivers have therefore become very effective and flexible method of solid and liquid waste disposal. The wastes from domestic dwellings, agricultural operations and commercial establishments are unarguably accompanied with contagion compounds which are detrimental to the portability and usability of streams. Ndongo stream within Mt Cameroon is the most disturbed stream that has witnessed blockage of some flow channels thereby creating temporary swampy conditions hampering movement of people within the neighborhood. Poldam stream within Mount Manengouba is the most disturbed stream as far as the disposal of solid and liquid waste is concern. Wastes dumped inside the stream is known to release a variety of colloidal inorganics and organic compounds thereby contaminating the water (Lone et al; 2012, Meyer et al., 2005).

Fig. 4. A: Dump site along Ndongo Mt Fako **B:** Dump sites along Poladam Mount Manaengouba

Statistical Summary of the Physico-Chemical and Biological Parameters of Water Samples within Mount Cameroon and Mount Manengouba in Compliance with WHO (2011) Drinking Water Standards

Compliance of the tested parameters and the 2011 World Health Organization (WHO) standard international norms was done and the results are presented on table 2 & 3 for Mount Manengouba and Mount Fako respectively.

Physical Parameters

Temperature

Temperature range for both seasons, varied from 20°C to 31.8°C and 20°C to 31°C within Nkongsamba and Buea respectively for all water samples collected during the sampled periods.

Nkongsamba during the dry season, temperature ranged from 20°C to 31.8°C with a mean temperature of 26.4°C and a range from 20°C to 29°C with a mean temperature of 23°C during the rainy season (Table 2) while within Buea, temperature for sampled streams during the dry season ranged from 21°C to 31°C with a mean of 25.3°C and from 20°C to 29°C with a mean of 24.3°C during the rainy period (Table 3). For both study locations, this suggest that the streams were warmer during the dry season as compared to the rainy season. These results indicate a consistent seasonal temperature shift, with higher stream temperatures during the dry period. This pattern aligns with the findings of Chapman (1996) and Boyd & Tucker (1998), who noted that reduced water volume, lower shading from riparian vegetation, and increased solar radiation during dry seasons often lead to elevated stream temperatures. Additionally, similar seasonal variations in tropical highland streams have been reported by Neba et al. (2019) in the Bamenda Highlands and Yidana et al. (2012) in Ghana, where dry season warming was linked to reduced rainfall and increased evaporation rates.

Table 2: Water Parameters tested within Mount Manengouba

Parameters	Units	Min	Max	Mean	WHO Limit	No of samples suitable for drinking	% compliance with WHO standards
Sample Number=9							
Dry season							
Temp	oC	20	31.8	26.4	30	7	77.8
pH	-	6.4	7.6	6.9	6.5 – 8.5	8	88. 9
EC	µS/cm	28	140	80.6	500	9	100
TDS	mg/L	14	60	40.1	500	9	100
Ca^{2+}	mg/L	1.8	10.3	7.2	75	9	100
Mg^{2+}	mg/L	1.3	3.5	2.8	100	9	100
k+	mg/L	15.4	35.4	22.9	12	0	0
NO_3^{2-}	mg/L	1.3	9.7	4.2	50	9	100
SO_4^{2-}	mg/L	0	20.4	2.7	250	9	100
Coliform	(count/ml)	0	250	88.7	0	3	33.3
Rainy season							
Temp	oC	20	29	23	30	9	100
pH	-	6.4	7.5	7.1	6.5 – 8.5	8	88. 9
EC	µS/cm	59	217	147.1	500	9	100
TDS	mg/L	37.7	139	94.1	500	9	100
Ca^{2+}	mg/L	5.3	39.9	19.9	75	9	100
Mg^{2+}	mg/L	1.9	4.2	2.8	100	9	100
k+	mg/L	14	37.1	23.9	12	0	0
NO_3^{2-}	mg/L	2.1	37.24	11.9	50	9	100
SO_4^{2-}	mg/L	11.4	53.8	17.5	250	9	100
Coliform	(count/ml)	0	210	92.7	0	3	33.3

From the 9 water samples tested, only two within Nkongsamba along human habitation upstream (HUS) Chambre noir (31.3°C) and human habitation downstream (HDS) of Poladam (31.8°C) during the dry season fell above the WHO standard of 30°C giving a total of 22.2% against 77.8% of the total samples for dry season while within Buea only one sample point, HDS Ndongo (31°C) fell above the WHO standard during the dry season giving a total of 11.1% against 88.9% of the total samples for dry season. All samples for other points across both study areas fell below the WHO permissible limit during the rainy season. The least temperature measurement of 20°C was observed for Chambre Noir stream in both seasons and for Koke stream during the rainy period (Fig. 5). The exceedances were all observed in streams located near dense human settlements, suggesting that anthropogenic activities such as vegetation clearance, channel modification, and waste discharge may exacerbate stream warming, as similarly observed by Ashton (2002) in South African catchments and Ngoye & Machiwa (2004) in Tanzania.

Table 3. Water parameters tested within Mount Cameroon (Buea)

Parameters	Units	Min	Max	Mean	WHO Limit	No of samples suitable for drinking	% compliance with WHO standards
Sample Number=9							
Dry season							
Temp	oC	21	31	25.3	30	8	88.9
pH	-	7.21	7.6	7.4	6.5 – 8.5	9	100
EC	µS/cm	138	309	202.3	500	9	100
TDS	mg/L	138	309	202.3	500	9	100
Ca2+	mg/L	100	260	158.7	75	0	0
Mg2+	mg/L	28	230	142.4	100	2	22.2
k+	mg/L	10	16	12.9	12	3	33.3
NO32^{-}	mg/L	14	31	22.3	50	9	100
SO42 -	mg/L	7	29	18	250	9	100
Coliform	(count/ml)	0	550	215.3	0	3	33.3
Rainy season							
Temp	oC	20	29	24.3	30	9	100
pH	-	7.25	7.67	7.4	6.5 – 8.5	9	100
EC	µS/cm	141.2	220	197.2	500	9	100
TDS	mg/L	141.2	220	197.2	500	9	100
Ca2+	mg/L	94	240	144.3	75	0	0
Mg2+	mg/L	110	190	143.3	100	0	0
k+	mg/L	9	19	14.9	12	1	11.1
NO32^{-}	mg/L	12	40	28	50	9	100
SO42 -	mg/L	7	29	21.4	250	9	100
Coliform	(count/ml)	0	3403	526.6	0	3	33.3

Power of Hydrogen (pH)

All pH value within Mount Manengouba ranged from 6.4 to 7.6 for both season whereas value of pH within Mount Cameroon ranged from 7.21 to 7.67 for both seasons (Table 2 & 3).

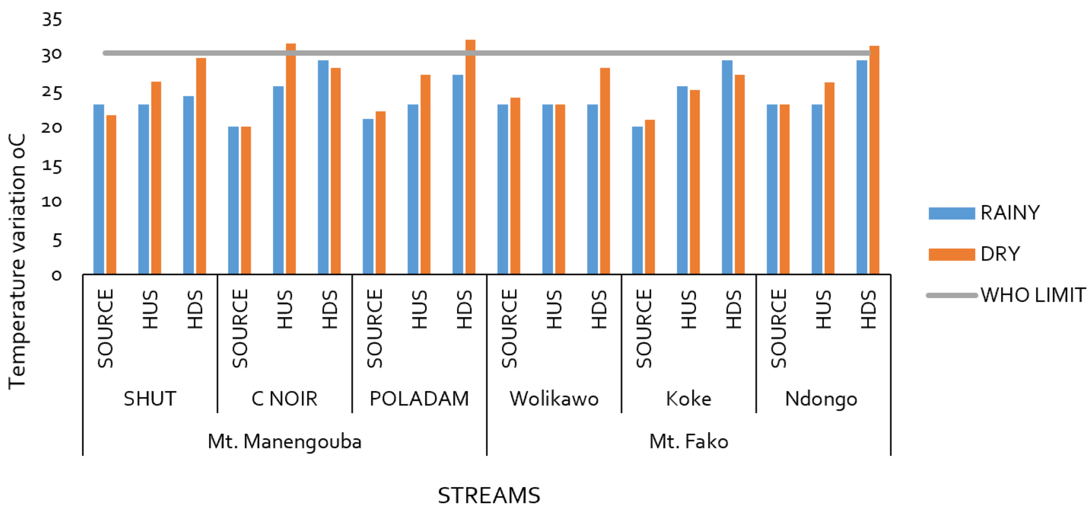


Fig. 5. Temperature variations of the stream samples

Within Nkongsamba during the dry season, pH value ranged from 6.4 to 7.6 with a mean pH of 6.9 and during the rainy season, pH value ranged from 6.4 to 7.5 with mean pH of 7.5 while for selected streams within Buea, pH values ranges from 7.21 to 7.60 and 7.25 to 7.67 with a mean pH value of 7.4 for the dry and rainy seasons respectively. Most samples across streams for both study areas registered pH values which fell within the WHO standard of 6.5 to 8.5. The lowest pH values recorded were 6.35 at HUS during the dry season and 6.4 at HDS during the rainy season, both within the Shut Stream. These values fall below the minimum pH threshold set by WHO standards. Overall, 11.1% of the total samples from Nkongsamba across both seasons were below the WHO minimum, while the remaining 88.9% met or exceeded the standard. In contrast, all water samples collected from Buea were above the WHO minimum pH requirement (Fig. 6).This therefore suggest that, pH of stream water in the study areas could be classified as suitable for drinking purposes except for these two samples at HUS and HDS of the Shut streams noted to be moderately acidic.

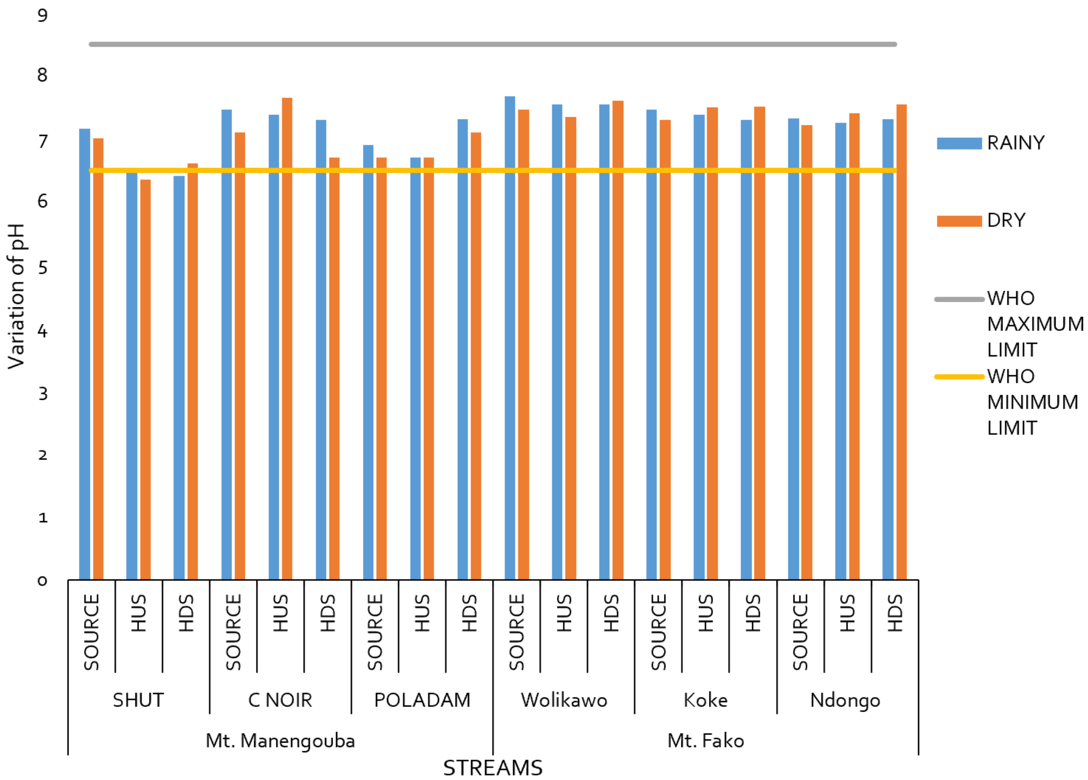


Fig. 6. pH variations of the stream samples

Electrical Conductivity (EC)

The electrical conductivity (EC) of stream water samples varied notably between Nkongsamba and Buea. In Nkongsamba, EC values ranged from 28 to 217 µS/cm across all samples collected during the study period. Specifically, EC concentrations during the dry season ranged from 28 to 140 µS/cm, with a mean of 80.6 µS/cm, while during the rainy season, values ranged from 59 to 217 µS/cm, with a mean of 147.1 µS/cm (Table 2). In contrast, EC levels in Buea stream samples were consistently higher, ranging from 138 to 309 µS/cm overall. For the dry season, EC values ranged from 138 to 309 µS/cm, with a mean of 202.3 µS/cm, and from 141.2 to 220 µS/cm during the rainy season, with a mean of 197.2 µS/cm (Table 3). On average, EC concentrations were higher in Buea than in Nkongsamba, suggesting greater human influence on water quality in that area. Nevertheless, all recorded EC values in both locations and across both seasons remained below the WHO permissible limit of 500 µS/cm (Fig. 7). This suggest acceptable salinity and ionic content for drinking purposes. However, persistently high EC in Buea—especially given its minimal seasonal variation—could signal continuous pollutant loading, as observed by Amadi et al. (2018) in peri-urban watersheds of Nigeria, where poor wastewater management sustained elevated EC year-round. If unmanaged, such conditions can alter aquatic ecosystem health and indicate emerging risks to water quality.

Total Dissolved Solid (TDS)

The concentration TDS in stream water samples varied significantly between the Mount. Manengouba and Mount. Cameroon regions. In the Mt. Manengouba area (Nkongsamba), TDS values across both dry and rainy seasons ranged from 14 to 139 mg/L, which was considerably lower than the TDS concentrations recorded in the Mt. Fako area (Buea), where values ranged from 138 to 309 mg/L (Figure 4).

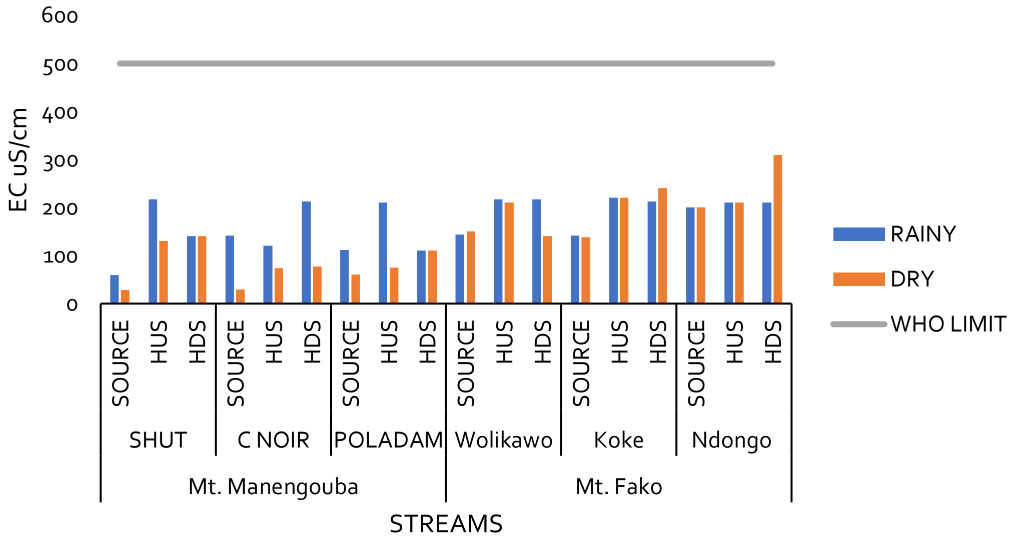


Fig. 7. EC variations of the stream samples

Specifically, during the dry season in Nkongsamba, TDS concentrations ranged from 14 to 60 mg/L, with a mean of 40.1 mg/L, while during the rainy season, values increased to between 37.7 and 139 mg/L, with a mean of 94.1 mg/L (Table 2). In contrast, Buea stream samples recorded higher TDS concentrations: 138 to 309 mg/L (mean = 202.3 mg/L) in the dry season, and 141.2 to 220 mg/L (mean = 197.2 mg/L) during the rainy season (Table 3). The relatively lower TDS values in Nkongsamba suggest limited anthropogenic influence compared to Buea, where higher TDS levels may be attributed to more intense human activities such as improper waste disposal, construction, and agricultural runoff. Similar findings were reported by Amadi et al. (2018) and Egbueri (2020), who observed that urbanized watersheds often record elevated TDS due to increased impervious surfaces and pollutant load. Seasonal increases in TDS during the rainy season, particularly in Nkongsamba, can be attributed to enhanced surface runoff transporting dissolved materials from catchment soils and human settlements into streams, a trend also noted in tropical catchments by Kakoi et al. (2016). Seasonal differences in TDS also reflect the influence of surface runoff during the rainy season, which can introduce additional dissolved solids into streams. According to water classification on the basis of TDS values by Todd (1980), all samples had values < 1000 classifying them as fresh water as none had value >1000 hence, none is classified as brackish water. However, all water samples for both seasons fell below the acceptable WHO permissible limit of 1000mg/L (Fig. 8).

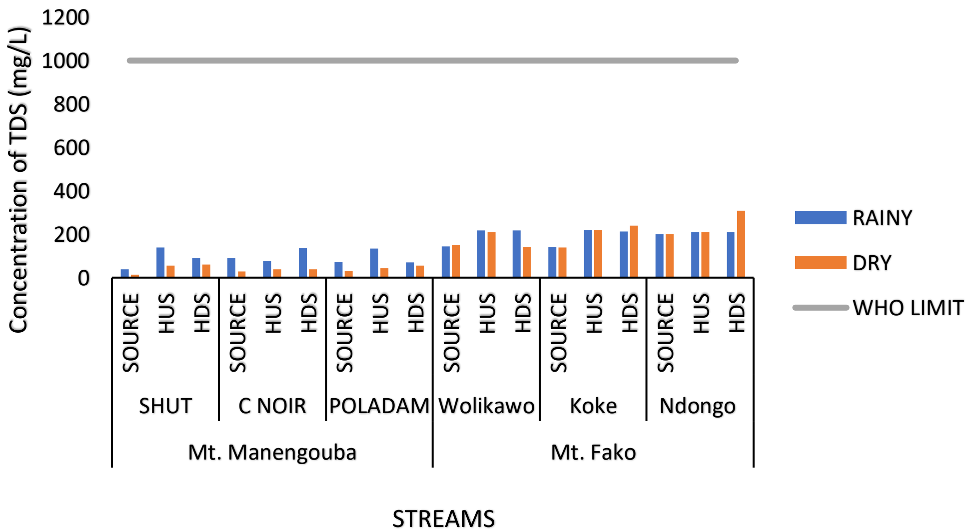


Fig. 8. TDS Variations of the Stream Samples

Variation in the concentrations (mg/L) of Major ions

Calcium (Ca^{2+})

The Ca^{2+} in water samples exhibited considerable variation between Nkongsamba (Mount. Manengouba) and Buea (Mount. Cameroon). Within Nkongsamba, Ca^{2+} levels ranged from 1.8 to 39.9 mg/L across the sampling periods, while in Buea, concentrations were significantly higher, ranging from 94 to 260 mg/L (Tables 2 & 3). Notably, all Ca^{2+} concentrations recorded within Mount. Fako exceeded the World Health Organization's (WHO, 2011) acceptable limit of 75 mg/L for drinking water (Fig. 9). This elevated calcium concentration may be attributed to intensified anthropogenic activities such as urban runoff, industrial discharge, and extensive construction, which are known to increase mineral loads in surface waters (Smith et al., 2018). Conversely, all water samples collected within Mount. Manengouba fell below the WHO permissible limit, suggesting relatively lower levels of human disturbance and better water quality with respect to calcium content. High calcium levels not only affect potability but can complicate water supply and treatment processes (Jones & Lee, 2015).

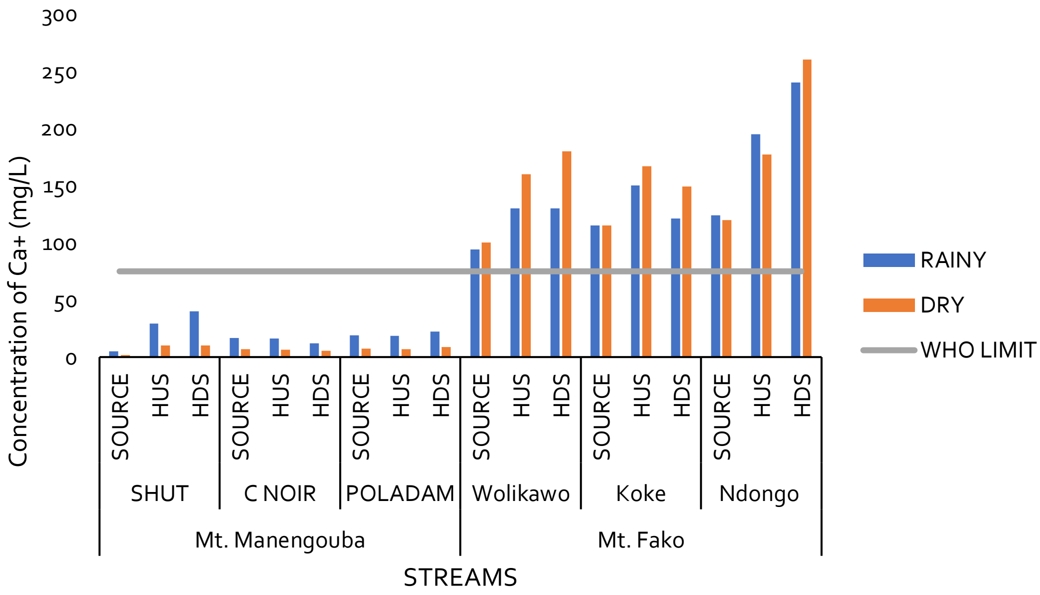


Fig. 9. Variation of calcium ions in the samples

Magnesium (Mg^{2+})

The concentration of magnesium (Mg^{2+}) in stream water samples collected from Nkongsamba during both the dry and rainy seasons ranged from 1.3 to 4.2 mg/L. Specifically, during the dry season, Mg^{2+} concentrations varied between 1.3 mg/L and 3.5 mg/L, with a mean value of 2.8 mg/L. In the rainy season, values ranged from 1.9 to 4.2 mg/L, also with a mean of 2.8 mg/L (Table 2). All Mg^{2+} concentrations recorded in Nkongsamba fell well within the World Health Organization's (WHO, 2011) permissible limit of 100 mg/L for drinking water (Fig. 10). These low levels are consistent with observations in other tropical highland watersheds dominated by silicate bedrock and low agricultural chemical inputs (Akoto et al.,). Seasonal variation was minimal, suggesting that runoff during the rainy season did not significantly alter Mg^{2+} loading in these streams.

In contrast, the Buea study area exhibited significantly higher Mg^{2+} concentrations. Stream samples from Buea recorded Mg^{2+} levels ranging from 28 to 230 mg/L across both seasons (Table 3). During the dry season, concentrations varied between 28 mg/L and 230 mg/L, with a mean of 142.4 mg/L. Only two sampling points—Wolikawo (28 mg/L) and Koke (32 mg/L)—fell within the WHO limit, accounting for just 22.2% of the total samples. The remaining 77.8% exceeded the permissible threshold (Figure 6). In the rainy season, all nine sampling points recorded Mg^{2+} concentrations above the WHO guideline, ranging from 110 to 190 mg/L, with an average value of 143.3 mg/L. Similar findings have been reported in volcanic terrains in East Africa (Nyenje et al., 2010) and in urbanized tropical watersheds (Amadi et al., 2018), where human activities amplify natural geochemical contributions.

Potassium (K^{+})

Measurements of potassium (K^{+}) concentrations in Nkongsamba showed values ranging from 14 to 37.1 mg/L across all water samples collected during both the dry and rainy seasons (Table 2). During the dry season, K^{+} levels varied from 15.4 to 35.4 mg/L, with a mean concentration of 22.91 mg/L.

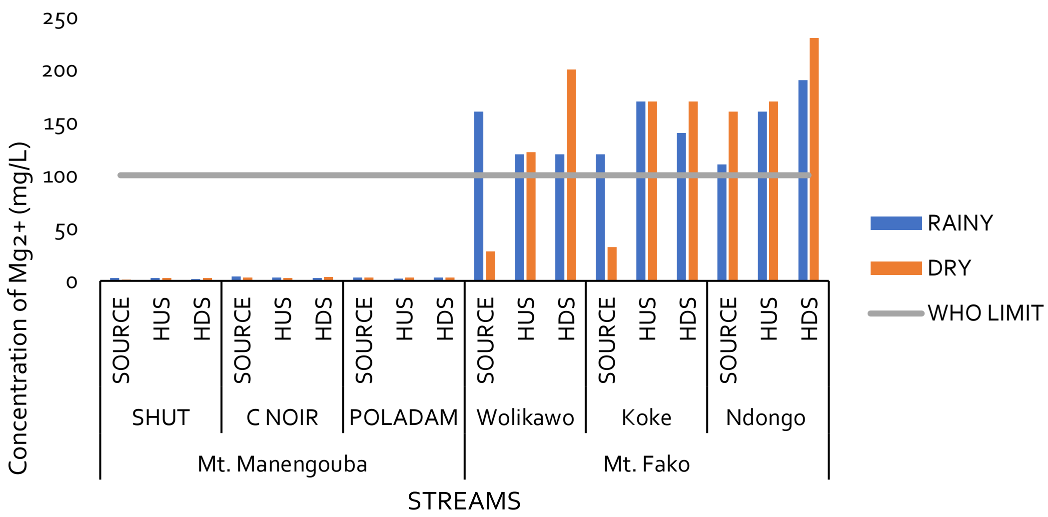


Fig. 10. Variation of magnesium ions in the sample

In the rainy season, concentrations ranged from 14 to 37.1 mg/L, with a slightly higher mean of 23.9 mg/L. Overall, all samples from Nkongsamba exceeded the WHO (2011) recommended guideline of 12 mg/L for potassium in drinking water.In contrast, potassium concentrations in Buea ranged from 9 to 19 mg/L for both seasons (Table 3). During the dry season, K^+ concentrations ranged from 10 to 16 mg/L, with a mean value of 12.9 mg/L. Approximately 33.3% of these samples fell within the WHO permissible limit, while 66.7% exceeded it. During the rainy season, concentrations ranged from 9 to 19 mg/L, with only 11.1% of samples within the WHO guideline and 88.9% exceeding it (Fig, 11).

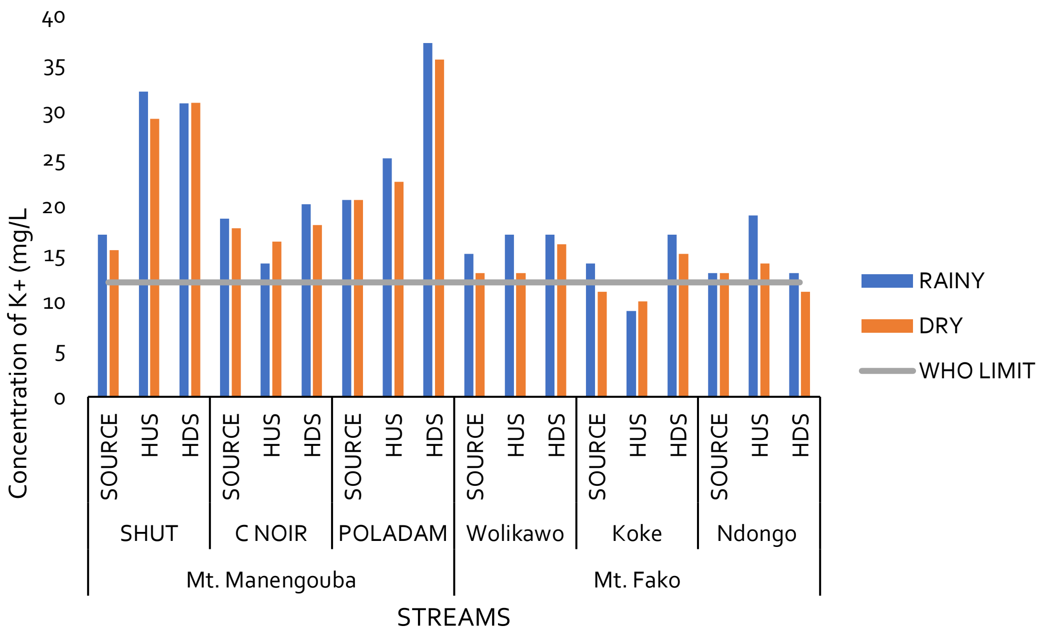


Fig. 11. Variation of potassium ions in the samples

Nitrate (NO_3)

The concentration of nitrate (NO_3^-) in water samples from Nkongsamba ranged from 1.3 to 37.2 mg/L across both the dry and rainy seasons. In comparison, water samples from Buea exhibited higher concentrations, ranging from 12 to 40 mg/L during the same sampling periods (Table 2 & 3). All recorded values in both locations remained below the WHO (2011) maximum permissible limit of 50 mg/L for nitrate in drinking water (Fig. 12). Despite all values being within acceptable limits, the data indicate that nitrate concentrations in Buea were generally higher than those in Nkongsamba across both seasons. This difference may be attributed to more intensive agricultural activities, increased application of nitrogen-based fertilizers, or higher levels of organic waste infiltration in Buea's catchment areas.

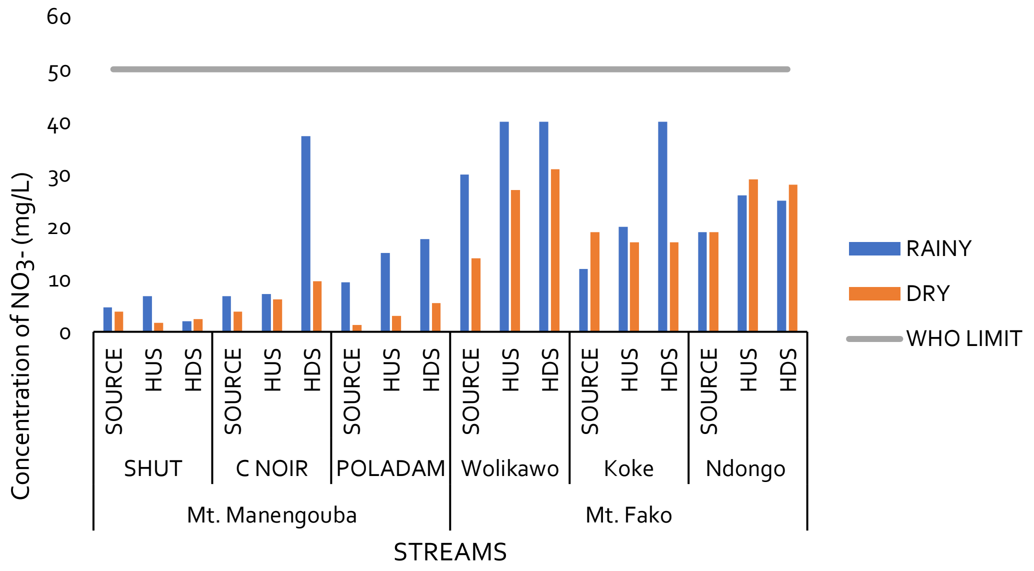


Fig. 12. Variation of nitrate ions in the samples

Sulphate (SO_4^{2-})

In Nkongsamba, the concentration of sulfate ions (SO_4^{2-}) in the water samples ranged from 0 to 53.8 mg/L during the sampling period (Table 2). The highest concentration was recorded at HDS within Shut during the rainy season, while Chambre Noir and Poladam streams exhibited no detectable SO_4^{2-} levels at any of the three sampling points during the dry season (Fig. 13). All recorded values were significantly below the World Health Organization (WHO, 2011) permissible limit of 250 mg/L. In comparison, SO_4^{2-} concentrations in Buea ranged from 7 to 29 mg/L across both the dry and rainy seasons, also remaining well below the WHO recommended threshold (Fig. 13). The observed increase in SO_4^{2-} concentrations from source to downstream points within both areas can be attributed to the region's rugged topography, which facilitates runoff, as well as inputs from domestic and chemical waste sources.

The relatively low sulfate concentrations in both regions are consistent with findings from similar tropical highland watersheds, where SO_4^{2-} levels typically remain low in less industrialized areas but may increase downstream due to anthropogenic inputs such as domestic wastewater, detergents, agricultural fertilizers, and atmospheric deposition (Howard et al., 2003; Rango et al., 2010). The slight increase in SO_4^{2-} from source to downstream sampling points in both Nkongsamba and Buea likely reflects cumulative contributions from surface runoff, erosion, and waste discharges, which are influenced by the steep topography of these mountain catchments.

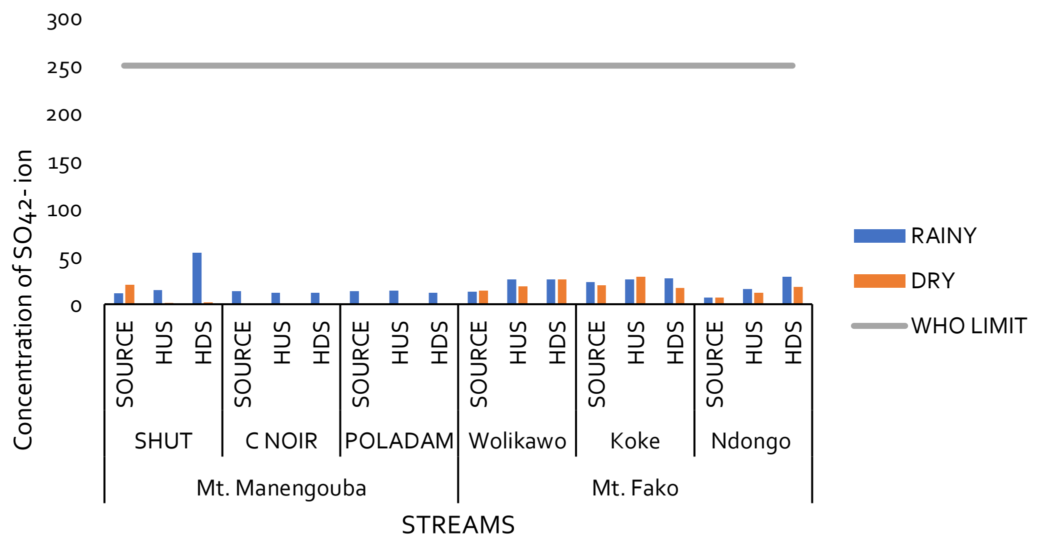


Fig. 13. Variation of sulphate ions in the samples

Microbial Analysis

The stream water samples were analyzed for total coliforms, and the results are shown on Figure 10. In Nkongsamba, coliform counts showed a progressive increase from the source downstream during both seasons. During the dry season, counts ranged from 0 to 250 cfu/mL with a mean of

88.7 cfu/mL, whereas in the rainy season, they ranged from 0 to 210 cfu/mL with a slightly higher mean of 92.7 cfu/mL (Table 2).In Buea, coliform contamination was more pronounced, especially at HUS, where concentrations peaked. During the dry season, values ranged from 0 to 550 cfu/mL with a mean of 215.3 cfu/mL, while the rainy season recorded values from 0 to 3,403 cfu/mL, with a significantly elevated mean of 526.6 cfu/mL (Table 3). The results revealed a consistent increase in contamination levels as the streams flowed from their source points through HUS to HDS locations across all sampled streams, in both study areas and during both seasons (Fig. 14). Notably, source points generally recorded the lowest counts in both areas. Across both study areas, 33.3% of the samples tested negative for total coliforms, while 66.7% tested positive, indicating widespread microbial contamination raising serious concerns about water quality and public health. The results indicate that coliform contamination is more severe in Buea than in Nkongsamba, with Buea registering both higher maximum values and mean counts across seasons. The elevated counts, particularly during the rainy season, suggest that surface runoff and poor sanitation infrastructure may be major contributing factors, especially in areas like HUS. According to WHO guidelines, drinking water should contain no detectable coliforms per 100 mL, indicating that the majority of these samples do not meet safe water standards.

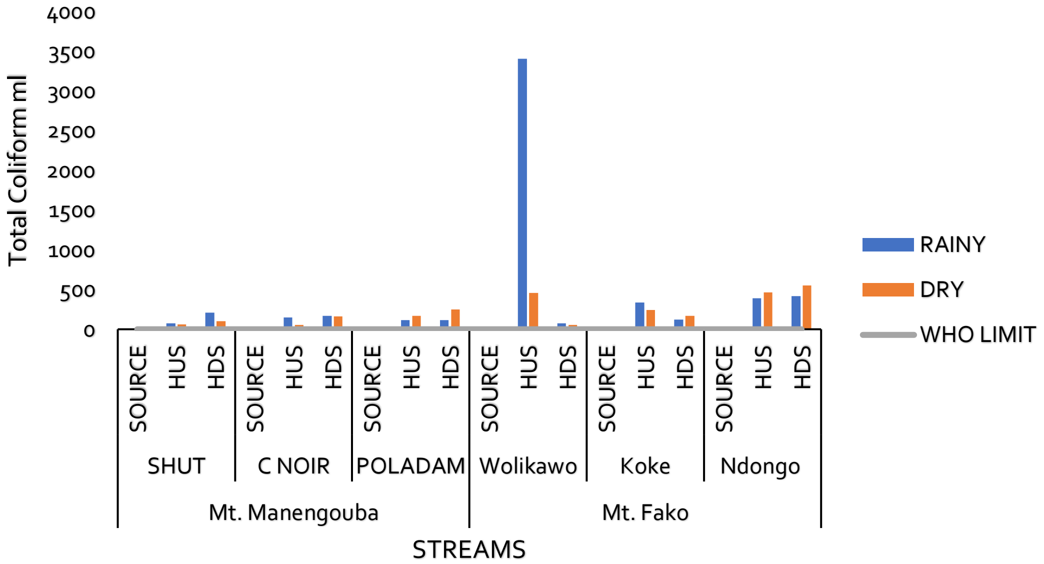


Fig. 14. Total coliform variation in the samples

Water Quality Index

Water quality index assessment was done to determine the suitability of water for an intended use. This assessment was done based on the summarization of the physio-chemical and biological parameters tested, and employed to assess the suitability nature in terms of potability and deterioration for each sampling point across all selected streams for the study. Suitability for drinking was drawn based on the score generated from the calculation ranging between 0 and 100. The lower the score the suitable the water is for drinking. From the calculations therefore, the following results indicated for each point within the Nkongsamba sampled streams that, all sample points were not suitable for direct consumption if not properly treated taking into consideration the Standard Permissible values. While most points of the sampled streams within Buea especially at the HUS and HDS are completely unsuitable for human consumption/drinking with values far above the Standard permissible values (Table 4&5) respectively.

From the results presented, WQI assessment showed significant changes in states from the source points in Shut, Chambre Noir and Poladam streams within Nkongsamba and in Wolikawo, Koke and Ndongo streams within Buea during the dry and rainy seasons. Progressive rise in the calculated WQI values from the source indicate alterations in water quality parameters as water flows through areas of human habitations up and down streams widely attributed to increase human interactions along these streams.). These findings are consistent with the work of Pesce and Wunderlin (2000), who observed significantly degraded WQI values in catchments experiencing rapid urbanization and intensive land use.

As illustrated in Fig. 15, the Water Quality Index (WQI) projections for all sampled streams in Nkongsamba during both the dry and rainy seasons reveal varying levels of water quality. During the dry season, only Chambre Noir exhibited *good* water quality, with a WQI of 49.42—falling within the 25–50 range. In contrast, Shut and Poladam streams recorded WQI values between 51 and 75, classifying them as having *fair* water quality. Although not immediately hazardous, water from these streams could pose health risks if consumed without treatment. At HUS and HDS, WQI values during the dry season ranged from 63 to 100, indicating *poor* to *very poor* water quality.

Table 4. Water Quality Index (WQI) values for all sampling sites along selected streams within Mt. Manengouba

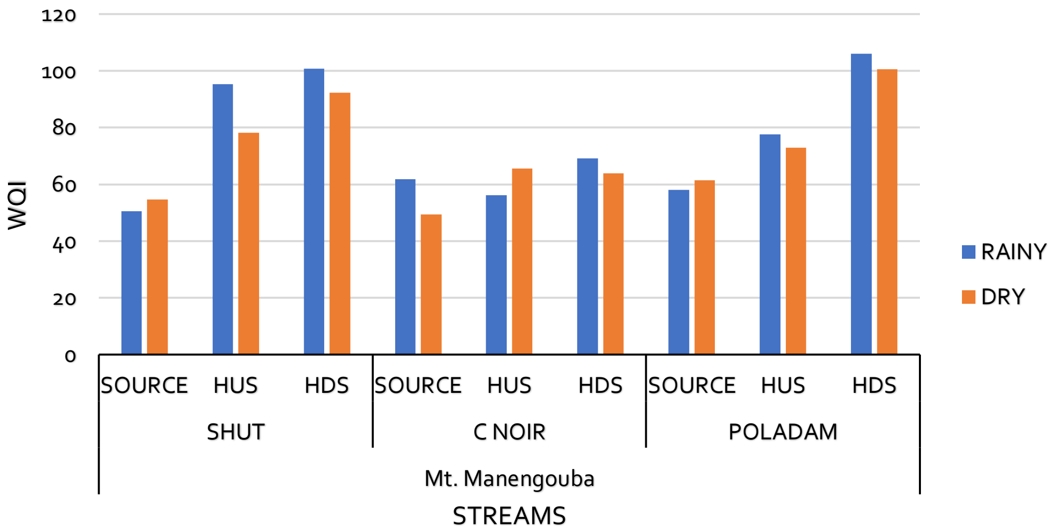
Mt. Manengouba (Nkongsamba)				
Stream	Season	Sampling Point	WQI	Status
Shut	Dry Season	Source	54.623047	Fair
		HUS	78.146486	Poor
		HDS	92.33466641	Very Poor
	Rainy Season	Source	50.56429412	Fair
		HUS	95.34513409	Poor
		HDS	100.7749756	Very Poor
Chambre Noir	Dry Season	Source	49.41615613	Good
		HUS	65.66293522	Fair
		HDS	63.78711793	Fair
	Rainy Season	Source	61.80257155	Fair
		HUS	56.18543241	Fair
		HDS	69.20863218	Fair
Poladam	Dry Season	Source	61.46001126	Fair
		HUS	72.82424374	Poor
		HDS	100.5661894	Very poor
	Rainy Season	Source	58.12098654	Fair
		HUS	77.55027664	Poor
		HDS	105.955752	Very poor

Table 5. Water Quality Index (WQI) values for all sampling sites along selected streams within Mount Cameroon

Mount Cameroon (Buea)				
Stream	**Season**	**Sampling Point**	**WQI**	**Status**
Wolikawo	Dry Season	Source	99	Very poor
		HUS	45985051	Unsuitable for drinking
		HDS	5198310	Unsuitable for drinking
	Rainy Season	Source	100.005151	Very poor
		HUS	340189412	Unsuitable for drinking
		HDS	7697497	Unsuitable for drinking
Koke	Dry Season	Source	99.9924118	Very poor
		HUS	23992200	Unsuitable for drinking
		HDS	16994475	Unsuitable for drinking
	Rainy Season	Source	99.997689	Very poor
		HUS	33289178	Unsuitable for drinking
		HDS	11996100	Unsuitable for drinking
Ndongo	Dry Season	Source	99.9933392	Very poor
		HUS	46584856	Unsuitable for drinking
		HDS	54982126	Unsuitable for drinking
	Rainy Season	Source	99	Very poor
		HUS	389	Unsuitable for drinking
		HDS	41586481	Unsuitable for drinking

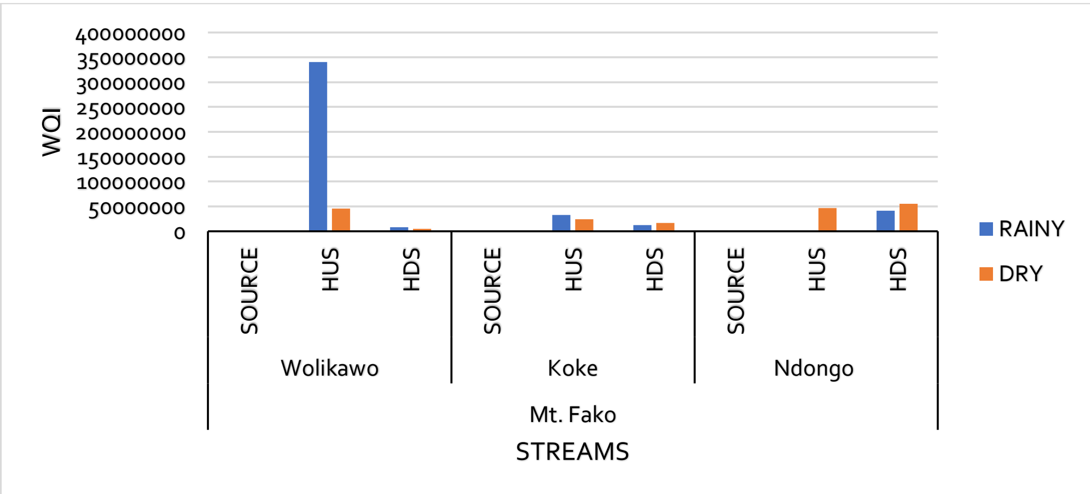
Water from these locations is considered unsafe for drinking or domestic use without adequate treatment. A similar pattern was observed in the rainy season. WQI values ranged from 50 to 61 at the source points, 56 to 95 at HUS, and 69 to 105 at HDS. These figures reflect a decline in water quality as streams progress from the source through areas of greater human activity, with HDS consistently showing the worst quality. The rainy season further exacerbated contamination levels, likely due to increased runoff from surrounding settlements and farmlands. Overall, the findings highlight the impact of anthropogenic factors on water quality and underscore the need for improved waste management and water treatment practices.

Assessment of WQI for the sampled streams within the Buea study area revealed extremely elevated values at all sampling points—source, HUS and HDS—across both the dry and rainy seasons (Table 4). During the dry season, WQI values ranged from 99 to an exceptionally high 54,982,126, while during the rainy season, values ranged from 99 to 340,189,412 (Fig. 16). These excessively high readings indicate severe water quality degradation, rendering the water unsafe for both drinking and domestic use without significant treatment.



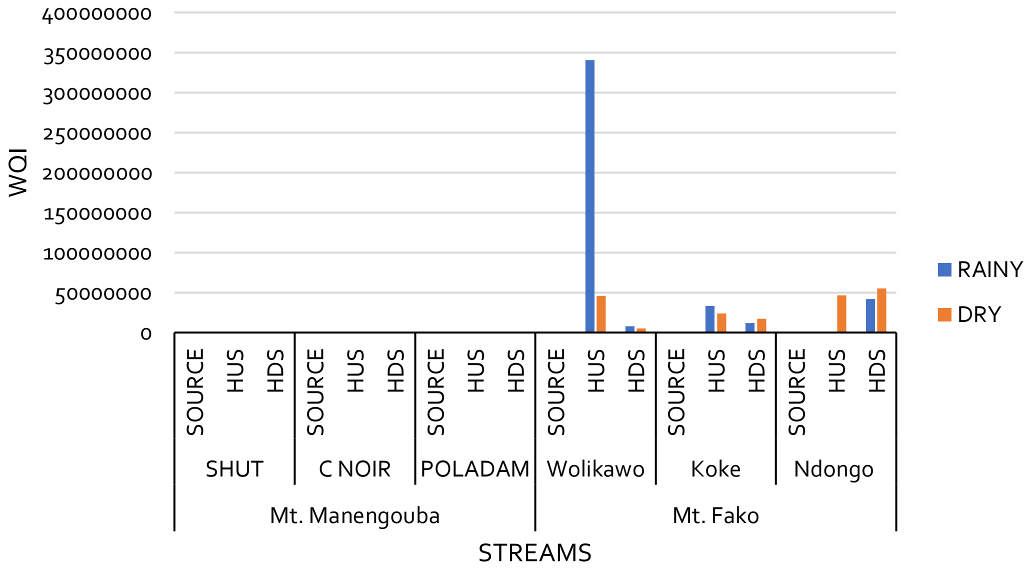
Source point; Human Habitation Upstream (HUS); Human Habitation Downstream (HDS)
Fig. 15. Water Quality Index Projections for Shut, Chambre noir and Poladam during the dry and rainy season within Nkongsamba.

In both seasons, a progressive increase in WQI values was observed along the stream flow—from the relatively less contaminated source points to the more polluted HUS and HDS. This trend strongly correlates with **intensified human activities** along the stream course, including improper waste disposal, open defecation, agricultural runoff, and informal settlements lacking adequate sanitation infrastructure. The extreme WQI values suggest a **critical level of pollution,** highlighting the urgent need for **interventions in water resource management**, environmental sanitation, and public health awareness in the Buea region.



Source point; Human Habitation Upstream (HUS); Human Habitation Downstream (HDS)
Fig. 16. Water Quality Index Projections for Wolikawo, Koke and Ndongo during the dry and rainy season within Buea

Overall, the WQI values recorded at all sampling points during both the dry and rainy seasons across the study areas indicate poor water quality, rendering the water unsuitable for drinking and potentially harmful to human health. The continuous degradation and contamination of these water channels can be attributed to various anthropogenic activities such as agricultural and industrial operations, indiscriminate dumping of municipal waste, bathing, and laundry along the streams. These practices have significantly compromised water quality, particularly at the HUS and HDS points, where the water was found to be especially unfit for consumption and other domestic uses. Observations from the results presented in Fig. 17 further reveal that contamination and degradation of water quality were more severe in the sampled streams within Buea compared to those in Nkongsamba. This disparity is likely due to higher levels of human interaction along the streams in Buea, especially around upstream and downstream areas near densely populated settlements.



Source point; Human Habitation Upstream (HUS); Human Habitation Downstream (HDS)

Fig. 17. Water Quality Index Projections within the different study sites during the rainy and dry season within Nkogsamba

Conclusions and Recommendations

This study assessed the impact of human activities on water quality within the Mount Kupe and Mount Cameroon regions, revealing substantial anthropogenic pressure on local ecosystem services. In both areas, declining water quality was closely associated with activities such as agriculture, irrigation, quarrying, vehicle washing, indiscriminate waste disposal, and direct abstraction of water resources. These practices have disrupted the ecological integrity of the watersheds and compromised the availability of safe drinking water. Several water quality parameters—including electrical conductivity, total dissolved solids (TDS), calcium, nitrate, sulfate, and bicarbonate (notably in Mount Manengouba), as well as temperature, calcium, and magnesium (in Mount Cameroon)—exhibited significant spatial or temporal variation. Importantly, most water quality parameters across both sites failed to meet WHO (2011) standards, and WQI assessments classified the majority of streams as unsuitable for direct human consumption without adequate treatment. To address these challenges and strengthen water security in Mount Manengouba and Mount Cameroon, the following integrated recommendations are proposed: strengthen legal and institutional frameworks; develop and enforce policies that protect water catchment areas from degradation and unsustainable exploitation; promote community-based watershed management and enhance water treatment infrastructure.

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