Physico-Chemical Contamination of Water Resources in Fako Division, South West Region, Cameroon

Abstract

Urban water resources have been under increasing threat of pollution in recent years due to increasing population growth and improper management of vast amounts of waste generated by various human activities. Water resources in the Fako Division which are major sources of drinking and domestic water are now major receptacles of untreated and partially treated industrial wastes. The study aims at investigating the physico-chemical contamination of water resources in the municipalities of Buea, Tiko and Limbe within the Fako Division. To understand and interpret the nexus, twenty water samples were collected from different sources as follows: three (3) streams, one (1) community water, five (5) springs, four (4) boreholes and seven (7) wells and analyzed. The Water quality parameters examined were physical parameters: Water Temperature (T^o), Electrical Conductivity (EC), Potential Hydrogen (pH), Total Dissolved Solids (TDS) and Salinity, Chemical parameters; major cations included sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and major anions included chloride (Cl^-), bicarbonate (HCO_3^-), sulphate (SO_4^{2-}), nitrate (NO_3^-) and fluoride (F^-). Major ions were determined using ion chromatography and alkalinity by titration. Results revealed that fifteen of the water samples recorded high levels of Nitrate concentrations during the rainy season while in the dry season 12 samples registered high levels above WHO standards. Results revealed that the levels of nitrates in the rainy season were higher than in the dry season. High concentrations of nitrates in water samples in Fako are a result of waste from septic tanks, indiscriminate waste disposal and agricultural practices with the intensive use of fertilizers and pesticides. Some of the wastes are washed off by runoff during the rainy season into surface water bodies while some infiltrate through the porous scoriaceous sub-soils into the water table polluting groundwater resources with excess nitrates. The study, therefore, recommends systematic waste management strategies, proper town planning measures. There should be operational monitoring of the domestic water system and the implementation of systematic water quality management and integrated water strategies.

Comment [HUR1]: It would be necessary to explain under what mechanisms it is maintained that the high concentrations of nitrates are the result of the waste from the septic tanks and the indiscriminate disposal of waste.

Keywords: contaminants, human health, municipal wastes, water quality

Introduction

Water quality has been deteriorating due to rapid population growth, industrialization, contamination of freshwater from household effluents, municipal waste and agricultural practices. As a result of water resources contamination from domestic and industrial effluents, many cities are facing an increase in organic and nutrient material in drinking water (Ray *et al*., 2006). Drinking water quality standards, particularly for issues concerning bacteria, are reported to be higher for surface water (WHO, 2004). Although the issue of the quality of drinking water has been taken up as a concern in the developed world, it remains under-explored in developing countries. In Africa, where the most common type of sanitation is the pit latrines, this poses a great risk to the microbial quality of water resources. A septic tank can introduce bacteria to water that seeps into the ground and eventually ends up in the water table where it can be drawn from boreholes and wells. Poor sanitary completion of boreholes and wells may lead to contamination of groundwater and proximity of some to solid waste dumpsites and animal droppings being littered around them (Bello *et al*., 2013) could also contaminate the quality of ground and surface water. The major factors affecting the microbiological quality of surface water are discharges from sewage works, runoff from informal settlements and indiscriminate dumping of waste around or close to water sources.

The South West Coast of Cameroon is characterized by rich volcanic soils and numerous watersheds from where streams and rivers take their rise. The growing population and their increase in water demand have reduced the availability of water alongside other factors such

as poor or no city planning in some towns in the world (UNEP, 2010). This situation does not differ from the four main towns of Buea, Tiko, Mutengene and Limbe in the South West Region in Cameroon. These towns are faced with high rivalry for available freshwater between the sectors such as industry, municipal water and agriculture.

Human activities can also alter the natural composition of water through the disposal or dissemination of chemicals and microbial matter on the land surface, into soils and the water bodies, or through injection of wastes directly into water bodies. Industrial discharges, urban activities, agriculture, groundwater plumage and disposal of municipal waste can affect water quality affecting its portability. Safe drinking water (potable) is a basic human right and prerequisite for a healthy life. In many parts of the world potable water has become limited and it is in scarcity. It is being predicted that it will become even more limiting due to increased population, urbanization and climate change (Jackson *et al*., 2001).

Drinking water quality is paramount for public health. Despite improvements in recent decades, access to good quality drinking water remains a critical issue. The World Health Organization estimates that almost 10% of the population in the world do not have access to improved drinking water sources (WHO, 2004) and one of the United Nations Sustainable Development Goals is to ensure universal access to water and sanitation by 2030 (United Nations, 2021). The key to sustainable water resources is to ensure that the quality of water resources is suitable for their intended uses, while at the same time allowing them to be used and developed to a certain extent. In Cameroon as of 2006, 70% of the population had access to safe drinking water and a supply coverage of 88% in urban areas and 47% in rural areas (Ako *et al.*, 2010). Water quality monitoring and testing is of paramount importance both in the developed and developing world (Nash and McCall, 1994).

Study Area and Methodology

Fako Division is in the South West Region of Cameroon and it is located between latitudes 4°4′ and 4°2′ North of the Equator and longitudes 8°7′ and 9°25′ East of the Greenwich Meridian (Figure 1). It is situated at the foot of Mount Cameroon, along the Bimbia River at the Gulf of Guinea. Fako Division is bounded to the North by Meme Division, to the West by Ndian Division, to the East by the Littoral Region and to the South by the Atlantic Ocean. It is made up of five Sub-Division, Muyuka, Buea, Tiko, Limbe and Idenau. The study is limited to the four main towns of Buea, Tiko, Mutengene and Limbe. Fako Division has a total surface area of 2060 km^2.

Figure 1: Location of the Study Area
Source: Administrative Limits of Cameroon (NIC, 2020)

Methodology

Measurement of Physico-Chemical and Microbial Parameters

A total of 20 water samples were collected within the study area during the sampling periods from different sources as follows; 3 streams, 1 community water, 5 springs, 4 boreholes and 7 wells. The boreholes, springs and community water serve as the major sources of water for drinking and domestic use for the population. A random sampling of settlements, built-up areas and dumpsite close to groundwater and surface water sources was done to determine the community's perception of ground and surface water contamination. This was done through data collection by both qualitative and quantitative methods. Data collection in the field involved the collection of water samples using plastic bottles of 0.5L, a cooler, taking of in situ parameters using an electrical conductivity meter, thermometer and potential hydrogen (pH) meter, observation, structured interviews and questionnaires. Four water samples each were collected from the randomly selected water sources in the different locations in the study areas, one sample for microbial analysis, one for alkalinity and the other two for chemical analysis (anions and cations). The water samples were taken to the laboratories for microbial and chemical analysis. The microbial analysis was carried out in the Microbiology

Comment [HUR2]: From the observations, structured interviews and questionnaires, not a single result is presented.

Comment [HUR3]: Nothing is mentioned in the results about microbial analysis. It is only taken up as part of the conclusion.
These are very important parameters in the degree of contamination of water resources.

Laboratory at the University of Buea while the chemical analyses were done at the Institute of Geological and Mining Research (IRGM) at Nkolbisson.

Measurement of In Situ Parameters

Water Temperature (T^{o}), Electrical Conductivity (EC), Potential Hydrogen (pH), Total Dissolved Solids (TDS) and Salinity were measured in the field at each sampling point before sample collection. The physical parameters were measured in-situ due to their unstable nature to avoid unpredictable changes in characteristics as per standard procedures (APHA, 1998). The in-situ parameters were measured using a five (5) In one (1) TDS/EC/ PH/Salinity/Temperature Meter Digital Water Quality Monitor Tester EZ-9909 instrument. The sampling procedure was carried out as described by IAEA, (2006). Water was drawn from the open wells using buckets tied with ropes, while hand pump wells and boreholes were pumped for 5-15mins before sampling to ensure the heterogeneity of the water. Surface water samples from rivers were collected by immersing the sampling bottles to a depth of about 30cm in the middle of the river channels where there was an active, but not turbulent flow, while springs were sampled at oozing points.

The water to be sampled was collected using a jar (collector) at each sampling point. The jar was first rinsed thoroughly with distilled water and the water was to be sampled at each point. The instrument was also thoroughly rinsed with distilled water and the water was to be sampled and then immersed into the collector and the readings of the different parameters recorded. The sample bottles were rinsed with distilled water and water from the collector which was to be sampled. The sampled water was filtered with a 0.45 micro filter and filled into two new 50ml and two 100ml capacity plastic bottles. The four samples were used for the analysis of microbial, anions, cations and alkalinity. Drops of nitric acid (HNO_3^-) were added to the set of bottles (100ml) that contained water samples for major cations (Na^+, K^+, C^{2+} and Mg^{2+}) and trace element analyses and the other bottle was filled with a water sample that was used for determining alkalinity (HCO3-). The two 50ml bottles that contained no nitric acid was filled with water samples for major anions (Cl-, SO42- and NO3-) and the other for microbial analysis. The bottles were labelled properly that is, sample name, number, location and date of sample collection, coked air-tight using cello tape to seal the mouth to avoid evaporation and immediately place in the cooler containing ice blocks to maintain a suitable temperature of 4°C. The procedure was repeated for all the water samples.

The first set of bottles contained water samples for major cations (Na^+, K^+, Mg^{2+} and Ca^{2+},) into which nitric acid was introduced to fix the cations so that they should remain in their stable state before the analyses. The second set of bottles that contained no nitric acid was filled with water samples for major anions (F^-, Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-) and alkalinity analyses and the third was for microbial analyses which were well cocked and taken to the laboratory within 24 hours from the time of collection for microbial to avoid bacteria multiplication in the water samples. The maximum time for chemical analysis is 48 hours during which it may be preserved in the refrigerator at 4°c before transportation. The analysis for the presence of total coliforms (*E. coli)* (bacterial indicator for faecal contamination) was carried out using the Violet Red Bile Lactose (VRBL) Agar (ISO), a selective medium for the isolation and enumeration of coliforms in environmental samples. The analysis was carried out in the Microbiology Laboratory at the University of Buea. Chemical analysis was done at the Institute of Geological and Mining Research (IRGM) at Nkolbisson, Yaounde.

Chemical Analysis

The water samples from the field were kept in the refrigerator at a suitable temperature of 4°C and transported in a cooler with ice to the Institute of Geological and Mining Research Laboratory at Nkolbisson in Yaounde for analysis. Chemical analysis of the water samples was carried out on major ions (cations and anions). Analyses for major ions included sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) chloride (Cl^-), bicarbonate (HCO3), sulphate (SO_4^{2-}), nitrate (NO_3^-) and fluoride (F^-). Major cations (Na^+, K^+, Mg^{2+} and Ca^{2+}) and major anions (F^-, Cl^-, SO_4^{2}, HCO_3^-, NO_3^-) were all analysed by ion chromatography (IC) (Small *et al*.,1975).

Comment [HUR4]: This is redundant or I just leave "Analyses for major ions included sodium (Na+), potassium (K+), calcium (Ca2+), magnesium (Mg2+) chloride (Cl-), bicarbonate (HCO3), sulphate (SO42-), nitrate (NO3-) and fluoride (F-)".
Or I leave the following "Major cations (Na+, K+, Mg2+ and Ca2+) and major anions (F-, Cl-, SO42, HCO3-, NO3-)". The fact that the two appear does not contribute anything to the work, later on he repeats it again.

IC is nowadays one of the most important methods for the determination of alkaline, alkaline earth and some transition metals as well as inorganic anions in water matrix, is most often used for the analysis of anions for which there are no other rapid analytical methods (Coulibaly & Paull, 2001; Small, 2004). IC offers an easy, fast, small sample volume demanding and fit-for-purpose methodology for the determination of routine ions in water samples, in a large dynamic range (Cickarik *et al.*, 2005). Major cations (Na^+, K^+, Mg^{2+} and Ca^{2+}) were determined with non-suppressed ion chromatography (DIONEX, ICS-900) and major anions (F^-, Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-) were analysed using a suppressed ion chromatography (DIONEX, ICS-1100).

The identity of the cations and anions was determined by their retention times. The concentration of the cations and anions were determined by preparing a calibration curve from a standard solution containing known concentrations of all the ions of interest. Before samples were introduced into the IC, some pre-treatments such as dilution and filtration were carried out. All samples were filtered using a 0.2µm cellulose filter. This was to avoid the blockage of the IC analytical column. Before analyses, samples with electrical conductivity (EC) values greater than 200, between 100-199, and less than 100 were diluted 10, 5, and zero times, respectively. The dilution of a sample was performed when the electric conductivity (EC) exceeded the working capacity of the column chosen and also to minimize the sample matrix effect. This was done to prevent the column of the IC from being overworked.

Suppressed ion chromatography was done with the use of a suppressor which is a device placed between the IC column and the detector and acts to reduce the background conductivity of the eluent and enhance the conductivity of the analytes. Eluent is an ion extraction liquid and as it runs through the column the absorbed ions begin to separate from the column. Before the IC analysis of water samples, a standard solution mixture of 1000mg/l was prepared by diluting the chemical powder which was dried at a prescribed temperature of 105+2°C for two hours. From the 1000mg/l solution, 0.2mg/l was used for the analysis. Preparation of the eluent was next and the eluent was degassed using an Elmasonic ultrasonic bath before introducing it into the machine. In the anion analysis, the ions elute through an anion ion exchange separator column, passes through the suppressor column and flow through the conductivity cell meter and recorder. Cation analysis is conducted and recorded without the suppressor column.

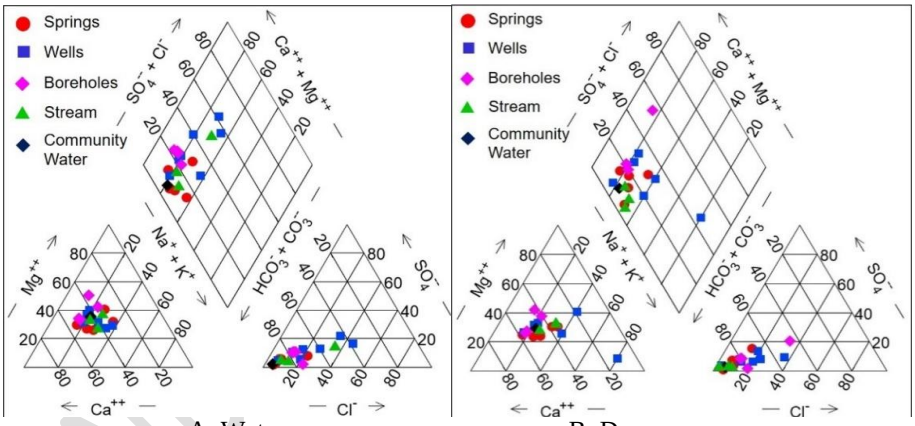
The measurement of alkalinity for each water sample was performed within 8–10 hours after sample collection to avoid oxidation of sulphides, ferrous ions, and precipitation of mineral phases. By using standard titration procedures as described in (Fantong *et al.*, 2009), alkalinity measurement was done three times for each sample and the average of at least two similar values of the three runs were used to obtain the alkalinity. The HNO_3^- concentration

for each sample was calculated from the titration parameters by using the following equation: HNO_3^- meq/l) = average of final volume x concentration of acid solution × (1000/average of the initial volume of sample).
On the field, Alkalinity was measured using a field Alkalinity Test kit (Hach Digital Titrator Operator model AL-DT) and Titration was carried out with chemical Indicators (phenolphthalein and methylene Blue) to obtain the desired end-point. These measurements were carried out within 24 hours after sample collection to avoid oxidation of sulphides, ferrous ions, and precipitation of mineral phases. In the lab, acid was being titrated from a known volume of 0.02 HCl and added to the water sample to reach the end-point titration which was marked by a pH of 4.8. Titration was done three times for each sample and the average of at least two similar values of the three runs were used to obtain the alkalinity.

Results and Discussion

Chemical Impact

A large number of studies have been carried out related to groundwater contamination by inorganic components such as NO_3^-, Cl^-, $PO4_3^-$ and NH4+ from sewerage effluents. Piper's diagram was used to characterise hydrogeochemical facies in the study area. The water samples of the springs, wells, boreholes, rivers and streams in the study area were of the Calcium and Magnesium Bicarbonate (Ca + Mg HNO_3^-) Sodium and Potassium Bicarbonate (Na + K- HNO_3^-) and Sodium Potassium Chloride (Na + K – Cl^-) facies (Figure 2).



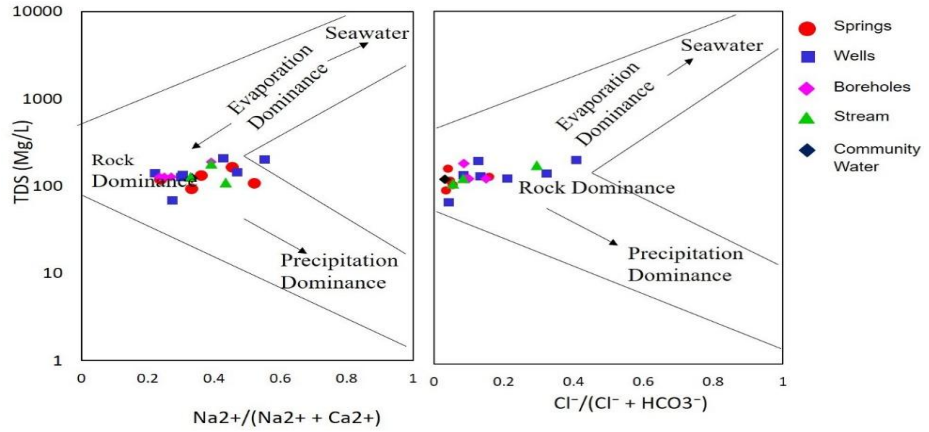
A: Wet season B: Dry season

Figure 2: Piper's diagram showing water facies for wet and dry seasons

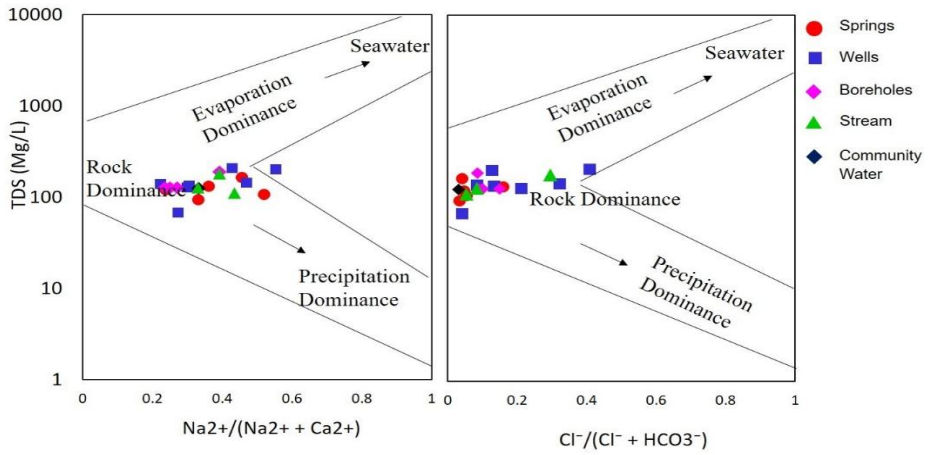
Most of the samples about 70% plots with a tendency towards Ca + Mg- HCO_3^- zone, about 20% towards the Na + K-HCO_3^- zone and about 10% towards Na + K – Cl^- zone. The bicarbonate could result from the interaction between organic matters, nitrate, iron and hydrogen sulphide. The Sodium and Potassium Bicarbonate suggest the presence of contaminants in the water resources.

The study area is made up of basic rocks. Basic rocks consist of olivines, pyroxenes and plagioclases, which are rich in the elements Ca, Mg, K and Na. Root respiration from the vegetation that abounds in the study area, produces CO_2. The CO_2 reacts with water to produce weak carbonic acid (HCO_3). The carbonic acid attacks the rocks by the process of incongruent dissolution (water-rock interaction), which releases the cations (Na^+, K^+, Mg^{2+} and Ca^{2+}) into solution and forms a secondary mineral clay. The water-rock interaction is

verified by Gibb's diagram, which represents the ratios of Na^+/ [Na^++Ca^{2+}] against TDS (Figure 3).



A: wet season



B: Dry season

Figure 3: Gibbs plots indicating water-rock interaction as the major process regulating the chemistry of waters in Fako for Wet (a) and Dry (b) Seasons (adapted from Gibbs, 1970).

This assesses the functional sources of dissolved chemical constituents, such as precipitation dominance, weathering dominance and evaporation dominance. The classification of water according to Gibbs (1970) shows that water in the central part of the boomerang is dominated by weathering of silicate minerals. Gibb's diagram plot of analytical data of spring, wells, boreholes, rivers and stream samples clustering around the weathering (water-rock interaction or rock dominance) domain with few samples trending towards precipitation and evaporation dominance for both wet and dry season samples.

Seasonal concentration of in water sources

There is seasonal variation in the concentrations of major ions, cations and anions, and microbial in waste as it affects the water quality. The water samples collected from water

resources in Fako were analysed from water in the 2020-2021 seasonal year for the following parameters; Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}) and, Magnesium (Mg^{2+}) for cations and Fluoride (F^-), Chloride (C^-), Sulphate (SO_4^{2-}), Phosphate (PO_4^{3-}), Bicarbonate (HCO_3^-) and Nitrate (NO_3^-) for anions. The variation in the changes in physical parameters like Electrical conductivity (EC), Potential of Hydrogen (pH), Total Dissolved Solids (TDS), Temperature and Salinity also have effects on water resources as a result of waste. The impact of waste on water resources varies between the dry and wet seasons.

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It has already been mentioned elsewhere in the text.

Sodium (Na^+)

The concentration of sodium in the water sample ranged from 7.23mg/l to 41.80 mg/l with a mean of 13.54 mg/l for dry season samples, with the spring along the Tiko Douala road having the least concentration of Na^+ of 7.23mg/l and the highest being the well in Mutengene 41.8mg/l (Figure 4).

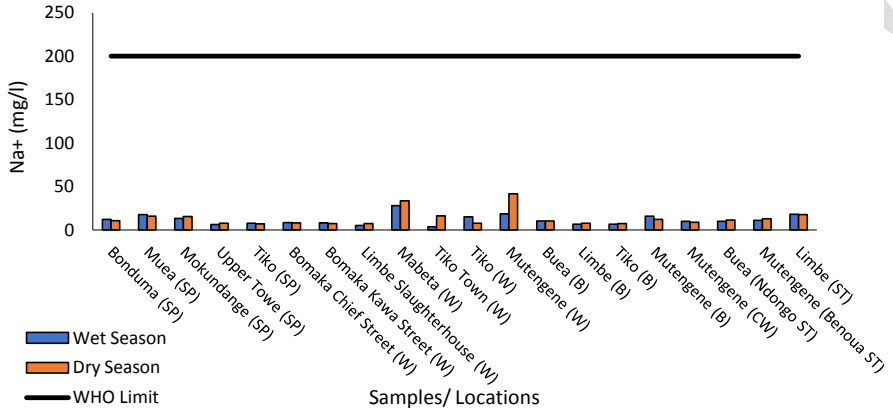


Figure 4: Variations in sodium concentration

For the rainy season samples, the well-situated at Mabeta in Limbe town registered the highest concentration of sodium (28.17mg/l) and the least concentration of sodium (3.67mg/l) was recorded in the well in Tiko town with a mean of 11.808mg/l. The water samples are below 200mg/l the threshold defined by WHO (2004) standard.

Potassium (K^+)

Analysis for K^+ concentration in water samples registered values which varied from 1.31 mg/l to 8.67 mg/l and a mean concentration of 3.76mg/l, representing wet season samples. The well in Tiko town showed the least concentration and the highest was registered in the stream in Limbe. The dry season samples had a mean potassium concentration of 3.32mg/l, with the spring at Upper Towe in Limbe recording the least concentration of 1.04 mg/l and the highest concentration of 6.45mg/l was observed at the stream in Limbe. In general, all water samples showed values that were below the WHO standard of 100mg/l (Figure 5).

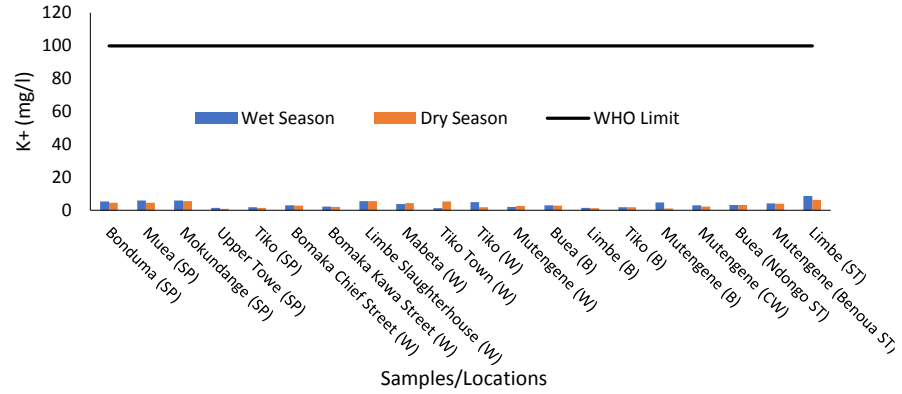


Figure 5: Concentration of Potassium

Magnesium (Mg^{2+})

The concentration of Mg^{2+} in observed water samples showed values ranging from 3.72 mg/l to 18.24mg/l and a mean concentration of 10.13 mg/l, representing wet season samples. The well in Tiko town had the least concentration and the highest was recorded at the borehole in Mutengene (Figure 6).

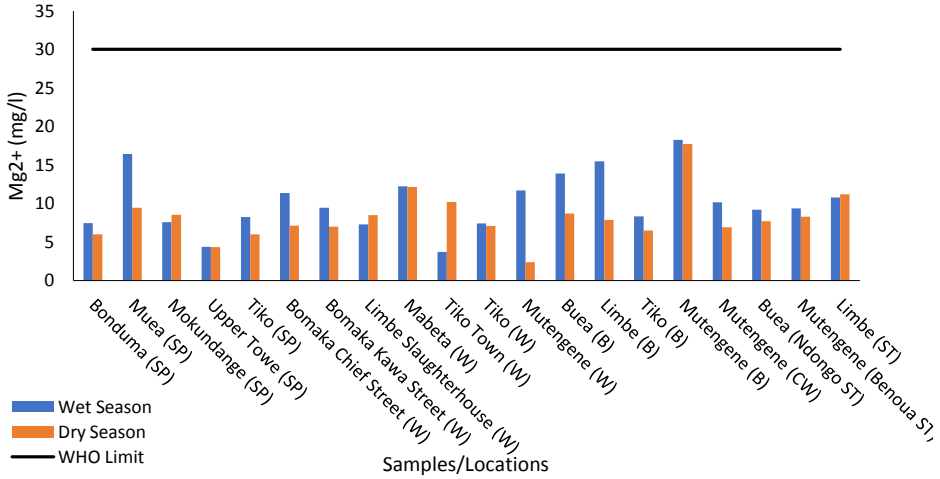


Figure 6: Concentration of Magnesium

The concentration of magnesium for the dry reason samples ranged from 2.39 to 17.73mg/l for well in Mutengene and borehole in Mutengene respectively with a mean value of 19.25mg/l. In general, all water samples recorded values that were far below the WHO standard of 150mg/l.

Calcium (Ca^{2+})

The mean concentration of Ca^{2+} for the wet season sample was 20.42mg/l. The lowest concentration was observed in the well in Tiko Town (9.78 mg/l) and the highest in the borehole in Buea (34.25 mg/l). The concentration of calcium for the dry reason samples ranged from 5.3 – 30.7 mg/l for well in Mutengene and borehole in Buea respectively with a mean value of 19.25 mg/l. The values of water samples are far below the WHO standard of 75mg/l (Figure 7).

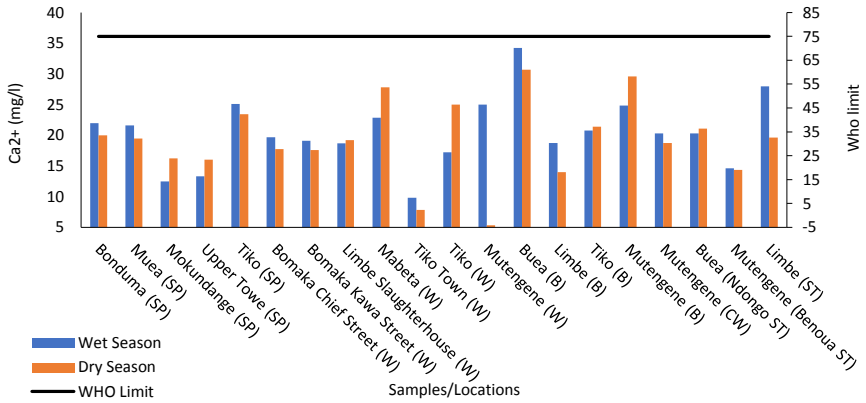


Figure 7: Concentration of calcium

The spatial distribution of potassium, magnesium and calcium shows a high concentration of calcium. The highest concentrations are located around waste dumpsites all over the study area.

Fluoride (F^-)

The concentration of fluoride (F^-) in the water sample varied from 0.07 mg/l to 0.18mg/l with a mean of 0.14 mg/l for wet season samples. The well in Tiko town registered the least concentration and the highest in River Benoua in Mutengene and well in Bomaka in Buea (Figure 8).

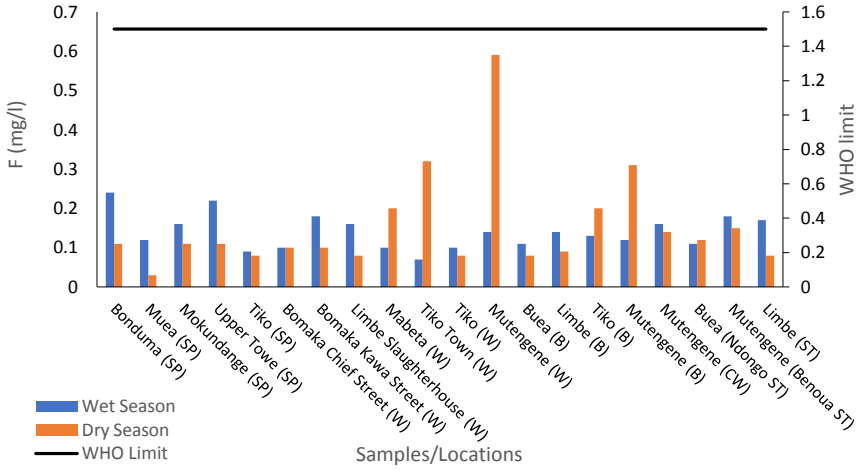


Figure 8: Concentration of Fluoride

The concentration of magnesium for the dry reason samples ranged from 2.39 to 17.73mg/l for well in Mutengene and borehole in Mutengene respectively with a mean value of 19.25mg/l. In general, all water samples recorded values that were far below the WHO standard of 150mg/l.

Chloride (Cl^-)

Chloride (Cl^-) concentration in water samples ranged from 1.77mg/l to 42.11mg/l with a mean concentration of 9.12mg/l, for the wet season samples (Figure 9).

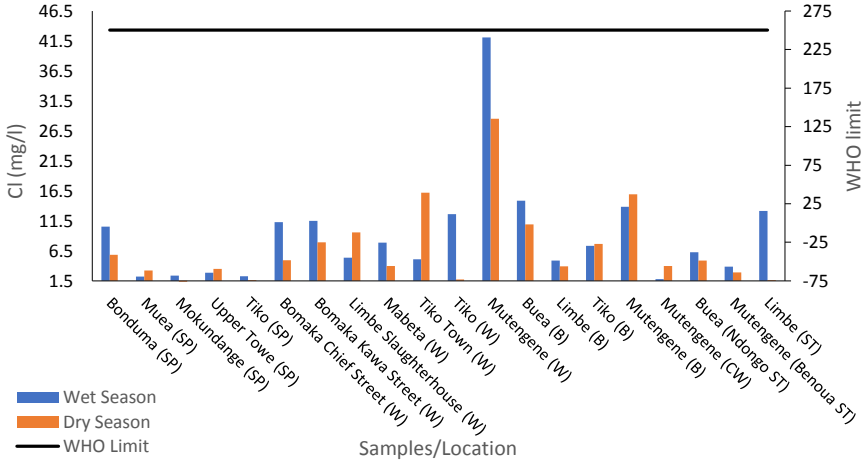


Figure 9: Concentration of chloride

Community Water in Mutengene had the least concentration and the highest at the Well in Mutengene. The dry season samples showed a mean chloride concentration of 7.2mg/l mg/l, with the spring at Mokundange in Limbe recording the least concentration of 1.38mg/l and the highest concentration of 28.54mg/l was observed at the well in Mutengene. The chloride level for the water samples was below the WHO standard (2004) of 250mg/l.

Sulphate (SO_4^{2-})

The concentration of sulphate (SO_4^{2-}) in the water sample fell between 0.85 mg/l to 20.21 mg/l with a mean of 5.76 mg/l for rainy season samples (Figure 10).

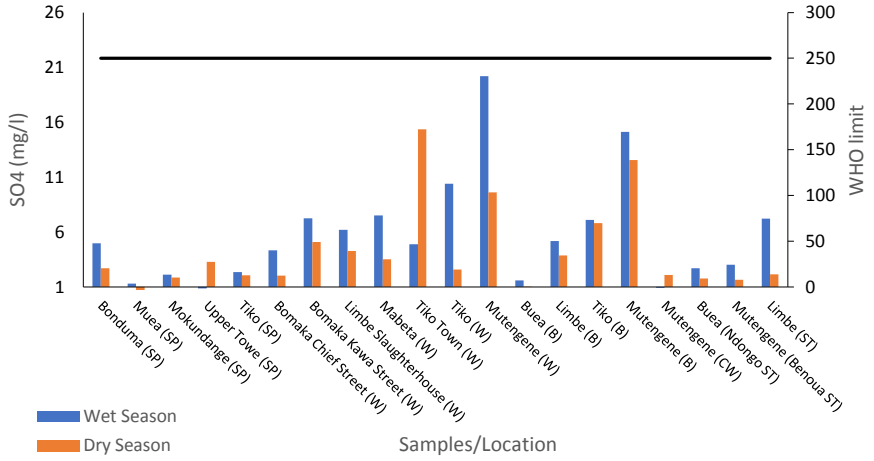


Figure 10: Concentration of sulphate

Spring at Upper Towe in Limbe had the least concentration of SO_4^{2-} and the highest being the well in Mutengene. The dry season samples showed a mean sulphate concentration of

4.23mg/l, with the spring in Muea in Buea having the least concentration of 0.31mg/l and the highest concentration of 15.36 mg/l was registered at the well in Tiko town. Water samples all fell below the WHO standard (2004) of 250mg/l.

Bicarbonate (HCO_3^-)

Bicarbonate (HCO_3^-) concentration in water samples of the wet season ranged from 26.5mg/l to 146mg/l with a mean concentration of 64.43 mg/l. The well along the Tiko Douala road had the least concentration and the highest was registered in the borehole in Mutengene in Mutengene (Figure 11).

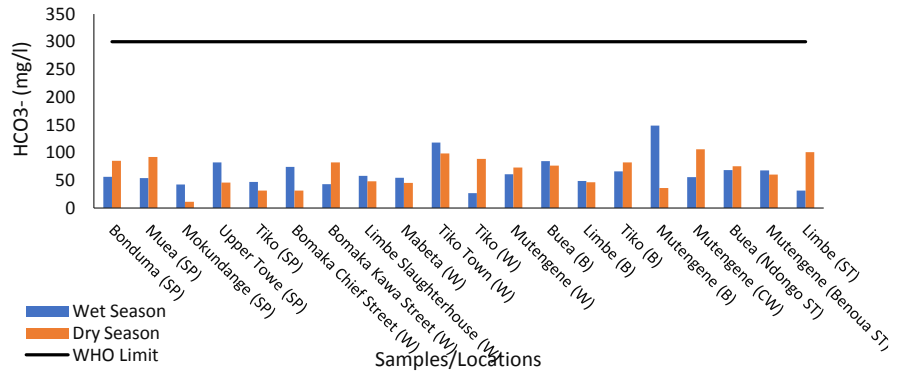


Figure 11: Concentration of bicarbonate

The concentration of HCO_3^- in the water sample ranged from 11mg/l to 106mg/l with a mean of 65.86 mg/l for dry season samples. The spring in Mokundange in Limbe showed the sample with the least concentration and the highest being the Community Water in Mutengene. Samples fell below the WHO drinking standard of 200mg/l making them fit for domestic, drinking and agricultural purposes.

Phosphate (PO_4^{3-})

The concentration of phosphate (PO_4^{3-}) for the wet season only two samples registered phosphate concentrations, and it was not detected in the remaining eight by the laboratory analysis (Table 1).

Table 1: Wet and dry season concentration of Phosphates

Sample Location	**Samples 20**	**PO_4^{3-} *mg/l***	
		Wet Season	***Dry Season***
Bonduma (SP)	SP001	ND	ND
Muea (SP)	SP002	ND	ND
Mokundange (SP)	SP003	ND	0.08
Upper Towe (SP)	SP004	0.22	0.15
Tiko (SP)	SP005	0.14	0.16
Bomaka Chief Street (W)	W001	ND	ND
Bomaka Kawa Street (W)	W002	ND	ND
Limbe Slaughterhouse (W)	W003	ND	ND
Mabeta (W)	W004	ND	ND
Tiko Town (W)	W005	ND	ND
Tiko (W)	W006	ND	0.07

Mutengene (W)	W007	ND	ND
Buea (B)	B001	ND	ND
Limbe (B)	B002	ND	0.1
Tiko (B)	B003	ND	0.33
Mutengene (B)	B004	ND	ND
Mutengene (CW)	CW	ND	ND
Buea (Ndongo ST)	R001	ND	ND
Mutengene (Benoua ST)	R002	ND	0.13
Limbe (ST)	ST	ND	0.13

The lowest concentration of 0.14 mg/l was observed in the spring along the Tiko Douala road while the highest by the spring at Upper Towe in Limbe had a value of 0.22mg/l. For the dry season sample, the machine did not detect the concentrations of phosphate in four water samples. Phosphate concentrations were detected in six water samples with a range of 0.07 – 0.33 mg/. The least concentration 0.07 mg/l was recorded at the well along the Tiko Douala road and the highest value of 0.33 mg/l was at the borehole in Tiko. Five water samples out of the six had values below the WHO standard (2004) of 0.3mg/l while the borehole along the Tiko Douala road registered value (**0.33mg/l**) slightly above the WHO standards of 0.3mg/l.

Nitrate (NO_3^-)

The concentration of nitrate (NO_3^-) in the water sample ranged from 2.46mg/l to 70.15mg/l with a mean of 25.86 mg/l in the wet season samples. The borehole in Limbe was the water source with the least concentration of NO_3^-, while the highest concentration was observed at the well in Mutengene. The concentration of nitrate for the dry season samples ranged from 0.4mg/l to 46.66 mg/l with a mean of 15.39 mg/l. The Stream in Limbe was the water source with the least concentration of NO_3^-, while the highest concentration was observed at the borehole in Molyko Buea. During the rainy season, five (25%) of water samples in Fako recorded nitrate concentrations below WHO standard (2004) of 10 mg/l while the remaining fifteen (75%) registered values far above the limits. During the dry season, nine (45%) of the samples registered values below while eleven (55%) recorded values above. It is worth noting that the rainy season recorded high levels and a high number of samples with nitrate concentrations with the highest concentration being **70.15mg/l** (Figure 12).

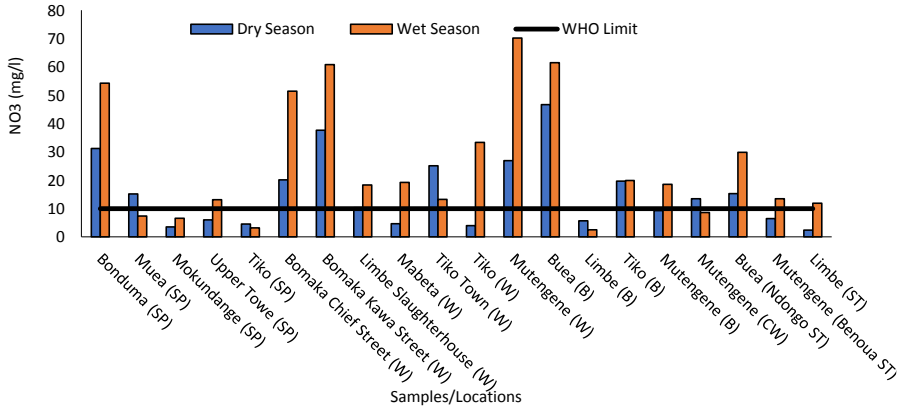


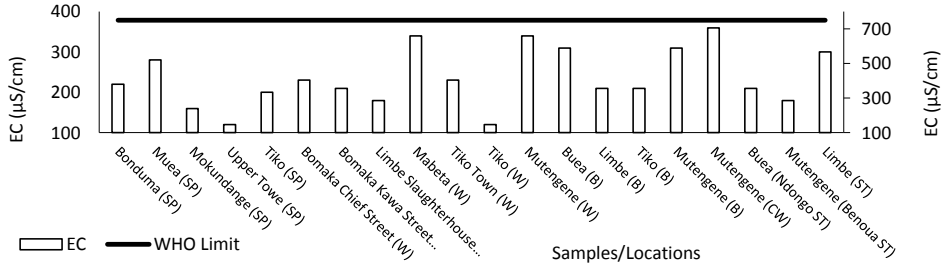
Figure 12: Concentration of nitrates

High concentrations of nitrates in water samples in Fako are a result of waste from septic tanks, indiscriminate waste disposal and agricultural practices with the intensive use of fertilizers and pesticides. Some of the wastes are washed off by runoff into surface water bodies while some infiltrate through the porous scoriaceous soils in Fako into the water table polluting groundwater resources with excess nitrates. High consumption of nitrates in water especially drinking water leads to a potentially fatal disorder called methaemoglobinaemia a blue baby syndrome disease for bottle-fed children. Nitrate reduction happens in the digestive system of infants and livestock and hence they are at risk at high nitrate levels. The nitrite binds strongly to the haemoglobin in the blood causing the infant to suffer from methaemoglobinaemia which can be fatal. The condition can be recognised by the colouration of the lips and other body parts and hence the term blue baby syndrome is widely used. In the case of sub-lethal levels (nitrate-nitrogen < 20 parts per million), children may show symptoms of failure to thrive, headache, fatigue, shortness of breath, and lack of energy. These results are similar to those of Akoachere *et al.,* (2019) who carried out a similar study on some water sources on the volcanic aquifers of Limbe and Fomenky et al., (2017) on the physico-chemical properties of
soils and some water sources on the eastern flank of Mount Cameroon. Razack *et al.,* (1988) and Thomson *et al.*, (1986) also observed elevated levels of nitrate in water samples in their studies as a result of leaching from effluent generated as a result of urbanization.

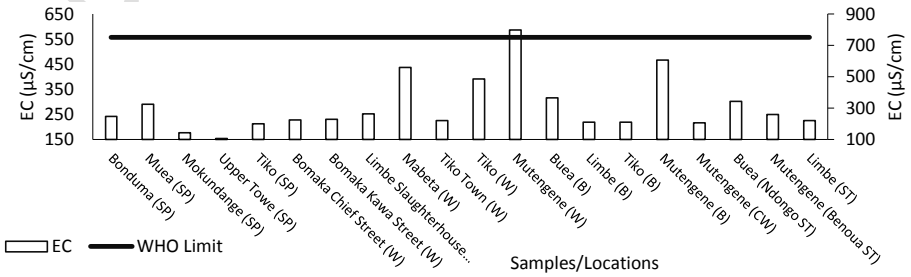
Comment [HUR6]: It would be necessary to explain under what mechanisms it is maintained that the high concentrations of nitrates are the result of the waste from the septic tanks and the indiscriminate disposal of waste.

Electrical conductivity (EC)

EC concentration in the water sources varied from 120-360 µS/cm in the rainy season with a mean of 236 µS/cm. The highest EC was registered at the community water in Mutengene and the least at the spring in upper Towe in Limbe while during the dry season it varied from 176 - 586 µS/cm with a mean of 281.6 µS/cm. The highest EC was registered at the well in Mutengene and the lowest was registered at the Spring in Mokundange in Limbe. All water samples except for well in Mutengene (586 µS/cm) were within the WHO standards of 500 µS/cm (Figure 13).



A: Rainy Season

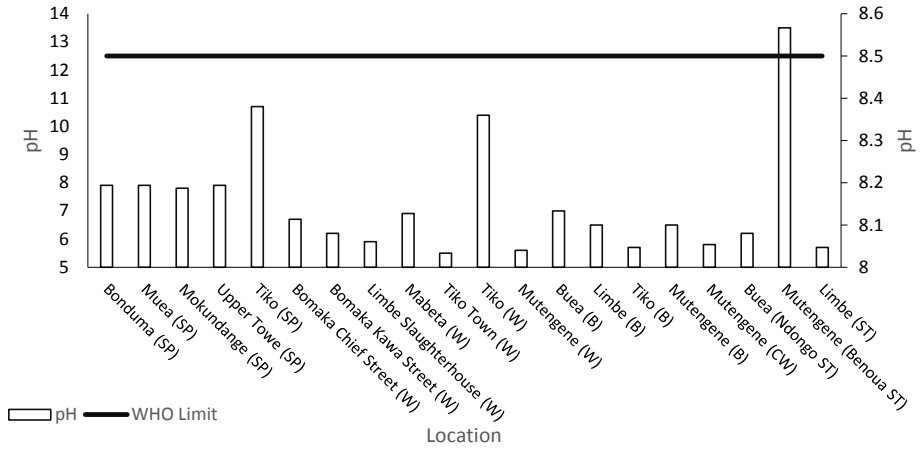


B: Dry Season

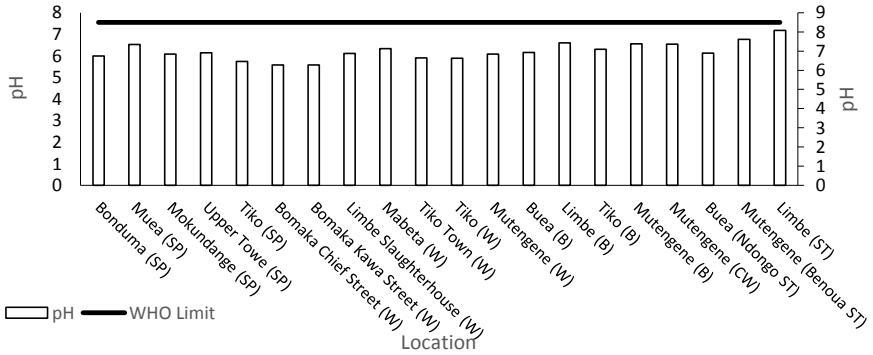
Figure 13: Seasonal variation of electrical conductivity

The potential of Hydrogen (pH)

The pH value of all the water samples ranged from 5.5 to 13.5 for the wet season samples with a mean of 7.3. pH is a measure of how acidic or basic water is. The spring and well along Tiko Douala road and the river Benoua in Mutengene registered the highest pH of 10.7, 10.4 and 13.5 which are above WHO limits and the least was recorded in the well in Tiko town. The pH values for the dry season samples ranged from 5.58 to 7.18 with a mean of 6.20 with all water samples registering pH within WHO limits of 6.5 – 8.5 (Figure 14).



A: Rainy Season

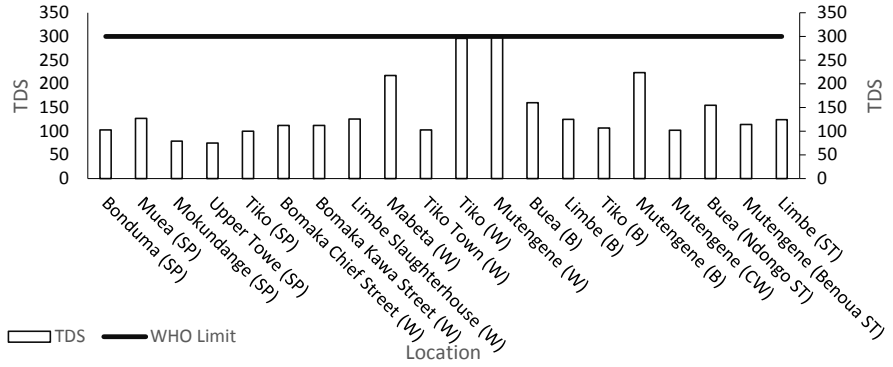


B: Dry Season

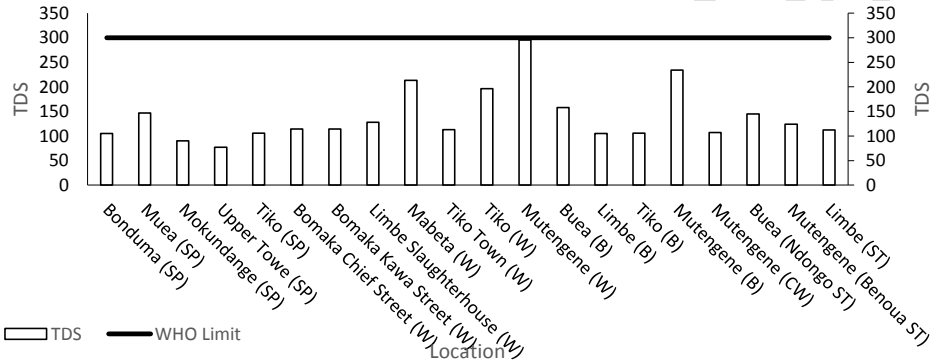
Figure 14: Seasonal concentration of pH

Total Dissolved Solids (TDS)

The TDS for water samples for the wet season ranged from 75 – 298 ppm with a mean of 143 ppm with the highest TDS concentration of 296 and 298 ppm at the well in Tiko Douala road and well in Mutengene respectively. The dry season samples had a TDS mean of 139.45ppm and a range of 77 ppm to 295 ppm for spring at Upper Towe and well in Mutengene respectively. All the water samples for both seasons fell below the WHO standard of 300ppm (Figure 15).



A: Rainy Season

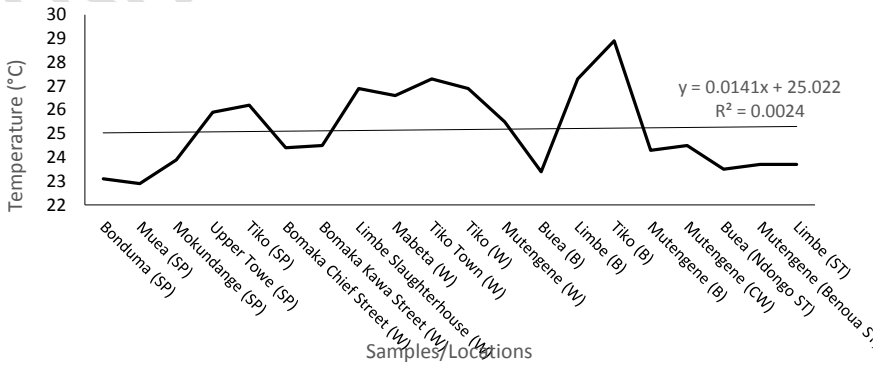


B: Dry Season

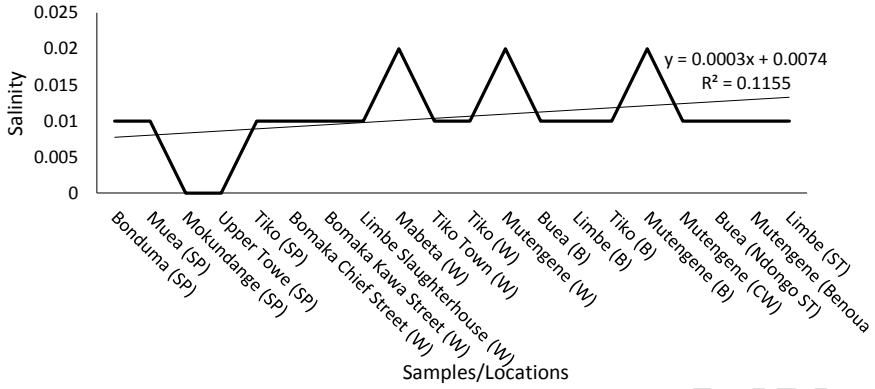
Figure 15: Seasonal variation of total dissolved solids

Temperature

The temperature range for water samples collected in the wet season varied between 22.9^{o}C to 28.9^{o}C with a mean temperature of 25.17^{o}C. The temperature for all water samples collected in the dry season ranged from 24.4^{o}C to 32.1^{o}C with a mean of 26.73^{o}C. The lowest temperature is that of the Bonduma spring in Buea while the sample with the highest temperature is that of the boreholes in Mutengene and Limbe (Figure 16).



A: Rainy Season

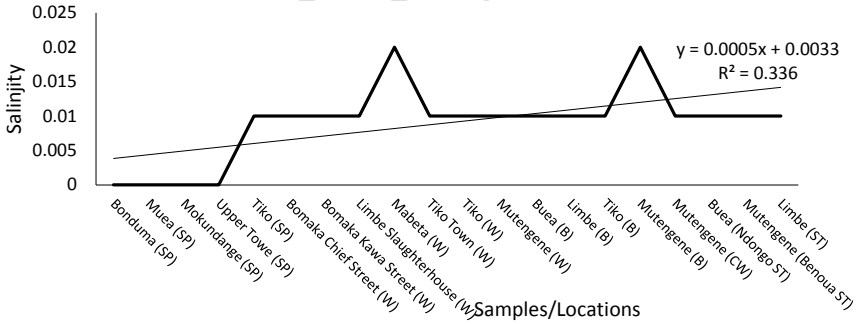


B: Dry Season

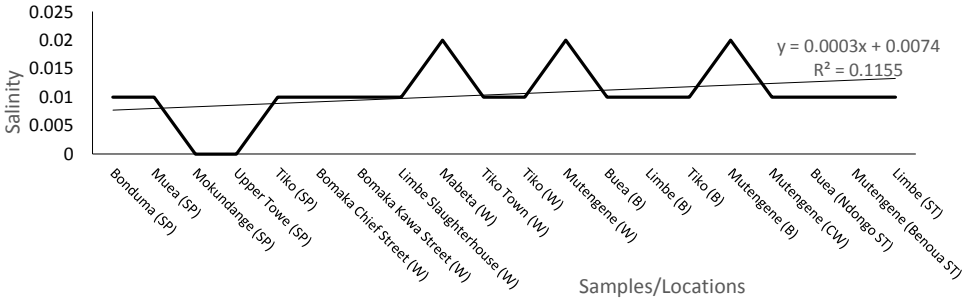
Figure 16: Seasonal variation of water temperature

Salinity

The salinity for water samples during the dry and wet seasons ranged from 0.00 to 0.02. For the wet season samples, four out of the five springs that were sampled registered 0.00 salinity while the lone spring inside the rubber plantation along the Tiko Douala road registered 0.0. The highest salinity of 0.02 was recorded in the well at Mabeta in Limbe and the Borehole in Mutengene. The dry season samples recorded more samples with salinity, two out of the five springs recorded 0.00 salinity while the remaining three recorded salinity of 0.01. The highest salinity of 0.02 was recorded in the a well in Mabeta in Limbe and a well and a Borehole in Mutengene (Figure 17).



A: Rainy Season



B: Dry Season

Figure 17: Seasonal variation in water salinity

Conclusion

These results have provided data on the level of physico-chemical properties of water from some wells, springs, streams, boreholes, pipe-borne water in the Fako Division. The chemical parameters in the samples tested were all within the WHO limits except for nitrate which was found in most of the water samples. However, *E. coli* was found in almost all the samples tested and this can be attributed to the proximity of the wells to pit latrines and indiscriminate disposal of waste into water resources and on land. This is dangerous to human health and leads to bacteriological contamination of the water. The water resources therefore should be properly treated before consumption.

Comment [HUR7]: Nothing is mentioned in the results about microbial analysis.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. 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.

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