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POSTGRADUATE SCHOOL OF SCIENCE, TECHNOLOGY AND GEOSCIENCE
LABORATORY OF GEOSCIENCE OF SUPERFICIAL FORMATIONS

Petrology of igneous rocks and water quality in Bamenda Town: North West Region, Cameroon

THESIS
Submitted in partial fulfillment of the requirements for the award of Ph.D/Doctorat in Earth Sciences

Par : **Alice MAGHA MUFUR**
M.Sc. Water Management

Sous la direction de
Véronique KAMGANG KABEYENE B.
Professor
University of Yaoundé I

Année Académique : 2017

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DEPARTMENT OF EARTH SCIENCES

DÉPARTEMENT DES SCIENCES DE LA TERRE

Option: GEOSCIENCE OF SUPERFICIAL FORMATIONS

Specialty: Geotechnical and Hydrotechnical studies

ATTESTATION OF CORRECTION OF PhD/DOCTORATE THESIS
ATTESTATION DE CORRECTION DE THESE DOCTORAT/PhD

Name of student: Alice MAGHA

Registration No: 09X0867

Title of thesis: "*Petrology of igneous rocks and water quality in Bamenda Town, North West region Cameroon*".

Date of defense: 29 November 2017
Grade: Trés Honorable

We, the undersigned members of jury of the PhD/Doctorat Thesis of Mrs Alice MAGHA, registration number: 09X0867, attest that she has effected the corrections in conformity with the observations made during her defense.

To this effect, this attestation is issued to serve the purpose for which it is intended.

28 FEV 2018

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12	NKOUMBOU Charles	Maître de Conférences	En poste
13	TEMDJIM Robert	Maître de Conférences	En poste
14	YENE ATANGANA Joseph Q.	Maître de Conférences	*Chef Cellule MINTP*
15	ABOSSOLO née ANGUE Monique	Chargé de Cours	**Chef DAASR**
16	BEKOA Etienne	Chargé de Cours	En poste
17	BISSO Dieudonné	Chargé de Cours	*Directeur Projet Barage Memve'ele*
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22	LAMILEN BILLA Daniel	Chargé de Cours	En poste
23	MBIDA YEM	Chargé de Cours	*CS/LABOGENIE*
24	MINYEM Dieudonné	Chargé de Cours	*Chef de Dépt IMIP/Maroua*
25	MOUAFO Lucas	Chargé de Cours	En poste
26	NGO BELNOUN Rose Noël	Chargé de Cours	En poste
27	NGO BIDJECK Louise Marie	Chargé de Cours	En poste
28	NGUEUTCHOUA Gabriel	Chargé de Cours	CEA MINRESI
29	NJOM Bernard de Lattre	Chargé de Cours	En poste
30	NYECK Bruno	Chargé de Cours	*S/Directeur/MINMIDT*
31	ONANA Vincent	Chargé de Cours	En poste
32	TCHAKOUNTE Jacqueline ép. NUMBEM	Chargé de cours	*CEA MINRESI*
33	TCHOUANKOUE Jean-Pierre	Chargé de Cours	En poste
34	ZO'O ZAME Philémon	Chargé de Cours	*S.G. MINTP*
35	ANABA ONANA Achille Basile	Assistant	*En Poste*
36	EYONG John	Assistant	*En Poste*
37	BINELI BETSI Thierry Olivier	Assistant	*En Poste*
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40	NOMO NEGUE Emmanuel	Assistant	En poste
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42	TEHNA Nathanaël	Assistant	CS/ *MINMIDT*
43	TEMGA Jean Pierre	Assistant	En poste

Répartition chiffrée des enseignants permanents par Département (31 Mars 2016)

Département	**Nombre d'enseignants**				
	Pr	**MC**	**CC**	**ASS**	**Total**
BC	6 (1)	8 (3)	16 (9)	14 (6)	**41 (19)**
BPA	10 (0)	9 (1)	14 (6)	10 (4)	**43 (11)**
BPV	1 (0)	7 (0)	12 (3)	7 (6)	**27 (9)**

C.I.	6 (1)	9 (1)	14 (3)	5 (2)	**34 (7)**
C.O.	9 (0)	10 (3)	12 (3)	2 (0)	**33 (6)**
IN	3 (1)	2 (0)	7 (0)	16 (4)	**28 (5)**
MA	3 (0)	7 (0)	18 (1)	7 (0)	**35 (1)**
MB	1 (0)	4 (1)	6 (2)	2 (0)	**13 (3)**
PH	8 (0)	10 (1)	18 (2)	3 (1)	**39 (4)**
ST	4 (0)	10 (1)	20 (4)	8 (0)	**42 (5)**
Total	**51 (3)**	**76 (11)**	**137 (33)**	**74 (23)**	***338 (70)***

Soit un total de : 338 (70) dont

- Professeurs 51 (3)
- Maîtres de Conférences 76 (11)
- Chargés de Cours 137 (33)
- Assistants 74 (23)
- ( ) = Nombre de femmes.

Le Doyen de la Faculté des Sciences

Pr Paul BILONG

DEDICATION

To my husband, Mufur William Asobo

To our kids, Wokwen Cordelia, Damaris Ning, Tencha Pinmbuh Mandela, Pinuh Ngwi and Nguh Apimnyu.

To my parents, Papa Jonas Muluhmusa and Mama Tabitha Wokoh.

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MINERAL ABBREVIATIONS ACCORDING TO KRETZ (1983)

Amp: Amphibole

Bt: Biotite

Kfs: Alkali Feldspar

Myr: Myrmikite

Op: Opaque mineral

Px: Pyroxene

Pl: Plagioclase

Qtz: Quartz

OTHER ABBREVIATIONS

ALS: Australian Laboratory Services

CFU: Colony Forming Unit

CVL: Cameroon Volcanic Line

E. coli: *Escherichia coli*

EPA: Environmental Protection Agency

FAO: Food and Agriculture Organisation

GPS: Global Positioning System

IRC: International Reference Center

MINEP: Ministry of Environment and Protection of Nature

MPN: Most Probable Number

NTU: Nephelometric Turbidity Unit

µS/cm: Microsiemens per centimeter

UNEP: United Nations Environment Programs

UNICEF: United Nation International Children Education Fund

ABSTRACT

Bamenda is a metropolitan Town that lies on the continental segment of the Cameroon Volcanic Line and in the central domain of the Pan-African North Equatorial Fold Belt. The volcanic rocks are underlain by basement rocks whose petrology has not been fully studied. The Town is drained by River Mezam whose water is susceptible to impairment from anthropogenic sources. The city dwellers are indulged in several sectors of activities thus ground and surface water is prone to pollution from diverse sources. This study was aimed at assessing water quality in Bamenda Town to establish its relation to the geology of the area . In order to attain the objectives, observations and measurements of some physical parameters were carried out on the field while chemical parameters were analysed in the laboratory from January 2013 to October 2014. Petrographic and geochemical results revealed that Bamenda Town is covered by igneous rocks of plutonic and volcanic types. The plutonic rocks are essentially granitoids (leucogranite and granite) while the volcanic rocks are basalt and trachyte. Hydrochemical studies revealed that both surface and groundwater were slightly acidic (pH =5.45-6.47 and 5.55-6.84 respectively). Hydrochemically, ground water presented Ca-Mg-HCO_3 water type in the dry season and Ca-Mg-HCO_3 and Ca-Mg-SO_4 water types in the rainy season. The ion concentration of the Mezam River water was low (41.67-237.00µS/cm). The water presented Ca-SO_4 and Ca-Mg-Cl +NO_3 water types in the dry season and Ca-Mg-SO_4 water type in the rainy season. High NO_3 values (50mg/l) were obtained from water samples from Nkimufueh sampling point. Bacteriologically, groundwater was shown to be heavily polluted with indicator bacteria as *Escherichia coli*, Streptococcus, Salmonella and Proteus, attending up to 300CFU/100ml and therefore required treatment before use for domestic purpose. The Mezam River water is heavily polluted with various bacteria (0-500CFU/100ml) whose concentrations increased from the reference point through sampling points in the city center, suggesting the influence of human-induced activities. The hydrochemistry of surface and groundwater in Bamenda Town is closely associated with the petrography of the watershed, as dominant ionic species of the water are predominant in the geologic formation of the area.

Key words: petrography, hydrochemistry, bacteriological analyses, pollution, Bamenda.

RESUME

La ville de Bamenda appartient à la fois à la Ligne Volcanique du Cameroun et au domaine centre de la Chaine Panafricaine Nord Equatoriale. Dans la zone d'étude, les roches volcaniques constituées essentiellement de Basalte et Trachyte recouvrent partiellement un socle granitique d'âge panafricain. Le principal bassin versant de la ville de Bamenda est la « Mezam » dont les affluents et la nappe souterraine sont sujettes à des polluants des sources diverses. L'étude pétrographique et géochimique des roches de Bamenda, La caractérisation des eaux superficielles et souterraines de Bamenda ont permis de mieux comprendre la géologie de la région, d'évaluer la pollution des eaux de la ville et d'établir un lien entre la nature des roches du bassin versant et la qualité des eaux. Pour atteindre ces objectives, les travaux ont été menés sur le terrain et en laboratoire. Les résultats des études pétrographique géochimiques révèlent que la ville de Bamenda est composée des roches ignés ; plutonique et volcanique. Les roches plutoniques sont principalement les granitoïdes (leucogranite et granite) et les roches volcaniques sont le basalte et le trachyte. L'étude hydrochimique révèle que les eaux souterraines ont un facies Ca-Mg-HCO_3 en saison sèche et un facies Ca-Mg-HCO_3 et Ca-Mg-SO_4 en saison pluvieuse. Les eaux du fleuve Mezam sont faiblement minéralisées (41.67-237.00µS/cm). La forte teneur en nitrate (50mg/l) observée au point Nkimufueh est attribuée aux déchets reçus de l'abattoir de Bamenda. Les eaux souterraines et superficielle sont légèrement acides (pH =5.45-6.47 and 5.55-6.84 respectivement). Sur le plan bactériologique, les eaux souterraines étaient fortement polluées avec les bactéries fécales tels que les *E. coli*, Streptocoques, Salmonella et Proteus (jusqu'a 300CFU/100ml) et requièrent un traitement préalable avant utilisation à but domestique. Le fleuve de la Mezam était aussi chargé en bactéries fécales et leur teneur augmentaient du point d'échantillonnage aux points de référence dans la ville (0-500CFU/100ml). L'augmentation de taux bactériens est due aux activités anthropiques. La minéralisation des eaux souterraines et superficielles dans la ville de Bamenda est fonction des matériaux géologiques puis que les minéraux préalables de ces eaux sont abondants dans les roches environnantes. Les études physico-chimiques et bactériologiques ont montrées que les ressources en eau dans la ville de Bamenda sont fortement polluées. Il est nécessaire de déterminer les paramètres caractéristiques isotopiques des eaux de pluie, les sédiments du fleuve de la Mezam et une étude radiométrique des roches ignés de Bamenda en vu de mieux comprendre l'interaction Roches-Eaux afin de mieux cerner la pollution des eaux afin d'y apporter une solution adequate.

Mots clés : pétrographie, hydrochimie, analyse bactériologique, pollution, Bamenda.

GENERAL INTRODUCTION

Water is a polar chemical compound that at room temperature is a tasteless, odourless and colourless liquid (Roy, 1992). The water molecule is composed of oxygen (O_2) and hydrogen (H_2) in the formula H_2O and occurs in the liquid, solid and gaseous forms. It is the most important and abundant substance on earth as well as the most precious resource the Earth provides for man (Byrne, 2001). Water plays crucial roles in the development and functioning of any community, as it is a prerequisite for activities such as domestic chores, irrigation, industrial and livestock production, aquaculture and hydroelectric power generation (Tietenberg, 1996; Bowers, 1997). It is the liquid of life because of its special physical and chemical properties (Roy, 1992). Of the vast amount of water found on Earth, only about 3% is fresh, found in surface reservoirs (lakes, streams, creeks and rivers) and under the ground, while about 97% is seawater and thus unfit for drinking and most agricultural and industrial activities (Anatole, 1996; Ricklefs, 1996; Marsh and Grossa, 1998). The amount of the fresh water readily available for domestic, agricultural and industrial activities represents less than 0.01% of the earth's total store of water as a vast amount of the fresh water is trapped in glaciers and ice caps and remains largely unavailable (Kemp, 1998). Organisms cannot function without water and if deprived of it, they will rapidly die (Mason, 1993; Owen and Unwin, 2002). Over time, the requirements of water have emerged for drinking, personal hygiene, fisheries, agriculture, navigation, industrial production, cooling in fossil fuel, power plants, hydropower generation and recreational activities (Mannion and Bowlby, 1992; Chapman, 1998).

The provision of adequate potable water is one of the major challenges in developing countries with about 2.6 billion people without access to improved drinking water (UNICEF, 2015). A greater proportion of this underprivileged population lives in the developing countries of Africa, South America, India, and South East Asia. Unsafe water, associated with low sanitation and hygiene represents the leading cause of death in these countries, and it is estimated that about 1.6 million people die every year from water-related diseases, 90% of whom are children under the age of five (WHO and UNICEF, 2012). Studies have shown that about 160 million people are infected with schistosomiasis causing tens of thousands of deaths yearly; 500 million people are at risk of trachoma from which 146 million are suffering from blindness and 6 million are visually impaired (UN-HABITAT, 2012). There are around 133 million people suffering from intestinal helminth infections and about 1.5 million cases of clinical hepatitis. The world bank estimates that access to safe drinking water and adequate sanitation could greatly reduce the number of deaths resulting from diarrheoa in children to half. Indeed, to remedy the water situation in the developing countries, the UN has instituted part of the Millennium

Developing Goals (MDGs) in target 7c to the provision of clean water and sanitation, intended to reduce to half by 2015, the proportion of the population without access to safe drinking water and basic sanitation (UN, 2016).

Bamenda is a cosmopolitan town located at the foot of the Bamenda Highlands which form part of the Cameroon Volcanic Line (CVL). The CVL is a megastructure in Central Africa oriented N30°E and extending approximately 2000km in length and about 100km in width, from the island of Pagalu in the Gulf of Guinea to Lake Chad (Fitton, 1987; Lee *et al*., 1994; Déruelle *et al*., 1991 and 2007). The Bamenda Highlands constitute the fourth largest massif in volume in the continental segment of the CVL (Gountie *et al*., 2011). It consists of volcanic rocks (alkali basalt, trachyte, rhyolite, and ignimbrite) which are of Tertiary-Quaternary age (Kamgang *et al*., 2007) and granito-gneissic basement of Pan-African age (Nzenti *et al*., 2010). The volcanic rocks have been studied in details by Kamgang *et al.* (2007, 2008) while the basement rocks remain poorly surveyed, probably because of the scarcity of the outcrop. The available data on the Bamenda basement is restricted to the petrogenesis of peraluminous magma from the Akum massif, located to the south of Bamenda Town (Nzenti *et al*., 2010).

Bamenda Town is drained by the Mezam River and its tributaries which originate from the Bamenda Highlands that serve as a prominent watershed to the Bamenda area (Molua and Lambi, 2006). The catchment areas for water supply in the town are situated at Mendakwe (Upstation) and Mbatu village for the Down Town area. The production and distribution of potable water in this Town was the responsibility of the state-owned water utility company referred to as "Société Nationale des Eaux Camerounaise" (SNEC) from 1967 to 2006 when another water supply company "Camerounaise des eaux" (CDE) took over. The existing water schemes constructed some 40 years ago could meet the water needs of the population at that time but as the population continued to increase without any concomitant expansion of the schemes, the supply of potable water became intermittent during the last decade. Following the creation of The University of Bamenda in 2010, there has been a massive influx of students and workers into Bamenda Town, and water shortage has become critical to the extent that some neighbourhoods have gone for years without a drop of water from their taps. In order to meet up with the scarcity and disappointment, many inhabitants are compelled to turn to other water sources, whose quality is uncertain, such as groundwater obtained through hand-dug wells, boreholes and springs, and surface water from the Mezam River and even rainwater during the rainy period. The quality of these water sources has not been assessed to determine their suitability for various activities.

Both surface and groundwater sources are prone to contamination. Microbiological contamination is a primary concern of urban settlements. Since River Mezam flows through the city of Bamenda, the quality of the river water is liable to be impaired by a variety of substances both from point and non-point sources. The city dwellers operate different sectors of activities such as garages, cottage industries and construction sites. Urban agriculture is carried out on small strips of land in the city center and in swamps along the river. This sector makes use of chemical fertilizers, herbicides and organic manure, whose residues end up in the river. Some city dwellers find the river an easy place for dumping their refuse. In addition, the Town of Bamenda does not have a central sewage collection system and so management of sewage depends on individual units, which in some cases are channeled into gutters which finally end up in the river. Inorganic contaminants can be present in ground and surface water, and other physical and chemical parameters can deteriorate water quality as well. It is therefore necessary to investigate the physical, chemical and bacteriological quality of the water used by the residents of Bamenda Town to prevent health hazards and to ensure sustainable development since these are important factors to consider before the water is used for domestic purposes (Suresh *et al*., 1991).

Besides, when water percolates through the subsurface, it encounters geologic formations, with which ions are exchanged especially during the process of weathering and alteration, during which rocks release minerals whose ions enter aquifers and alter the chemical composition of water (Demlie *et al*., 2007; Tay, 2012). Therefore, the petrology of igneous rocks in Bamenda Town that constitute the main geological formations on which water flows will help in understanding their chemical composition, the origin of solutes and the processes that generate the constituents in water. Physical, chemical and bacteriological studies from ground and surface water can provide a better understanding of potential water quality variations due to geology and land use practices (Entry and Farmer, 2001). This quality is controlled by many factors, some of which include the composition of precipitation, climate and topography and mineralogy of rocks of the watershed, as well as anthropogenic influences such as urban, industrial and agricultural activities. These factors combine to create diverse water types that change spatially and temporally (Wegelin, 1991).

The main objective of this study was to assess water quality in Bamenda Town in relation to its geological settings so as to determine its suitability for domestic chores.

The specific objectives were:

- To carry out a detailed petrography and whole rock geochemistry of the various igneous rock types in Bamenda Town.
- To assess the physical, chemical and bacteriological quality of ground and surface water in Bamenda Town.

To attain these objectives, field studies were carried out seasonally during which rocks and water samples were collected for laboratory analyses from where results were obtained for the discussion.

The thesis has been partitioned into four chapters, in addition to a general introduction and a general conclusion as follows:

Chapter One: Geographical setting of the study area and literature review

Chapter Two: Materials and methods

Chapter Three: The petrology of igneous rocks of Bamenda Town

Chapter Four: Ground and surface water quality in Bamenda Town

CHAPTER 1
GEOGRAPHICAL SETTING OF THE STUDY AREA AND LITERATURE REVIEW

Bamenda Town is situated along the Cameroon Volcanic Line between the Western Highlands and Mount Oku. Being the capital of the North West Region, it receives many migrants in transit to the South West, West, Littoral, Centre and all the other regions of Cameroon, as well as, neighbouring Nigeria. This chapter explores the natural setting of the study area, so as to, appreciate its contribution to the hydrogeochemistry of the area. It also reviews relevant information on the geology of Bamenda Town and hydrochemical studies carried out along the CVL.

1.1. GEOGRAPHICAL SETTING

1.1.1. Physical Geography

- **Location of the Study Area**

Bamenda is the regional head quarter of the North West Region of Cameroon and the divisional head quarter of the Mezam Division. It is bounded to the North by Bafut, to the North East by Bambui, to the West by Mbengwi, to the South by Santa and to the South West by Bali (figure 1). It extends from latitude 5°43′ to 7°10′ north and longitude 9°35′ to 11°12′ east. Bamenda lies at an altitude of about 1200m to 1865m above sea level and occupies a surface area of about 3125ha (Acho, 1998).

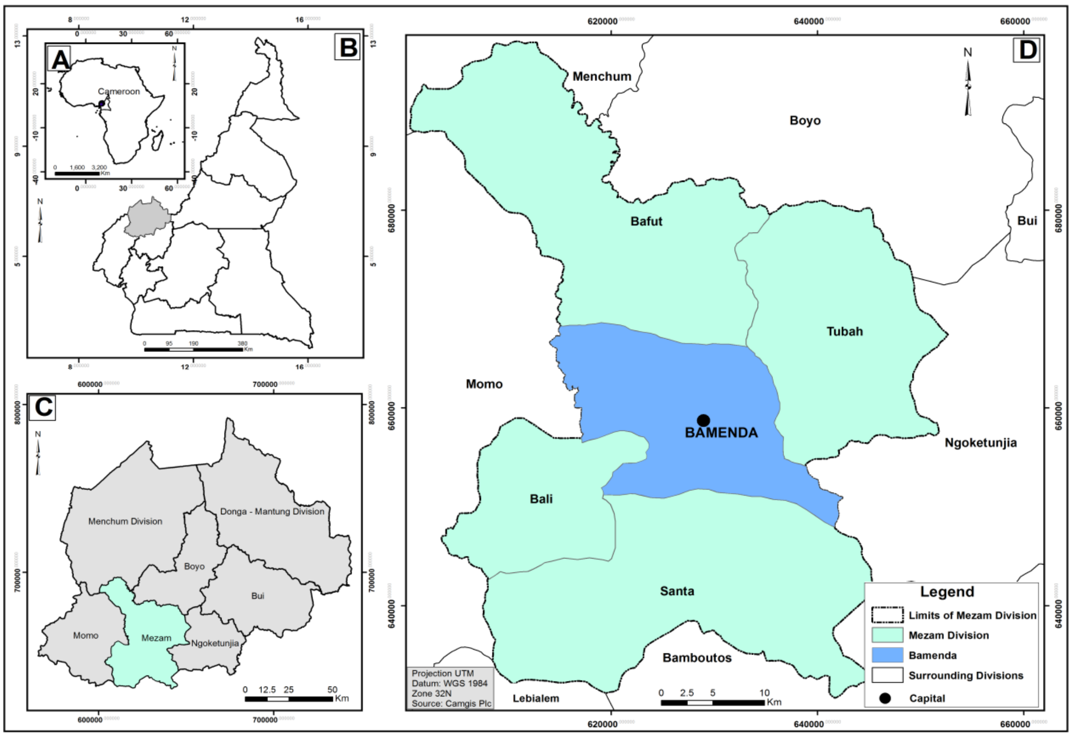

Figure 1: Location of the Study Area. A: Cameroon in Africa; B: NW Region in Cameroon; C: Mezam Division in the NWR; D: Bamenda in Mezam Division

Source: Camgis (Cameroon Geographic Information System Ltd)

- **Relief**

The study area lies along the Cameroon Volcanic Line, thus the topography is influenced by a series of volcanic activities that affected the area in the geologic past. The relief falls within the range of 1200-1868m and is characterised by very steep slopes, with slope angles ranging from 45° to 60° (Ndenecho and Eze, 2004). The morphology is characterised by a gentle sloping 'Up Station' area, with an altitude of about 1800m separated by an escarpment from an undulating to flat 'Down Town' area with an altitude of about 1200m (figure 2). The slopes along the escarpment are more than 35°. On the basis of elevation, Bamenda can be divided into nine geomorphologic units ranging from 1200m to about 1768m (figure 3).

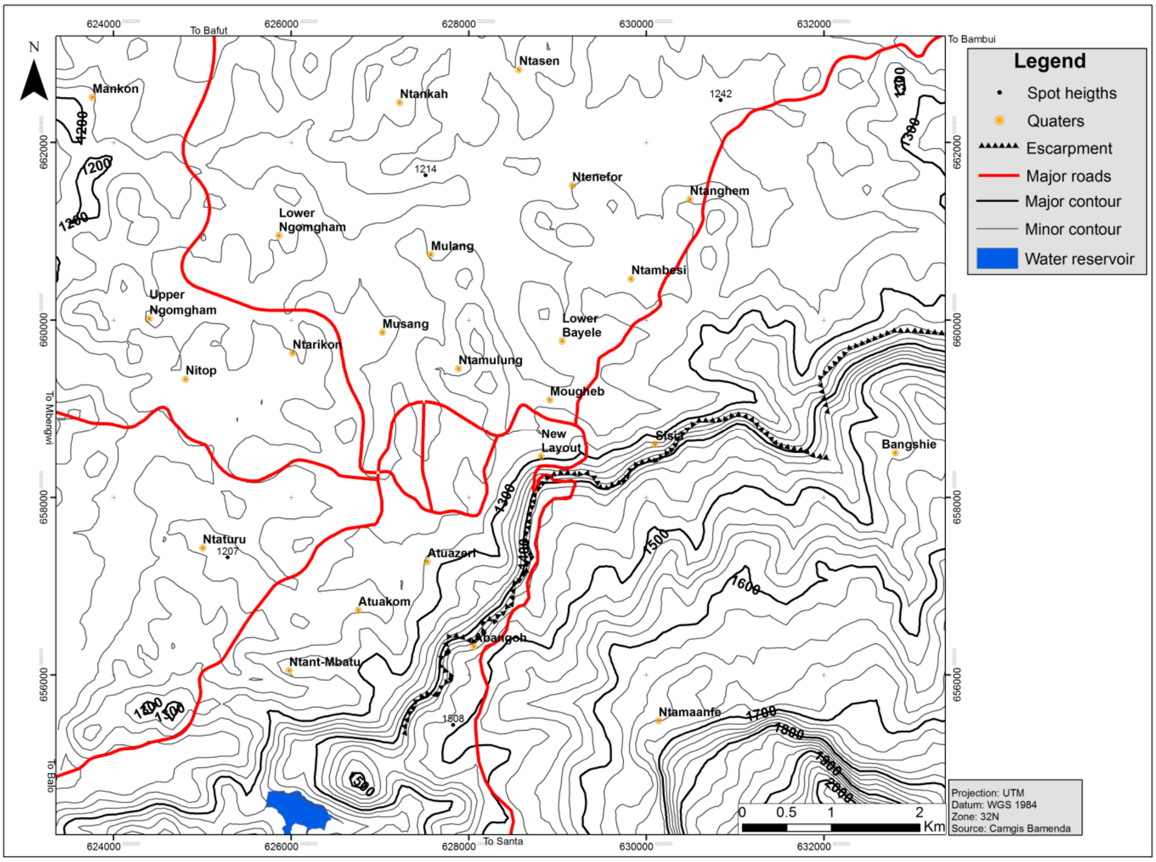

Figure 2: Relief map of the study area
Source: Camgis (Cameroon Geographic Information System Ltd)

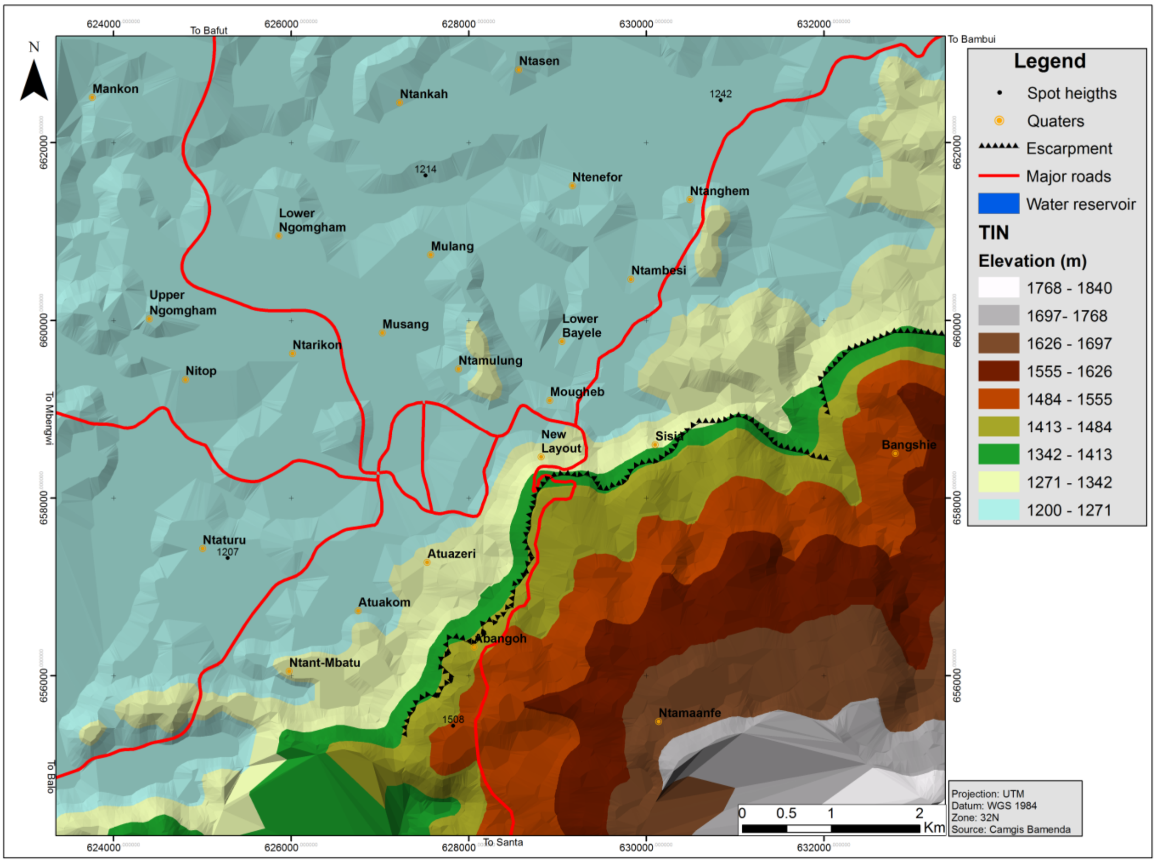

Figure 3: Triangulated Irregular Network (TIN) map of Bamenda showing the different geomorphologic units (Source: SRTM data)

- **Hydrography**

The hydrographical network of Bamenda portrays a typical dendritic pattern. The different streams that culminate to form River Mezam take their rise essentially from Mendankwe village and flow through Bamenda Town. The tributary streams then flow and drain the Town, merging at the lower part of the municipality to form River Mezam. Major streams include Yambot, Ayaba, Nkimufueh, Muogheb and Naaka streams (figure 4). In effect, there is a series of waterfalls aligned along the Bamenda escarpment, with some reaching heights above 150m and rejuvenating the streams. Since Bamenda Town is relatively a plan, the streams slow down creating floodplains with meanders where there is rapid deposition of sediments. This reduction in the velocity of streams plays a fundamental part as the contact time with the rocks is lengthened. During the months of August and September when the discharge of the waterfalls is greatly increased, they could be used to generate electricity. The waterfalls from the Bamenda escarpment could serve as touristic sites if developed.

❖ Climate

Bamenda experiences an equatorial type of climate with two major seasons: a long wet season of about eight months and a short dry season of about four months (table 1). The lowest annual precipitation occurs in January (3.96mm) and the highest in August (441.13mm). Monthly annual temperatures are lowest in August (17.15°C) and highest in March (20.65°C). The mean monthly rainfall and temperature are shown in table 1 and figure 5.

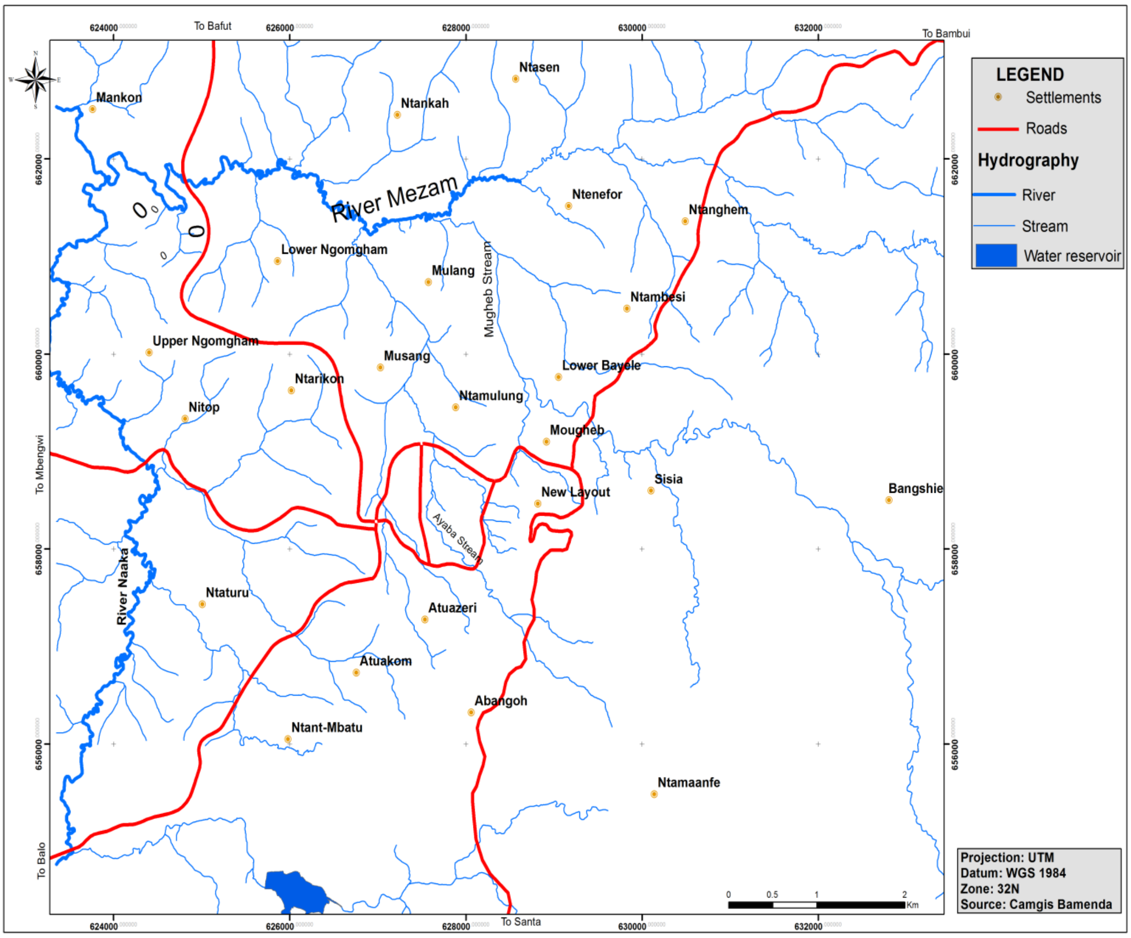

Figure 4: Drainage Network of Bamenda Town
Source: Camgis (Cameroon Geographic information System Ltd)

Table 1: **Mean monthly rainfall (mm) and temperature (°C) of Bamenda (2000-2011)**

Parameter / Month	Mean monthly Rainfall (mm)	Mean monthly Temperature (°C)	2T(°C)
January	3.96	19.25	38.50
February	20.19	19.65	39.30
March	85.89	20.65	41.30
April	191.77	19.4	38.80
May	186.43	19.05	38.10
June	316.57	18.7	37.4
July	397.71	17.25	34.5
August	441.13	17.15	34.30
September	417.21	17.45	34.90
October	235.58	18.1	36.2
November	54.86	18.6	37.20
December	18.14	18.95	37.90

Source: Bamenda Up Station Meteorological Service

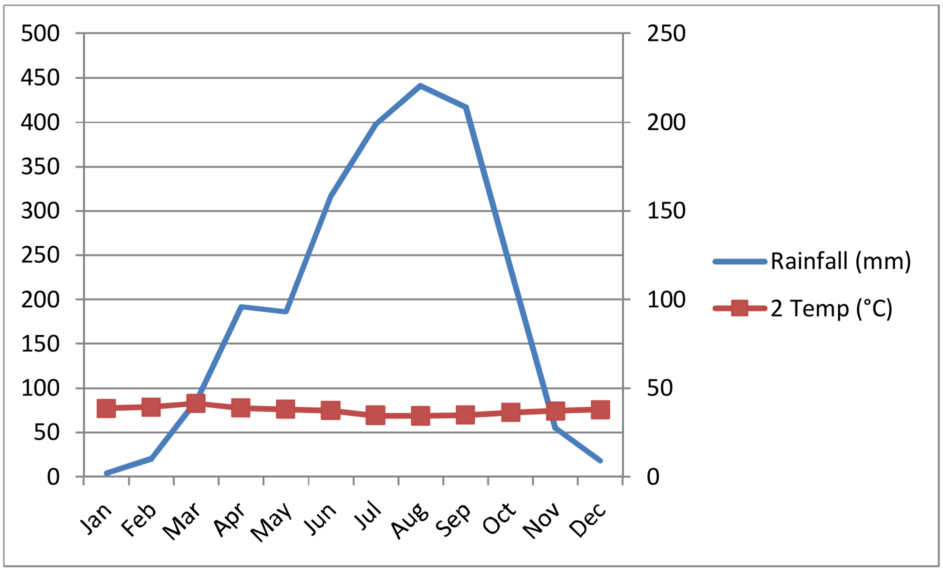

Figure 5: Rainfall-temperature diagram of Bamenda (Ombrothemic diagram)

- **Vegetation**

The North West Region is generally grassland savannah, that is, Sudan savannah which gives rise to the grassfield. However, the overall landscape coupled with climate gives varied vegetation, which is peculiar to the Region. Thus, the vegetation is partly savannah found in surrounding areas like Mbatu and Chomba highlands, part of Mendankwe, Banjah and most of Mankon. Little patches of forest area are found doted here and there. Due to population expansion, most of the natural forest has been destroyed for settlement and agriculture. The savannah vegetation is characterised by grasses such as elephant grass (*Pennisetumm purpareum*), short and stunted trees and shrubs. Raffia palms (*Raffia vinifera*) occur mostly in valleys. In some parts, the vegetation has been modified by the planting of eucalyptus trees (*Eucalyptus amygdalin*) especially in Mendankwe and on the Up Station escarpment in areas that are considered not suitable for agriculture in order to check erosion and landslides.

1.1.2. Human Geography

- **Population**

The population of Bamenda is estimated at 302,749 inhabitants from the third General Population and Housing Census of 2005, covering a total surface area of 3125ha. The population density is high with 352.30 persons per sq km (Neba, 2004). The highest concentration of population is found in Mankon and Nkwen. Other neighbouring zones with an appreciable population size include Mendakwe, Mbatu, Chomba, Banja and Nsongwa.

- **Economic activities**

Most economic activities are concentrated in the central part of Bamenda Town. The main roads, especially those that are tarred, function as nuclei of economic activities. The majority of commercial enterprises, the main market, Regional hospital, banks, and insurance companies, food processing industries, garages, metal working industries and delegations of ministries are concentrated in the core of the town. In short, in the city of Bamenda, there are people of all occupations, ranging from the “buyam-sellams”, business people, civil servants and farmers. Urban agriculture is practiced everywhere in the city of Bamenda on small strips of land in between houses and near waterways (Anschütz *et al*., 1995).

1.2. LITERATURE REVIEW

1.2.1. Geological setting

The geological setting of Bamenda forms part of two important geological events: the Cameroon Volcanic Line (CVL) and the Pan-African North Equatorial Fold Belt (PANEFB). Volcanic rocks of the study area are associated with activities of the CVL while the basement rocks are linked to activities of the PANEFB. The Bamenda Highlands are an integral part of the West Cameroon Highlands of the CVL, which include the Bambouto, Bamenda and Oku Mountains (figure 6). The Bamenda Highlands are found between Mount Oku to the Northeast and Mount Bambouto to the Southwest (Kagou *et al*., 2010). The Bamenda Highlands (600km^2) are the fourth largest volcano of the CVL and is the NE extention of the Mount Bambouto, with no clear-cut distinction.

❖ **The Pan-African North Equatorial Fold Belt**

The crystalline basement rocks (granites and gneisses) of Bamenda Town are associated with the Pan-African North Equatorial Fold Belt formations (Nzenti *et al*., 2010). This Fold Belt in Cameroon has been demarcated into 3 major domains (figure 7), namely, a Northern domain, a Central domain and a Southern domain (Nzenti *et al*., 1994; Ngnotué *et al*., 2000; Nzenti *et al*., 2006). The Central domain constitutes a bridge between the Northern and Southern domains. The Bamenda Highlands in the Pan-African North Equatorial Fold Belt (PNEFB) in Cameroon or Central African Orogen, is a major Neoproterozoic Orogen linked to the Trans-Saharan Belt of Western Africa and to the Brasiliano Orogen of NE Brazil. The Central Cameroon domain is characterised by many syn-to post tectonic granitoid outcrops and, through fracturing, there was the formation of the Central Cameroon Shear Zone (CCSZ), which is a series of strike-slip faults trending N70°E (Ganno *et al*., 2010; Kouankap *et al*., 2013). The principal characteristics of the PANEFB in Cameroon have been presented in earlier works by Nzenti *et al*. (1992) ; Nzenti (1998) ; Ngako (1999); Ngako *et al*. (2003); Ngnotué *et al*. (2000), Toteu *et al*. (2004); Nzolang *et al*. (2003) and Tanko Njiosseu *et al*. (2005).

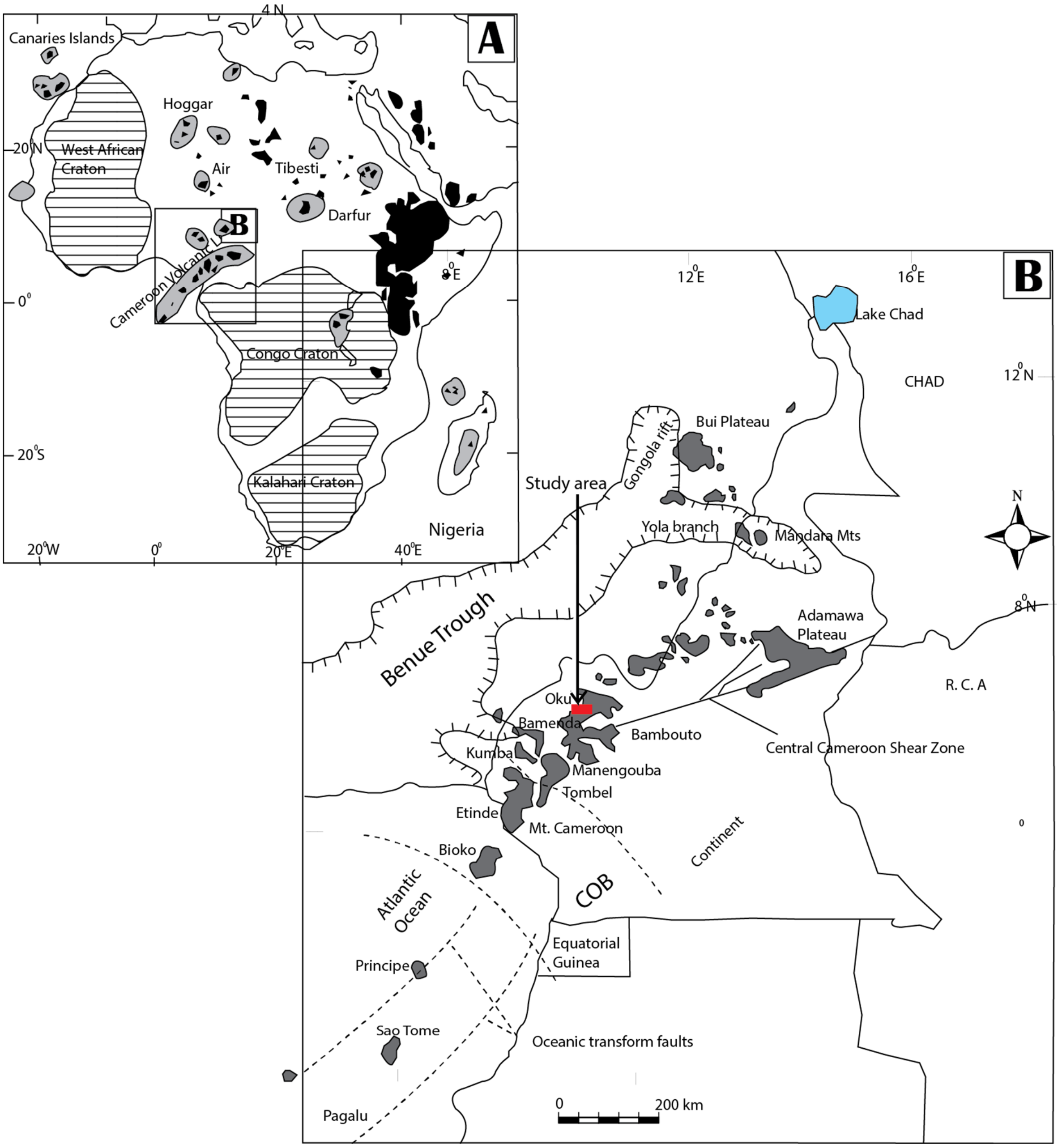

**Figure 6: Geological setting of the study area (Modified from Kamgang *et al*., 2010). A: The position of the CVL in the African continent;
B: Alignment of oceanic-continental volcanic massifs in Cameroon.**

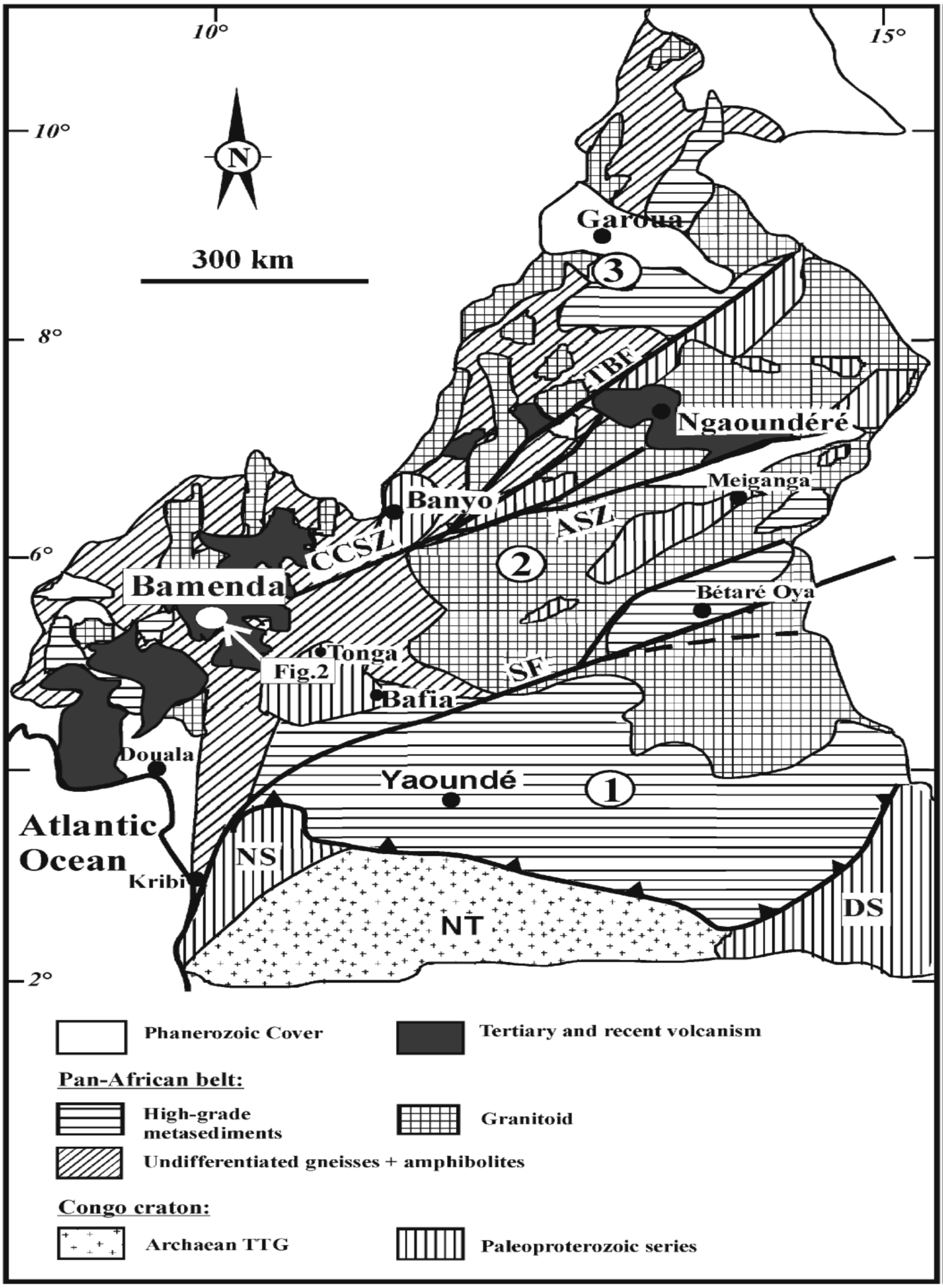

Figure 7: Geological map of Cameroon with the three domains of the Pan-African North Equatorial Fold Belt (modified from Nzenti *et al*., 2010). 1: southern domain corresponding to the Yaoundé series thrust on the Congo Craton; 2: Central domain; 3: northern domain. Granitoid groups are not distinguished owing to large scale. TBF, Tibati-Banyo fault; CCSZ, Central Cameroon Shear Zone; SF, Sanaga Fault; ASZ, Adamaoua Shear zone; NT, Ntem complex; DS, Dja series; NS, Nyong series The Bamenda area is marked by a circle

❖ The Cameroon Volcanic Line

The Cameroon Volcanic Line is characterized by alignments of oceanic and continental volcanic massifs that stretch from Pagalu Island in the Atlantic Ocean to Lake Chad (figure 6) and is composed of an active intraplate alkaline magmatic chain that transects both the oceanic and continental lithospheres (Fitton, 1987; Déruelle *et al., 1991;* Déruelle *et al*., 2007). The volcanism of the CVL started at the end of Cretaceous and a few volcanoes are still active today at Mount Cameroon as exemplified by the 1999 and 2000 eruptions (Suh *et al*., 2003). From previous studies carried out along the CVL, three distinct sectors have been identified: 1) The oceanic sector (Annobon, Sao Tome and Principe), 2) The continent/ocean sector (Bioko, Etinde and Mt. Cameroon) and 3) The purely continental sector. This sector of the chain is constituted of tens to hundreds of kilometers of volcanic massifs that include Manengouba, Bambouto, Bamenda and Oku mountains (Tchuimegnie *et al*., 2015). The volcano of the Bamenda Highlands differs from the other volcanoes of the continental segment of the CVL by the presence of large volumes of ignimbritic flows, mafic and felsic lavas which occur in abundance (Kamgang *et al*., 2008). The origin of the mafic rocks of the Bamenda Highlands is shown to have come from magmas originating in the mantle but later research by Kamgang *et al*. (2010) revealed that there has been contamination of the original mantle magma as it traversed the continental crust to the surface. Petrographical and geochemical studies revealed that the Bamenda Highlands consist of basanites, basalts, hawaiites, mugearites, benmoreites, trachytes, phonolite and rhyolitic ignimbrite (Kamgang *et al*., 2008). Ignimbritic deposits are found mainly in the continental part of the CVL, particularly in the Bamenda Highlands and Mount Bambouto. Radiometric dating of the rocks of the Bamenda Highlands revealed ages ranging from Recent to 17.4Ma for the basaltic lava and 18.98Ma to 27.40Ma for the felsic lavas (Kamgang *et al*., 2010).

1.2.2. Hydrochemistry of the Cameroon Volcanic Line

The volcanic massifs of the continental sector of the CVL (consisting of Mount Cameroon, Manengouba, Bambouto, Bamenda and Oku) constitute a predominant watershed to the country (Molou and Lambi, 2006). There are many crater lakes (Manengouba, Barombi Mbo, Monoun, Awing, Bambili, Nyos, Wum, etc) along the CVL that resulted from explosive volcanic activities. Some of the rivers taking their rise from the Western Highlands include the Mezam River which originates from the Bamenda Highlands, the Manyu River originating from Mount Bambouto, River Mbam from the Oku, Bambouto and Bamenda massifs.

Many hydrochemical research works have already been carried out along the CVL. These include the work of Tanyileke *et al*. (1996) that examined the chemical and isotopic characteristics of fluids along the CVL and showed that Lake Nyos and Lake Monoun have Fe-Mg-Ca-HCO_3 meanwhile the soda spring was found to be of Na-HCO_3 type. Kotaba spring was found to be the least mineralized (TDS=8mg/l) and most acidic (pH=4) and lacks the common outgassing feature of the CVL springs. The author indicated that Na^+ (40-95%) was the dominant cation in the springs while Fe^{2+} and Mg^{2+} (70%) were abundant in the CO-rich lakes. HCO_3 (>90%) was found to be the most abundant anion with the exception of the soda spring except for the coastal lakes where $Cl^-$was predominant. The author established that the dominant source of CO for Lake Nyos, Monoun and other lakes along the CVL is magmatic.

In the Upper Plateau of West Cameroon, Nono *et al*. (2004) investigated the influence of lithology and geologic structures on the quality and dynamism of groundwater and found out that the water contained calcium and magnesium chloride, calcium and magnesium bicarbonate, as well as sodium and potassium bicarbonate, which were not related to the geology of the area. They observed that the mineralization was as a result of the rock types at depth and the low degree of alteration of the rocks (≤587mg/l). High values were gotten from basaltic terrains. They noted that the productivity of boreholes ($20m^{3/}h$) was linked to the degree of fracturation and nature of the rocks.

Chakam *et al*. (2005) investigated the physico-chemical characteristics of the two Manengouba stratovolcanic lakes (Eboga: Male and Female Lakes) and Baré springs and showed that the water contained calcium, magnesium and sodium (Ca> Mg > Na), and bicarbonates (31.72±0.02mg/l for the Male Lake and 13.42±0.02mg/l of HCO_3^- for the Female Lake). This work reports that the water of the Lakes was soft (15.00±0.02mg/l and

80.00±0.01mg/l of $CaCO_3$ respectively), slightly mineralized (50.09±0.02mg/l and 120.85±0.2mg/l) and with low electrical conductivity (52.86 and 127.53µS/cm). Also, the spring presented different characteristics, with the cations in the order of Na> Mg> Ca, high bicarbonate ion concentrations (683±2mg/l for $Baré_1$ and 1128±2mg/l for $Baré_2$) and were hard (230±1mg/l of $CaCO_3$ for $Baré_1$ and 306±1mg/l of $CaCO_3$ for $Baré_2$), relatively mineralized (961.31±2mg/l and 1325.84±2mg/l) and had higher conductivity (1267 and 1748 µS/cm).

The hydrochemistry of shallow groundwater and surface water in Ndop plain, North West Cameroon was studied by Wirmvem *et al.* (2013) and showed that the water sources were acidic, with average pH values of 5.9 for groundwater samples and relatively higher pH values of 6.8 for surface water samples. Both surface and groundwater samples were low mineralized and fresh, presented low values of electrical conductivity and total dissolved solids of 60µS/cm and 39mg/l respectively, showing major ion concentrations in the order of Ca^{2+}>Mg^{2+}>K^+ for cations and HCO_3^->> NO_3 ≥Cl >SO_4^{2-} for the anions. The author noted concentrations of SiO_2 that were higher than those of the individual cations but below the mean value of HCO_3^-. They observed that the SiO_2 emanates from the weathering of granitic rocks which are rich in silicate minerals. They noted that the high total dissolved solid contents of groundwater resulted from the granitic bedrock materials through which the water percolates. The hydrochemical facies revealed a mixed water type of Na-Ca-HCO_3.

Nitrate contamination of groundwater in two areas of the CVL (Banana Plain and Mount Cameroon area) was investigated by Ako *et al.* (2014) and discovered that groundwater in the Banana Plain was moderately acidic to mildly alkaline with pH values varying between 4.30 and 7.85, while in the Mount Cameroon area groundwater was neutral to mildly alkaline (pH 6.97–7.98). Average cation concentrations occurred in the order Ca > Na > Mg > K in the Banana Plain, while in the Mount Cameroon area the order was Ca > Na > K > Mg. For the anions, the order was HCO_3> NO_3> SO_4> Cl in the Banana Plain and HCO_3> SO_4> Cl > NO_3 in the Mount Cameroon area. Water groups represented by Ca–Mg-HCO_3 and Na–K-HCO_3 were weakly mineralized, circulating within the basaltic and scoriaceous aquifers of the Banana Plain and the Mount Cameroon area. They observed that Ca–Mg-Cl and Na–K-Cl water types were indicative of anthropogenic pollution. According to the authors, the source of Cl, SO_4, NO_3 and Na ions in groundwaters were mostly agricultural fertilizers, animal wastes and industrial and municipal sewage, indicating the influence of human activities on water chemistry. They noted that about 6% of groundwater samples in the Banana Plain and 0% in the Mount Cameroon area were not suitable for drinking without prior treatment, with respect to the WHO and Cameroon Water Quality Norms for drinking water, nitrate concentration should not exceed 50mg/l in drinking water (WHO, 2004). The authors established that nitrate was the main anionic species in both agricultural and urban areas and that in the Banana Plain, nitrate was the second most abundant anionic species, while in the Mount Cameroon area, it occupied the last position.

Studies carried out in the lake Nyos area by Kamtchueng *et al.* (2014) showed that both spring and surface water samples had mean pH values of 7.1 and were weakly acidic. The soda spring presented a relatively higher mean temperature (24°C), attributed to heat generated due to exothermic and thermodynamic reaction between CO_2 rich water and the surrounding rock. All the investigated samples were fresh (TDS$<$1,000 mg/l) and soft (TH$<$60 mg/). Chemically, they noticed that about 95% of the investigated samples were rich in alkaline earth metals (Ca and Mg) and weak acid (HCO_3). The average concentration (mg/l) of dissolved species in the samples was in the order of Ca $>$Mg $>$Na $>$K for the cations and HCO_3 $>>>$ Cl $>SO_4$ $>NO_3$ for the anions. The author pointed out that high concentration of HCO_3 is indicative of intense chemical weathering processes taking place in the aquifer.

Also in the lake Nyos area Kamtchueng *et al.* (2015) worked on groundwater and surface water observed a narrow seasonal variation in surface and groundwater temperature but noticed that surface water temperatures were lower in the dry season than in the wet season, suggesting that the surface water was supplied by groundwater in the dry season. However, higher temperature values were recorded in both seasons in the soda spring. The observed pH range suggests a slightly acidic to alkaline water. Lower values of EC and TDS were obtained in the wet season possibly due to dilution by precipitation. With the exception of soda springs, the sampled waters were generally oxic as the dissolved oxygen (DO) concentration ranged from 1.02 to 5.25 mg/l.

In the Nkoup River System in Foumbot Tita *et al.* (2009) investigated the microbiological pollution and observed high concentrations of indicator bacteria from almost all the water samples, exceeding the WHO (1993) limits for drinking water. Specific pathogens investigated were Salmonella, Shigella and Vibrio cholera which were detected at the sampling sites at different times, with Salmonella being more recurrent than Shigella and *Vibrio cholera* and the highest concentrations were recorded in the dry season and at the start of the rainy season.

A microbial investigation of the Mezam River system in Bamenda was equally carried out by Tita *et al.* (2013) and found out that all water samples contained all the indicator bacteria that were analysed, exceeding the WHO (2001) limits except tap water. Coliforms and *Clostridium* spores were shown to be dominant while further analysis of the coliforms showed that faecal coliforms were present in all the samples. However, faecal Streptococci were more abundant than *Pseudomonas* sp. They observed a spatial difference in the faecal indicator bacteria with urban sites recording the highest counts while lower counts were measured at upstream sites. They showed that this low quality water could be the source of the high prevalence of waterborne diseases in Bamenda Town as less than 20% of the population use tap water for drinking and more than 60% use either spring, well or river water for domestic chores and irrigation of vegetables.

1.3. Conclusion

The study area is situated at an altitude of about 1200-1840m above sea level with a cold climate where temperatures vary from17.15-20.65°C. There are two main seasons and rainfall varies throughout the year with the lowest recorded in January and the highest in August. The vegetation is typically grassland savannah, which has been modified in many areas by the planting of secondary forest (eucalyptus). Bamenda Town is drained by the Mezam River and tributary streams which originate below the Bamenda Highlands and flow through residential and commercial centers. The study area is covered by volcanic massifs of the CVL which are underlain by granito-gneissic basement of the Panafrican North Equatotial Fold Belt. Earlier hydrochemical studies along the CVL have revealed that water chemistry is a function of the lithological types and various anthropogenic activities carried out in different geographical settings. Agricultural practice in Bamenda Town coupled with industrial activities and wastes from point and non-point sources that flow into the Mezam River lead to impairment of the water quality. This research was therefore intended to analyse water quality in Bamenda Town in function to its geological setting in order to determine its fitness for domestic purpose.

CHAPTER 2
MATERIALS AND METHODS

2.1. INTRODUCTION

This chapter presents the field and laboratory methods used in the investigation of rock samples and ground and surface water samples from Bamenda Town. Petrological studies involved field work during which rock outcrops were identified, located and field occurrences were studied. Fresh rock samples were collected and macroscopic observations were made. The petrography was determined from rock thin sections prepared in the laboratory and whole rock geochemical information was gotten through laboratory analyses of the rock samples. Water quality assessment comprised analyses of the physical, chemical and bacteriological characteristics of the ground and surface water samples conducted on the field and in the laboratory.

2.2. FIELD WORK

2.2.1. Sampling Points

The study area stretches from Mendankwe village below the Bamenda Highlands through the Bamenda escarpment to Down Town Bamenda, covering Bamenda I, II and III Subdivisions to the Lower Ngomgham area where River Mezam exits the Town of Bamenda. In order to select suitable sampling points, reconnaissance surveys were carried out to identify rock exposures and the most appropriate points at which rock samples, ground and surface water samples could be collected. The selected sampling points and their corresponding codes are presented in table 2. The altitudes, latitudes and longitudes at the various sampling points were obtained with the help of a Garmin Vista CX GPS.

Table 2: Sampling points and their corresponding codes in the study area

Sampling Point	Rock sample codes	Ground water codes	Surface water Codes	Elevation (m)	Latitude	Longitude
Yambot (Mendankwe)	RSY21-27	SW0	YB	1652	N05°55’56”	E10°11’12”
Bayelle segment	RSB1-8	SW1	BB	1216	N05°57’58”	E10°09’49”
Nkimufueh segment (Mile 4)	RSK1-5	SW4	NM	1234	N05°59’08”	E10°10’31”
Ayaba segment	*	SW2	AS	1237	N05°57’33”	E10°08’51”
Lower Ngomgham	RSL1-6	WW2	LN	1222	N05°59’07”	E10°07’40”
Naaka	*	SW3	NB	1221	N05°55’22”	E10°06’55”

*rock samples that were not selected

The sampling point at Yambot (YB) is located below the Bamenda Highlands where the water flows on trachytic rocks. There is neither habitation nor agricultural activity above this point to interfere with the quality of the water. The YB sampling point therefore serves as a reference point. At sampling point BB, the water has drained a considerable section of habitation, the Nkwen market, garages and agricultural land. The sampling point NM is found along the stream where wastewater from the Bamenda slaughterhouse is discharged. The sampling point AS is located where drainage from the Old Town quarter, the Commercial Avenue, garages, hair dressing salons and a dense population has been emptied into the stream. The LN sampling point is found after the Mile 6 Mankon dumpsite where River Mezam flows out of the Bamenda municipality. Sampling point NB is located in a sparsely populated area where the dominant activity is agriculture.

SW_0 is a spring source found below the Bamenda Highlands where the water comes out from rocks beneath a thick over burden and there is no habitation in the vicinity. This point serves as a reference point for the groundwater sampling points. SW_1 is equally a spring source having a thick overburden where the water comes out from rocks below the Bamenda escarpment and is highly used by the population of Sisia quater as a source of drinking water and for domestic chores. SW_2 is located in a densely populated area while SW_3 and SW_4 are found in sparsely populated areas where agriculture is carried out. WW_1 and WW_3 are hand-dug wells that are used for domestic chores and drinking by some residents with water abstracted using buckets meanwhile WW_2 is a borehole with a submerge engine which pumps the water out. The different sampling points are shown in figure 8.

2.2.2. *In situ* measurement of physical parameters

The following physico-chemical parameters of water were determined on the field:

- **Temperature**

This parameter was measured with the aid of a thermometer. At each sampling point, a sample of water was collected in a 1.5 liter container and the bulb end of the thermometer dipped into it for two minutes for the thermometer reading to stabilise. Once it was stable, the temperature was taken.

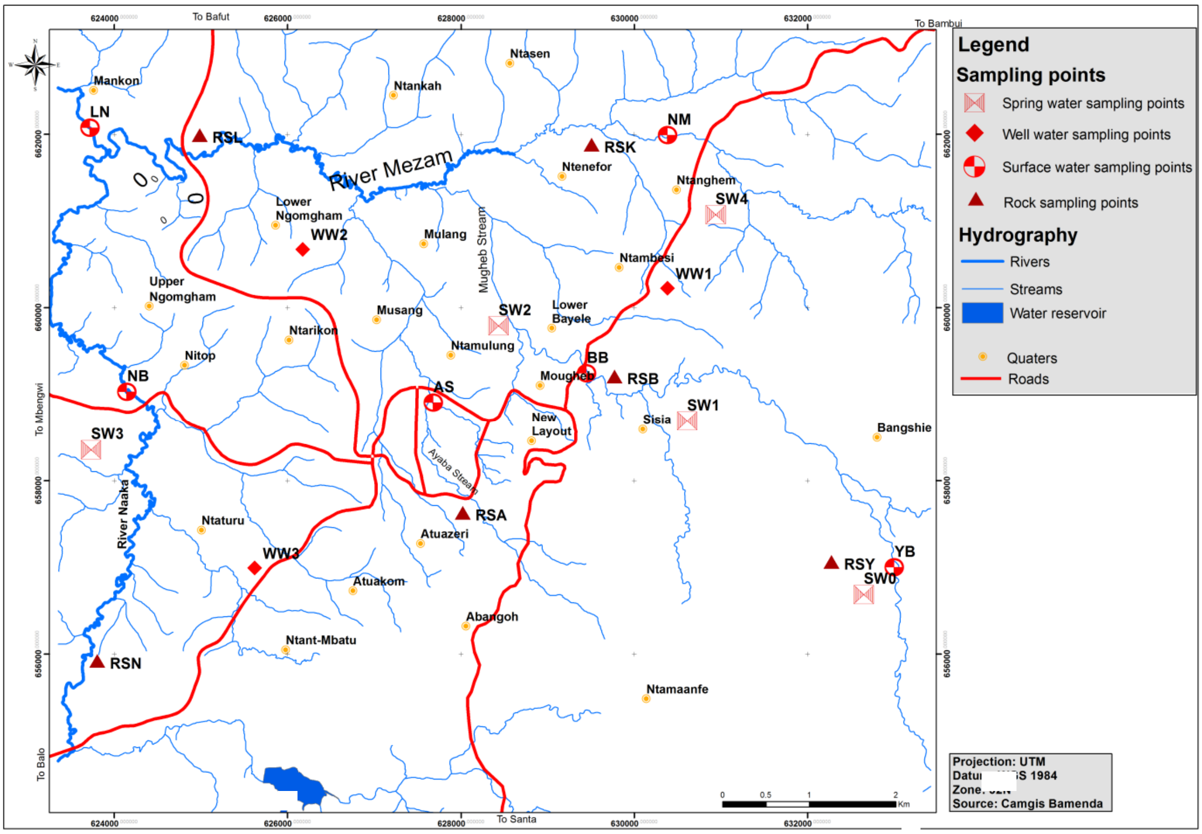

Figure 8: Location of sampling points in the study area
Source: Field work in 2013

- **pH**

This was measured with the use of pH test strips. A water sample was collected and the test strips were dipped into it and removed immediately. The pH test pads were compared with the colours on a pH meter. The pH values were later on validated in the laboratory.

- **Turbidity**

The turbidity was measured using a turbidimeter by allowing a beam of light to be projected towards a container of the water sample and the proportion of light which was reflected at an angle of 90° by the particles present in the sample was measured. The reflected light measured was proportional to the turbidity measured in Nephelometric turbidity units (NTU).

- **Electrical Conductivity**

This parameter was measured with the help of a TDS hand-held meter

- **Disolved Oxygen**

The dissolved oxygen (DO) was determined using a portable oxymeter.

2.2.3. Collection of Samples and Preservation

- **Rock sampling**

Rock exposures were identified during the reconnaissance survey. These exposures were selected in the vicinity of the surface and groundwater sampling points. Three fresh rock samples were collected at each site using a 3kg geological hammer: one for a macroscopic observation, a second sample for thin section preparation and a third one for whole rock geochemical analysis.

- **Water sampling**

Water sample were collected between 6.00am and mid-day in January (dry season), April (onset of rains), and October (end of rainy season) in 2013.

All the sampling points were fairly accessible, so collection was done directly by submerging the container facing the upstream direction for surface water at fast flowing points of the water body. The samples were collected in 1 liter plastic containers and all the containers were rinsed thoroughly, with distilled water and then, with the water to be sampled.

Sampling from hand-dug wells involved the use of a bucket with a rope tied to it and lowered into the well and when sufficient quantity was collected, it was pulled out and its content poured into the container. Water samples from boreholes were collected by pumping the water directly into the container. Immediately after collection, each sample was capped, labeled and placed in an ice box for transportation to the laboratory. Samples for major ion analyses were filtered through a 0.45 m membrane filter which allowed the removal of particles and bacteria that could modify the contents as specified by Atteia (2005). For the samples meant for cation analysis, 1% nitric acid with a pH of less than two was added to keep metal ions in solution (Rodier, 1996). A total number of 64 samples were collected; 36 from the Mezam River and tributary streams, and 28 from springs and wells.

2.3. LABORATORY ANALYSES

2.3.1. Analyses of rock samples

Analyses of rock samples involved petrography and whole rock geochemistry.

- ❖ **Petrography**

Representative fresh samples of igneous rocks from the study area were selected and sent to Geotech Laboratory in Vancouver, Canada, where thirty standard thin sections were made. Microscopic observation was carried out with the use of a petrographical microscope in the Laboratory of Geology of the Higher Teacher Training College (HTTC) Bambili in The University of Bamenda.

- ❖ **Whole rock geochemistry**

The whole rock geochemistry for full elements was performed by the commercial laboratory ALS based in Vancouver, Canada.

- **Major elements**

The method used for the analyses of major elements was the Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). A prepared sample (0.200g) was added to lithium metaborate/lithium tetraborate flux (0.90g), thoroughly mixed and fused in a furnace at 1000°C. The resulting melt was then cooled and dissolved in 100ml of 4% nitric acid/2% hydrochloric acid. The solution was then analysed by ICP-AES and the results corrected for spectral inter-element interferences. The oxide concentration was then calculated from the determined elemental concentration.

- **Heavy metals**

The analysis of heavy metals was carried out by the Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS). A prepared sample (0.200g) was added to lithium borate flux (0.90g), thoroughly mixed and fused in a furnace at 1000°C. The resulting melt was then cooled and dissolved in 100ml of 4% nitric/2% hydrochloric acid solution. The solution was then analysed by the ICP-MS method.

2.3.2. Analyses of ground and surface water samples

The physical and chemical parameters were analysed in the Laboratory of Soils and Environmental Chemistry while the bacteriological parameters were conducted in the Laboratory of Animal Physiology and Microbiology, all of the Faculty of Agronomy and Agricultural Sciences (FASA) of the University of Dschang.

- **Physico-chemical Parameters**

- **Suspended Solids**

The suspended solid load of the water samples was determined by directly evaporating 1 liter of the sample in a 105ºC oven in an evaporation dish for 24 hours. The evaporation dish was weighed before and after the experiment, when all the water has evaporated, it was allowed to cool to room temperature in a decicator and weighed again. The suspended solid content was gotten from the difference between the weight of the dried residue plus dish after 24 hours at 105ºC and the weight of dish.

- **Major cations**

The major cations that were determined in the water samples included calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K). The techniques employed was the Flame Atomic Absorption Spectrometry (FAAS) for Ca and Mg while Na and K were determined using the Flame Atomic Emission Spectrometry (FAES) as described by Fifield and Haine (1997). All values are expressed in mg/l.

- **Major anions**

The chloride ion was determined by titration method in which 10ml of the water sample was pipette into a 250ml flask and diluted by adding 65ml of distilled water. 1ml of potassium chromate was added to the flask. The water sample was titrated by adding $AgNO_3$ which reacted with the chloride to form a brown coloration. The bicarbonate ions were determined spectrophotometrically using bromocresol green (BCG). The sulphate ion was measured using barium iodate because sulphate ions react with it liberating iodate ions that oxidized tannin to form a brown-red compound that is determined photometrically.

- **Nutrients (PO_4^{3-}, NO_3^- and NH_4^-)**

The phosphate was measured using ammonium molybdate and potassium antimonyl tartrate which react in acid medium with orthophosphate to form phosphomolybdic acid that is reduced to molybdenum blue by ascorbic acid and determined photometrically (Franson, 1995). The nitrate ion was measured using concentrated sulphuric acid because nitrate ions react with a benzoic acid derivative to form a red nitro compound that is determined photometrically. The ammonium ions were obtained using indophenol blue in the colometric method in which the NH_3 in the water sample reacted with pheate to produce a blue colour in the presence of hypochlorite as an oxidizing agent (Koroleff, 1976).

- **Heavy Metals**

The heavy metals (iron (Fe), copper (Cu), lead (Pb), cyanide (CN), zinc (Zn), boron (B) and arsenic (As)) were determined using the atomic absorption spectrometry method and X-ray fluorescent analyses as described by Bassett *et al.* (1986).

➢ **Bacteriological Analyses**

Surface and groundwater samples were analysed for indicators of faecal contamination. The analyses were carried out for coliform bacteria such as *Escherichia coli (E.coli)*, *Streptococci, Salmonella* and *Pseudomonas* which provide a definite evidence of faecal pollution (Sandy and Feachem, 1998).

- ***E. coli***

E. coli was determined using sterile MacConkey broth by the Most Probable Number (MPN) method described by Cheesbrough (1991). The method consists of filling five tubes of 10ml and one of 50ml containing the sterile MacConkey broth (purple) with the sampled water and using lactose as an indicator. The culture was then incubated at 44^oC for 24 hours in a water bath. The fermentation of lactose produced an acid which was indicated in the bottles by a change in colour from purple to yellow, and a gas bubble observed in the tube. With the use of probability tables, the quantity of coliforms in the water sample was then established.

- **Salmonella**

A Salmonella agar plate was prepared from Salmonella agar, which is a selective medium for the growth and identification of Salmonella bacteria following the instructions of the manufacturer. 1ml each of the water sample was spread on each of the plates and incubated at 44°C for 24 hours under aerobic conditions (Cheesbrough, 1991). The salmonella colonies appeared dark green in colour.

- **Streptococcus**

Agar plates were prepared from a Columbia medium following the manufacturer's instructions. This is a selective medium for the growth and identification of Streptococcocus. 1ml of each water sample was spread on the prepared agar and incubated at 44°C for 24 hours under anaerobic conditions and the Streptococcus colonies appeared black (Cheesbrough, 1991).

- **Enterobacteria**

Enterobacteria was determined by the methyl red and Voges-Proskauer (MR-VP) tests. The methyl red and Voges-Proskauer broth was prepared as directed by the manufacturer. The MR-VP broth was incubated for 48 hours at 35°C. This is based on the fact that microbes ferment sugars and release CO_2 and H_2. The Enterobacteria culture had a yellow colour indicating low acidic medium (Madigan and Martinko**,** 2008).

- **Proteus**

Proteus in the water samples was determined by the triple sugar iron (TSI) technique described by MacFaddin (2000) in which the Proteus utilized thiosulfate anion as a terminal electron acceptor, reducing it to sulfide. The hydrogen sulfide (H_2S) reacted with ferrous sulfate in the medium to form ferrous sulfide, which was visible as a black precipitate observed at the bottom of the medium.

2.4. CONCLUSION

After collecting the various rock and water samples, and performing the different scientific analyses described above, sufficient data was obtained on the petrology of igneous rocks, physico-chemical and bacteriological characteristics of surface and groundwater in Bamenda Town and is presented in the preceding chapter.

CHAPTER 3
PETROLOGY OF IGNEOUS ROCKS OF BAMENDA TOWN

3.1. INTRODUCTION

The Town of Bamenda is composed mainly of igneous rocks of two main groups: plutonic and volcanic. The plutonic rocks are granite and leucogranite, linked to the Pan-African North Equatorial Fold Belt and are K-granitoid and Na-granitoid respectively. The volcanic rocks are made up of basalt and trachyte, which are basic and acid rocks respectively. This chapter presents the results of thin section observations and whole rock geochemistry of the studied rock samples.

3.2. PETROGRAPHY

Bamenda Town is made up mainly of igneous rocks: plutonic rocks, which constitute the basement formation and are in turn covered in many areas by volcanic rocks.

3.2.1. Petrography of Plutonic rocks from Bamenda Town

Plutonic rocks are mainly granitic rocks, which outcrop mostly in streambeds, valleys and on hill slopes in Bamenda Town. Based on the colour of fresh samples and the relative abundance of minerals, the granitic rocks have been separated into two groups corresponding to two different rock types: leucogranite for the leucocratic or light group and granite for the mesocratic or light grey group of rocks. Plotted in the nomenclature or classification diagram of Total Alkali versus Silica of Middlemost (1994), all the samples fall into the granite domain (figure 9).

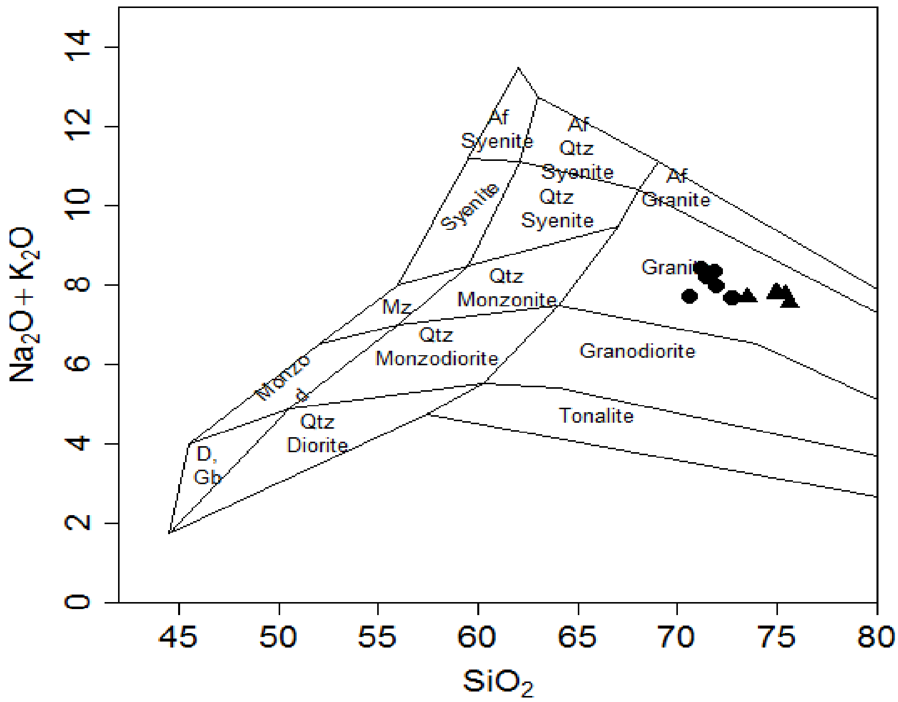

Figure 9: TAS diagram of Middlemost (1994), showing the positions of the samples within the granite domain (Granite●, Leucogranite ▲)

❖ Leucogranite

Leucogranite outcrops as boulders of varying sizes ranging from about 5 meters to about 25 meters in diameter and at stream channels, as flagstones. Fresh samples show a light colour with some dark patches (figure 10A &B). Thin section studies present a granular porphyritic texture with the main minerals being quartz (50–60 vol.%), plagioclase (20–25 vol.%), K-feldspar (10–15 vol.%), micas (5–10 vol.%) and opaque minerals (1–05 vol.%). Quartz crystals are polycrystalline sub-automorphs to xenomorphs in association with plagioclase. They are the main minerals of the rock. Plagioclase displays different forms and sizes (1-1.5mm). The larger crystals are automorphs, and contain inclusions of opaque minerals. Some of the large plagioclase crystals are fractured and these cracks are filled with fine grains of quartz. Micas are present as both biotite and muscovite. Their crystals are anhedral (mica flakes) and contain inclusions of opaque minerals.

❖ Granite

Granite also outcrops as boulders of various dimensions, ranging from about 5 meters to about 50 meters in diameter. The rocks are medium-grained and light grey in colour (figure 10E & F). Under the microscope, the sample displays heterogranular texture with modal composition made up of K-feldspar (20–30 vol.%) , quartz (15–25 vol.%), plagioclase (10–20 vol.%), biotite (15–20 vol.%), amphibole (5–10 vol.%) and opaque minerals (1–05 vol.%). Quartz presents two habitus, phenocrystals which are xenomorphs with undulatory extinction and varying crystal sizes (0.3-3.8mm) which are sub-automorphs generally associated with K-feldspars. K-feldpars present here are large xenomorphic crystals of orthoclase exhibiting various sizes (1-4.3mm) which at some portions react with quartz to form myrmekites (figure 10G). Amphiboles are greenish hornblende with elongated-shaped crystals that present a destabilization with biotite at some portions.

❖ Gneisses

Gneisses outcrop at Newlayout-Nkwen and in the River between Nkwen market and Bayelle. At Newlayout they align with quartzofelspathic veins. Boudin structures are visible on some while on others pinch and swell could be observed. Between Nkwen market and Bayelle, the stream bed consists of gneisses, some showing folded structures, with normal and recumbent folds being common.

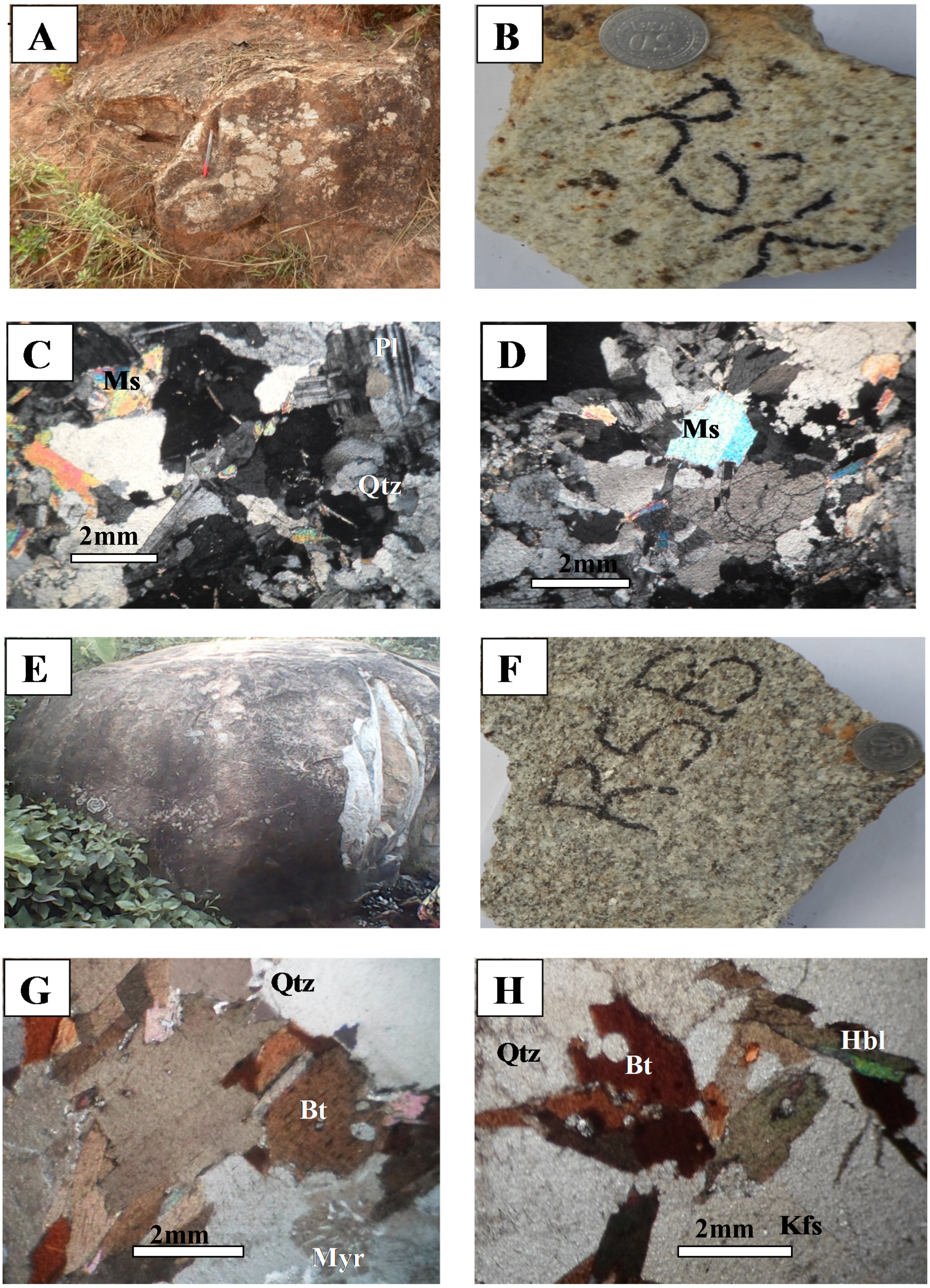

Figure 10: Photographs and Photomicrographs of the granitoids of Bamenda Town. ***Leucogranite***- **A**: photo of an outcrop; **B:** photo of a hand specimen sample; **C** and **D** are photomicrographs displaying texture in leucogranites and its mineral content. ***Granite***- **E:** photo of an outcrop; **F:** photo of a hand specimen sample;, **G** and **H** are photomicrographs displaying texture in granites and its mineral content

3.2.2. Petrography of Volcanic rocks from Bamenda Town

The volcanic rocks observed in Bamenda Town are of two main petrographic types: basalt and trachyte.

- **Petrography of Basalt**

Basalt (figure 11A) occurs on the field as boulders of varying sizes (2-4m). They are dark grey to black with massive structures. Microscopically, it has a microlitic porphyritic texture characterized by the presence of micro crystals of plagioclase (0.1-0.7mm) associated with some opaque minerals, olivine and pyroxene, all embedded in a groundmass made up of fine-grained crystals (figure 11C). Olivine is the main mineral phase in the studied basalt and occupies about 30% of the rock and occurs as subeuhedral to anhedral phenocrysts and in groundmass. Plagioclase forms the bulk of the groundmass and appears as small laths with sizes varying from 0.4 to 0.8mm long in the form of microlites. These microlites of plagioclase are very abundant and occupy nearly 39% of the volume of the rock (figure 11F). Clinopyroxene with size varying from 1 to 4mm occur as euhedral to anhedral crystals forming about 2% volume of the rock. Some crystals of clinopyroxene contain opaque minerals as inclusion (figure 11.D). Opaque minerals are common in all the basalt samples. Some are subhedral, abundant and occur as inclusions within olivine and pyroxene crystals (figure11.D). They range in size from 0.06mm to 2mm, forming about 29% volume of the rock.

- **Petrography of Trachyte**

Trachyte appears as domes in the study area (figure 10E) and presents a mesocratic or dark grey colour and abundant white visible sanidine phenocrysts (figure 10F). The texture is porphyritic with phenocrysts of sanidine (2.5mm × 1.2mm) and plagioclase (6mm × 2.1mm) enclosed in a fine-grained groundmass. The groundmass is made up of microlites of feldspars, pyroxene, and very fine crystals of opaque minerals. The microlites show a preferred orientation and simple twinning (figure 10H). The alkaline feldspars are represented by sanidine. They form about 30-40% by volume of the rock and are the most abundant phenocrysts. The crystals are subeuhedral to euhedral in shape, ranging in size from about 6mm x 1.5mm. In the groundmass, they are also abundant and occurring in the form of microlites. Clinopyroxene is represented by augite which presents a prismatic section that is subautomorphic and a size range between 1.5mm x 2mm. The cleavages have been corroded by the groundmass and constitute less than 2% by volume of the rock. The opaque minerals constitute 10-13 volume % of the rock, with sizes ranging from 0.15mm x 0.15mm and are sub rounded in shape.

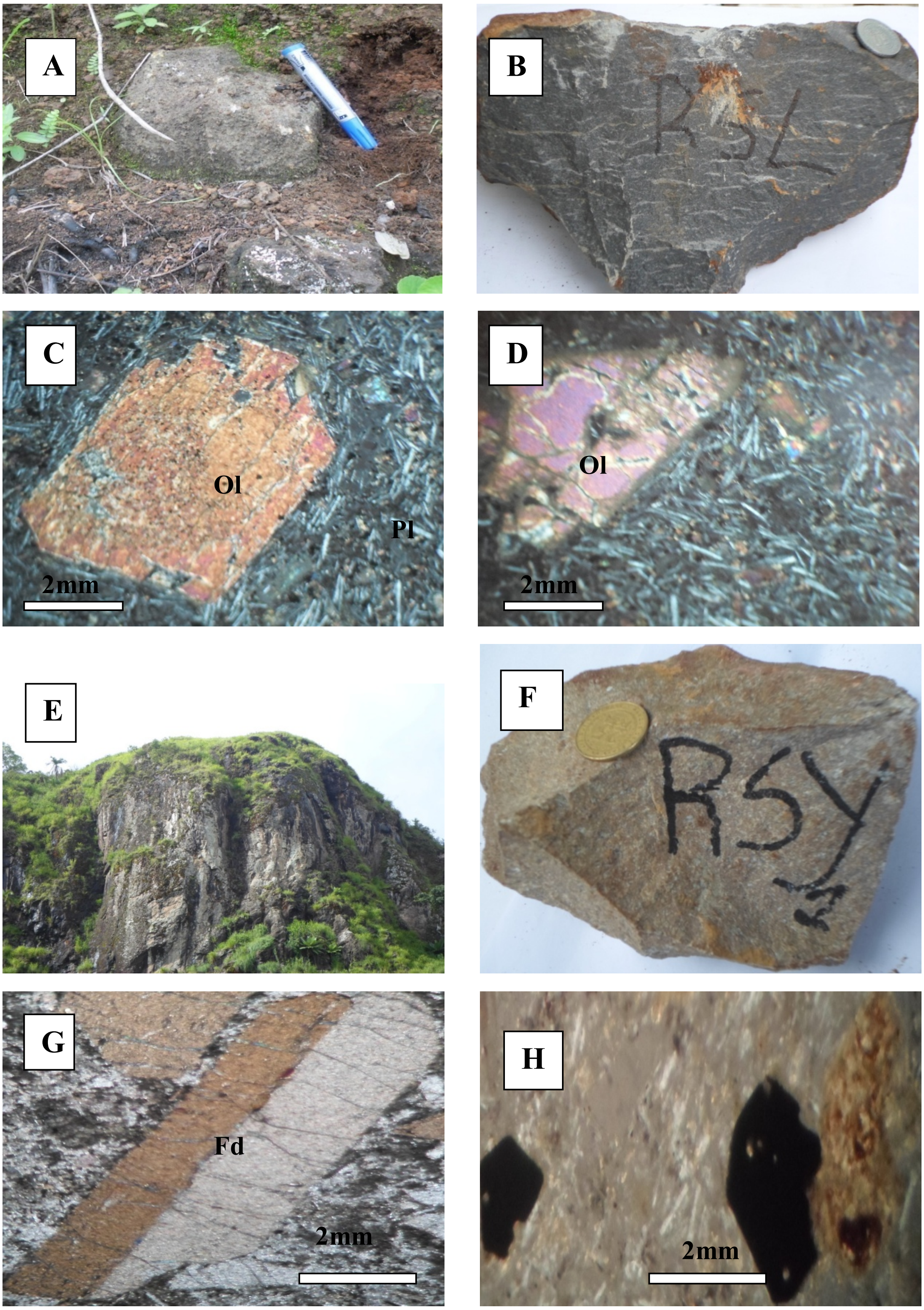

Figure 11: **Photographs and photomicrographs of volcanic rocks of Bamenda Town.**
Basalt- A: field occurrence; B: hand specimen view; C&D: photomicrographs showing texture and various minerals of basalt. Trachyte- E: field occurrence; F: hand specimen view; G&H: photomicrographs showing texture and minerals of trachyte

Geologically, a greater proportion of Bamenda Town is made up essentially of granite, constituting about 55% of the geology and is exposed in the neighbourhoods of Bayelle, Musang, Azire, Nsongwa and Ntenefor. This is followed by trachyte which constitutes about 35% of the geology and is exposed essentially along the Bamenda escarpment, Mendakwe village and Sisia quarter. Basalt comprises about 10% of the geology of Bamenda Town and is exposed in the vicinity of Ntamulung and Ngomgham quarters. Leucogranite is the least petrographic type, constituting about 5% of the geology of Bamenda Town and exposed at Bayelle and Ntenefor quarters of Bamenda Town. The geology of Bamenda Town is presented in figure 12.

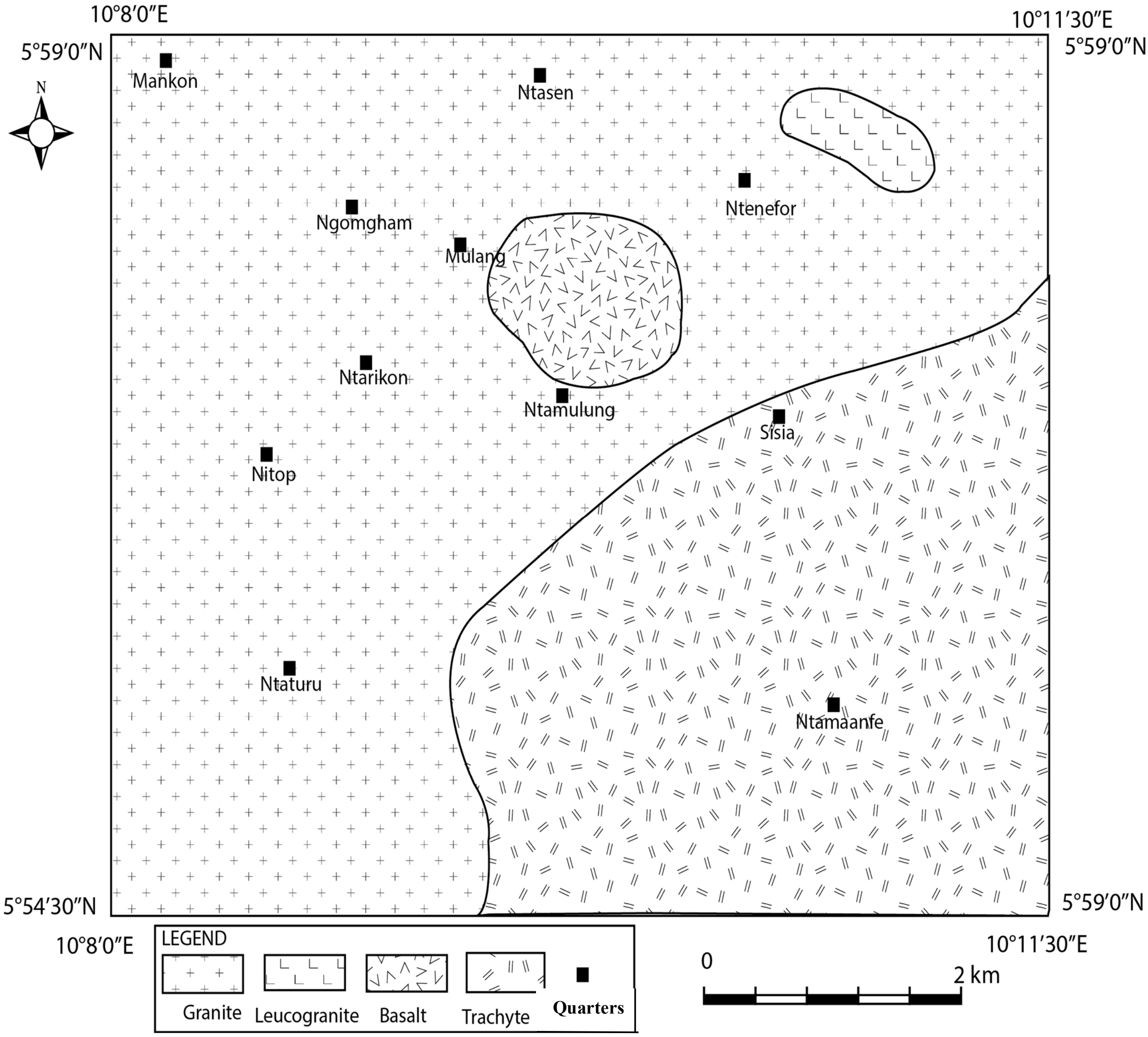

Figure 12: Geological map of the study area

3.3. GEOCHEMISTRY

3.3.1. Geochemistry of plutonic rocks

- **Major elements of plutonic rocks**

The whole rock geochemical data of granite and leucogranite from Bamenda are presented in table 3. The rocks are rich in silica with leucogranite having a comparatively higher SiO_2 content, ranging from 73 to 76%, while the silica content of granite varies from 70 to 73%. The Harker diagrams (figure 13) showing the variation of major elements versus SiO_2 revealed well pronounced negative and positive correlations. AL_2O_3, Na_2O and MnO concentrations exhibit a positive correlation with increasing silica, whereas, the concentrations of Fe_2O_3, MgO, CaO, K_2O and P_2O_5 exhibit a negative correlation.

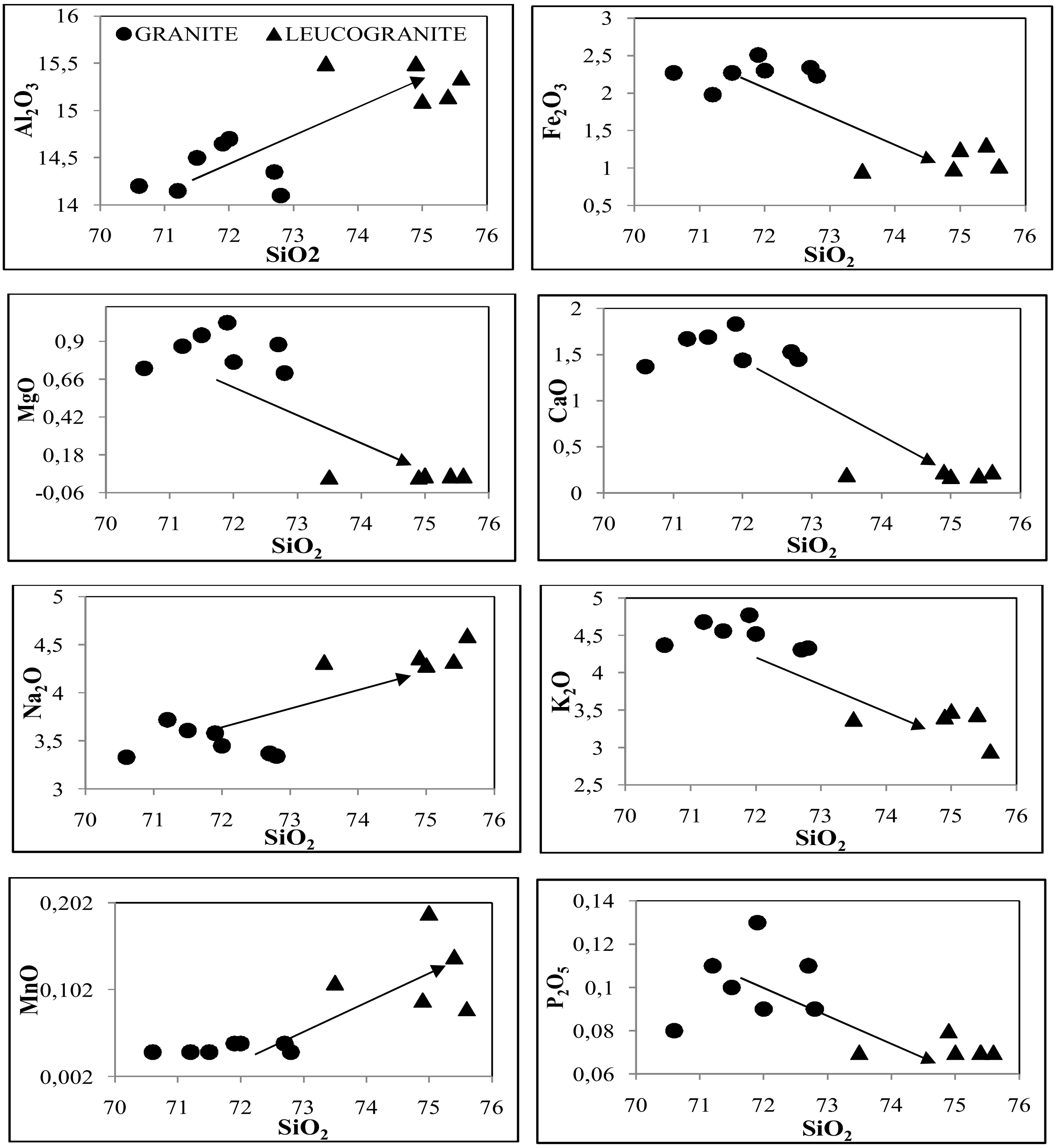

Figure 13: Harker diagrams showing variation of major elements versus silica content

The SiO_2 versus K_2O diagram of Peccerillo and Taylor (1976) shows that the studied granite and leucogranite belong to high-K calc-alkaline series with one sample of leucogranite ploting into calc-alkaline series field (figure 14). The sum of alkaline elements (Na_2O+K_2O) are relatively constant and high, varying from 7.55 to 7.78% in leucogranite and from 7.67 to 8.35% in granite.

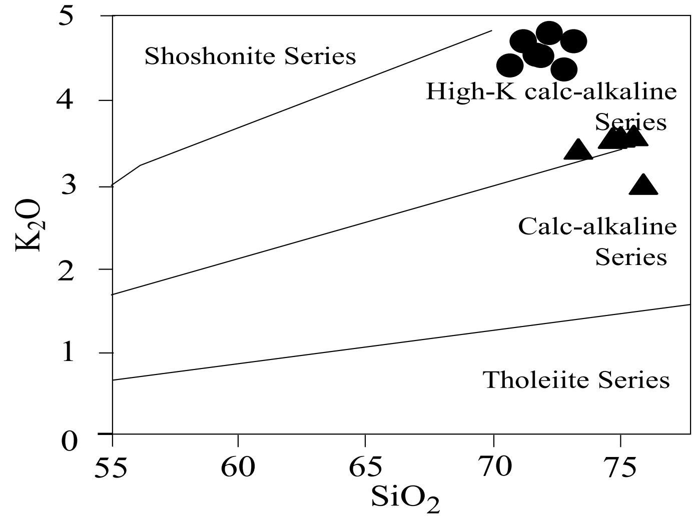

Figure 14: K_2O vs SiO_2 diagram of Peccerillo and Taylor (1976) showing the calc-alkaline to high K- calc-alkaline affinities of granite and leucogranite of Bamenda Town

The major difference between the studied leucogranite and granite is their alkali content. Granite is richer in K_2O than leucogranite. The Na_2O/K_2O versus SiO_2 diagram of Gills (1981) defining Na-granitoids and K-granitoids revealed that leucogranite is Na-granitoids whereas granite is K-granitoids (figure 15).

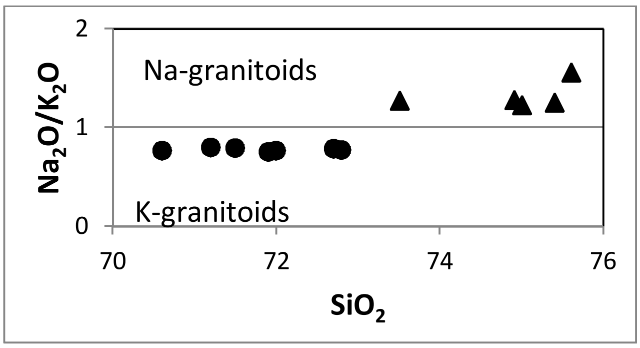

Figure 15: Na_2O/K_2O versus SiO_2 defining Na-granitoids field and K-granitoids field after Gills (1981)

The granite is also richer in calcium than leucogranite. Plotted in the Aluminium Saturation Index diagram A/CNK-A/NK of Chappell and White (1992), leucogranite plots in the peraluminous field and all samples conform to S-type granitoids (figure 16) whereas granite plots mostly in the peraluminous field, and correspond to I-type granitoids.

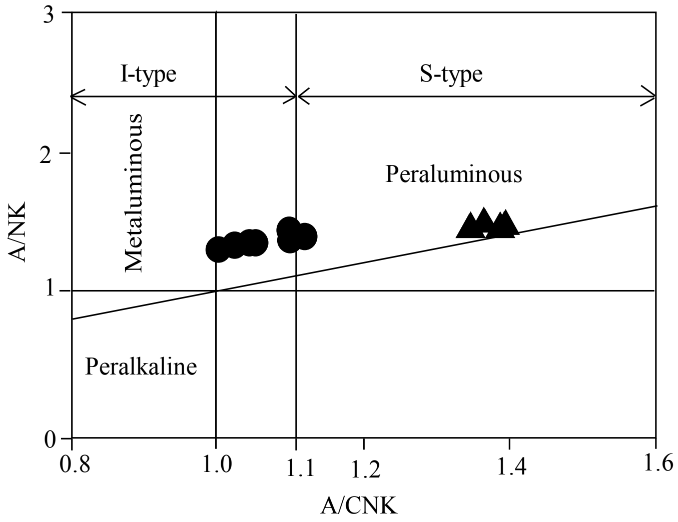

Figure 16: Alumina index diagram A/CNK-A/NK for Bamenda Town granitoids. Boundary between I-type and S-type granite is after Chappell and White (1992).

Granite has a high mafic content (Fe_2O_3 + MgO + TiO_2 = 3.16 to 3.91%) compared to leucogranite (Fe_2O_3+MgO+TiO_2= 1.01 to 1.37%). The classification diagram of Frost *et al.* (2001), discriminating ferroan granitoids and magnesian granitoids, revealed the magnesian and ferriferous characters for granite and leucogranite respectively (figure 17A). The Millications Fe+Mg+Ti *vs* Mg/Mg+Fe diagram of the same author confirms those geochemical characters, with granite plotting in the field of magnesian series whereas leucogranite plots in the ferriferous field (figure 17B).

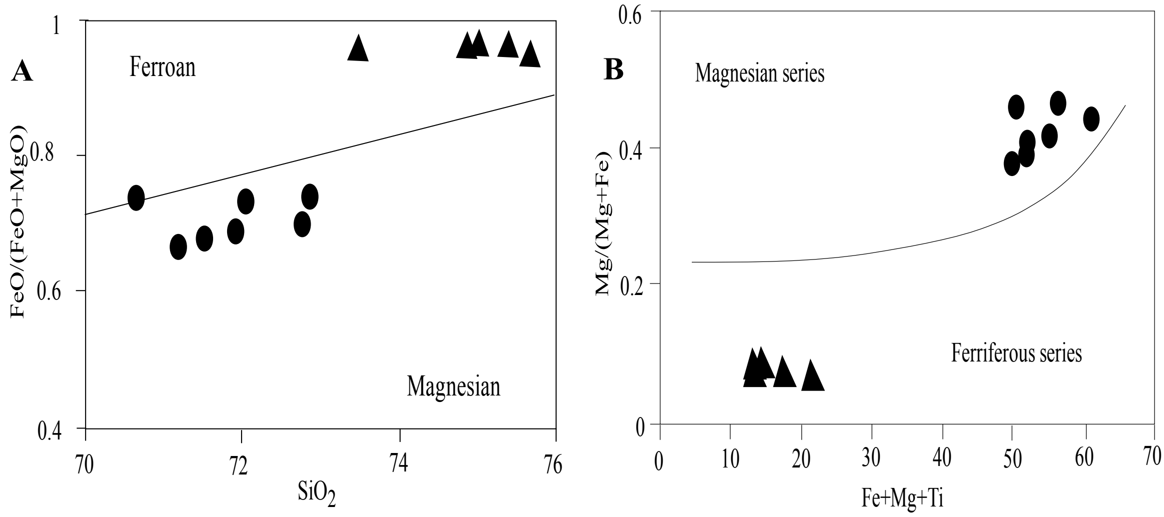

Figure 17 A: The SiO_2 *vs* FeOt/ (FeOt + MgO) diagram, axis units are wt%; B: Millications diagram Fe+Mg+Ti *vs* Mg /Mg+Fe.

- **Trace elements and REE of plutonic rocks**

Data of major, trace elements and rare earth elements from whole rock geochemistry of granites and leucogranites are presented in table 3.

Table 3: Major elements, trace elements and rare earth elements of leucogranite and granite from Bamenda Town. All values are in ppm

	Rock	LEUCOGRANITE					GRANITE						
	Codes	**RSK1**	**RSK2**	**RSK3**	**RSK4**	**RSK5**	**RSB1**	**RSB2**	**RSB4**	**RSB5**	**RSB6**	**RSB7**	**RSB8**
Major Elements	SiO2	75.4	73.5	74.9	75.6	75	71.9	71.2	70.6	72.7	71.5	72.8	72
	Al2O3	15.15	15.5	15.5	15.35	15.1	14.65	14.15	14.2	14.35	14.5	14.1	14.7
	Fe2O3	1.31	0.96	0.99	1.03	1.25	2.51	1.98	2.27	2.34	2.27	2.23	2.3
	CaO	0.19	0.2	0.23	0.23	0.18	1.83	1.67	1.37	1.53	1.69	1.45	1.44
	MgO	0.05	0.04	0.04	0.05	0.05	1.02	0.87	0.73	0.88	0.94	0.7	0.77
	Na2O	4.33	4.32	4.37	4.6	4.29	3.58	3.72	3.33	3.37	3.61	3.34	3.45
	K2O	3.44	3.38	3.41	2.95	3.49	4.77	4.68	4.37	4.31	4.56	4.33	4.52
	Cr2O3	<0.01	0.01	0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	TiO2	0.01	0.01	0.01	0.01	0.01	0.38	0.31	0.27	0.33	0.33	0.27	0.29
	MnO	0.14	0.11	0.09	0.08	0.19	0.04	0.03	0.03	0.04	0.03	0.03	0.04
	P2O5	0.07	0.07	0.08	0.07	0.07	0.13	0.11	0.08	0.11	0.1	0.09	0.09
	SrO	0.01	0.01	0.01	0.01	0.01	0.17	0.17	0.14	0.14	0.17	0.14	0.15
	BaO	0.01	0.01	0.01	0.01	0.01	0.3	0.27	0.22	0.23	0.27	0.23	0.23
	LOI	1.53	1.86	1.64	1.94	1.8	0.62	0.64	0.61	0.72	0.79	0.53	0.56
	Total	101.6	99.95	101.3	101.9	101.4	101.9	99.8	98.22	101.1	100.8	100.2	100.5
Trace and Rare Earth Elements	**Ba**	18.6	7.5	8.2	9.8	23.5	2670	2430	2060	2120	2510	2170	2120
	Ce	4.4	4.1	4.8	5.3	5	112.5	94.6	81.9	94.3	98.3	89	96.2
	Cr	10	10	10	10	10	40	30	30	30	40	30	30
	Cs	9.19	9.07	8.85	7.37	9.04	3.36	3.14	2.88	3.1	3.99	2.78	2.9
	Dy	0.94	0.83	0.82	0.75	1.09	2.39	2.21	1.35	1.68	2.16	1.6	1.55
	Er	0.42	0.39	0.41	0.31	0.46	1.24	0.94	0.6	0.9	1.03	0.81	0.77
	Eu	0.09	0.1	0.13	0.07	0.1	1.27	1.24	1.09	1.08	1.28	1.16	1.03
	Ga	38.4	38.7	37.2	35.5	36.9	21.2	18.7	17.7	18.8	19.5	17.8	18
	Gd	0.83	0.81	0.92	0.74	0.83	3.7	3.02	2.23	2.79	3.43	2.49	2.63
	Hf	2.6	2.2	2.3	2.3	2.7	6.1	5.6	3.9	4.6	5.1	4.5	4.3
	La	4.7	4.6	6.8	3.5	5.6	62.4	52.7	45.3	51.5	53	48.3	52.3
	Lu	0.07	0.08	0.07	0.07	0.08	0.17	0.15	0.1	0.14	0.15	0.12	0.13
	Nb	34	44.5	36	26.5	38.8	12.8	11.5	8.9	10.6	12	9.6	9.8
	Nd	3.7	4	5.3	3.1	4.6	42.9	35.3	28.7	33.4	35.9	31	33.4
	Pr	1.11	1.18	1.55	0.89	1.33	12.05	10.5	8.6	9.94	10.6	9.45	10.15
	Rb	370	362	365	303	365	109	99.1	87.9	90.5	104.5	84.5	88.8
	Sm	0.99	0.97	1.29	1.08	1.08	6.18	5.29	4.2	4.81	5.73	4.45	5.04
	Sn	34	34	33	27	31	2	2	2	2	3	2	2
	Sr	8.4	5.1	5.3	5.6	5.3	1470	1360	1220	1245	1420	1260	1240
	Ta	4	7.7	4.9	2.6	8.2	1.3	1.3	0.7	0.8	1.1	0.8	0.8
	Tb	0.16	0.13	0.17	0.13	0.19	0.46	0.41	0.27	0.34	0.42	0.3	0.3
	Th	1.43	1.14	1.11	1.81	2.22	13.9	13.15	12.25	12.95	16.85	12.75	13.9
	U	3.12	2.56	2.62	3.47	3.48	2.93	4.19	2.99	2.95	10.45	5.78	4.68
	V	<5	<5	<5	<5	<5	24	20	19	22	23	18	19
	Yb	0.47	0.54	0.44	0.49	0.52	1.29	1.06	0.67	0.74	0.88	0.79	0.73
	Zr	33	31	32	32	37	222	195	156	188	201	176	172
	Bi	1.56	1.49	4.43	7.84	1.95	0.32	0.84	0.13	0.14	0.87	0.17	0.11
	Co	1	2	1	2	1	4	4	4	4	4	3	4
	Cu	<1	1	1	1	1	11	10	10	13	17	12	11
	Li	60	60	50	50	50	30	30	30	40	30	30	30
	Ni	1	1	<1	<1	1	19	16	14	17	17	16	15
	Pb	12	12	11	13	15	57	60	57	54	60	57	54
	Zn	21	22	22	20	18	47	43	39	48	46	40	42
	∑REE	18.13	17.93	22.92	16.62	21.15	247.17	207.96	175.34	202.09	213.4	189.89	204.63
	(Ce/Sm)N	1.07	1.02	0.90	1.19	1.18	4.40	4.32	4.71	4.73	4.14	4.83	4.61
	(La/Yb)N	6.75	5.75	10.43	4.82	7.27	32.65	33.56	45.64	46.98	40.65	41.27	48.36
	(Gd/Yb)N	1.43	1.21	1.69	1.22	1.29	2.32	2.30	2.69	3.05	3.15	2.55	2.91
	(Gd*Sm)N	26.12	24.97	37.72	25.40	28.49	726.78	507.78	297.69	426.54	624.68	352.19	421.31
	(La/Lu)N	6.97	5.97	10.08	5.19	7.27	38.10	36.47	47.02	38.18	36.68	41.78	41.76
	(La/Sm)N	2.99	2.99	3.32	2.04	3.27	6.36	6.27	6.79	6.74	5.82	6.83	6.53
	(Gd/Lu)N	1.47	1.26	1.63	1.31	1.29	2.71	2.50	2.77	2.48	2.84	2.58	2.51
	Eu/Eu*	0.30	0.35	0.37	0.24	0.32	0.81	0.95	1.09	0.90	0.88	1.07	0.88

Note: A/Nk=Al_2O_3/ (Na_2O+K_2O) and A/CNK=Al_2O_3/(CaO+Na_2O+K_2O), molar ratio (1000 * wt% / Molecular mass).

The Harker diagrams of selected trace elements, show negative correlations for Ba, Sr, Zr, Zn and Y, which decrease from granite to leucogranite with increasing SiO_2 content. Nb, Rb, and Y+Nb show positive correlations, with increasing concentrations of SiO_2 from granite 21to leucogranite (figure 18).

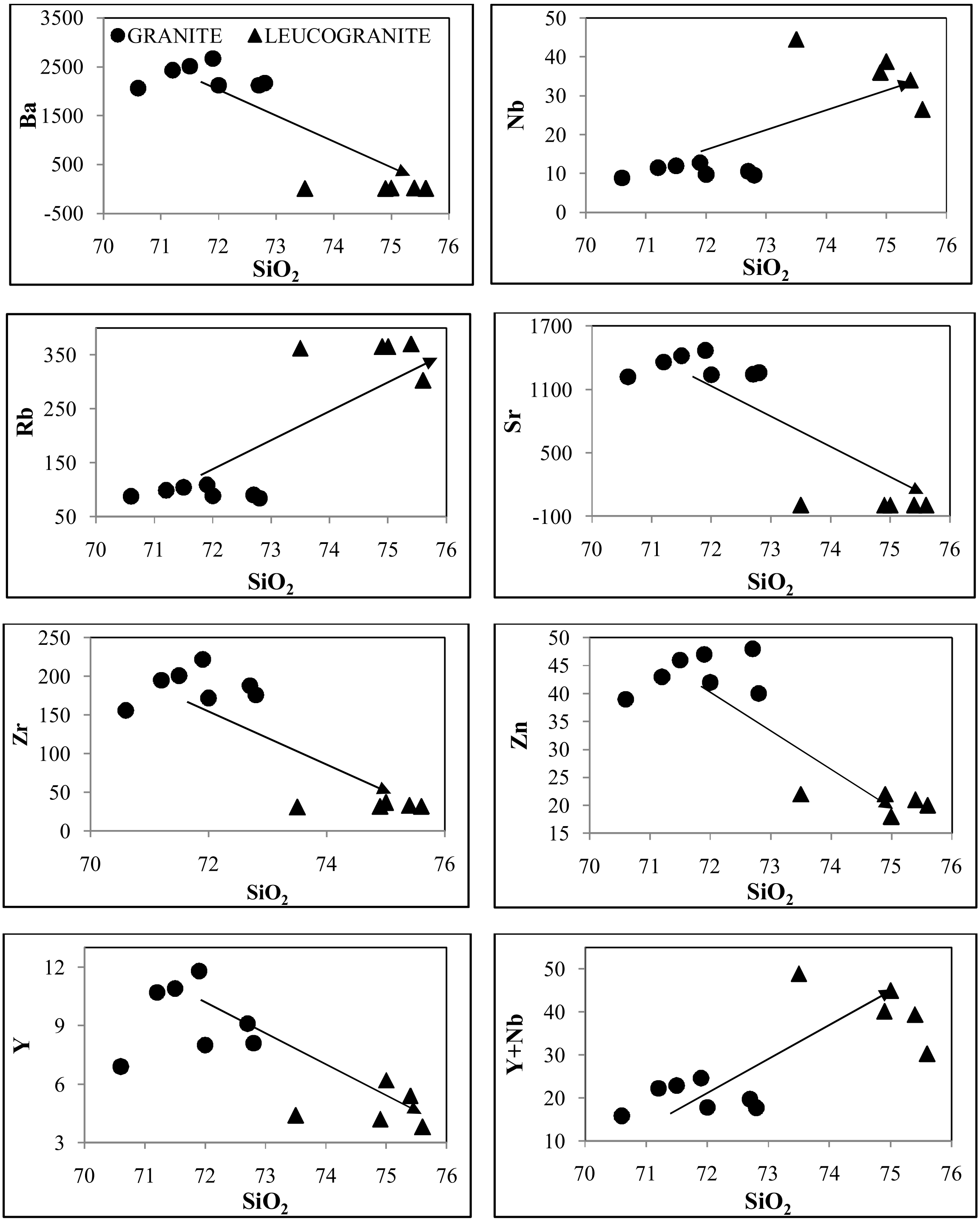

Figure 18: Harker diagrams of selected trace elements

❖ **Trace Elements**

❖ The Ba/Rb ratios are very low in the leucogranite and range between 0.02 to 0.06. On the contrary, the granite, these ratios are relatively high (23.43-25.68) compared to the values observed in continental calc-alkaline igneous granitoids in Mali, West Africa (Bertrand *et al.*, 1984). Regarding the Ba/Sr ratios, granite and leucogranite yield values within the same ranges from 1.4 to 2.2 with sample RSK5 of leucogranite having 4.434.

❖ **Rare Earth Elements**

The rare earth element (REE) patterns (figure 19A & B) of the Bamenda studied rocks normalized with chondrite (Evensen *et al.*, 1978) are quite different. Leucogranite patterns are more or less parallel, less fractionated, showing a weak LREE (light rare earth element) enrichment with La_N/Yb_N ratios <11 and Gd_N/Yb_N ratios of 1.21–1.69. Negative Eu anomalies (Eu/Eu* = 0.23-0.36) are pronounced in leucogranite which also show negative anomalies in Ce. In contrast, granite patterns normalized with the same chondrite values are quite parallel, showing strong LREE enrichment with La_N/Yb_N ratios of 32.65-48.36 and Gd_N/Yb_N ratios of 2.30–3.15. Eu anomalies are variable in granites (Eu/Eu* = 0.81-1.08). The multi elements spider diagrams (figures 20&21) of all the studied rocks show similar trends in general, but with a distinctive depletion in Ba and TiO_2 which are well pronounced in leucogranites. Regarding P_2O_5, opposite anomalies were noticed, weakly positive in leucogranites and strongly negative in granite. Negative anomalies were also observed for Ce.

The chondrite normalized patterns show that granite have higher concentrations of LREE than leucogranite, respectively >100*chondrite and >10*chondrite. In contrast, their HREE concentrations are similar in both granitoid types.

A

B

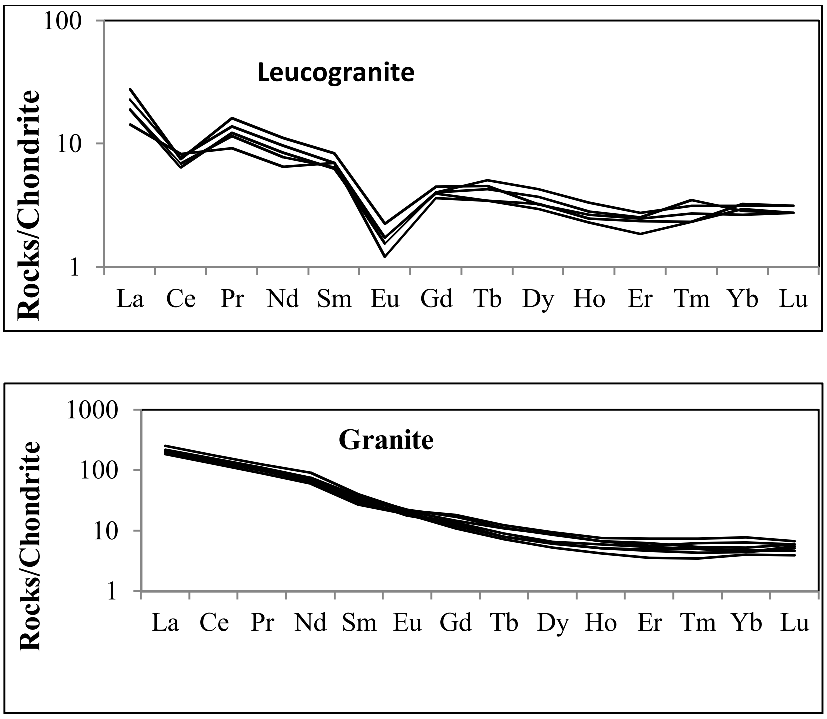

Figure 19: **REE spider diagrams of leucogranite and granite of Bamenda Town normalized to chondrite values from Evensen *et al.* (1978). A: leucogranite; B: granite**

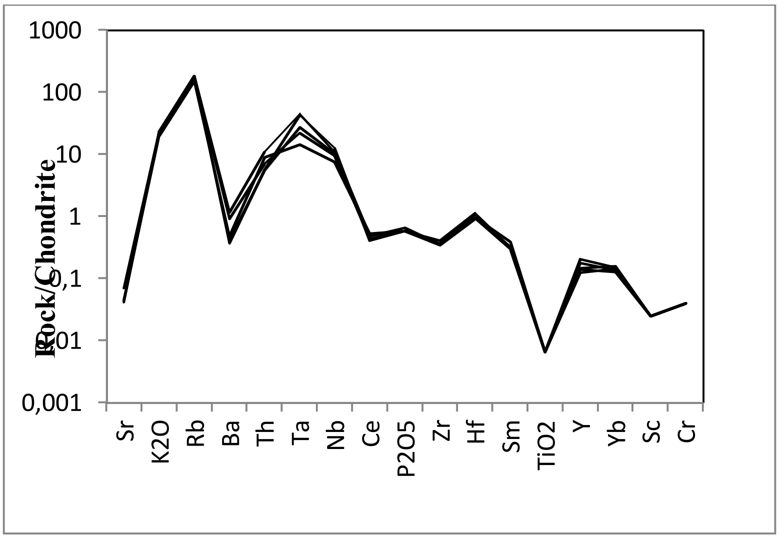

Figure 20: **Multi-elements spider diagram of leucogranites: Values used for normalization are chondrite values from Pearce (1983). Sc and C values are from Pearce (1982)**

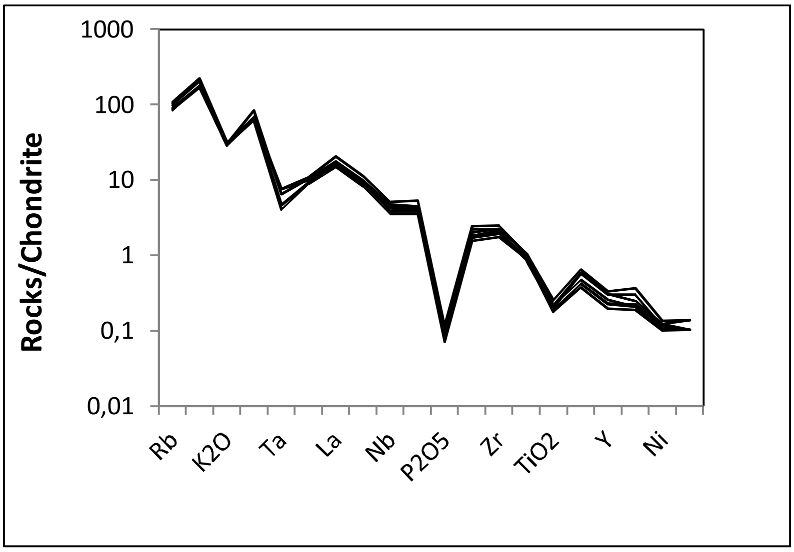

Figure 21: **Multi-elements spider diagram of granite: Values used for normalization are chondrite values from Bevin *et al.*, (1984)**

3.3.2. Geochemistry of volcanic rocks from Bamenda Town

Thirteen fresh samples of volcanic rocks were carefully selected and sent to a commercial laboratory ALS for whole rock geochemistry. Six (o6) of the samples were basaltic and seven (07) trachytic type.

- **Major elements of volcanic rocks**

The major elements concentrations from whole rock geochemistry of selected studied volcanic rocks from Bamenda Town are presented in table 4. The concentrations of SiO_2, TiO_2 and MgO in basalt and trachyte are 45.50–47.60 wt% and 64-66.20 wt%, 2.96–3.02 wt% and 0.54-0.56 wt%; 6.38-7.08 wt% and 0.12-0.17 wt%, respectively. Alkaline content ranges from 4.13–5.37 wt% for basalt and 9.58-10.23 wt% for trachyte.

The total alkali versus silica classification diagram (figure 22) of Cox *et al*. (1979), with the boundary line between alkaline and subalkaline series according to Irvine and Baragar (1971), all the points representing the studied volcanic rock fall within the alkaline series domain. It is therefore clear from a geochemical standpoint that the studied volcanic rocks of Bamenda Town are basalt and trachyte.

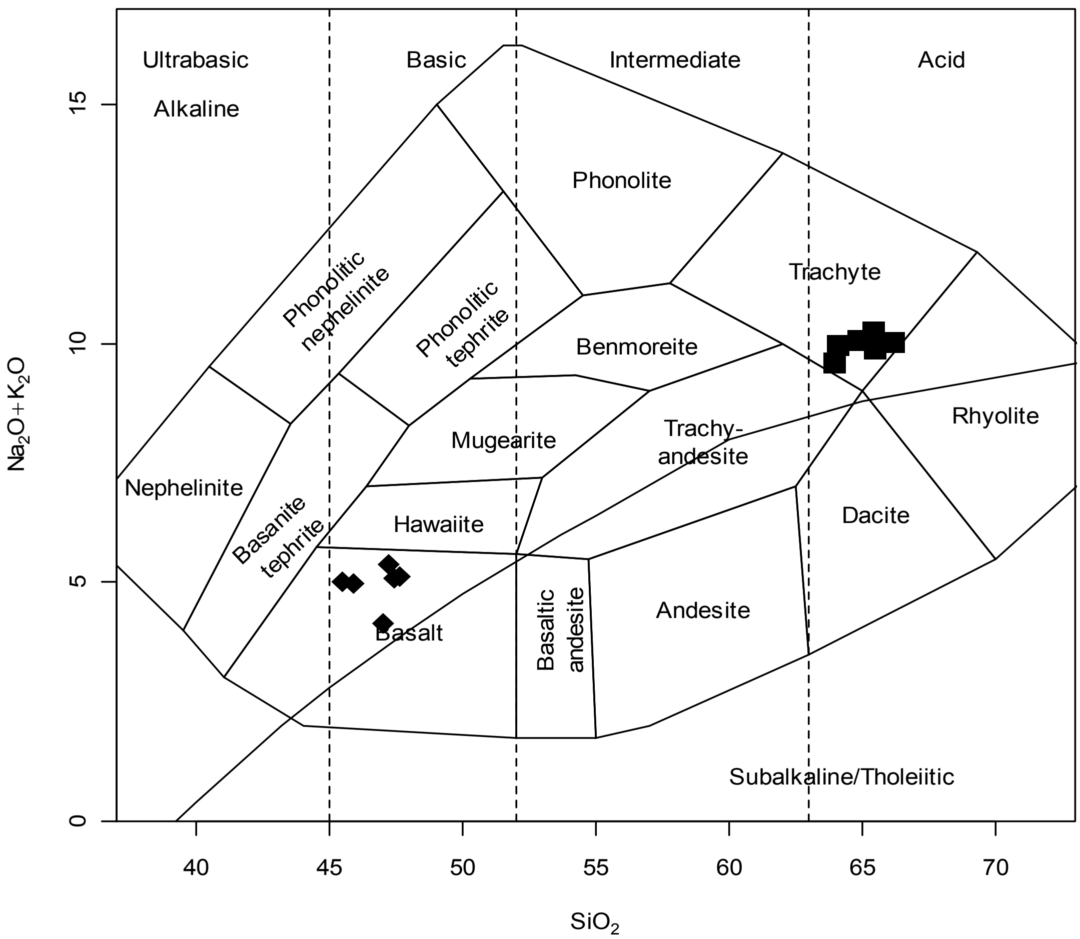

Figure 22: Total alkalis versus silica variation diagram showing the composition range and evolutionary trend of Bamenda lavas (rock classification from Cox *et al*., 1979)

- **Trace Elements and Rare Earth Elements**

Samples analyzed for whole rock full elements, trace elements and rare element concentrations are presented in table 4.

Harker diagrams (figure 23) of some trace elements versus SiO_2 revealed a marked difference between the two groups of rocks. They denote positive correlations of Nb, Rb, Zr, Y and Y+Nb and negative correlations of Ba, Sr and Zn with increasing concentration of SiO_2.

Spider diagrams (figure. 24 and 25) of rare earth elements (REE) normalized with chondrite of Evensen *et al*. (1978) show fractionation, marked by a relative LREE enrichment. Basalt and trachyte are characterized by negative anomalies of Europium (Eu/Eu*=1.013-1082) and (Eu/Eu*=0.74-0.832). The multi-elements spider diagram (figure 26) shows negative anomalies for Sr, Zr, Y and Sc and positive for Ba, Nb and Cr for basalt, and negative anomalies for Sr, Ba, P_2O_5, TiO_2 and Sc and positive Rb, Th, Zr and Yb for trachyte (figure 27).

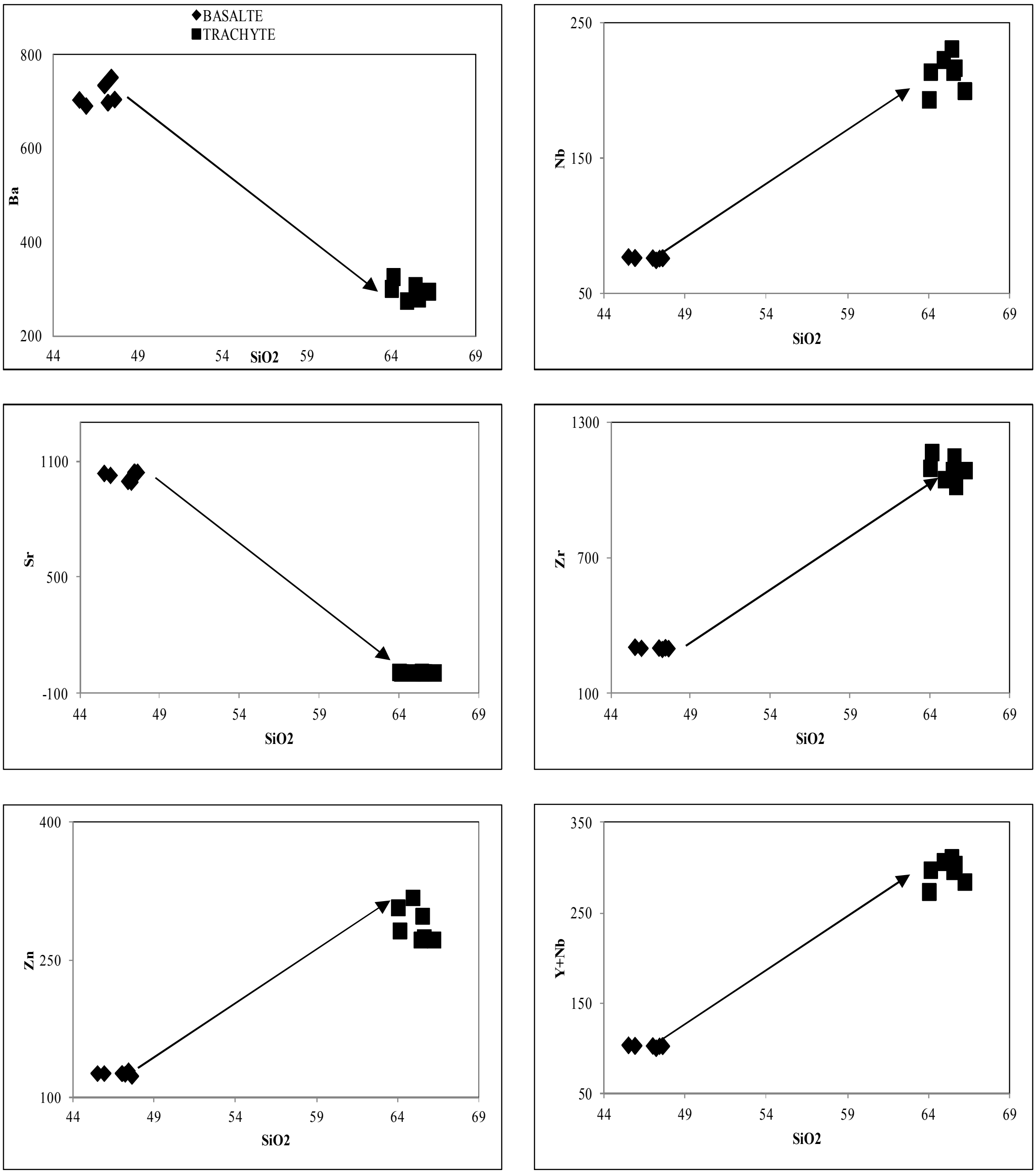

Figure 23: Harker diagrams showing variations of trace elements based on SiO_2

Table 4: Major elements, trace elements and rare earth elements of basalt and trachyte from Bamenda Town, all values are in ppm

	ROCK	TRACHYTE							BASALT					
	Code	RSY21	RSY22	RSY23	RSY24	RSY25	RSY26	RSY27	RSL1	RSL2	RSL3	RSL4	RSL5	RSL6
Major Elements	SiO2	64.1	64.9	65.6	65.4	66.2	64	65.5	45.9	47.6	47	47.4	47.2	45.5
	Al2O3	12.15	12.05	11.9	12.1	12	11.75	11.9	15.2	15.35	15.55	15.2	14.85	14.9
	Fe2O3	8.98	8.46	8.8	8.9	8.58	8.44	8.25	11.95	12.4	12.1	12.05	12.5	11.9
	CaO	0.4	0.38	0.41	0.47	0.4	0.46	0.43	8.45	8.85	8.89	8.73	8.87	8.6
	MgO	0.13	0.12	0.13	0.13	0.12	0.17	0.14	6.49	6.81	6.38	6.7	7.08	6.47
	Na2O	5.46	5.57	5.54	5.68	5.49	5.14	5.37	3.29	3.41	2.57	3.36	3.63	3.38
	K2O	4.51	4.49	4.5	4.55	4.54	4.44	4.51	1.67	1.7	1.56	1.71	1.74	1.64
	Cr2O3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.02	0.02	0.02	0.03	0.03
	TiO2	0.56	0.56	0.54	0.56	0.54	0.54	0.55	2.93	2.96	3.02	2.97	2.88	3
	MnO	0.48	0.52	0.52	0.44	0.41	0.55	0.45	0.21	0.2	0.22	0.19	0.21	0.21
	P2O5	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.87	0.9	0.89	0.92	0.88	0.85
	SrO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.13	0.13	0.12	0.13	0.12	0.12
	BaO	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.08	0.08	0.09	0.09	0.08	0.08
	C	0.76	0.61	0.71	0.68	0.7	0.87	0.71	0.07	0.03	0.06	0.02	0.04	0.07
	S	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.02
	LOI	3.17	2.68	3.11	2.84	2.93	3.86	3.19	2.34	1.57	3.28	1.46	0.81	2.23
	Total	100	99.79	101.1	101.12	101.27	99.41	100.35	99.54	101.98	101.69	100.93	100.88	98.91
Trace and Rare Earth Elements	Ba	327	276	281	308	296	302	292	692	706	736	753	699	705
	Ce	335	324	317	328	328	318	318	103.5	105	107.5	106	103	104
	Cr	20	20	20	20	20	10	<10	190	180	170	180	190	190
	Cs	0.14	0.14	0.13	0.16	0.14	0.17	0.17	0.28	0.28	0.46	0.3	0.44	0.22
	Dy	17.05	16.7	16.85	16.45	17.25	17.6	17.95	5.85	5.81	6.17	5.69	5.57	5.93
	Er	8.58	8.17	8.22	7.72	8.4	8.67	8.51	2.73	2.91	3.02	2.64	2.46	2.69
	Eu	6.09	5.98	5.72	5.99	6	5.81	5.86	2.8	2.87	3.11	2.92	3	3.04
	Ga	35.1	33.2	33.2	33.8	33.7	33.3	33.2	21.5	21.2	21.3	21.2	20.5	21.7
	Gd	19.85	20.1	19.5	19.55	20.1	20.7	22	7.66	7.92	8.38	7.93	7.71	7.92
	Hf	25.7	22.4	22	23.3	23.4	23.5	23.9	6.2	6.5	6.5	6.5	6.2	6.5
	La	160.5	156	151.5	156.5	157.5	150	152.5	52.4	53.6	54.5	54	52.5	53
	Lu	1.14	1.09	1.06	1.06	1.12	1.06	1.11	0.3	0.3	0.31	0.31	0.29	0.3
	Nb	214	223	217	231	200	193.5	214	76.9	76.7	76.8	76.5	75.1	77.5
	Nd	144	140.5	136	141.5	141	138	137.5	46.7	48.8	48.5	48.7	46.4	47.6
	Pr	39	38	36.9	38	38.7	35.6	36.3	11.95	12.3	12.35	12.35	11.9	12.1
	Rb	99.6	96.2	96.1	99	96.7	90.6	95	36.6	37.7	38.2	38.3	40.3	36.8
	Sm	25.2	24.9	24.8	25.5	24.9	25.7	26.2	9.23	9.48	9.65	9.61	9.45	9.31
	Sn	7	7	7	8	7	6	7	2	2	2	2	2	2
	Sr	10.2	8.8	9.2	10.6	9.6	12.7	9.9	1030	1045	999	1045	995	1040
	Ta	12.8	12.1	11.7	12.2	11.8	11.7	11.7	4.3	4.2	4.3	4.2	4.2	4.3
	Tb	3.12	3.04	2.98	2.89	3.03	3.16	3.31	1.12	1.09	1.11	1.13	1.06	1.1
	Th	17.6	17.05	16.35	17.35	17.3	16.3	16.7	6.37	6.32	6.4	6.29	6.21	6.51
	U	6.41	6.2	5.36	5.95	6.11	6.03	6.25	1.69	1.61	1.7	1.66	1.67	1.75
	V	6	<5	5	<5	5	<5	<5	215	213	213	210	208	217
	Yb	7.32	7.19	6.97	7.13	7.57	6.89	7.17	2.01	2.17	2.15	2.04	1.96	2.19
	Zr	1170	1050	1020	1090	1090	1100	1150	303	302	304	305	298	308
	Bi	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01
	Co	1	<1	<1	<1	<1	<1	<1	51	41	49	45	44	48
	Cu	<1	<1	<1	1	<1	<1	<1	38	37	37	37	38	39
	Ni	<1	2	<1	<1	<1	1	1	101	92	103	94	105	100
	Pb	12	11	10	7	11	10	13	<2	2	2	4	<2	<2
	Zn	282	318	275	272	272	307	298	127	124	127	130	126	127
	∑REE	771.36	750.05	731.86	754.53	757.99	735.55	741	247.63	253.61	258.23	254.77	246.65	250.71
	(Ce/Sm)N	3.21	3.14	3.09	3.11	3.18	2.99	2.93	2.71	2.67	2.69	2.667	2.63	2.70
	(La/Yb)N	14.08	14.64	14.67	14.82	14.04	14.69	14.36	17.60	16.67	17.11	17.87	18.08	16.34
	(Gd/Yb)N	2.19	2.26	2.26	2.22	2.15	2.43	2.48	3.08	2.95	3.15	3.14	3.18	2.92
	La/Lu)N	14.61	14.86	14.84	15.33	14.60	14.69	14.26	18.13	18.55	18.25	18.08	18.79	18.34
	(La/Sm)N	4.01	3.94	3.85	3.86	3.98	3.67	3.66	3.57	3.56	3.56	3.54	3.50	3.58
	Eu/Eu*	0.83	0.82	0.80	0.82	0.82	0.77	0.75	1.02	1.01	1.06	1.02	1.07	1.08

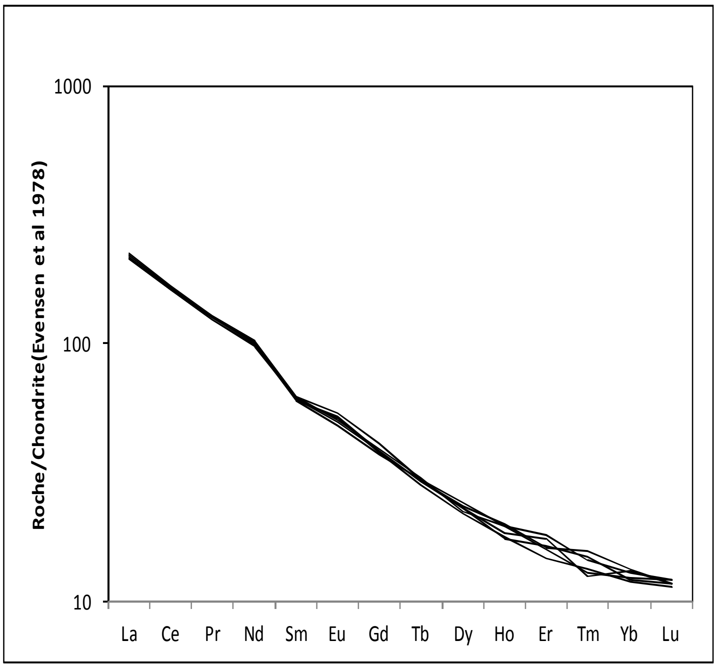

Figure 24: Spider diagram of REE normalized with chondrite of the studied Basalt

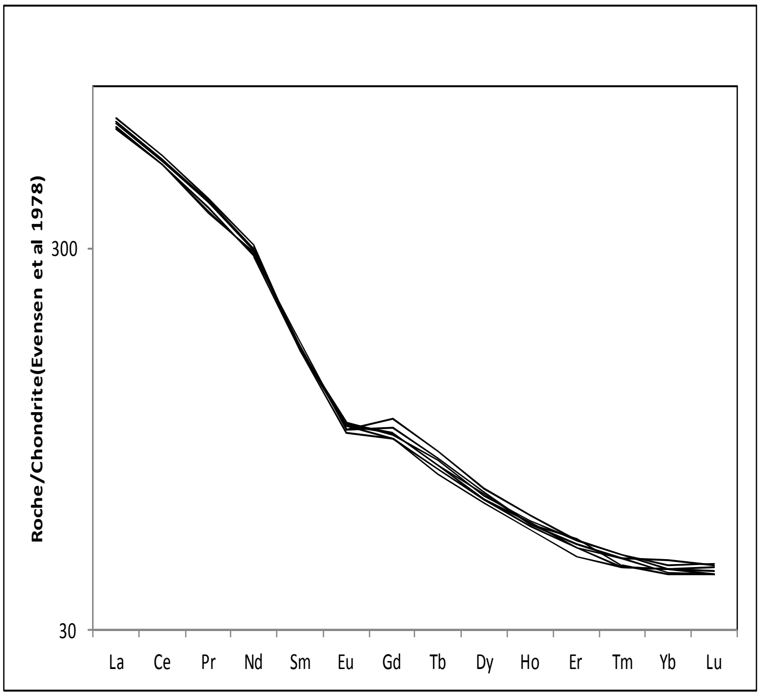

Figure 25: Spider diagram of REE normalized with chondrite of the studied trachyte

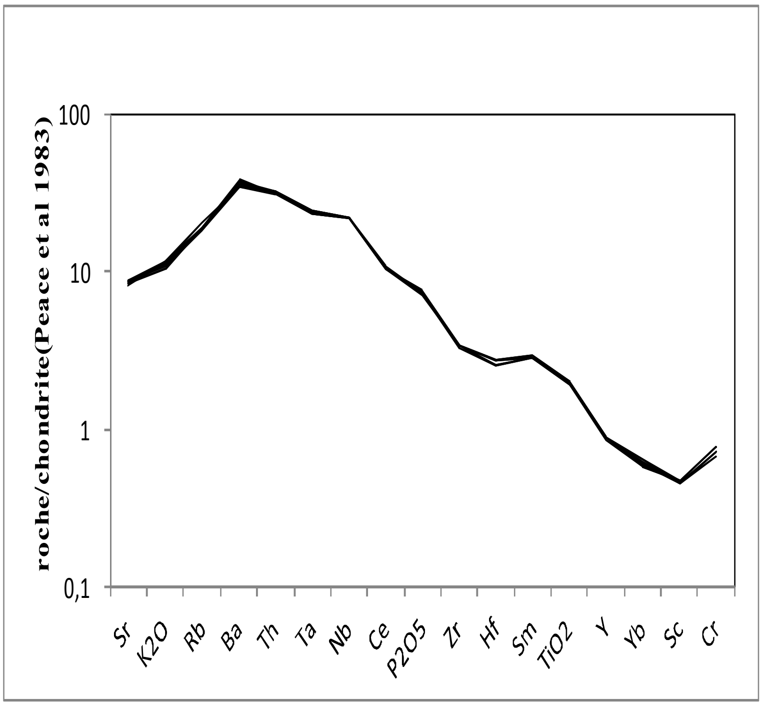

Figure 26: Multi-elements spider diagram of basalt

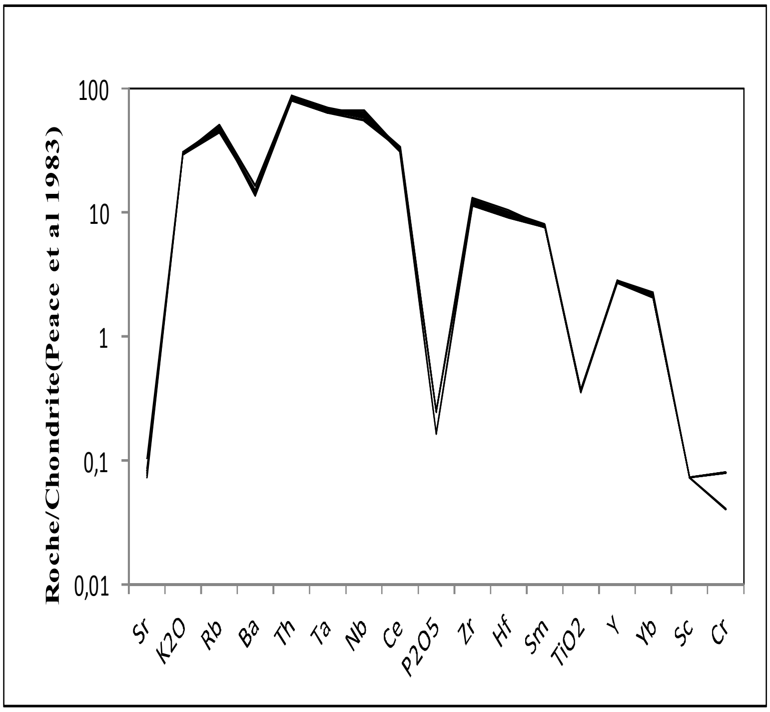

Figure 27: Multi-elements spider diagram of trachytes

3.4. DISCUSSION AND INTERPRETATIONS

3.4.1. Plutonic rocks in Bamenda Town

Plutonic rocks studied in Bamenda Town during this study are granites. They present a close field spatial relationship and the difference in their colour is related to their mineral content. Granite is relatively richer in mafic minerals (biotite and amphibole) than leucogranite and this major difference between the same rock type in the same geological setting may be either due to their sources or to different magmatic processes involved in their formations. In granite, the ondulatory extinction of the quartz crystal and the transformation of amphibole to biotite are key elements of the syntectonic characteristics of granite which undergoes relative low deformation in contrast to leucogranite which shows no signs of deformation.

K-rich granites are generally derived from the partial melting of metamorphosed hydrous intermediate calc-alkaline rocks (Roberts and Clemens, 1993). In the molar Al_2O_3/(MgO+FeOt) versus CaO/(MgO+FeOt) diagram (figure 28), the Bamenda granite plots in the field of rocks resulting from the melting of metagreywackes, whereas, the Bamenda leucogranite plots in the field of partial melts from metapelitic materials. This fact highly clarifies their petrographical and geochemical differences but could also be a reflection of the complex geological context and the relative geochronology.

The high contents of LREE in leucogranite could be related to the enrichment of their source materials in LREE because Y and Yb show no negative anomalies, suggesting that garnet was not involved in the residual phase. The enrichment of LREE together with depletion in HREE observed in Bamenda granitoids had also been noticed by Nzenti *et al.* (2006) and interpreted as compatible with fractionation of amphibole which tends to concentrate the HREE.

The Eu anomalies variation (negative and positive) may indicate melting under low and high hydrous (H_2O) conditions respectively (Shang *et al.*, 2007). The well pronounced Eu anomalies in leucogranite is indicative of melting in low hydrous condition. For granite samples with negative to weakly positive Eu anomalies, it can be suggested that their melting took place in less or more hydrous conditions. According to Nzenti *et al.* (2006), negative anomalies of some trace elements result either from the low content of these elements in the source, or their retention in the residue during partial melting.

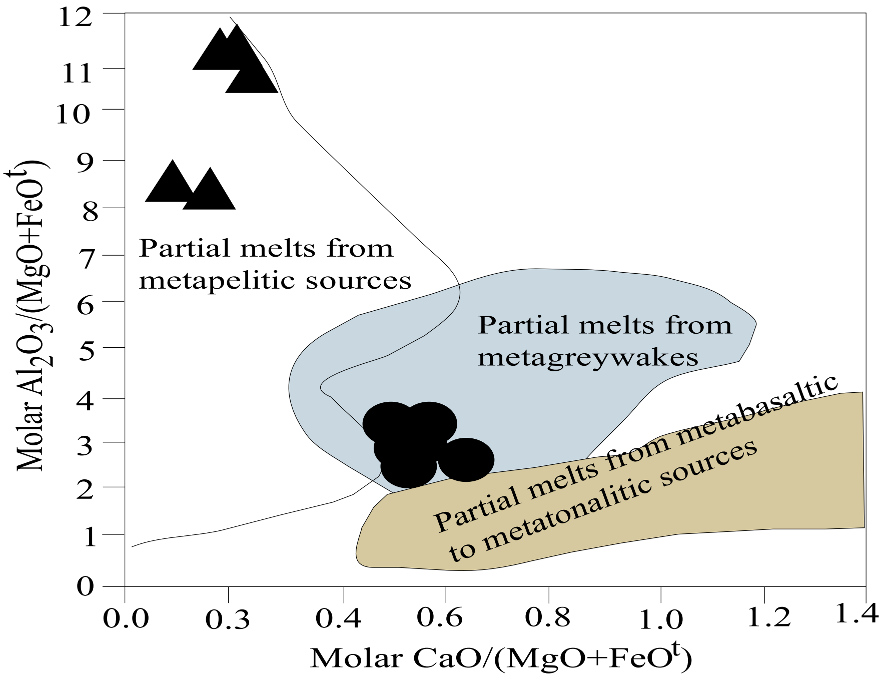

Figure 28: Molar diagram CaO/(MgO+FeOt) *vs* Al_2O_3/(MgO+FeOt) for the studied granitoids

High-K granitoids are generally indicative of major crustal thickening as a result of continental collision. The peraluminous character of the Bamenda leucogranite could be ascribed to the geotectonic setting. In the Millications R1 versus R2 diagram (figure 29) of Batchelor and Bowden (1985), the Bamenda granite plots in the syn-collision field, whereas the leucogranite plots in the post-tectonic field. From the two geotectonic settings proposed by Altherr *et al*. (2000) to ascertain the generation of high-K-magma, the syn-to post-collisional settings could be reasonably ascribed to Bamenda granitoids assuming that crustal source rocks may occur as a consequence of decompression following the lithospheric root delamination (Liégeois *et al*., 1994).

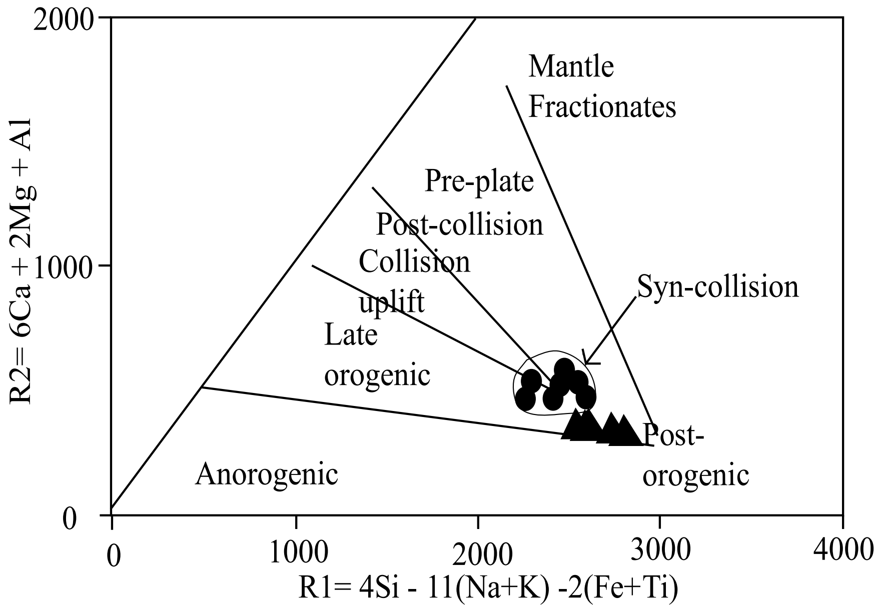

Figure 29: Millications diagram R1 versus R2 of Batchelor and Bowden (1985) showing the positions of granite in the syn-collision domain and the leucogranite in the post-orogenic domain

The Bamenda granitoids are made up of two distinct types of granitic rocks (granite and leucogranite) displaying close relationship on the field. Granite samples are grey in colour, medium to coarse-grained exhibiting heterogranular texture with the main minerals being K-feldspar, quartz, plagioclase, biotite, amphibole, and opaque minerals. Leucogranite samples are milky white in colour, exhibiting granular porphyritic texture with the main minerals being quartz, plagioclase, K-feldspar, muscovite and opaque minerals.

Granite and leucogranite from Bamenda area when plotted in the geochemical classification diagram both plotted in the same granite field. The difference in their colour and mineral contents is related to their different sources and probably also to the magmatic processes involving melting of their respective sources and magma evolution within the crust. Granite and leucogranite both have high K-calc-alkaline characters, negative and positive correlations of some elements of the rocks, which also fitted in the high K-calc-alkalines series. Granite is of K-granitoid type whereas leucogranite is of Na-granitoid. The two groups of rocks are peraluminous with leucoganite more peraluminous and of S-type granite, while granite is just slightly peraluminous and is of I-type. Granite shows magnesian characters whereas leucogranite shows ferriferous characters. The chondrite normalized patterns show that the granite has higher concentrations of LREE than leucogranite, respectively >100*chondrite and >10*chondrite. In contrast their HREE concentrations are similar.

Negative Eu anomalies (Eu/Eu* = 0.23-0.36) are pronounced in leucogranite which also show negative anomalies in Ce, Eu anomalies are variable in granite (Eu/Eu* = 0.81-1.08). Bamenda granitic magma was derived from the partial melting of metagreywackes whereas Bamenda leucogranitic magma resulted from the partial melting of metapelites. The Bamenda granitoids are syn-to post-tectonics and are similar to those described by various authors in the central domains of Pan African North Equatorial Fold Belt in Cameroon.

3.4.2. Volcanic rocks in Bamenda Town

The volcanic rocks of Bamenda Town are basalt and trachyte. The basalt is dark in colour and shows a microlitic porphyritic texture with essential minerals being plagioclase, olivine, pyroxene, and opaque minerals. The trachyte presents a dark grey colour with a microlitic porphyritic texture with phenocrysts of sanidine and plagioclase in a microlitic groundmass of feldspars, pyroxene and opaque minerals. Geochemical data of the studied volcanic rocks showed that the basalt has lower silica and alkaline contents than trachyte. When the data was plotted on a total alkali versus silica diagram, the basalt falls in the basic field and the trachyte in the acid field. Spider diagram normalized with chondrites for the volcanic rocks showed uniform patterns and fractionation with a relative LREE enrichment and a high concentration of the HREE which is an indication of these materials at the source. The negative anomaly presented by the REE when normalized with chondrites of the volcanic rocks is indicative of their origin from the partial melting of garnet peridotite at 12%. The source of the Bamenda lavas could be comparable to that of alkali basalt of Bangangte studied by Wotchoko *et al*. (2015) which resulted from a partial melting of garnet peridotite at 13%. Both the basalt and trachyte showed negative anomalies for Eu which might have resulted from melting under water deficient conditions (Shang *et al*., 2007).

The volcanic rocks (basalt and trachyte) originated from different sources with variable proportions. A chemically homogenous mantle can give rise to various petrographic types from partial melting of peridotite. Plotted on a binary diagram of La/Yb versus Dy/Yb (Bogaard and Wörner, 2003) showing the melting curve for garnet peridotite and spinel peridotite, the studied volcanic rocks were shown to have originated from a partial melting of garnet peridotite at about 12% melting for trachyte and about 10% partial melting for basalt (figure 30). The source for the studied basalt is similar to that of alkali basalt from the Bamenda Highlands, studied in detail by Kamgang *et al*. (2008) and Gountie *et al*. (2009) while the source of the trachyte is closer to that of Mount Cameroon lavas (Déruelle, *et al*. (2000) and Yokoyama *et al*. (2007).

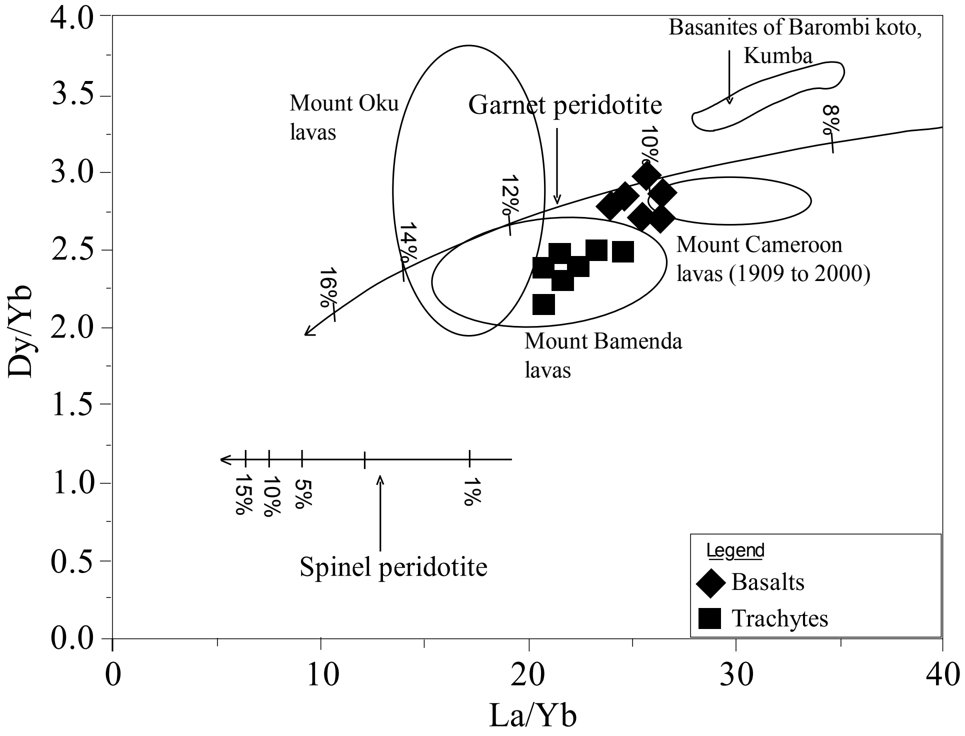

Figure 30: Melting curves of a garnet peridotite and spinel peridotite from Bogaard and Wörner (2003). Also shown are the basic lavas from Mounts Cameroon (Deruelle *et al.*, 2000; Oku (Njilah *et al.*, 2007); Yokoyama *et al.*, 2007) and Bamenda (Kamgang *et al.*, 2013)

3.5. CONCLUSION

Bamenda Town is composed of plutonic and volcanic igneous rocks. The plutonic rocks form the basement complex and include granite and leocogranite, both having high K-calc-alkaline characteristics. The granite is of the K-granitoid and leucogranite is Na-granitoid. Volcanic rocks are basalt and trachyte with SiO_2 of < 50% for basalt and and >62% for trachyte. Both are characterized by negative anomaly for europium (Eu/Eu*= 1.013-1082) and (Eu/Eu*= 0.74-0.832). Both lavas resulted from the partial melting of garnet peridotite at 12% for trachyte and 10% for basalt.

CHAPTER 4
GROUND AND SURFACE WATER QUALITY IN BAMENDA TOWN

4.1. INTRODUCTION

This chapter presents the physical, chemical and bacteriological characteristics of ground and surface water of Bamenda Town and investigates if the water meets the basic requirements for various usages, especially domestic which requires the highest quality of water. Sampling was done seasonally in 2013 and laboratory analyses provided data which are presented in the following paragraphs.

4.2. CHARACTERISTICS OF GROUNDWATER IN BAMENDA TOWN

4.2.1. Physical and chemical characteristics

There was no much disparity in the physical and chemical characteristics of groundwater, whether from the springs or wells but significant seasonal variations were noted.

➢ **Physical characteristics**

The values of the physical parameters are presented in table 5.

Table 5: Seasonal Variation of T°, pH, EC and Turbidity of spring and well water samples in Bamenda Town

	Temperature (°C)		**pH**		**Electrical conductivity (EC)**		**Turbidity (NTU)**	
Sampling points	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season
SW_0	18.4	19.6	6.75	6.06	0.26	0.03	5.6	2.0
SW_1	27.7	24.7	5.4	6.5	0.03	0.05	7.3	2.8
SW_2	21.6	26.4	5.8	6	0.04	0.04	5.6	2.2
SW_3	21.2	24	6.0	5.4	0.03	0.05	9.6	2
SW_4	22.4	26.2	5.2	6.3	0.20	0.03	7.6	4.4
WW_1	24	27.9	6.7	6.2	0.29	0.11	13.5	1.9
WW_2	22.3	27	5.3	5.4	0.16	0.13	6.9	1.8
WW_3	22	25	5.6	4.1	0.05	2.38	6.5	1.7
Average	**22.08**	**25.48**	**5.84**	**5.55**	**0.11**	**0.73**	**7.83**	**2.35**

- **Temperature**: Water temperatures were higher during the dry season and lower in the rainy season for all sampling points with an average of 22.08°C in the rainy season and 25.48°C in the dry season (figure 31A).

- **pH**: The average pH values were higher in the rainy season (5.84) than in the dry season (5.55) as shown in figure 31B, but all water points yielded acidic to barely acidic water.
- **Electrical conductivity (EC)**: EC was very low regardless of the sampling point and season. The highest value (2.38µS/cm) was recorded at WW_3 in the dry season (figure 31C).
- **Turbidity**: Turbidity was higher in the rainy season than in the dry season with average values of 7.83 and 2.35 recorded respectively (figure 31D).

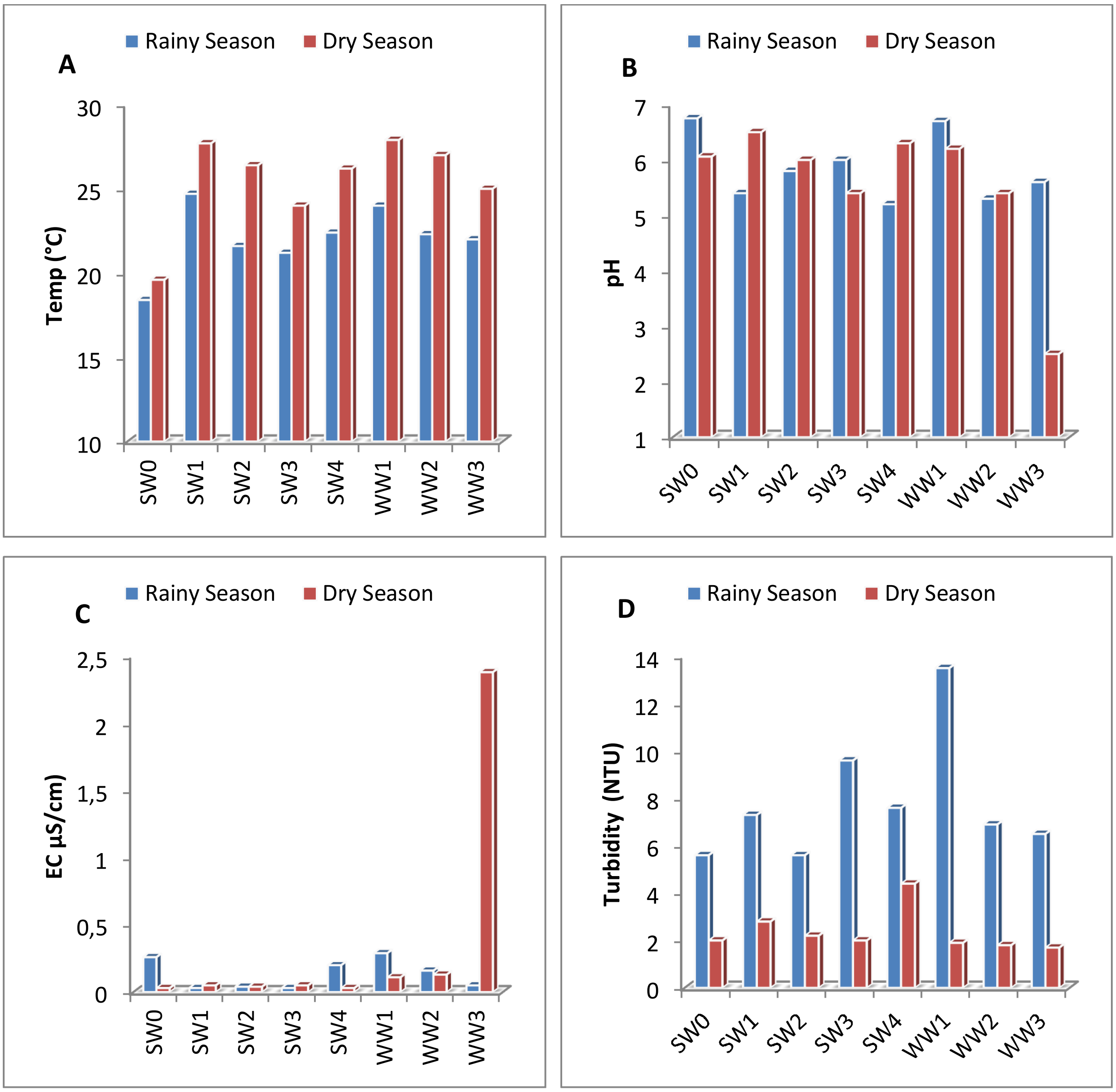

Figure 31: Seasonal variations of physical parameters of springs and wells in Bamenda Town. A: Temperature; B: pH; C: Electrical conductivity; D: Turbidity.

- **Chemical characteristics**

- **Major cations**

Ca^{2+} was the most abundant major cation in all the water samples with an average value of 477.55mg/l (table 6). Ca^{2+} concentrations were higher in the dry season than in the rainy season for all samples. Mg^{2+} was the second abundant cation with an average of 203.25 mg/l in the rainy season and 110.78 mg/l in the dry season. K^+ and Na^+ concentrations were high in the dry season and just barely detectable in the rainy season (there were no differences for different sampling points). Average values for the rainy season were 0.35mg/l and 0.27mg/l, and 21.65mg/l and 9.95mg/l for the dry season respectively.

Table 6: Seasonal variations of major cations (mg/l) in spring and well water in Bamenda Town

	K^+		**Na^+**		**Ca^{2+}**		**Mg^{2+}**	
Sampling points	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**
SW_0	0.02	0.11	0.05	0.02	0.06	0.39	0.0	0.24
SW_1	0.39	23.64	0.11	7.94	240	320	194.4	194
SW_2	0.4	25.39	0.37	8.01	280	400	109.4	219
SW_3	0.39	25.55	0.37	12.38	60	160	145.8	255
SW_4	0.4	24.68	0.37	8.38	260	500	206.6	170
WW_1	0.39	24.89	0.37	5.54	256	980	328.1	12
WW_2	0.39	24.72	0.37	26.67	340	800	461.7	12
WW_3	0.39	24.18	0.11	10.64	180	660	180	24
Average	**0.35**	**21.65**	**0.27**	**9.95**	**202.01**	**477.55**	**203.25**	**110.78**

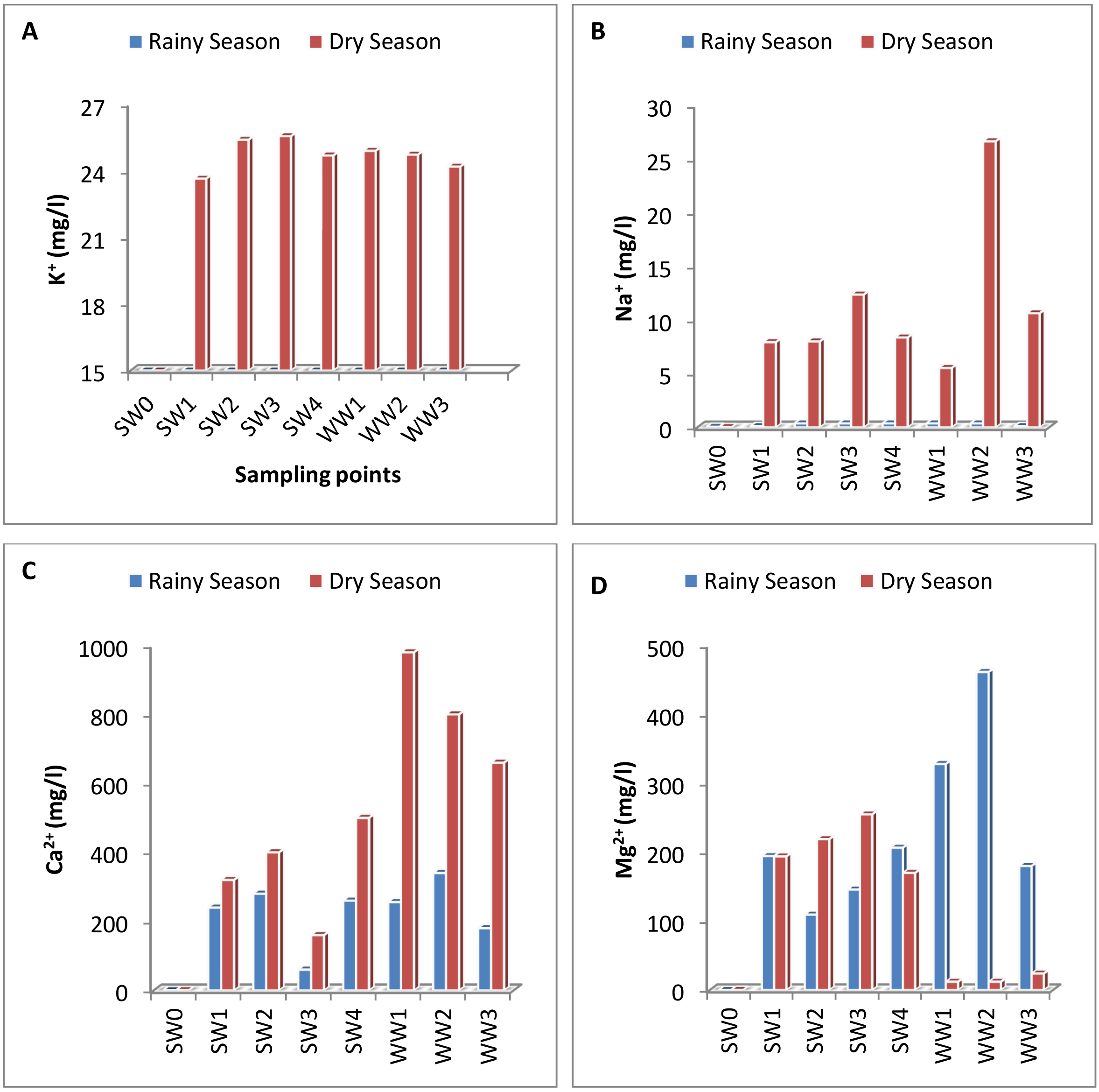

Figure 32: Seasonal variations of major cations in springs and wells of Bamenda Town. A: Na^+; B: K^+; C: Ca^{2+}; D: Mg^{2+}

- **Major anions**

The Cl^- ion varied from 0.0-0.02mg/l in ground water in Bamenda Town in the dry season and from 0.0-270mg/l in the rainy season (table 7). Higher concentrations were measured in the rainy season than in the dry season and the highest value (270mg/l) was obtained at WW_2 in the rainy season (figure 33A). The HCO_3^- ion on the other hand ranged from 0.0-115.55mg/l in the dry season to 26.46-231.8mg/l in the rainy season. The lowest value was measured at WW_3 in the dry season while the highest value of 231.8mg/l was obtained at WW_1 in the rainy season (figure 33B). SO_4^{2-} concentrations varied from 0.03 to 26mg/l in the study area. Higher values were gotten in the rainy season than in the dry season (figure 33C). The highest value (26mg/l) was obtained at WW_1 in the rainy season and the lowest (0.03mg/l) was measured in the dry season at SW_0.

Table 7: Seasonal variations of anions (mg/l) in spring and well water in Bamenda Town

	Cl^-		HCO_3^-		SO_4^{2-}	
Sampling points	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Rainy Season**
SW0	-	0.02	26.47	16.25	0.31	0.03
SW_1	-	-	57.95	75.6	15	0.05
SW_2	-	-	30.5	40.32	12	0.05
SW_3	-	-	39.65	42.84	18	0.06
SW_4	158	-	33.55	37.8	12	0.05
WW_1	-	-	231.8	116.55	26	0.06
WW_2	270	-	30.5	37.8	23	0.05
WW_3	-	-	33.55	-	17.3	0.05
Average	**53.5**	**0.0025**	**60.49**	**45.89**	**15.70**	**0.05**

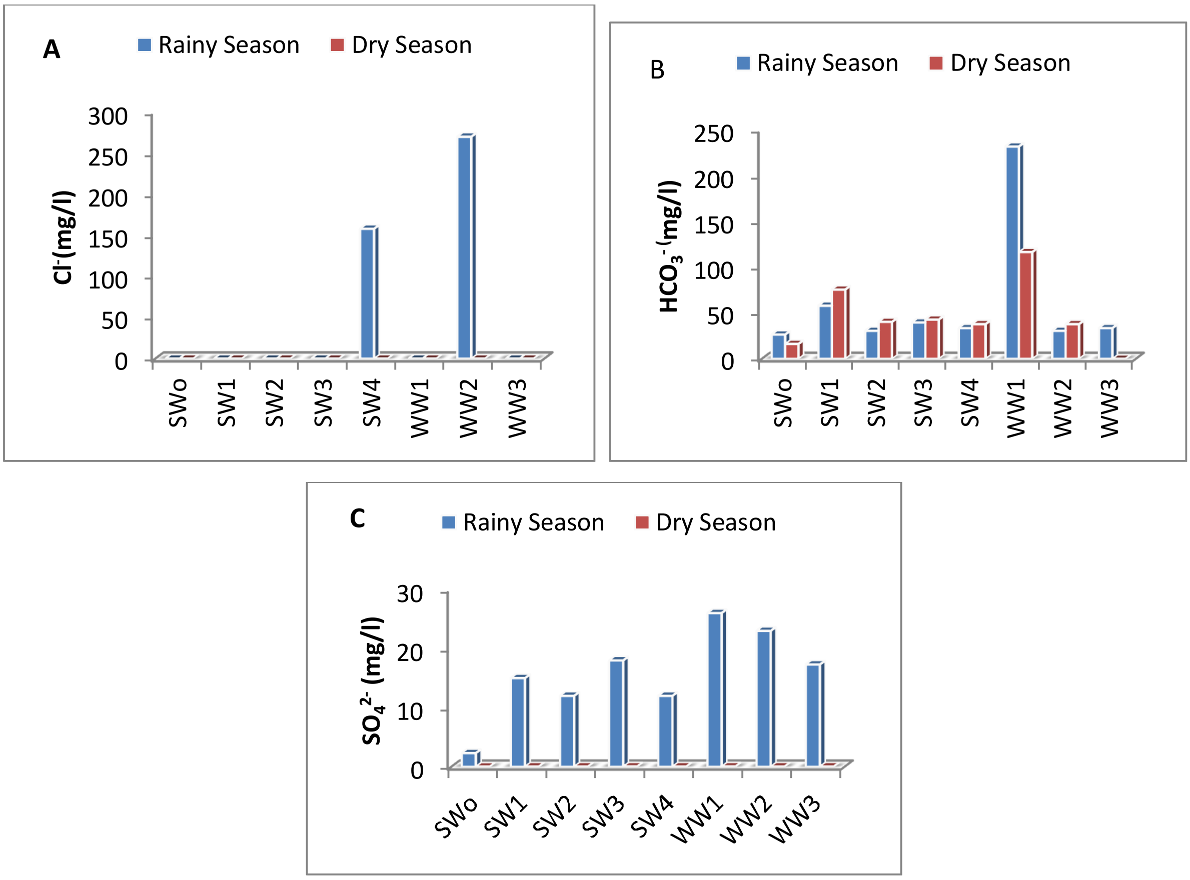

Figure 33: Seasonal variations of anions in spring and well water of Bamenda Town. A: Cl^-; B: HCO_3^-; C: SO_4^{2-}

- **Nutrients (PO_4^{3-}, NO_3^- and NH_4^+)**

Average values of PO_4^{3-} ranged from 0.94mg/l to 0.16mg/l during the study period (table 10). Higher values were obtained in the dry season (0.8-1.67mg/l) than in the rainy season (0.12-0.25mg/l) (figure 34A). The highest value of PO_4^{3-} (1.67mg/l) was measured at SW_1 in the dry season and the lowest value (0.12mg/l) was obtained at SW_0 in the rainy season. NO_3^- concentration ranged from 0.0006 to 11.2mg/l. Values were higher in the rainy season than in the dry season (figure 34B). The lowest value (0.0006mg/l) was at SW_2 in the dry season and the highest (11.2mg/l) was obtained at SW_1 in the rainy season (table 8). The NH_4^+ varied from 11.78 mg/l in to 0.0521mg/l during the study period. Higher values (8.4-16.8mg/l) were obtained in the rainy season and were barely detectable (0.0011-0.0087mg/l) in the dry season (figure 34C). Spatial variations were noticeable with the highest concentrations (16.8mg/l) measured at SW_4 in the rainy season and the lowest (0.0011mg/l) at SW_0.

Table 8: **Seasonal variations of nutrients in spring and well water in Bamenda Town**

	PO_4^{3-}		NO_3^-		NH_4^+	
Sampling points	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Rainy Season**
SW0	0.12	-	0.6	0.0026	9.80	0.0011
SW_1	0.25	1.67	11.2	0.0028	8.4	0.0062
SW_2	0.19	1.23	8.4	0.0006	12.88	0.0048
SW_3	0.19	1.23	5.6	0.0022	14	0.0070
SW_4	0.13	0.8	7.28	0.0034	16.8	0.0083
WW_1	0.13	1.23	5.88	0.0048	10.36	0.0084
WW_2	0.13	0.8	7	0.0045	12.77	0.0076
WW_3	0.13	0.8	8.4	0.0048	9.24	0.0087
Average	**0.16**	**0.94**	**6.79**	**0.0032**	**11.78**	**0.0065**

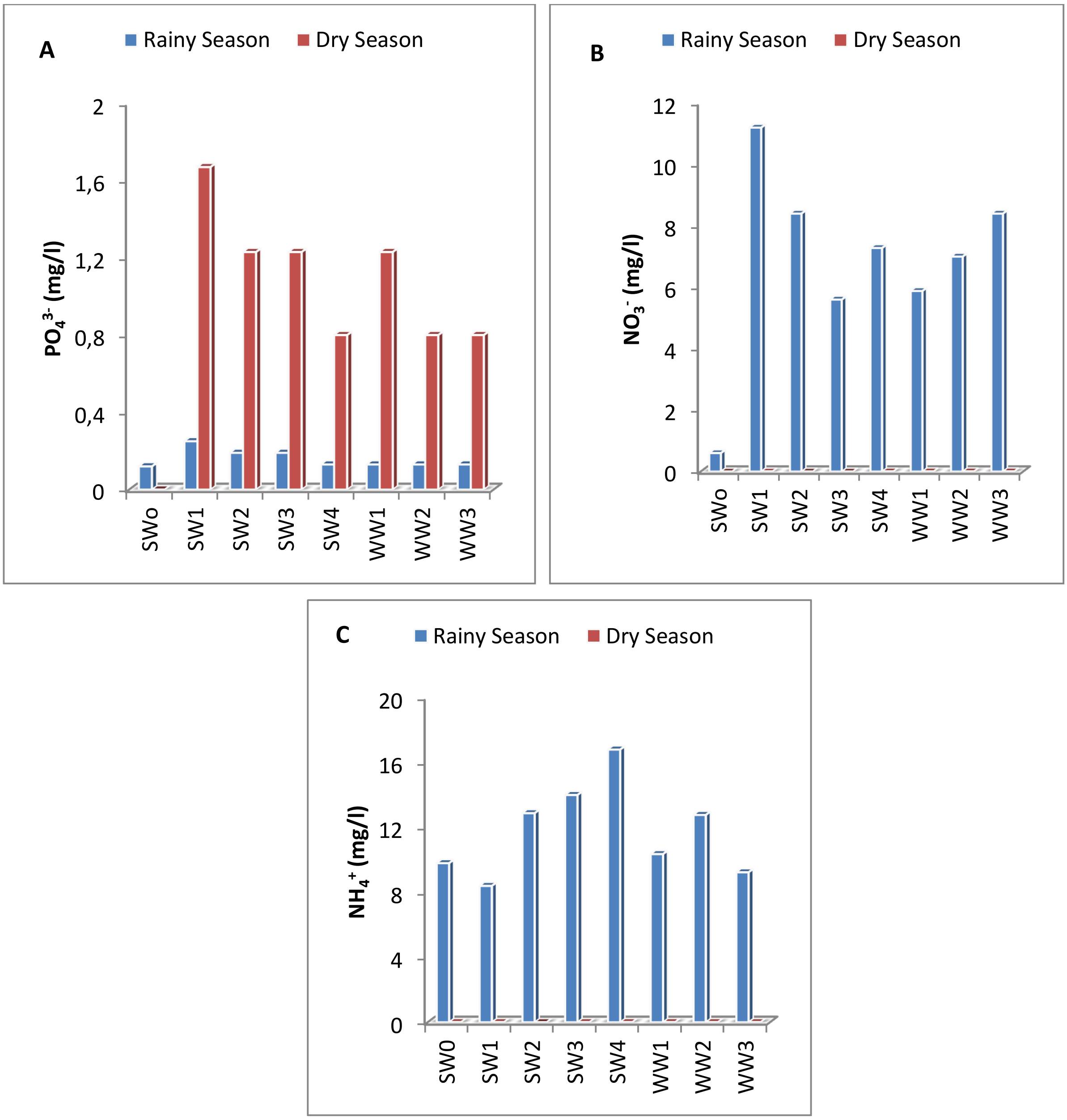

Figure 34: Seasonal variations of nutrients in spring and well water in Bamenda Town. A: PO_4^{3-}; B: NO_3^-; C: NH_4^+

- **Hydrochemical facies**

The Piper diagram provides information on the different chemical facies of the analysed groundwater. In the dry season, the major cations and anions presented one facies of the Ca-Mg-HCO_3 type (figure 35A), whereas in the rainy season, the major cations and anions presented two facies of Ca-Mg-HCO_3 type and Ca-Mg-SO_4 type (figure 35B).

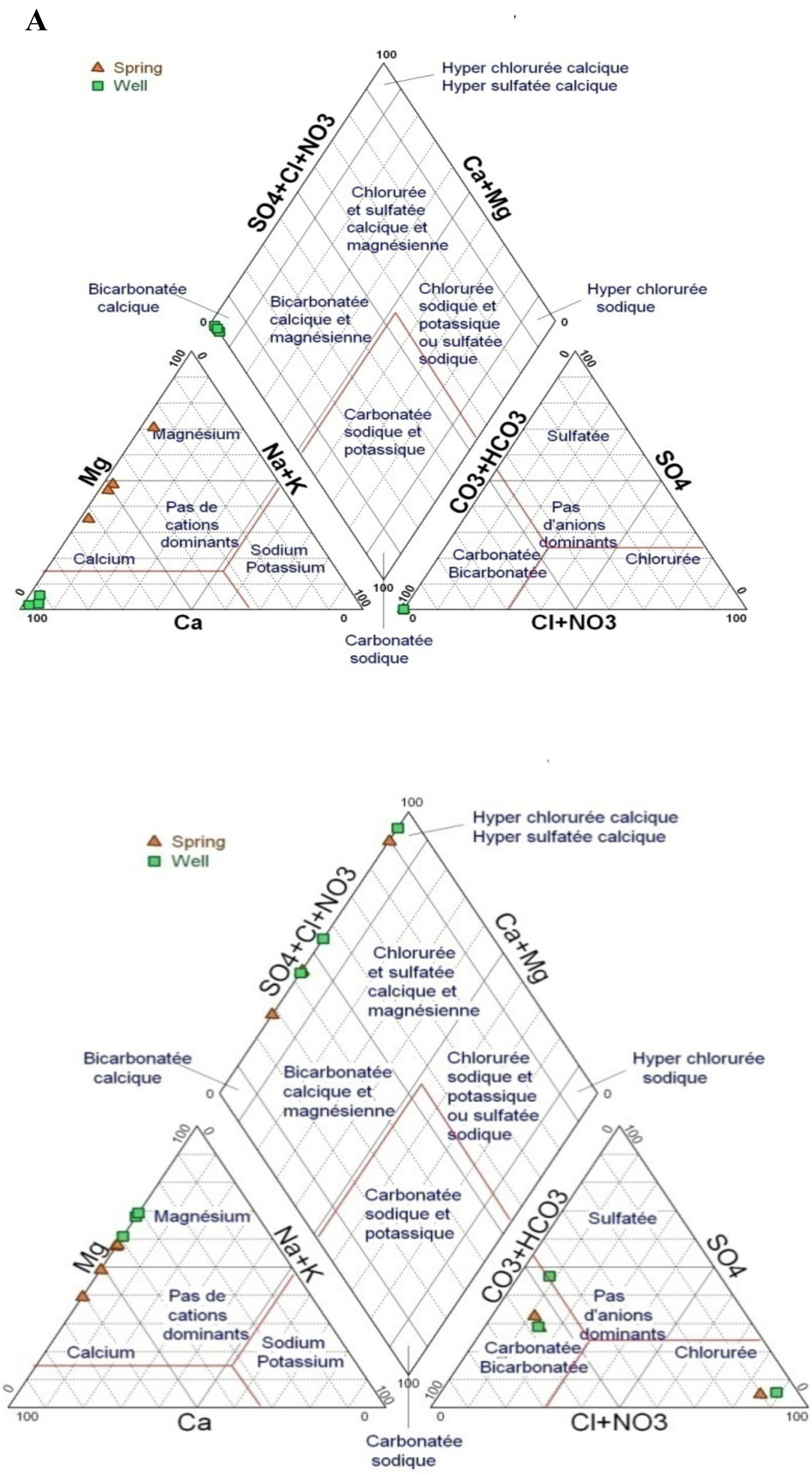

Figure 35: Piper's diagram showing the water types of springs and wells in Bamenda Town. A: dry season; B: rainy season

- **Heavy metals in spring and well water in Bamenda Town**

The heavy metals analysed in groundwater in Bamenda Town were Cu, Pb, As, Zn, B, Fe, Ni, Cd, Hg and Cr. Most of these elements were measured in minute concentrations and others were not detected at some sampling points in the rainy season (table 9). These were: Cu in SW_2, SW_4 and WW_3; Pb in SW_0 and WW_1; As in SW_0; Zn in SW_1 and SW_3 while B was not detected in SW_0 and WW_3 water samples. Seasonal variations in the heavy metals were not conspicuous (figure 36). High concentrations were measured for Pb (0.023mg/l) at WW_1 during the dry season. Fe^{2+} was the most abundant heavy metal in the water samples with the highest concentration of 1.14 mg/l in WW_2 during the dry season. In the rainy season, Fe^{2+} was not detected in SW_3, SW_4, WW_1, WW_2 and WW_3 while in the dry season, it was not detected in SW_1 and SW_2. No trace of Ni, Cd, Hg and Cr was measured in spring and well water in Bamenda Town during the study period.

Table 9: Seasonal Variations of heavy metals in spring and well water in Bamenda Town

	Cu		Pb		As		Zn		B		Fe	
Sampling points	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**
SW0	0.001	0.001	0	0.003	0	0.002	0.001	0.001	0	0.002	-	0.09
SW_1	0.001	0.004	0.001	0.014	0.003	0.002	0	0.003	0.003	0.001	0.89	-
SW_2	0	0.006	0.001	0.002	0.011	0.014	0.002	0.003	0.001	0.003	0.83	-
SW_3	0.004	0.002	0.003	0.004	0.016	0.003	0	0.002	0.001	0.002	-	0.39
SW_4	0	0.001	0.001	0.006	0.001	0.004	0.001	0.011	0.002	0.001	-	0.05
WW_1	0.001	0.004	0	0.023	0.002	0.012	0.012	0.004	0.001	0.004	-	0.05
WW_2	0.003	0.002	0.003	0.004	0.003	0.013	0.014	0.013	0.003	0.002	-	1.14
WW_3	0	0.003	0.002	0.004	0.002	0.003	0.002	0.012	0	0.003	-	0.18
Average	**0.002**	**0.003**	**0.001**	**0.007**	**0.005**	**0.007**	**0.004**	**0.006**	**0.004**	**0.002**	**0.86**	**0.32**

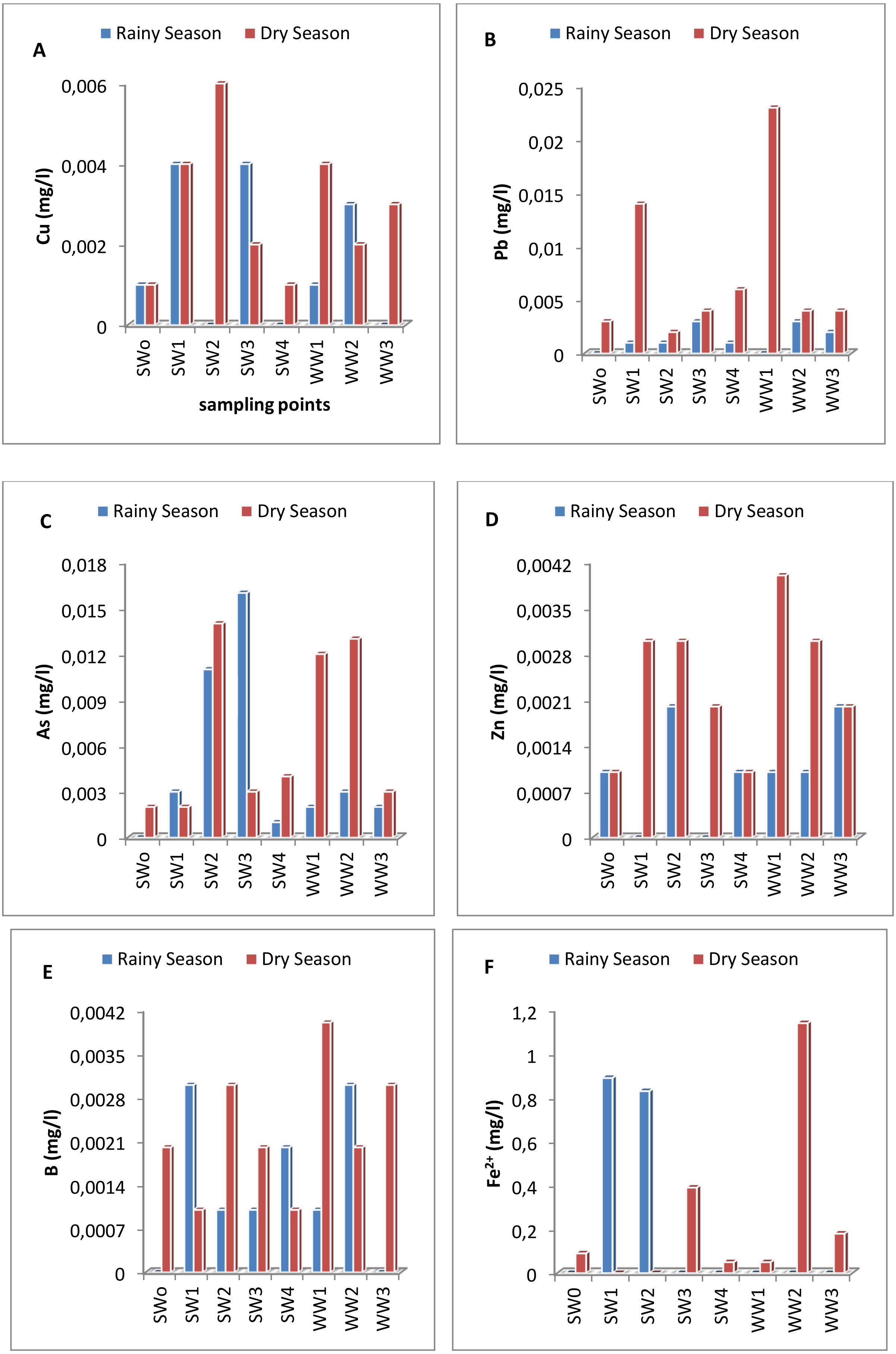

Figure 36: Seasonal variations of heavy metals in spring and well water in Bamenda Town. A: Cu; B: Pb; C: As; D: Zn; E: B; F: Fe^{2+}

4.2.2. Bacteriological characteristics

Four (04) water points (SW_0, SW_1, SW_2 and WW_2) were analysed for bacteria indicators of pollution, as well as for specific pathogens (table 10).

Table 10: Bacterial counts of specific microbes isolated in springs and wells in the rainy and dry seasons

Sampling points	Enterobacteria (CFU/100ml)		*E. coli* (CFU/100ml)		Streptococcus (CFU/100ml)		Salmonella (CFU/100ml)		Proteus (CFU/100ml)	
	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season
SW0	20	100	10	20	100	50	0	0	10	20
SW_1	50	100	20	30	200	50	0	0	0	10
SW_2	20	200	10	20	100	70	0	10	0	50
WW_2	200	300	100	200	300	200	60	15	10	0
Total	290	700	140	270	700	370	60	25	20	80
Average	**72.5**	**175**	**35**	**67.5**	**175**	**92.5**	**15**	**6.25**	**5**	**20**

Enterobacteria*, Escherichia coli,* Streptococcus, Salmonella and Proteus were detected in the water samples and the species richness varied from one water point to another: Enterobacteria, *Escherichia coli* and Streptococcus were present in all the sampling points. Higher counts were recorded in the dry season than in the rainy season with Streptococcus presenting an exception with higher counts in the rainy season (100 to 300 CFU/100ml) than in the dry season (50 to 200 CFU/100ml) (figure 37). Enterobacteria levels were particularly high during the rainy season (20 to 200 CFU/100ml) but increased greatly during the dry season (100 to 300CFU/100ml). On the other hand, Salmonella and Proteus were absent in springs (SW_0, SW_1 and SW_2) in the rainy season but registered an increase in the dry season. Salmonella was measured at SW_2 and WW_2 while Proteus was detected at SW_0 and WW_2 in the rainy season and at SW_0, SW_1 and SW_2 in the dry season sampling points.

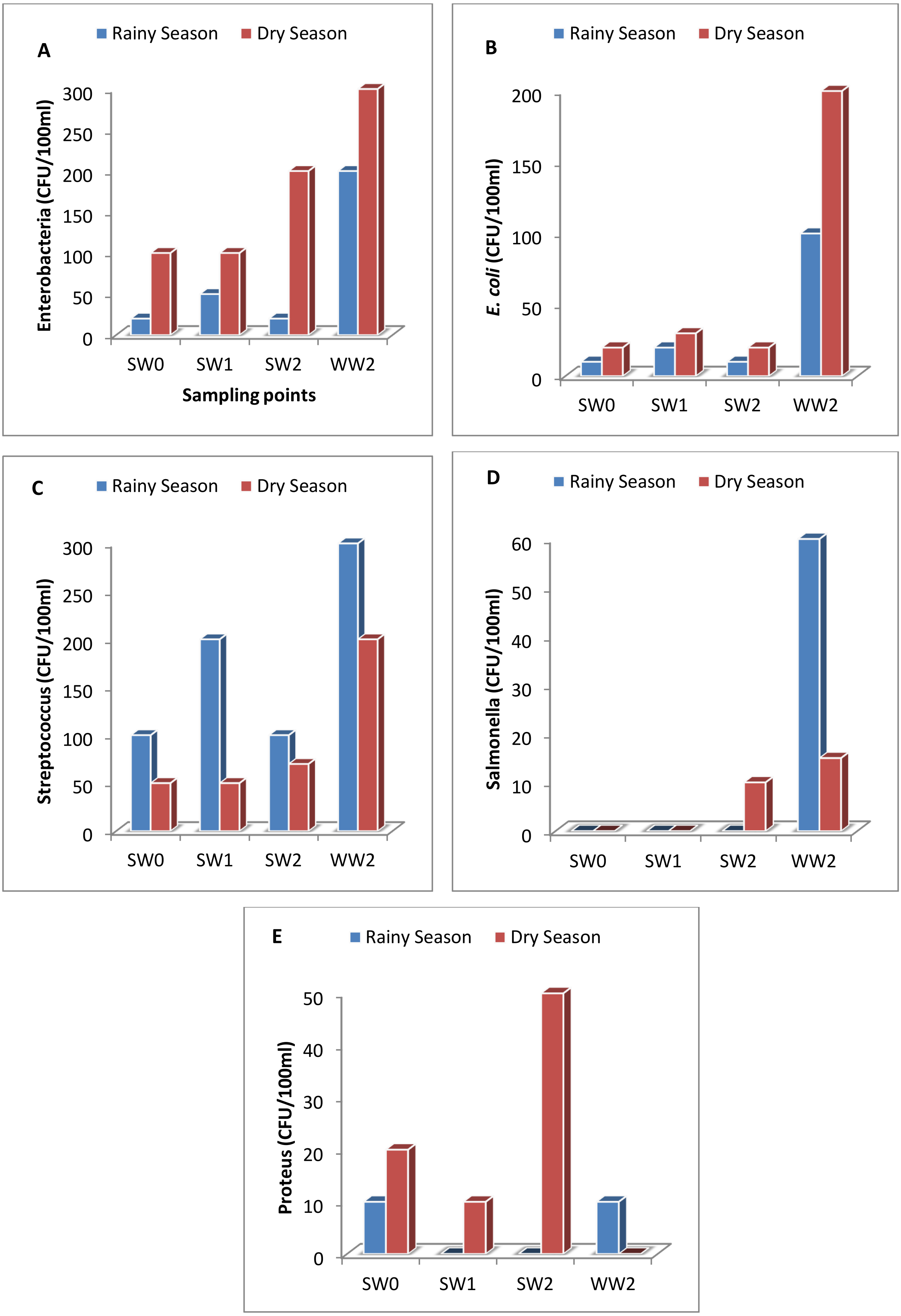

Figure 37: Seasonal variations of bacteria indicators of pollution and specific microbes in spring and well water of Bamenda Town. A : Enterobacteria; B: *E. coli;* C: Streptococcus; D: Salmonella; E: Proteus

4.3. CHARACTERISTICS OF SURFACE WATER IN BAMENDA TOWN

Surface water in Bamenda Town consists of the Mezam River and tributary streams which constitute the Mezam River System and whose characteristics are thus:

4.3.1. Physico-chemical characteristics

- **Physical characteristics**

- **Temperature**

The mean water temperature ranged from 18.3°C at YB to 23.4°C at LN (table 11). Seasonal temperature variations were not significant at all sampling points. The lowest temperature values were recorded at YB and the highest values at LN (figure 38).

Table 11: Seasonal variations in temperature (°C) in the Mezam River System

	YB	BB	NM	AS	LN	NB
Minimum	17.6	20.3	19.6	20.7	23.2	21.3
Maximum	18.4	22.6	21.3	21.2	23.6	21.7
Mean	18.3	21.7	20.3	20.9	23.4	21.5
S.D.	0.40	1.27	0.87	0.26	0.2	0.23

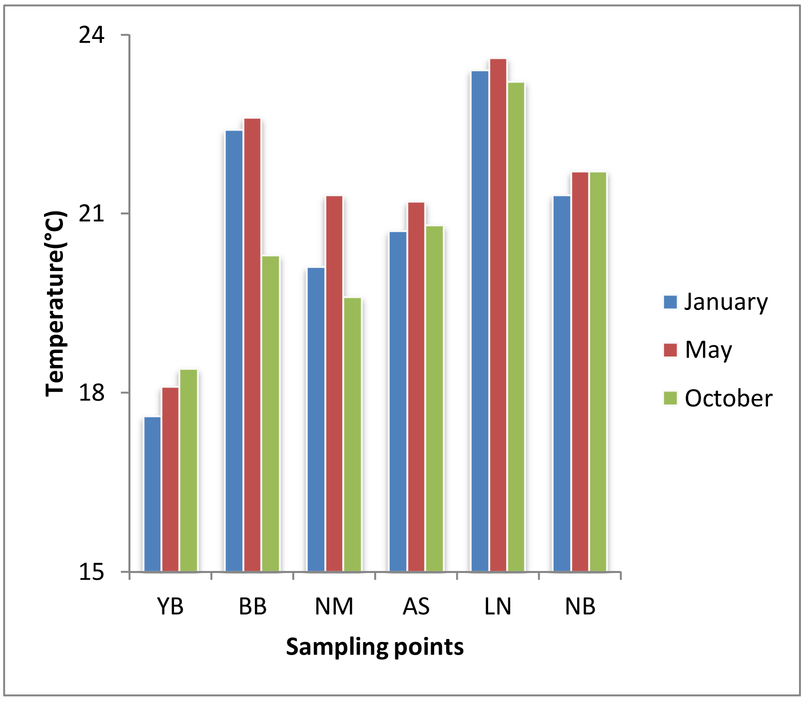

Figure 38: Seasonal variations in temperature of the Mezam River System

- **pH**

The mean pH values in the Mezam River system ranged from 5.45± 0.49 at Nkimufueh (NM) to 6.47±0.18 at Naaka Bridge (NB) (table 12). Seasonal variations were eminent; with highest values measured during the October sampling period and lowest at NM during all sampling occasions, and the highest value was at NB (figure 39).

Table 12: Variations in pH values in the Mezam River System

	YB	BB	NM	AS	LN	NB
Minimum	6.06	5.48	5.12	5.63	6.21	6.25
Maximum	6.75	6.71	6.03	6.54	6.34	6.84
Mean	6.3	5.9	5.45	6.04	6.33	6.47
S.D.	0.39	0.69	0.49	0.69	0.18	0.047

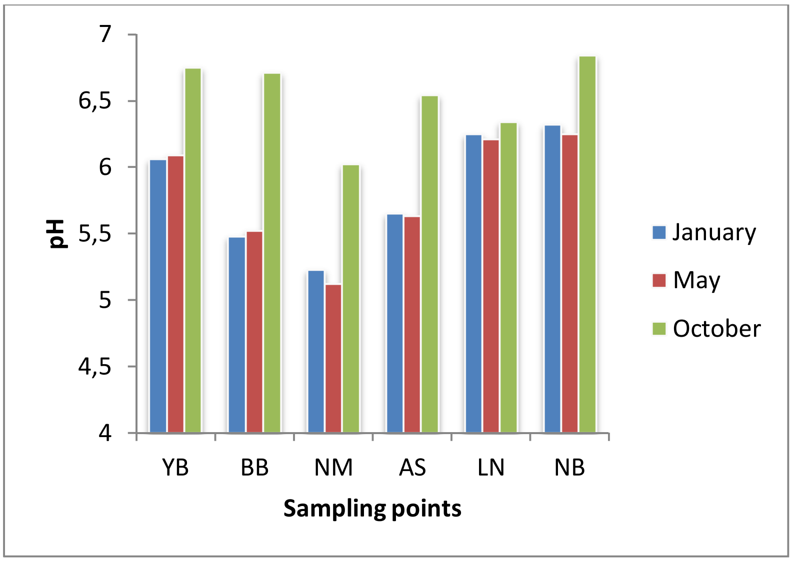

Figure 39: Seasonal variations in pH values of the Mezam River System

- **Turbidity**

The mean values of turbidity ranged from 3.27±2.02NTU at YB to 52.93±34.64NTU at NM (table 13). There was a marked seasonal variation at YB, BB, AS, LN and NB with the lowest values measured during the January sampling period, and the highest values in October (figure 40). The minimum value of turbidity (2.00NTU) was measured at YB in January.

Table 13: Variations in Turbidity (NTU) in the Mezam River System

	YB	BB	NM	AS	LN	NB
Minimum	2.0	10.5	13.0	16.3	10.0	20.7
Maximum	5.6	25.9	74.9	17.5	42.4	42.9
Mean	3.27	16.4	52.93	16.73	21.6	35.3
S.D.	2.02	8.31	34.64	0.67	18.05	12.48

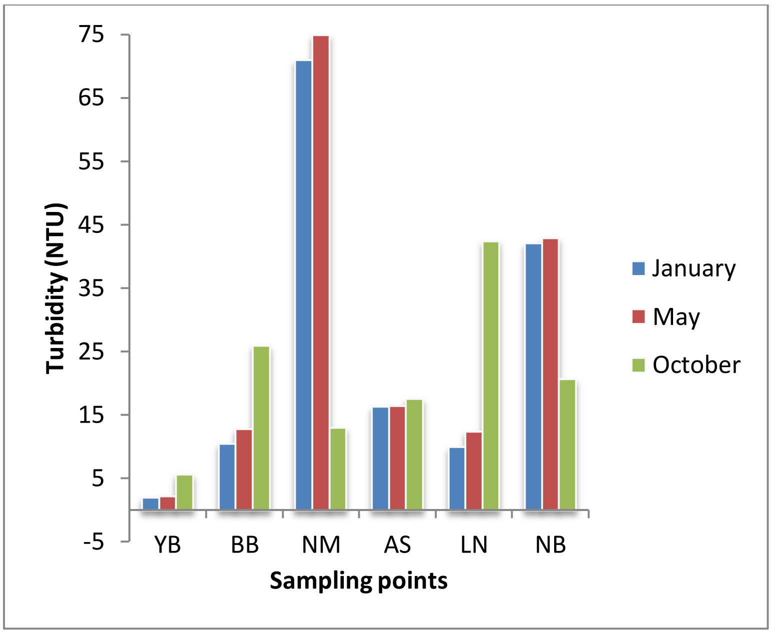

Figure 40: Seasonal Variations of turbidity in the Mezam River System

- **Electrical conductivity**

Values of electrical conductivity (EC) varied greatly in the Mezam River System. Mean values ranged from 41.67±26.58µS/cm at Yambot (YB) to 237.0±63.22µS/cm at Ayaba Stream (AS) during the period of study (table 14). Seasonal variations were also noted at YB, Lower Ngomgham (LN) and Naaka Bridge (NB). Except for the NM sampling points, the highest values were recorded in January while the lowest values were measured in October. The lowest value measured during the study period was at YB (figure 41).

Table 14: Variation in EC (µS/cm) in Mezam River System

	YB	BB	NM	AS	LN	NB
Minimum	6.09	38.00	182.00	165.00	42.00	18.00
Maximum	58.00	92.00	267.00	285.00	123.00	84.00
Mean	41.67	71.33	214.67	237.00	93.33	58.33
SD	26.58	29.14	45.79	63.22	44.64	35.36

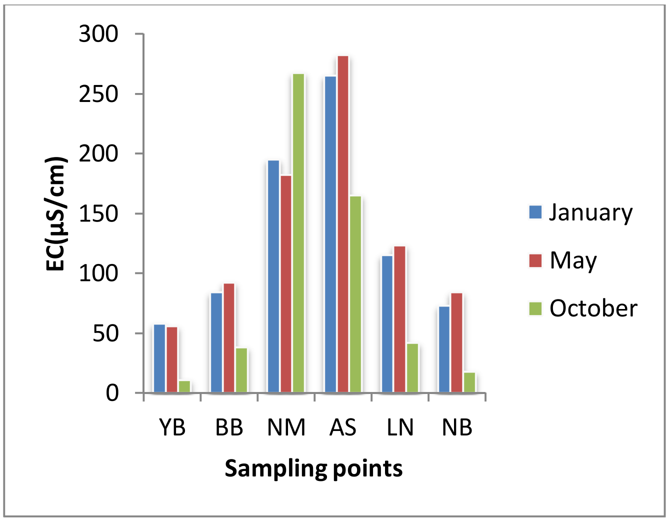

Figure 41: Seasonal variations in EC (µS/cm) of the Mezam River System

- **Dissolved oxygen**

The concentrations of dissolved oxygen (DO) ranged from 4.5 ±2.49 mg/l at BB to 15.24 ±1.05 mg/l at YB (table 15). The lowest DO values were measured in January and the highest recorded in October at all the sampling points (table 15). There was a great 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 (figure 42).

Table 15: Variations in dissolved oxygen (mg/l) in the Mezam River System

	YB	BB	NM	AS	LN	NB
Minimum	13.31	4.54	6.43	5.23	7.57	7.34
Maximum	15.24	9.51	8.75	9.27	10.47	12.67
Mean	14.03	9.09	7.79	7.44	8.76	9.51
S.D.	1.05	2.49	1.21	2.05	1.51	2.80

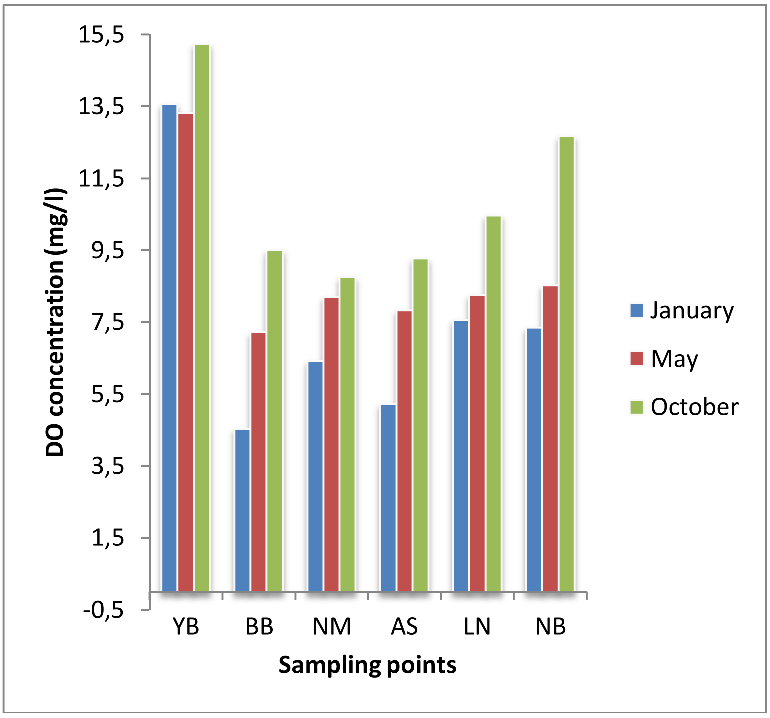

Figure 42: Variations in dissolved oxygen (mg/l) of the Mezam River System

- **Suspended solids**

The mean values of suspended solids (SS) ranged from 0.37±0.15mg/l at YB to 5.24±5.24mg/l at NM (table 16). The highest value of this variable was recorded during the October sampling occasion meanwhile seasonal variations were not very marked between the January and May sampling periods. The lowest value of suspended solids was 0.24mg/l measured at YB, which was the reference point while the highest value was 5.82mg/l, measured at NM (figure 43).

Table 16: Variation in suspended solids (mg/l) in the Mezam River System

	YB	BB	NM	AS	LN	NB
Minimum	0.24	1.29	4.37	1.34	1.22	3.10
Maximum	0.53	2.34	5.82	3.12	2.54	3.67
Mean	0.37	1.73	5.24	2.40	1.66	3.33
S. D.	0.15	0.55	0.77	0.94	0.76	0.30

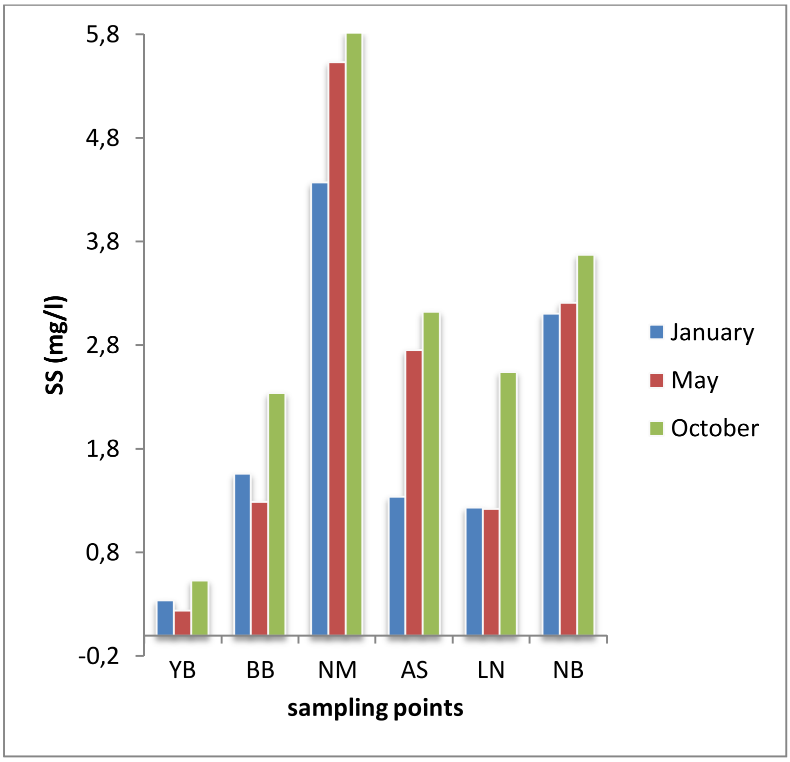

Figure 43: Variations in suspended solids (mg/l) in the Mezam River System

- **Chemical characteristics of water in the Mezam River System**

- **Major cations (Ca^{2+}, Mg^{2+}, $K^{+}$and Na^{+})**

The cations were measured in the Mezam River system in minute amounts (0.00-1.36) at all the sampling points. The lowest values were measured at YB (table 17). All the major cations were present in water samples in the May sampling period (figure 44). The highest concentrations of the cations during the study period were measured for Ca^{2+} (1.36mg/l) at NM during the May sampling session and the least values were obtained during the October sampling occasion when Na^{+} was not detected at all the sites. Low values of Na^{+} and K^{+} were measured at all the sites while Mg^{2+} was absent at the NB and YB sampling points.

Table 17: Variations of major cations (mg/l) in the Mezam River System

		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}
	Minimum	0.06	0.24	0.02	0.02
	Maximum	0.39	0.26	0.12	0.04
YB	Mean	0.28	0.2	0.08	0.02
	S.D.	0.19	0.14	0.05	0.02
	Minimum	0.09	0.69	0.07	0.07
	Maximum	1.03	0.76	0.67	0.09
BB	Mean	0.72	0.73	0.46	0.05
	S.D.	0.54	0.42	0.34	0.047
	Minimum	0.37	0.23	0.02	0.12
	Maximum	1.36	1.04	0.99	0.14
NM	Mean	0.98	0.76	0.71	0.09
	S.D.	0.53	0.46	0.44	0.075
	Minimum	0.14	0.05	0.01	0.00
	Maximum	1.25	0.59	0.43	0.08
AS	Mean	0.86	0.39	0.29	0.05
	S.D.	0.62	0.30	0.23	0.046
	Minimum	0.08	0.1	0.05	0.04
	Maximum	1.20	0.47	0.35	0.05
LN	Mean	0.78	0.33	0.25	0.03
	S.D.	0.61	0.20	0.17	0.026
	Minimum	0.05	0.50	0.04	0.07
	Maximum	0.95	0.58	0.35	0.09
NB	Mean	0.61	0.36	0.22	0.05
	S.D.	0.40	0.31	0.15	0.047

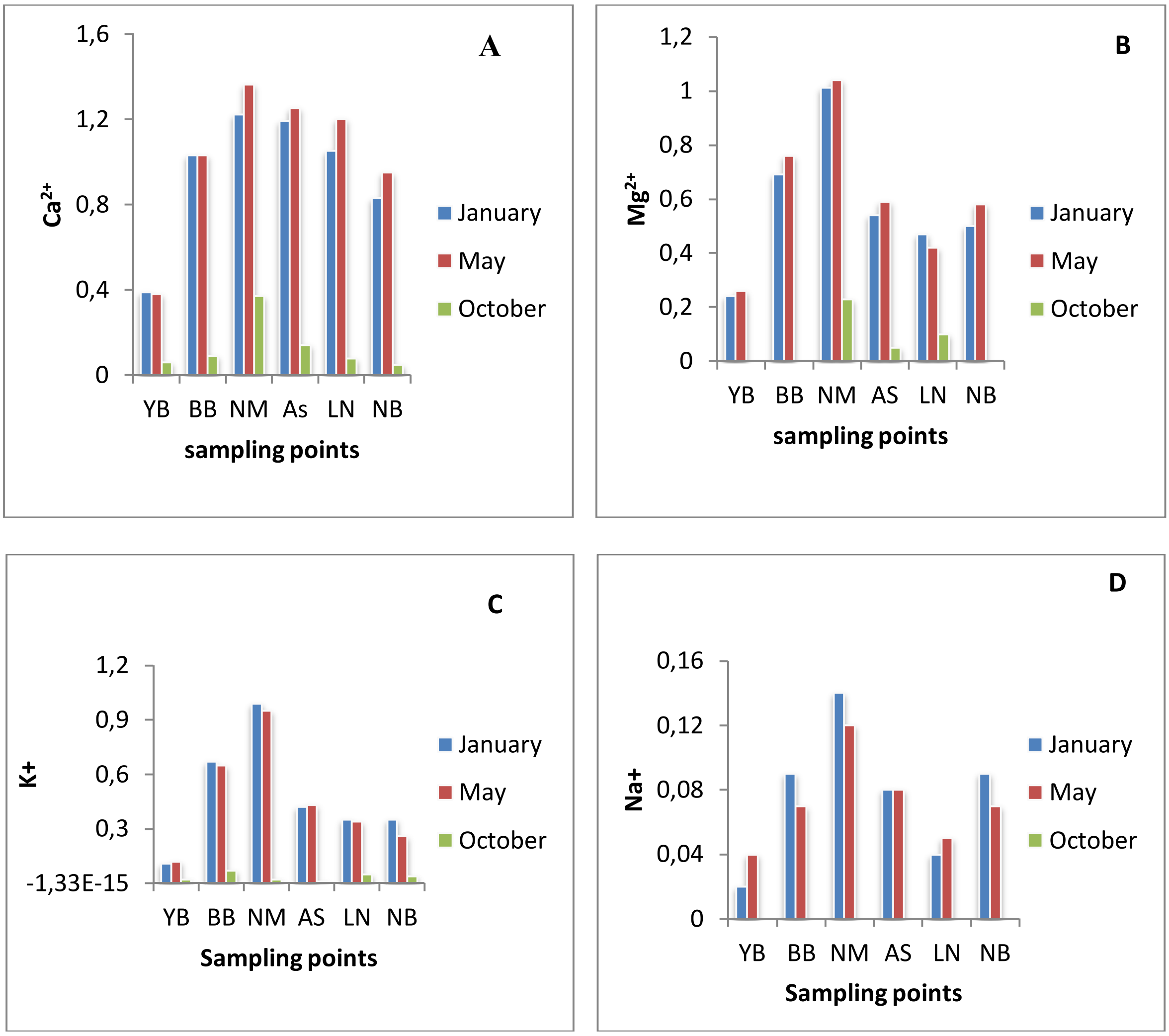

Figure 44: Seasonal variations in major cations (mg/l) in the Mezam River System. A: Ca^{2+}; B: Mg^{2+}; C: K^{+}; D: Na^{+}

- **Major Anions (Cl^{-}, HCO_3^{-}, SO_4^{2-})**

Major anions were measured in very low concentrations in the Mezam River system, ranging from 0.00-3.2mg/l. The chloride ion varied from 0.00mg/l to 0.09mg/l (table 18). Seasonal variations were not very distinct except at the BB, NM and LN sampling points (figure 45A). The highest mean concentration (0.09mg/l) was recorded at NM during the May sampling event and the lowest at YB. The bicarbonate ion ranged from 0.11mg/l to 3.2 mg/l and seasonal variations were observed with lowest concentrations recorded during the October sampling occasion and about 95% of the highest concentration was obtained in January (figure 45B). The lowest value for the bicarbonate ion was 0.86mg/l at YB and the highest was 3.2mg/l at NB. Mean values of the sulphate ion ranged from 0.18mg/l to 0.31mg/l (table 20). Low levels of the sulphate ion (0.01mg/l) were measured during the May and October sampling periods with no noticeable trend, while higher concentrations were measured in the January sampling session (figure 45C).

Table 18: Variations of major anions (mg/l) in the Mezam River System

		YB	BB	NM	AS	LN	NB
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00
	Maximum	0.06	0.06	0.09	0.06	0.07	0.02
Cl^-	Mean	0.03	0.03	0.05	0.04	0.04	0.02
	S.D.	0.012	0.012	0.047	0.035	0.036	0.023
	Minimum	0.11	0.15	0.6	0.15	0.9	0.38
	Maximum	1.7	2.5	1.5	3.1	2.7	3.2
HCO_3^-	Mean	0.86	1.45	1.13	1.68	1.73	2.06
	S.D.	0.803	1.193	0.473	1.478	0.907	1.499
	Minimum	0.01	0.12	0.13	0.30	0.12	0.10
	Maximum	0.18	0.27	0.33	0.032	0.24	0.24
SO_4^{2-}	Mean	0.15	0.21	0.26	0.31	0.20	0.19
	S.D.	0.042	0.082	0.61	0.012	0.067	0.078

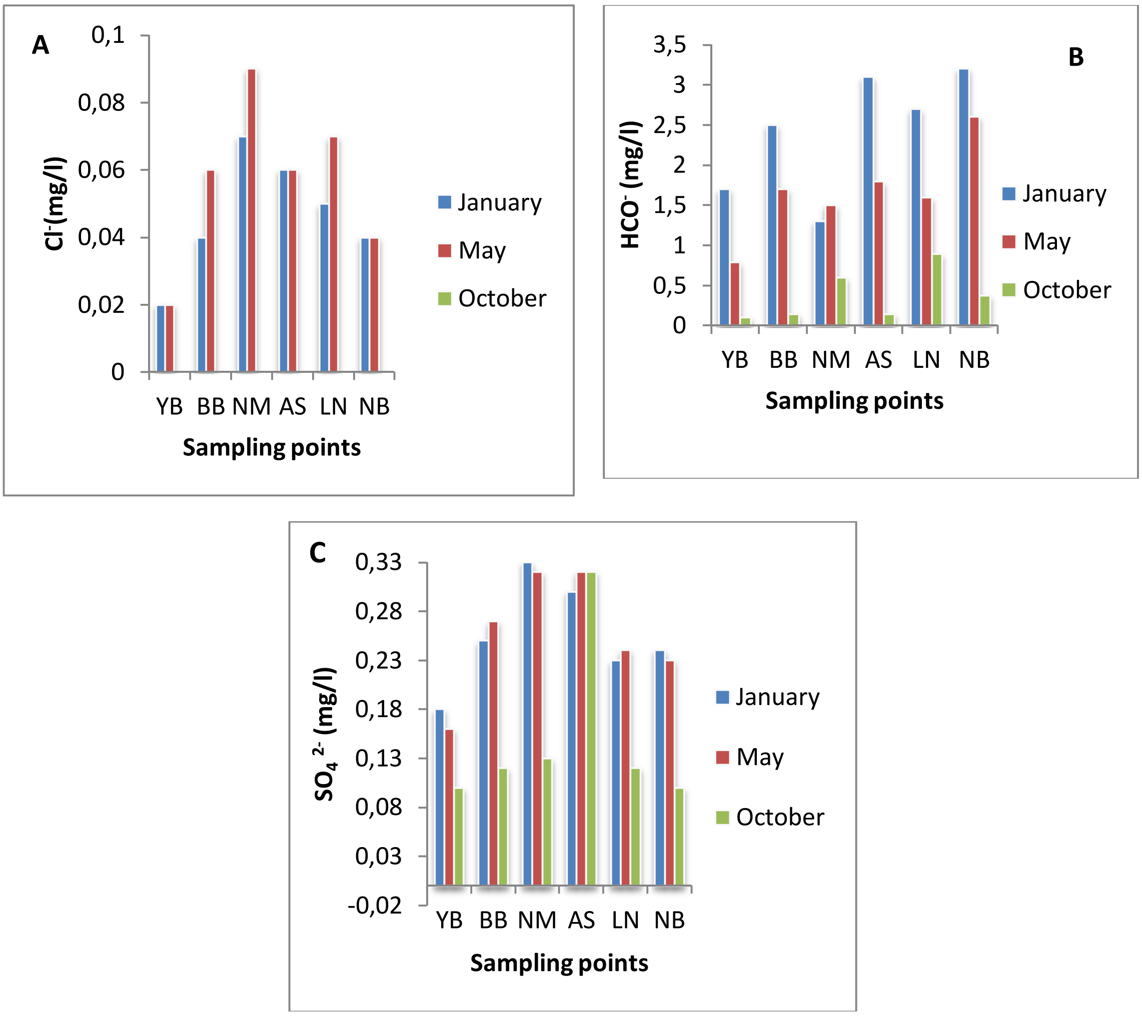

Figure 45: Seasonal variations in major anions of the Mezam River System. A: Cl^-; B: HCO_3^-; C: SO_4^{2-}

- **Nutrients (PO_4^{3-}, NO_3^- and NH_4^-) in the Mezam River System**

The phosphate ion varied from 0.03mg/l to 0.12mg/l, with no significant variation from one season to the other, and among the sampling points (figure 46C). The lowest mean concentration for the phosphate ion was 0.05mg/l at YB, and the highest was 0.075mg/l at NB. The nitrate ion varied from 13.25±17.42mg/l to 19.77±21.68mg/l in the Mezam River system. The lowest concentration (0.04mg/l) was measured during the May sampling session and the highest (50mg/l) was obtained in January (figure 46B). The highest concentration (50mg/l) was recorded at NM and the lowest (0.04mg/l) at YB. The mean of the ammonium ion ranged from 33.27±22.23mg/l to 44.79±24.18mg/l (table 19). Seasonal variations were noted with the lowest concentration (7.84mg/l) measured during the October sampling period (rainy season) and the highest (63mg/l) during the May sampling period except at AS. Spatial variations were also noted with the highest content (63mg/l) recorded at LN in May and the lowest (7.8mg/l) at NM in October (figure 46A).

Table 19: Seasonal variations of Nutrients (mg/l) in the Mezam River System

		YB	**BB**	**NM**	**AS**	**LN**	**NB**
	Minimum	0.03	0.04	0.05	0.05	0.024	0.05
	Maximum	0.07	0.07	0.12	0.11	0.08	0.12
PO_4^{3-}	Mean	0.05	0.05	0.07	0.07	0.048	0.075
	S.D.	0.014	0.006	0.007	0.006	0.008	0.013
	Minimum	0.04	0.07	0.12	0.08	0.05	0.07
	Maximum	33	38	50	43	44	49
NO_3^-	Mean	13.25	14.93	19.69	19.77	17.48	19.34
	S.D.	17.42	20.25	26.62	21.68	23.34	26.07
	Minimum	9.8	20.31	7.84	8.96	17.36	13.44
	Maximum	54	56	62	48	63	59
NH_4^+	Mean	33.27	40.77	41.95	34.32	44.79	43.81
	S.D.	22.23	18.41	29.69	21.99	24.18	26.30

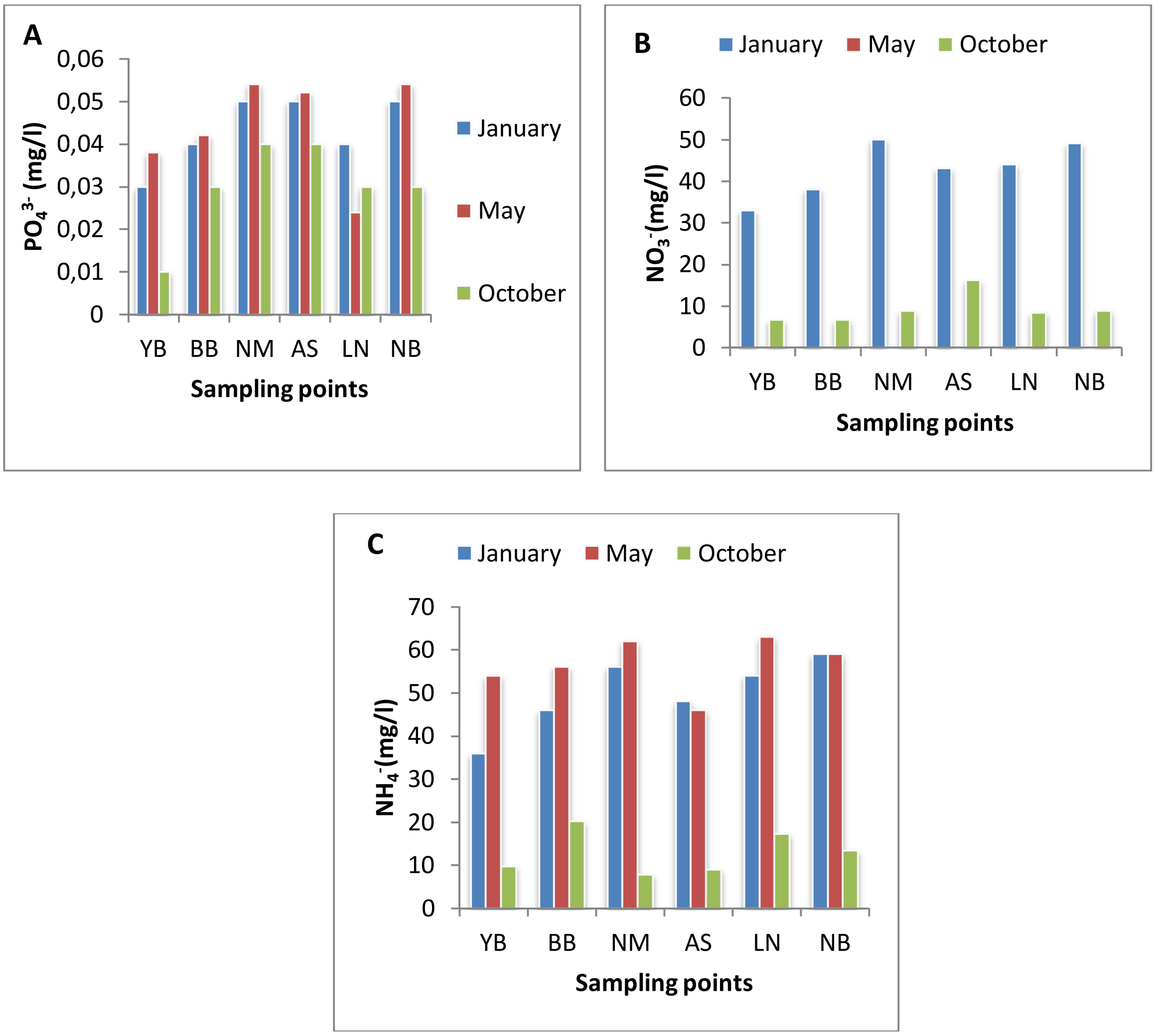

Figure 46: Seasonal variations of nutrients in the Mezam River System. A: PO_4^{3}; B: NO_3^-; $^-$ C: NH_4^+

- **Hydrochemical facies**

The hydrochemical compositions of the water samples were plotted on Piper ternary plots (figure 47) to investigate the processes controlling the surface water quality of the study area (Piper, 1953). Three main hydrochemical water types were observed. In the dry season, two water types were presented, that is, the Ca- SO_4 and Ca- Mg- Cl+ NO_3 water types as some of the samples plot in the calcium and others in the magnesium fields for the cations and most of the samples plot in the sulphate and some in the Cl+NO_3 fields for the anions. In the rainy season, the water type was Ca- Mg- SO_4 since the samples plot in the Ca and Mg fields for the cations and almost all samples plot in the SO_4 fields.

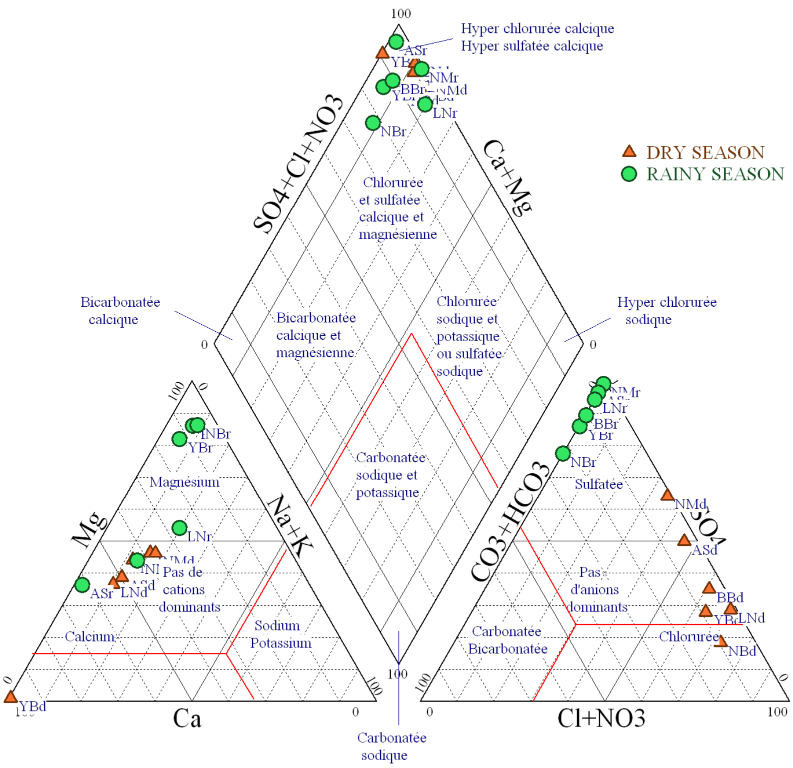

Figure 47: Piper diagram showing variation in ion composition of the Mezam River System

- **Heavy metals in the Mezam River System**

The heavy metals were measured in small amounts in the Mezam River system. Those measured were Fe, Cu, Pb, CN, Zn, B and As. There was no noticeable variation in the concentrations of the trace elements (table 20). Amongst these components, Fe had the highest concentration of 0.29mg/l at NM (figure 48A) during the January sampling period. Pb and As were not detected in October. The concentrations of the heavy metals are shown in table 20.

Table 20: Variations of heavy metals (mg/l) in the Mezam River System

		Fe	Cu	Pb	CN	Zn	B	As
YB	Maximum	0.09	0.04	0.03	0.00	0.04	0.03	0.01
	Minimum	0.087	0.03	0.02	0.00	0.03	0.02	0.00
	Mean	0.089	0.04	0.03	0.00	0.02	0.03	0.003
	SD	0.051	0.006	0.015	0.00	0.021	0.017	0.006
BB	Maximum	0.23	0.08	0.06	0.01	0.04	0.05	0.02
	Minimum	0.19	0.04	0.05	00	0.02	0.04	0.00
	Mean	0.21	0.06	0.06	0.003	0.02	0.05	0.01
	SD	0.123	0.021	0.032	0.000	0.020	0.026	0.012
NM	Maximum	0.29	0.07	0.05	0.03	0.08	0.07	0.04
	Minimum	0.26	0.04	0.04	0.00	0.06	0.05	0.00
	Mean	0.28	0.06	0.05	0.01	0.05	0.06	0.013
	SD	0.159	0.017	0.026	0.017	0.042	0.036	0.023
AS	Maximum	0.18	0.07	0.08	0.03	0.06	0.07	0.02
	Minimum	0.17	0.04	0.06	0.02	0.05	0.05	0.00
	Mean	0.17	0.06	0.07	0.023	0.04	0.04	0.01
	SD	0.101	0.017	0.042	0.012	0.032	0.036	0.012
LN	Maximum	0.17	0.08	0.06	0.03	0.06	0.06	0.05
	Minimum	0.16	0.04	0.04	0.02	0.05	0.04	0.00
	Mean	0.17	0.06	0.05	0.02	0.04	0.03	0.02
	SD	0.095	0.021	0.031	0.017	0.020	0.031	0.023
NB	Maximum	0.28	0.08	0.05	0.02	0.05	0.05	0.02
	Minimum	0.27	0.04	0.03	0.01	0.04	0.04	0.00
	Mean	0.27	0.06	0.04	0.01	0.04	0.04	0.01
	SD	0.159	0.021	0.025	0.012	0.029	0.029	0.012

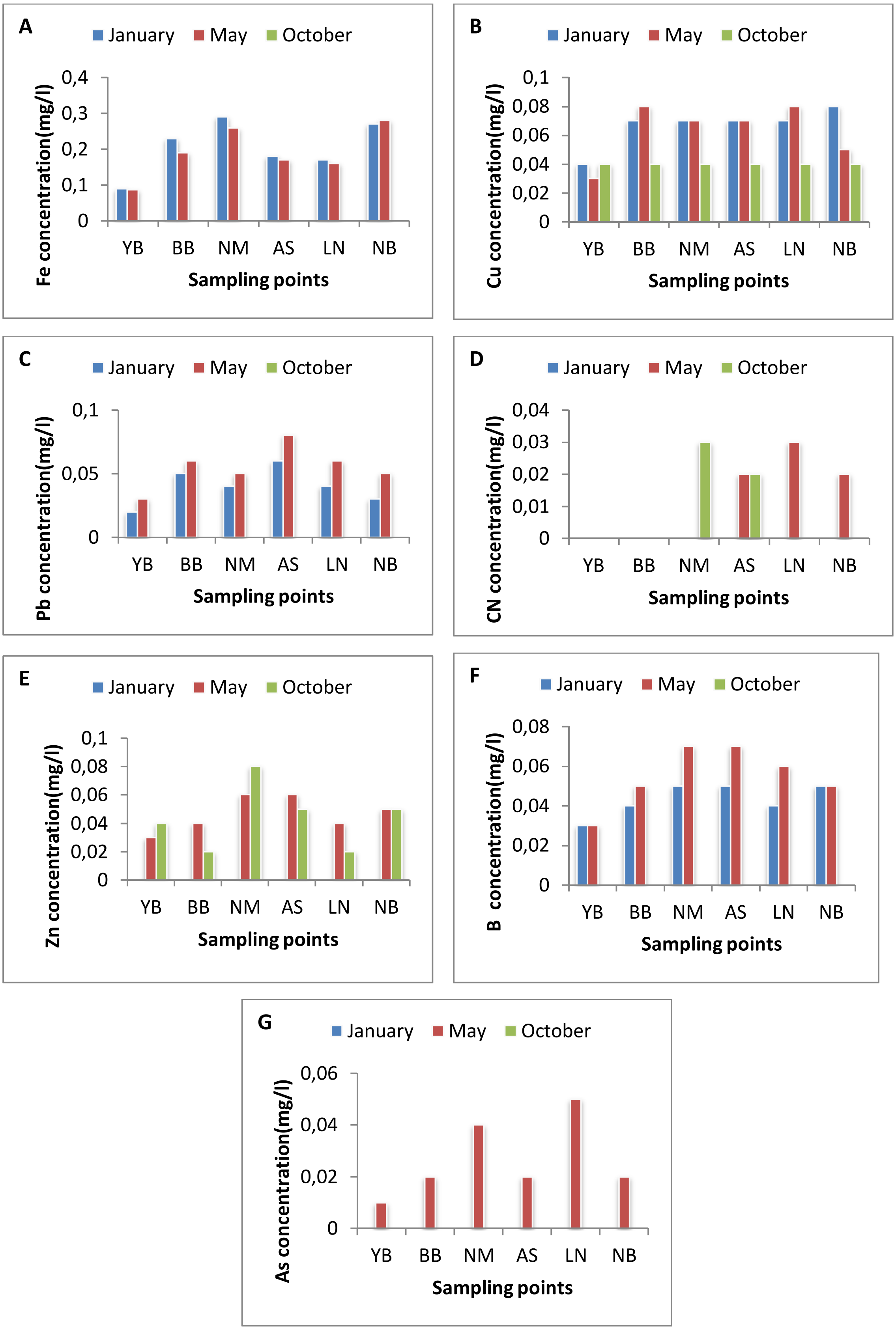

Figure 48: Seasonal variations of heavy metals in the Mezam River System. A: Fe; B: Cu; C: Pb; D: CN; E: Zn; F: B; G: As

4.3.2. Bacteriological characteristics of surface water in Bamenda Town

The bacteriological parameters which are indicative of pollution were investigated in water samples from the Mezam River System. *E.coli,* Streptococcus, Salmonella and Proteus species were detected at the different sampling points and at varying sampling periods. The indicator bacteria were detected at least once at the sampling points with varying counts. *E. coli* had the highest concentration, followed by Streptococcus, Salmonella and finally Proteus. *Vibrio cholerae* was not detected at any of the sites during the study period.

- **Seasonal variation in indicator bacteria**

- ***E. coli***

E.coli was detected at all the sampling points. The mean concentrations ranged from 186CFU/100ml at YB to 500CFU/100ml at NM (table 21). Seasonal variations were not conspicuous (figure 49A). The least concentrations (100CFU/100ml) were measured at YB and AS during the May sampling period and the highest (500CFU/100ml) at BB, NM, AS during the study period.

- **Streptococcus**

Streptococcus was also abundant at all the sampling points. The mean concentration ranged from 166CFU/100ml at YB to 366CFU/100ml at NM (table 21). The highest concentrations (500CFU/100ml) were recorded at NM and NB during the January sampling period and the least (100CFU/100ml) were measured at YB, BB, AS, LN and NB (figure 49B).

- **Salmonella Spp.**

The mean concentration ranged from 3CFU/100ml to 193CFU/100ml (table 21). Salmonella was detected once at YB during the October sampling event and twice at BB, LN and NB. It was present during all sampling periods at NM and AS (figure 49C). The lowest concentration (0.0CFU/100ml) was recorded at YB in January and May and the highest (500CFU/100ml) was at NM during the May sampling period.

- **Proteus Spp.**

Proteus species was not detected at the AS and BB sampling points. The mean ranged from 63CFU/100ml to 233CFU/100ml (table 21). There was no observable trend in seasonal variation (figure 49D). The lowest concentration (0.00CFU/100ml) of Proteus was measured at AS and BB and the highest (500CFU/100ml) at NM.

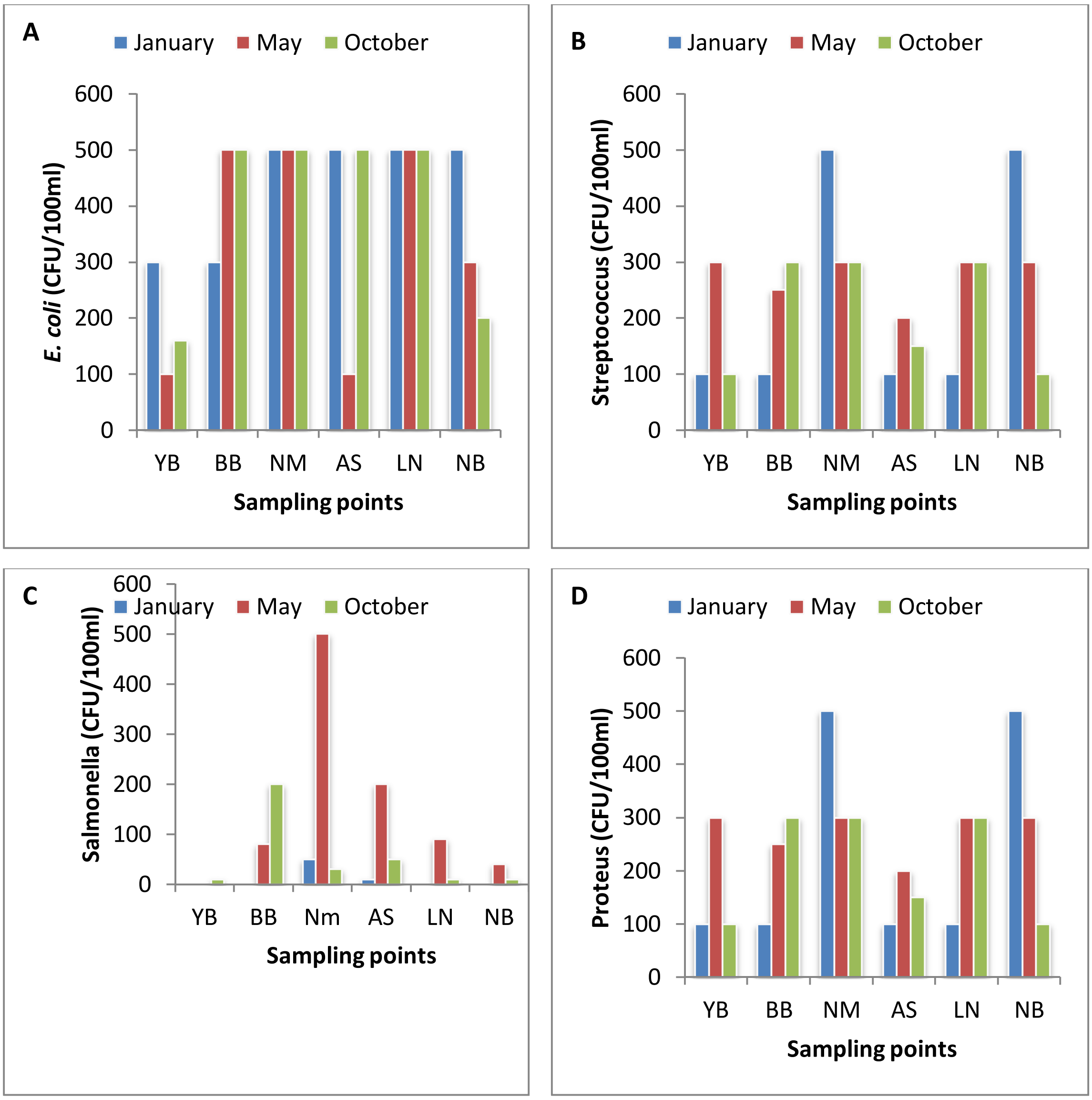

Figure 49: Seasonal variations in A: *E. coli*; B: Streptococcus; C: Salmonella; D: Proteus counts in the Mezam River System

- **Spatial variation in indicator bacteria**

The indicator bacteria were measured at varying concentrations at the different sampling points. At LN, *E. coli* had the highest mean concentration of 466 CFU/100ml and its least mean concentration was 186 CFU/100ml at YB. The highest mean concentration of Streptococcus was measured at NM (366 CFU/100ml) and the least was at AS (150 CFU/100ml). The mean concentration of Salmonella ranged from 3 CFU/100ml at YB to 193 CFU/100ml at NM. Proteus was most abundant at NB, with a mean concentration of 233 CFU/100ml and least at NM, with a mean concentration of 27 CFU/100ml (table 21). Proteus was absent at BB and AS. The variations in the mean concentrations of the indicator bacteria are shown in figure 50.

Table 21: Statistical summary of bacteriological parameters (CFU/100ml) in the Mezam River System

		E.coli	Streptococcus	Salmonella	Proteus
	Minimum	100	100	0.00	40
	Maximum	160	300	10	100
YB	Mean	186	166	3	63
	SD	102.63	115.47	5.77	115.77
	Minimum	300	100	0.00	0.00
	Maximum	500	300	200	0.00
BB	Mean	433	216	93	0.00
	SD	115.47	104.08	100.66	0.00
	Minimum	300	300	30	0.00
	Maximum	500	500	500	0.00
NM	Mean	433	366	193	0.00
	SD	0.00	115.47	265.77	0.00
	Minimum	100	100	10	0.00
	Maximum	200	200	200	0.00
AS	Mean	150	150	87	0.00
	SD	282.84	70.71	134.35	0.00
	Minimum	100	100	00	100
	Maximum	300	300	90	200
LN	Mean	233	233	33	150
	SD	0.00	115.47	49.33	115.47
	Minimum	100	100	00	011
	Maximum	500	500	40	500
NB	Mean	300	300	17	233
	SD	70.71	141.42	21.21	141.42

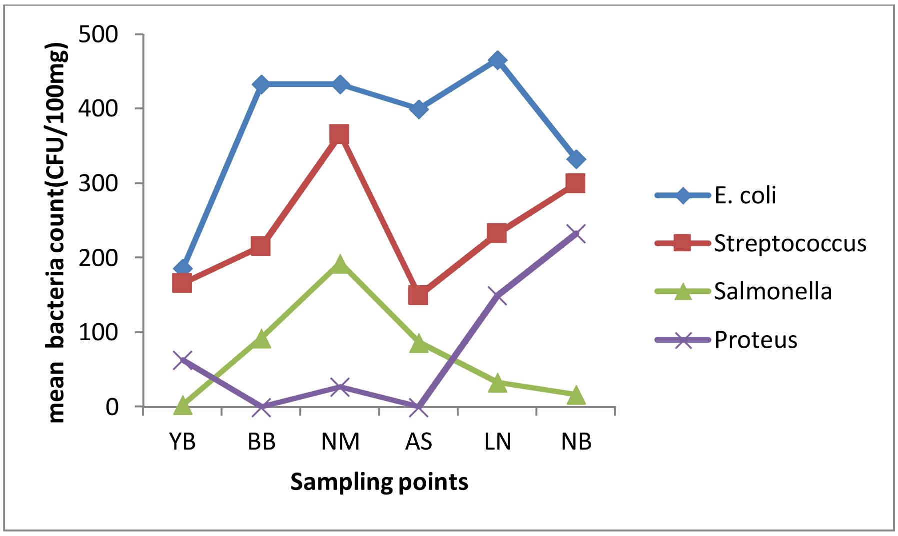

Figure 50: Mean concentrations of indicator bacteria in the Mezam River System

4.4. DISCUSSION AND INTERPRETATION

4.4.1. Groundwater

Groundwater in Bamenda Town is a predominant source of water supply that is used widely by the inhabitants for domestic chores including drinking, as such, knowledge of its physical, chemical and bacteriological characteristics is fundamental in determining its suitability for various activities.

- **Physico-chemical characteristics**

During the study period, average groundwater temperature ranged from 22.08-25.48°C with a marked increase in the dry season. These temperatures are significantly higher than the average ambient temperature of less than 20°C for the study area. The average pH value on the other hand oscillated between 5.55 and 5.84. The acidic to barely acidic nature of the groundwater may be an indication that the dissolved carbonates were predominantly in the form of HCO_3^-. Low pH values have also been reported from the lake Nyos area by Tanyileke *et al* (1996) and from granitic basement complex aquifers in Ghana (Adomako *et al.*, 2011) and in Nigeria (Edet *et al.*, 2011) and were related to the same processes. Meanwhile, the average electrical conductivity values of 2.35µS/cm to7.83µS/cm are low compared to those obtained for groundwater in Foumbot (Tita *et al.*, 2007), in the Banana Plain and the Mount Cameroon area (Ako *et al.*, 2014) and in the Manengouba area (Chakam *et al.*, 2005).

Chemically, the major cations abound in the order $Ca^{2+} > Mg^{2+} > K^+ > Na^+$. Ca^{2+} and Mg^{2+} may be derived from the weathering of calco-sodico feldspars and hornblende in the basic rocks of the study area. Marzoli *et al*. (2000) explains that these minerals are common in basic rocks.

2 Hornblende + $30H^+$ + $9H_2O$ → Kaolinite + $12H_4SiO_4$ + $4Ca^{2+}$ + $10Mg^{2+}$ + $2Na^+$.

The relative abundance of anions in different samples was in the order: $HCO_3^- > SO_4^{2-} > NO_3^- > PO_4^{3-} > Cl^-$. HCO^-_3 concentrations were high with average values ranging from 16.78 – 174.18mg/l. The dominance of HCO_3^- is consistent with most natural waters along the CVL (Tanyileke *et al*., 1996). Weathering, precipitation and organic decay probably account for the dominance of this ion: $CO_2 + H_2O \rightarrow H^+ + HCO_3^-$ or $CO_2 + H_2O + CO_2 \rightarrow 2HCO_3^-$. Infact, the primary source is the dissolved CO_2 in rainwater and the decay of organic matter at the surface which may release CO_2 for dissolution (karanth, 1987).

- **Bacteriological characteristics**

Indicator bacteria were detected in groundwater samples from Bamenda Town in varying concentrations at the different water points. For about 80% of the indicator bacteria detected, the lowest concentrations were recorded at SW_0 which is located in a sparsely populated area while the highest counts were recorded in the water points located in the city centre in densely populated areas. The presence of indicator bacteria from groundwater samples could stem from the fact that in constructing these water points basic requirements such as a thick overburden, perimeter of protection and location in an uphill to habitation were not respected. Under such conditions, it is possible for faecal matter to flow or leak from nearby latrines, septic tanks, slaughter houses and agricultural fields to the point of withdrawal (spring or well). Faecal coliforms such as *E. coli* are prevalent in the digestive tracts of warm- blooded animals and their presence in water is definite evidence of faecal contamination (Hancock *et al*., 1997; Cairncross and Feachem, 1998).

For all the groundwater sampling points lower bacteria concentrations were recorded in the spring water samples while higher counts were measured from the wells. This is probably because most of the wells are locally constructed without the respect of basic conditions stated above making them more prone to contaminants than the springs which are points where groundwater emerges naturally to the surface. Drinking water containing indicator bacteria can pose a serious threat to human health in the short or long run (McGeary *et al*., 2001).

➢ **Groundwater Suitability for drinking and domestic use in Bamenda Town**

To ascertain the suitability of groundwater in the study area for drinking and domestic purposes the results were evaluated with respect to the WHO (2004) standard (table 22) and the Cheesbrough (1991) classification (table 23).

Table 22: Groundwater quality in Bamenda Town in compliance with WHO (2004) drinking water standard

Parameter	Range in study area	WHO limit (2004)
pH	**4.5- 6.5***	6.5- 8.5
T (°C)	**20.7-25.9***	15
EC (µs/cm)	0.04-2.38	750
Ca^{2+} (mg/l)	**110-1770***	75
Mg^{2+} (mg/l)	**97.05- 236.85***	30
Na^{+} (mg/l)	4.02- 13.52	200
K^{+} (mg/l)	12.02- 12.97	100
Cl^{-} (mg/l)	**0- 270***	250
NO_3^{-} (mg/l)	2.801- 5.601	10
SO_4^{2-} (mg/l)	6.025- 11.525	250
HCO_3^{-} (mg/l)	16.78- 174.18	200

* values not in the range of WHO (2004) guideline

pH, EC, Na^+, K^+, NO_3^-, SO_4^{2-}, and HCO_3^- concentrations of the analysed water were within the limits required by the WHO (2004) drinking water norms whereas T (°C) values, Ca^{2+}, Mg^{2+}, and Cl^- concentrations exceeded the WHO limits. Although pH has no effect on human health, it is closely related to other chemical constituents of water (Ako, 2011). Temperature values were high which may favour bacterial growth and may increase taste, odour, colour and corrosion problems.

Values of Ca^{2+} and Mg^{2+} were much higher than the norms for WHO (2004) for drinking water. The presence of these alkaline earth metals determines water hardness. Todd (1980) expresses Hardness of water as Total Hardness (TH) which is given by: TH = 2.5Ca + 4.1Mg. Though hardness has no adverse effect on human health, there is an aesthetic concern because of the unpleasant taste that it imparts. Besides, it can prevent the formation of lather with soap, increase the boiling point of water and may cause encrustation in water supply distribution system. According to Durvey *et al.* (1991), there is some compelling evidence that long term comsumption of extremely hard water might lead to increase urolithiasis, ancephaly, mortality and some kind of cancer and cardiovascular disorders. On the other hand, water softness (low in Ca^{2+} and Mg^{2+}) could pose a health problem since soft water has been linked to cardiovascular ailments (Kozisek, 2005).

The WHO limit for Cl^- is 250mg/l and sample WW_2 exceeded this limit in the rainy season. Higher concentrations may cause gastrointestinal irritation when associated with Na^+ and Mg^{2+} (Garg *et al*., 2009). Heavy metals in the groundwater samples had concentrations below the permissible limits (0.01mg/l) of WHO (2004) for drinking water except Pb that attained 0.014mg/l at SW_1 and 1.023mg/l at WW_1. High concentrations of Pb in drinking water has been shown to have serious health effects on humans (Nriagu, 1978). When lead is ingested in water it may bind to enzymes to produce toxic effects (Byrne, 2001). It is associated with nerve damage, birth defects, mental retardation, certain forms of cancers and an increased susceptibility to disease (Gurer-Orhan *et al*., 2004).

Bacteriologically, the mean bacteria counts in the sampled groundwater at SW_1 and WW_2 were 30 CFU/100ml and 35 CFU/100ml, and 40 CFU/100ml and 90 CFU/100ml in the rainy and dry season respectively, thus placing them under category C following the Cheesbrough (1991) classification. SW_0 and SW_2 with bacteria counts of 10 CFU/100ml and 15 CFU/100ml and 10 CFU/100ml and 30 CFU/100ml respectively in the rainy and dry season fall under category B (table 23). WW_2 with counts greater than 50 CFU/100ml fall in category D. Water points in category B could be accepted as drinking water sources but with regular sanitary checks. Category C is unacceptable as a source of drinking water except when treatment is applied. Category D signifies gross pollution and the sources require disinfection for the water to be used for drinking.

Table 23: Category of water samples according to Cheesbrough (1991) classification of drinking water

Sampling points	Season	Mean count	Category
$\mathbf{SW_0}$	Rainy	10	B
	Dry	15	C
$\mathbf{SW_1}$	Rainy	30	C
	Dry	35	C
$\mathbf{SW_2}$	Rainy	10	B
	Dry	30	C
$\mathbf{WW_2}$	Rainy	40	C
	Dry	90	D

4.4.2. Surface water

Eventhough water from the Mezam River System is not used directly as drinking water, it is used widely in the dry season to irrigate crops grown in the swamps of the River. If the water used is of low quality, it can have a considerable impact on plants grown and soil properties, which in turn will affect the population that consumes the crops.

- **Physico-chemical characteristics**

The temperature of the Mezam River System did not show any significant variations and generally reflected the average ambient temperature. All the samples had pH values below neutral, ranging from 5.12 at Nkimufueh 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). The values of electrical conductivity varied from 6.09µS/cm at Yambot to 28.5µS/cm at the Ayaba Segment. These values were consistently higher than those obtained for groundwater in this study. Infact, EC for the downstream sampling points at Nkimufueh, Ayaba and lower Ngomgham were always in excess of 50µS/cm, an indication of anthropogenic sources of ions in water. This is corroborated by the higher values of suspended solids recorded in these downstream sites.

Dissolved oxygen was generally low (<10mg/l) and the sampling points in the urban areas (BB and AS) maintained a substandard level (<5mg/l) for most of the time. The amount of dissolved oxygen in water is a good indicator of water quality and the kinds of life the water can support. Organic waste such as food processing waste, runoff from feedlots and piggery, stimulates 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 in a decrease in the oxygen content. The AS and BB sampling points (figure 51) are characterized by huge amounts of refuse deposited from the commercial as well as the residential areas of the town.

Figure 51: Refuse dumped at some sampling points in the Mezam River water. A: AS; B: BB

Chemically, the major ions in the Mezam River system are similar to those detected in the groundwater, viz: Ca^{2+} >Mg^{2+} >K^{+} >Na^{+} and HCO_3^{-} >SO_4^{2-} >PO_4^{3-} >Cl^{-}. This suggests that surface water results for the main part from these underground sources. 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 season at BB, NM, AS and NB river segments. Similarly, nitrate concentrations attained the FAO (1994) limits of 50mg/l at NM during the May sampling season.

- **Bacteriological characteristics**

The concentration of faecal bacteria indicator at all the sampling points reflected the different human activities carried out in the neighbourhood as well as the population density. The lowest concentration of bacteria indicator of pollution were gotten at the YB sampling point which is situated in an undeveloped area below the Bamenda Highlands where contributions from human influence is expected to be almost zero. The occurrence of elevated bacteria counts here indicates that the source is not necessary human but rather other warm-blooded animals (Barrow, 1995; Park, 2001). 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 channeled 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. In particular, the NM sampling point is located downstream to the Bamenda slaughterhouse where many cattle are slaughtered on a daily basis and the waste is conveyed into the river channel, possibly raising the concentrations of faecal bacteria.

The bacteria concentrations also showed seasonal variations with comparatively higher levels in the dry season and onset of rains, and lower levels in the rainy season. In the dry season the volume of water in the river is greatly reduced rendering it more accessible to both humans and animals. This trend had also been observed by Tita *et al.* (2013).

4.4.3. Geochemical determinants of ground and surface water quality in Bamenda Town

The geochemistry of ground and surface water is greatly influenced by the lithology of watersheds. Water-rock interaction starts by leaching bedrock minerals into solution and by so doing, major cations, anions, silica and other essential minerals are released into the hydrosphere. Thus, the chemical composition of natural water in a drainage basin is a direct function of the geology of the catchment (Artimes *et al*., 2011).

- **Sources of cations in ground and surface water in Bamenda Town**

Rock weathering is an important source of chemical constituents in water. The weathering of plagioclase feldspar (Ca-rich) produces clay minerals and can supply Ca^{2+} and HCO_3^- ions, as well as silica to water. If soluble ions and silica are not precipitated as solids, they remain in solution and may eventually find their way into a stream or river (McGeary *et al*., 2001).

Ternary plots (Piper, 1953) for major cations (Mg^{2+}, Ca^{2+}, Na^+ and K^+) for the studied ground and surface water samples revealed different water types with different proportions. The ionic concentration of the Bamenda area was Ca^{2+}> Mg^{2+}> K^+> Na^+. Petrochemical studies revealed that felsic rocks are more abundant, constituting about 85% of the petrographic types. One would therefore, expect Na and K to dominate over Ca and Mg, since these elements are dominant in felsic rocks. It is also likely that Ca^{2+} ion originates from the plagioclase feldspars and hornblende minerals which are abundant in the granitic rocks of the study area. The abundance of Ca^{2+} in surface and groundwater could be because it is released into solution faster than Na^+ (Deutsch, 1997). The Ca and Mg could also result from an additional input from land-derived dust particles in the atmosphere (Musa *et al*., 2014). Using the two ternary plots for cations and anions (figure 44), the samples plotted in the sub fields of alkaline earth metals (Ca and Mg), indicating their dominance over the alkali metals (Na and K) in surface water in the Mezam River water. Mg^{2+} ion originates from the weathering of ferromagnesian minerals such as pyroxenes, biotite and olivine, which are found in rocks of the study area as seen in this equation:

$Mg_2SiO_4 + 4CO_2 + 2H_2O \longrightarrow H_4SiO_4 + 2Mg^{2+} + 4OH^-$
(fosterite)

High Ca^{2+} content probably results from the alteration of the surrounding rocks that are rich in calcic minerals (basic plagioclase) according to the following equation:

$CaAl_2Si_2O_8 + 3H_2O + 2CO_2 \longrightarrow Al_2Si_2O_5(OH)_4 + Ca^{2+} + 2HCO_3^-$
(Plagioclase) (kaolinite)

The early rains are rich in dissolved ions which lead to the leaching of the base-forming ions (Ca^{2+}, Na^+, Mg^{2+} and K^+) from the soils, chemically enriching the water during infiltration in the subsurface (Appelo and Postman, 2005).

The source of sodium in ground and surface water in Bamenda Town could either come from the sericitisation of plagioclase feldspar (albite: $Na[AlSi_3O_8]$) or from the alteration of pyroxene (augite: $(Ca, Mg, Fe, Al)_2[(Si, Al)O_3]_2$). In addition, the Na^+ could also come from cation exchange reaction between water and clay minerals in the surrounding bedrock:

$2NaAlSi_3O_8 + 2H^+ + 9H_2O \longrightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2Na^+$
(Albite) (Kaolinite)

K^+ is equally abundant in silicate minerals such as orthoclase, nepheline, leucite and biotite (karanth, 1987). Besides, the basement rock of the study area is composed of granite and K^+ probably results from the dissolution of orthoclase ($KAlSi_3O_{8)}$) and ferromagnesian (FeMg) minerals like biotite ($K\ (Mg\ Fe)_3\ (AlSi_3)O_{10}\ (OH, Fe)_2$) present in the granites as presented in the following equations:

$2KAlSi_3O_8 + 2H^+ + 9H_2O \longrightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2K^+$
(Orthoclase) (Kaolinite)

$2KFe_3AlSi_3O_{10}(OH)_2 + 13H^+ + CO_2 + 2H_20 \longrightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 6Fe^{2+} + 6Fe^{3+} + HCO_3^- + 2k^+$
(Biotite) (Kaolinite)

The probable source of Fe in ground and surface water in Bamenda Town is from the hydrolysis of ferromagnesian minerals such as pyroxene (augite: $(Ca, Mg, Fe, Al)\ (Si, Al)_2$), olivine: $(Mg, Fe)_2[SiO_4]$, amphibole (hornblende: $Ca_2(Mg, Fe)_4\ Al[(Si_{7,}Al)_{22}(OH, F)_2]$. The Fe could also come from opaque minerals in water such as ulvospinel (Fe_2TiO_4), hematite (Fe_2O_3) and magnetite (Fe_3O_4) (Goldschmidt**,** 1954; Millot, 1964).

$2KFe_3AlSi_3O_{10}(OH)_2 + 13H^+ + CO_2 + 2H_20 \longrightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 6Fe^{2+} + 6Fe^{3+} + HCO_3^- + 2k^+$
(Biotite) (Kaolinite)

- **Sources of anions in surface and groundwater in Bamenda Town**

The most abundant anion in the studied ground and surface water samples during the study period was HCO_3^-. This is because of the reaction of silicate minerals with carbonic acid in the presence of water releasing HCO_3^- as in this equation:

$$\underset{\text{(Albite)}}{2NaAlSi_3O_8} + 2CO_2 + 11H_2O \longrightarrow \underset{\text{(Kaolinite)}}{Al_2Si_2O_5(OH)_4} + 2Na^+ + 2HCO_3^- + 4H_4SiO_4$$

This confirms the dominance of HCO_3^- in the groundwater sources, resulting from the reactions of rocks with percolating groundwater.

The concentration of NO_3^- was low in surface and groundwater. The potential source of this ion is probably the oxidation of organic matters in biochemical processes:

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O$$

Low concentrations of NO_3^- in the dry season suggest their adsorption in organic colloids (Fonge *et al.*, 2012). The potential source may also be shallow latrines and oxidation of organic matter in biochemical processes.

PO_4^{3-} could result from the leaching of phosphate fertilizers from nearby farmlands while SO_4^{2-} may derive from natural sources such as sulphate minerals that are also found in igneous rocks (Karanth, 1987). It can also originate from the oxidation of pyrite:
$Fe S_2 + 2O_2 + H_2O \rightarrow 2 SO_4^{2-} + H_2$. The low concentrations may be a consequence of gradual dissolution (Ngwa, 2013).

Cl^- was detected only at SW_4 and WW_2 in the rainy season and at SW_0 in the dry season. According to Benedetti *et al.* (2003), at high altitude, the decrease in Cl^- concentration is due to smaller rainfall inputs caused by rapid decrease of the absolute humidity and temperature with elevation resulting in a smaller condensation.

4.5. CONCLUSION

Surface and groundwater of Bamenda Town is slightly acidic with pH values varying from 4.1 to 6.7 for groundwater and 5.12 to 6.84 for surface water. When the acidic water comes into contact with geological materials of the surroundings, it is able to dissolve some minerals and incorporate them into the water, thereby enriching the chemical content of the water. The cation concentration for both ground and surface water during the study period was in the order: $Ca^{2+} > Mg^{2+} > Na^+ > K^+$. The high content of Ca^{2+} is derived from feldspar and hornblende minerals in the rocks. The anion concentration was in the order: $HCO_3^- > SO_4^{2-} > NO_3^- > Cl^-$. High HCO_3^- ion is a characteristic of natural waters along the CVL, resulting from dissolved CO_2 in precipitation. The concentrations of most physico-chemical parameters (EC, Na^+, K^+, SO_4^{2-}, NO_3^- and HCO_3^-) in the studied groundwater samples were below the permissible limits recommended by WHO (2004) for drinking water while the values of Ca^{2+}, Mg^{2+} and Cl^- exceeded the limits. Heavy metals in both ground and surface water were detected in very low concentrations at some sampling points and were completely absent in most groundwater samples. High faecal bacteria indicators were measured in both ground and surface water samples, even in the springs and wells that are used as sources of drinking water. High levels exceeding 500CFU/ml were measured in sampling points in the urban center. The concentrations of some physical and bacteriological parameters showed great variations from the reference point and other sampling points, increasing as one traversed the sampling points in the urban center. Remarkable seasonal variations were noted in the physical, chemical and bacteriological parameters in the studied surface and groundwater samples of Bamenda Town. The high pollutant loads degrade the quality of surface and groundwater in Bamenda Town. Major cations and anions in the studied surface and groundwater in Bamenda Town is shown to result predominantly from the alteration of various petrographic types that constitute the watershed of the Mezam River system.

GENERAL CONCLUSION

The main objective of this research work was to assess the quality of both ground and surface water in relation to their geological setting in order to determine their suitability for domestic chores. The results obtained show that:

Petrographically, Bamenda Town is covered by igneous rocks of two distinct groups: 1) plutonic rocks made up of granite and leucogranite, associated to the Pan African North Equatorial Fold Belt; and 2) volcanic rocks made up of basalt and trachyte, which on their part are related to the Cameroon Volcanic Line.

The granite and leucogranite have high K-calc-alkaline characteristics and revealed negative and positive correlations with SiO_2, which correspond to high K-calc-alkaline series. The granite is of the K-granitoid type and leucogranite of the Na-granitoid type. Both rocks are peraluminous, with leucoganite being more peraluminous and of the S-type granite, while granite is just slightly peraluminous and of the I-type. Granite shows magnesian characteristics but leucogranite shows ferriferous characteristics. The chondrite normalized patterns show that granite has higher concentrations of LREE than leucogranite, respectively >100*chondrite and >10*chondrite, but both rock types have similar concentrations of HREE. Negative Eu anomalies (Eu/Eu* = 0.23-0.36) are pronounced in leucogranite which also show negative anomalies in Ce, but Eu anomalies are variable in granite (Eu/Eu* = 0.81-1.08). The Bamenda granitic magma resulted from the partial melting of metagreywackes whereas the Bamenda leucogranitic magma was derived from the partial melting of metapelites. The Bamenda granitoids are syn-to post-tectonics and are similar to those described by various authors in the central domains of the Pan-African North Equatorial Fold Belt in Cameroon.

Basalt and trachyte are both alkaline rocks, basic and acid respectively, with SiO_2<50wt% for basalt and >62wt% for trachyte. They denote positive correlations for Nb, Rb, Zr, Y and Y+Nb and negative correlations for Ba, Sr and Zn with increasing SiO_2 content. The sum of REE varies from 731 ppm to 772 ppm for trachyte and from 246 ppm to 259 ppm for basalt. Basalt and trachyte are characterized by negative anomalies for Europium (Eu/Eu*=1.013-1082) and (Eu/Eu*=0.74-0.832) respectively, and originated from the partial melting of garnet peridotite at about 10% melting for trachyte, and for about 12% partial melting for basalt. The source for the studied basalt is similar to that of alkali basalt from the Bamenda Highlands while that of the studied trachyte is closer to that of Mount Cameroon lavas.

Groundwater samples from hand-dug wells and springs had pH range between 4.1 and 6.5 which is below the WHO standard for drinking water. The low EC and TDS classified the water as low-mineralised and freshwater. The relative abundance of major cations and anions (mg//l) in the water was $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ and $HCO_3^{-} > SO_4^{2-} > NO_3^{-} > PO_4^{3-}$ respectively. Major ion concentrations were low, and below the permissible values of WHO standards for drinking water, except for Ca^{2+} and Mg^{2+} which were higher and therefore, classifying the water as hard. From a bacteriological standpoint, the sampled groundwater contained high levels of faecal bacteria, which were above the WHO and Cheesbrough limits for drinking water for most of the points. Different levels of *E. coli*, Streptococcus, Salmonella and Proteus were gotten for the sampled springs and wells thus necessitating a treatment before the water could be used for drinking.

Surface water from the Mezam River is low mineralised, yielding pH values below the neutral limit. The turbidity of all the studied samples exceeded 5NTU, except at Yambot. The concentration of dissolved oxygen varied from 4.54mg/l at BB to 15.24mg/l at YB. The low dissolved oxygen levels at the urban sites relates to large quantities of suspended solids deposited at those sites. The ionic species in the Mezam River system presented the following order: $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ for the cations and $HCO_3^{-} > SO_4^{2-} > PO_4^{3-} > Cl^{-}$ for the anions. High concentration of nitrate occurred at NM in the dry season probably resulted from the slurry of the Bamenda slaughterhouse and can be detrimental to the aquatic system as it can induce euthrophication while the ammonium and phosphate ions were detected in small amounts. Iron had the highest concentration amongst the heavy metals while Cu, Pb, CN, Zn and B exist in very small amounts below the limit recommended by FAO (1994) for irrigation water, except for lead and arsenic that had greater values possibly resulting from anthropogenic sources.

From a bacteriological point of view, the Mezam River system is polluted with different faecal bacteria. High levels of pollution occurred at urban sites such as BB, NM, AS, LN and NB because these segments receive domestic sewage and urban runoffs. In addition to urban runoff, the NM sampling point also receives sewage from the town’s abattoir. The lowest concentrations of faecal bacteria were gotten at the YB sampling point which is situated in an unhabitated area where contributions from human activities is minimal except for other warm-blooded animals in the environment.

Geochemically both surface and groundwater sources in Bamenda Town have similar ionic species, resulting essentially from the weathering of silicate minerals. Calcium constitutes the dominant cation and probably results from the weathering of plagioclase and hornblend that are abundant in the granitic rocks of the area. Potassium is derived from the dissolution of orthoclase and biotite which are also dominant in granitic rocks. The HCO_3^{-} ion was the dominant anion in the surface and groundwater probably resulted from dissolved CO_2 in rainwater in the atmosphere.

The composition of surface and groundwater in Bamenda Town varies from one sampling point to the other reflecting the lithology of the watershed. The major source of dissolved ions in surface and groundwater are the rocks which the water flows on. As the slightly acidic water encounters the rocks, their minerals are dissolved and incorporated into the composition of the water thus leading to the various water types.

The conservation of the aquatic environment constitutes an important entity in the management of economic and industrial development of every community and as such the various stakeholders are urged to assume their responsibility in protecting the quality of this resource not only for the health benefits of its population but also for the conservation of its biodiversity. To this effect, the City council should ensure that refuse in the City is collected for disposal more regularly and sanitary campaigns of residence organized to attenuate the quantity of sewage that flows into the Mezam River. For potable water crisis, the distribution pipeline should be extended to quarters which do not have access to pipe-borne water as they are obliged to use water for domestic chores from shallow wells and the Mezam River which are of uncertain qualities. The population on its part should adopt responsible behaviours and avoid the disposal of solid and liquid wastes into the River channel in order to limit the negative health impacts to the population and for the conservation of aquatic life. Water abstracted from wells and boresholes for domestic chores should be boiled and filtered to deactivate any microorganisms that could be found.

PERSPECTIVES

It will be necessary for further research to be carried out on the following aspects:

-A radiometric dating of the igneous rocks of Bamenda Town to determine when the volcanism took place.

-An assessment of the riverbed sediments is necessary as pollutants in water usually settle at the bottom and could constitute a source of pollutants to the river water during turbulent flow.

-A determination of the isotopic characteristics of rainwater, ground and surface water in Bamenda Town as to apprehend the origin of groundwater in the study area.

-A study of the effects of the ions and bacteria on human health will be necessary.

REFERENCES

Acho C., 1998. Human interference and environmental instability addressing the environmental consequences of rapid urban growth in Bamenda, *Cameroon Environment and Urbanization* Univ.Buea. 10(2): pp 161-174.

Adomako D., Osae S., Akiti T.T., Faye S., Maloszewski P., 2011. Geochemical and isotopic studies of groundwater conditions in the Densu River Basin of Ghana. *Environ. Earth Sci*. 62: pp 1071-1084.

Ako A.A., **2014**. Hydrogeological study on groundwater in the Banana Plain and Mount Cameroon Area-Cameroon Volcanic Line. Kumamoto University.

Ako A.A., Eneke G.T.E., Jun S., Katsuaki K., Takahiro H., Kimpei I., Akoachere R., Ke tchemen B. T., Elambo G. N., Ntankouo N. R., 2014. Nitrate contamination of groundwater in two areas of the Cameroon Volcanic Line (Banana Plain and Mount Cameroon area). *Appl Water Sci.* 4: 99. doi:10.1007/s13201-013-0134.

Altherr F.F., Holl A., Hegner E., Langer C., Kreuzer H., 2000. High potassium, calc-alkaline I-type plutonism in the European variscides: northern Vosges (France) and northern Schwarzwald (Germany). *Lithos* 50. pp 51-73.

Anatole, D., 1996. Physical Geology. D.C. *Health and Company*, Canada. 628p.

Anschütz J., Groeneveld M., Knape M., Kwant R. and Oosterink E., 1995. Solid waste management in Bamenda, Cameroon. 99p.

Appelo C., and Postma D., 2005. Geochemistry, groundwater and pollution. 2^{nd} edition, Balkema, *Amsterdam*. 635p.

Artimes G. D., Ramin S. and Nagaraju D., 2011. Hydrochemical and rock water interaction studies in East of Kurdistan, North West of Iran. *IJESR*. 1(1): pp 16-22.

Atteia O., 2005. Chemistry and pollution of underground waters. In**:** Engome, R. W, Ayonghe, S.N., Fantong, W Y., Mengnjo, J. W. and Takeshi, O., 2013. Hydrogeochemical and anthropogenic influence on the quality of water sources in the Rio del Rey Basin, South Western, Cameroon, Gulf of Guinea. *Afr. J. Environ. Sci. Technol*. 7(12): pp 1054-1070.

Barrow C. J., 1995. Developing the environment: Problems and Management. *Longman Group Limited*, New York. 313p.

Bassett J., Denney E. C., Jeffery G. H., Mendham J., 1986. A textbook of quantitative inorganic analysis. *Longman Group Ltd*. England. 877p.

Batchelor R. A. and Bowden P., 1985. Petrogenetic interpretation of granitoid rock series using multicationic parameters. *Chemical Geology* 48. pp 43-55.

Benedetti M.F., Dia A., Riotte J., Chabaux F., Gerald M. Boulegue J., Fritz B., Chauvel C., Bulourde M., Deruelle B., IIdefonse P., 2003. Chemical weathering of basaltic lava flows undergoing extreme climatic conditions: the water geochemistry record. *Chemical geology* 2011-17.

Bertrand J. M., Dupuy C., Dostal J. and Davidson I., 1984. "Geochemistry and geotectonic interpretation of granitoids from Central Iforas (Mali, West Africa)". *Precamb. Res*. 26: pp 265-283.

Bevins R.E., Kokelaar B.P. Dunkey P.N., 1984. Petrology and geochemistry of lower to middle Ordovician igneous rocks in Wales: A volcanic arc to marginal basin transition. Proc. *Geol. Ass*. 95: pp 337-347.

Bishop V. and Prosser R., 2002. Water Resources: Processes and Management. 2nd edition. Collins, Birmingham. 417p.

Bogaard P.J.F.and Wörner G., 2003. Petrogenesis of basanitic to tholeiitic volcanic rocks from the Miocene Vogelsberg, Central Germany, *J. Petrol.* 44: pp 569-602.

Bowers J., 1997. Sustainability and Environmental Economics. *Library of Congress*, Singapore. 238p.

Byrne K., 2001. Environmental Science. 2nd edition. *Nelson Thornes*, United Kingdom. 333p.

Cairncross S. and Feachem R.G., 1998. Environmental Health Engineering in the Tropics. *John Wiley and Sons*, Great Britain. 283p.

Chakam P.J.T., Wandji P., Bardintzeff J.M. and Laminsi S., 2005. Nature physico-chimique des utiles du stratovolcan Manengouba (Ligne du Cameroun): les lacs de l'Eboga et les sources de Baré. *Review of the Bulgarian Geological Society* 66: pp107-114.

Chapman D., 1998. Water Quality Assessment. A guide to the use of Biota, Sediments and Water in Environmental Monitoring. 2nd edition. *E and F N SPON*, London. 626p.

Chappell B. W. & White A. J. R., 1992. I- and S-type granites in the Lachlan Fold Belt. Transactions of the Royal Society of Edinburgh: *Earth Sciences* 83: pp 1-12.

Cheesbrough M., 1991. Medical Laboratory Manual for Tropical Countries. *Low Priced edition*. Daddington, Cambridgshire. 324p.

Cox K.G., Bell J. D., & Pankhurst R. J., 1979. The Interpretation of Igneous Rocks. George Allen & Unwin.

Demlie M., Wohnlich S., Wisotzky F., Gizaw B., 2007. Groundwater recharge, flow and hydrogeochemical evolution in a complex volcanic aquifer system, Central Ethiopia. *Hydrogeol. J.* 15: pp 1169-1181.

Déruelle B., 2007. The «Cameroon Hot Line» (CHL): A unique example of active alkaline intraplate structure in both oceanic and continental lithospheres. *C.R. Geosciences* 339: pp 589-600.

Déruelle B., Bardintzeff J.M., Cheminée J.L., Ngounouno I., Lissom J., Nkoumbou C., Etamé J., Hell J.V., Tanyileke G., N'ni J., Bekoa A., Ntepe N., Nono A., Wandji P., Fosso J., Nkouathio D.G., 2000. Éruptions simutanées de basalte alcalin et de hawaiite au mont Cameroun. *Acad. Sci. Paris, Ser. Iia* 331: 525-531.

Déruelle B., Moreau C., Nkoumbou C., Kambou R., Lissom J., Njongfang E., Ghogomu R.T., Nono A., 1991. The Cameroon Line : a review, in : kampuzu A.B.(Ed.), Magmatism in Extensional Structure Settings , The phanerozoic African plate, *Springer verlag*,Berlin. pp 274-327.

Deutsch W.J., 1997. Groundwater geochemistry: Fundamentals and applications to contamination. *CRC Press*, Florida. 221p.

Durvey V.S., Sharma L.L., Saini V.P., Shama B.K., 1991. Handbook on the methodology of water quality assessment in India: ajasthan Agriculture University.

Edet A., Nganje T.N., Ukpong A.L., Ekwere A.S., 2011. Groundwater chemistry and quality of Nigeria: A status review. *Afr. J. Environ. Sci Technol*. 5 (13): pp 1152-1169.

Entry J.A. and Farmer N., 2001. Movement of coliform bacteria and nutrients in groundwater flowing through basalt and sand aquifers. *J. Environ. Qual*. 30: pp 1533-1539.

Evensen N. M., Hamilton M. J. and O'Nions R. J., 1978. Rare earth abundances in chondritic meteorites, *Geochem. Cosmochim. Acta*, 42: pp 1199-1212.

FAO., 1994. Irrigation and Drainage paper 29, *FAO*, Rome. 107p.

F.W. Fifield and P.J. Haines., 1997. Environmental Analytical Chemistry. *Blackie Academic and Professional*. London. 514p.

Fitton J.G., 1987. The Cameroon Line-West Africa: A comparison between ocenic and continental alkaline volcanism. *Geology Soceity*. Vol.30: pp 273-291.

Fonge B.A., Egbe E.A., Fongod A.N., Tening A.S., Achu R.M., Yinda G.S., Mvondo Z., 2012. Effects of land use on macrophyte communities and water quality in the Ndop wetland plain, Cameroon. *J. Agric. Soc. Sci*. 12: pp 41-49.

Franson M. A., 1995. Standard Methods for the Examination of water and wastewater. 19th edition. Washington D. C. 532p.

Ganno S., Nzenti J P., Ngnotue T., Kankeu B. and Kouankap N G D., **2010**. Polyphase deformation and evidence for transpressive tectonics in the Kimbi area, Northwestern Cameroon Pan-African Fold Belt. *J. Geology and Mining Research*, 2(1): pp 001-015.

Garg V.K., Suthar S., Singh S., Sheoran A., Garima M., Jain S., 2009. Drinking water quality of Southwestern Hanyana India: Assessing human health risks associated with hydrochemistry. *Environmental Geology*. Dio: 10. 1007/s00254–008 1636 –y.

Gill J.B., 1981. Orogenic andesites and plates tectonics. *Springe*r, Berlin.

Goldschmidt., 1954. Geochemistry. A Muir (éd). *Clarendo Press*, Oxford. 730p

Gountie D.M., Nono A., Njonfang E., Kamgang P., Zangmo T. G., Kagou D.A., Nkouathio D.G., 2009. Le volcanisme ignibritique des monts Bambouto et Bamenda (ligne du Cameroun, Afrique Centrale): Signification dans la formation des caldeiras. *Bulletin de I'institut scientifique*. 33 : 1-15.

Gountié Dedzo M., Nédélec A., Nono A., Njanko T., Font E., Kamgang P., Njonfang E. and Launeau P., 2011. Magnetic fabrics of the Miocene ignimbrites fromWest-Cameroon: Implications for pyroclastic flow source and sedimentation, *J.Volcanology and Geothermal Research,* 203: pp 113-132.

Gurer-Orhan., Sabir R.A., Ozgunes H., 2004. Correlation between clinical indicators of lead poisoning and oxidative stress parameter in controls and lead-exposed workers. *Toxicol*. 195: pp 147-154.

Hancock D.D. Besser T. E., Rice D. H., Herriot D. E. and Tarr P. I., 1997. Longitudinal study of *Escherichia coli* 0157 in fourteen cattle herds. *Epidemol. Infect*. 118: pp 193-195.

Hunter C., Perkins J. and Gunn J., 1999. Agricultural land-use effects on the indicator bacterial quality of an upstream in the Derbyshire peak district in the UK. *Water Res*. 33 (17): pp 3577-3586.

Irvine T.M. and Baragar W.R., 1971. A guide to the chemical classification of common volcanic rocks. *Canadian J.Earth Sciences*. Vol. 8: pp 523-548.

Kagou DA, Nkouathio DG, Pouclet A, Bardintzeff JM, Wandji P, Nono A., 2010. The discovery of late Quaternary basalts on Mount Bambouto: Implications for recent widespread volcanic activity in the Southern Cameroon Line. *JAES* 57: pp 96-108.

Kamgang P., Chazot G., Njonfang E. and Tchoua F. M., 2008. Geochemistry and geochronology of mafic rocks from Bamenda Mountains (Cameroon): Source composition and crustal contamination along the Cameroon Volcanic Line. C.R. *Géoscience* 340: pp 850-857.

Kamgang P., Chazot G., Njonfang E., Ngongang Tchuimegnie N.B., Tchoua F., 2013. Mantle sources and magma evolution beneath the Cameroon Volcanic Line: Geochemistry of mafic rocks from the Bamenda Mountains (NW Cameroon). *Gond. Res* 24: pp 727-741.

Kamgang P., Njonfang E., Chazot G. and Tchoua F. M., 2007. Géochimie et géochronologie des laves felsiques des Mounts Bamenda (ligne volcanique du Cameroun). *C.R. Géoscience* 339: pp 659-666.

Kamgang P., Njonfang E., Nono A., Gountie D.M., Tchoua F., 2010. Petrogenesis of a silic 95 magma system: Geochemical evidence from Bamenda Mountains, NW Cameroon 596 Volcanic Line. *J. African Earth Sciences* 58: pp 285-304.

Kamtchueng B.T., Fantong W.Y., Ueda A., Tiodjio E.R., Anazawa K., Wirmvem M.J., Mvondo J.O., Nkamdjou L.S., Kusakabe M., Ohba T., Tanyileke G., Hell J.V., 2014. Assessment of shallow groundwater in Lake Nyos catchment (Cameroon, Central Africa): Implications for hydrogeochemical controls and uses. *Environ. Earth* 72 (9): pp 3663-3678.

Kamtchueng B.T., Fantong W.Y., Wirmvem M.J., Tiodjio E.R., Takounjou A.F., Kazuyoshi A., Serges L.B.D., Kusakabe M., Ohba T., Tanyileke G., Hell J.V., Akira U., 2015. A multi-tracer approach for assessing the origin, apparent age and recharge mechanism of shallow groundwater in the Lake Nyos catchment, Northwest, Cameroon. *J. Hydrology* 523: pp 790-803.

Karanth K.R., 1987. Groundwater Assessment: Development and management; Tata *McGrawl Hill*, New Delhi. 488p.

Kemp D.D., 1998. The Environment Dictionary. *Library of Congress*, New York. 546p

Koroleff F., 1976. Determination of ammonia. Method of seawater analysis. *Verlag chemie*. 238p.

Kouankap N. G. D., Wotchoko P., Ganno S., Njinchuki D. N., Nzenti J P., and Suh E. C., 2013. Petrochemical characterization of two distinct types of Dolerites from Bafoussam area, West Cameroon. *International J. Geoscience* 4: pp 1131-1144.

Kozisek F., 2005. Health risks from drinking demineralised water. In: Nutrients in drinking water. *World Health Organization*, Geneva. pp 148-163.

Lee D.C, Halliday A.N., Fitton J.G., Poli G., 1994. Isotopic variation with distance and time in the volcanic islands of the Cameroon Line, evidence from mantle plume origin. *Earth and Planetary Science Letter*. 123: pp 119-138.

Liégeois J. P., Black R., Navez J., and Latouche L., 1994. Early and Late Panafrican orogenies in the Aïr assembly of terranes (Tuarey Shield, Niger). *Precambrian Research* 67: pp 59-88.

MacFaddin J.F., 2000. Biochemical Tests for Identification of Medical Bacteria, 3rd. ed. *Lippincott Williams & Wilkins*, Philadelphia.

Madigan M. T., and J. M. Martinko., 2008. Brock biology of microorganisms, 12th ed. *Benjamin Cummings*, Upper Saddle River, NJ.

Mannion A. M. and Bowlby S. R., 1992. Environmental issues in the 1990s. *John Wiley and Sons*, United Kingdom. 349p.

Marsh W.M. and Grossa, J.M., 1998. Environmental Geography: Science, Landuse and Earth Systems. 2nd edition. *John Wiley and Sons Inc*, New York. 442p.

Marzoli A., Piccirillo E.M., Renne P.R., Bellien G., Facumin G.M., Nyobe J., Tongwa A.T., 2000. The CVL Revisited: Petrogenesis of continental basaltic mangmas form lithospheric and asthenospheric mantle sources; *J. Petrology*. 41(1): pp 87-109.

Mason C.F., 1993. Biology of Fresh Water Pollution. 2nd edition. *Library of Congress*, Singapore. 316p.

McGeary D., Plummer C. and Diane C., 2001. Physical Geology: *Earth Revealed*. 4th edition. McGraw Hill, Toronto. 578p.

Middlemost E. A. K., 1994. Naming material in the magma/igneous rock system. *Earth-Science Review* 37: pp 215-224.

Millot G., 1964. Geologie des argiles Masson et cie (ed) Paris. 499p.

Molua E. L., and Lambi C. M., 2006. Climate, hydrology and water resources in Cameroon. *CEEPA*, Pretoria. 37p.

Musa O. K., Kudamnya E. A., Omali A. O. and Akuh T. I., 2014. Physicochemical characteristics of surface and groundwater in Obajana and its envrirons in Kogi State, Central Nigeria. *Academic J*. 8 (9): pp 521-531.

Ndenecho E., and Eze B.E., 2004. Geomorphic and anthropogenic factors influencing landslides in the Bamenda highlands. N.W Province, Cameroon. *J. Applied Social Sciences*. Vol.1: pp 15-26.

Neba A.S., 2004. Modern Geography of the Republic of Cameroon. *Neba Pub*. Bamenda, Cameroon. 147p.

Ngako V, Affaton P, Nnange J.M, Njanko T., 2003. Panafrican tectonic evolution in central and southern Cameroon: Transpression and transtention during sinsistral shear movements. *J. Afr. Earth Sci*. 36: pp 207-214.

Ngako V., 1999. Les déformations continentales panafricaines en Afrique Centrale. Résultat d'un poinçonnement de type himalayen. Thèse d'Etat Univ.Yaoundé I. 301p.

Ngnotué T., Nzenti J.P., Barbey P., Tchoua F.M., 2000. The Ntui-Betamba High-grade gneiss: a northward extension of the Pan-African Yaounde gneiss in Cameroon. *J. African Earth Sciences* 2: pp 369-381.

Ngwa M., 2013. Hydrochemical variation of groundwater in Bafut Subdivision (North West Region, Cameroon).

Njilah I.K., 1991. Geochemistry and petrogenesis of the Tertiary-Quaternary volcanic rocks from Oku-Ndu area, North West Cameroon. PhD Thesis, Leeds University, 350pp+1map.

Njilah I.K., Temdjim R., Nzolang R.T., Ghogomu R.T., Tchuitchou C., Rose H.N., Ajonina H,N., 2007. Geochemistry of Tertiary-Quaternary lavas of Mt Oku North West Cameroon. *Revista Facultad de Ingenieria* 40: pp 59-75.

Nono A., Biaya S. M. O. H., Wabo H., 2004. Influences comparées de la lithologie et de la tectonique sur la dynamique et la chimie des eaux souterraines sur les hauts plateaux de l'Ouest-Cameroun et sur le socle panafricain à l'Est du Cameroun. *20è colloque de géologie africaine. Orléans,* Fr. 317-318.

Nriagu J.O., 1978. Biochemistry of lead in the environment. In: Fongo B.E., 2008. Pollution, flooding and water resource management in the Mfoudi River Basin, Yaounde, Cameroon. Ph.D Thesis, University of Yaounde I.

Nzenti J. P., Abaga B., Suh C. E. and Nzolang C., 2010. Petrogenesis of peraluminous magmas from the Akum-Bamenda Massif, Pan-African Fold Belt, Cameroon, *International Geology Review*. pp 1-29.

Nzenti J. P., Barbey P., Bertrand J. M. and Macaudière J., 1994. "La chaîne panafricaine au Cameroun : cherchons suture et modèle!**"** In: S. G. F. (ed.), 15ème Réunion des Sciences de la Terre, Nancy, France**.**

Nzenti J. P., Kapajika B., Wörner G. and Lubala R. T., 2006. "Synkinematic emplacement of granitoids in a Pan-African shear zone in Central Cameroon". *J. Afr. Earth Sci*., 45: pp 74-86.

Nzenti J.P., 1998. L'Adamaoua panafricain (région de Banyo): une zone clé pour un modèle de la chaîne panafricaine nord-équatoriale au Cameroun. Thèse Doctorat D'Etat, Université Cheikh Anta Diop-Université de Nancy I. 176p.

Nzenti J.P., Ngako V., Kambou J., Penaye J., Bassahak J., Njel O.U., **1992**." Structures Régionales de la chaîne panafricaine du Nord-Cameroun ", *Comptes Rendus de l'Académie des Sciences, Paris*, 315(.2): pp 209-215.

Nzolang C., Kagami H., Nzenti J.P., Holtz F., **2003.** Geochemical and Priliminary Sr-Nd isotopic data on the Neoproteroic granitoids from the Bantoum Area, West Cameroon: Evidence from a derivation from a Paloeproterozoic to Archean Crust," *Polar Geosciences*, vol. 16, pp 196-226.

Owen L. and Unwin T., 2002. Environmental Management: Reading and Case Studies. *Blackwell*, London. 437p.

Park C., 2001. The Environment: Principles and Applications. 2nd edition. *Routledge*, New York. 546p.

Pearce J. A., 1982. Trace element characteristics of lavas from destructive plate boundaries. In: Hugh R. Rollison, Using Geochemical data: Evaluation, Presentation, Interpretation. *Longman scientific & technical*. 352p.

Pearce J. A., 1983. Role of the sub-continental lithosphere in magma genesis at active continental margins. In: Hugh R. Rollison, Using Geochemical data: Evaluation, Presentation, Interpretation. *Longman scientific & technical*. 352p.

Peccerillo A. & Taylor S. R., 1976. Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, Northern Turkey. *Contrib. Mineral. Petrol*. 58: pp 63-81.

Piper A.M., 1953. A graphic procedure in the geochemical interpretation of water analysis. *US Geological Survey*, Washington D.C.

Ricklefs R., 1996. The Economy of nature. 4th edition. Freeman and Company, New York. 627p.

Roberts M. P. and Clemens J. D., 1993. "Origin of high-potassium, calcalkaline, I-type granitoids", *Geology* 21: pp 825-828.

Rodier J., 1996. L' analyse de l'eau. Eaux naturelles, eaux residuaires, eaux de la mer. 8th edition. Dunod. 1383p.

Roy M.H., 1992. Understanding Our Environment. An Introduction to Environmental Chemistry and Pollution. 2nd edition. *Royal Society of Chemistry,* Birmingham. 373p.

Russel S. H., Lyons W. B., Gardner C. B., Goldsmith S. T., Long D. T., Motisova H. and Welch, S., 2013. Surface water geochemistry and chemical weathering across Panama. *ScienceDirect* 7: pp 342-345.

Sandy C. and Feachem., 1998. Environmental Health Engineering in the Tropics. *John Wiley and Sons*. Great Britain. 278p.

Shang C. K., Satir, M., Nsifa E. N., Liegeois J. P., Siebel W. and Taubald H., 2007. Archaean high-K granitoids produced by remelting of earlier Tonalite-Trondhjemite-Granodiorite (TTG) in the Sangmelima region of the Ntem Complex of the Congo craton, southern Cameroon. *International J. Earth Sciences* 96: pp 817-841.

Suh C.E., Sparks R.S.J., Fitton J.G., Ayonghe C., Annen Nana R., and Luckman A., 2003. "The 1999 and 2000 Eruptions of Mount Cameroon: Eruption Behaviour and Petrochemistry of Lava", *Bulletin of volcanology* 65(4): pp 267-287.

Suresh T.S., Nagana C. and Srinivas, G., 1991.Study of water quality for agricultural use in Hemavathy River (Kamataka). *J. Indian Association of Hydrology* 14(4): pp 247-254.

Tanko Njiosseu E.I, Nzenti J.P., Njanko, T., Kapajika B., Nédelec A., 2005. New U-Pb zircon ages from Tonga (Cameroon). Coexisting Eburnean-Transamazonian (2.1Ga) and Pan-African (0.06 Ga) Imprint. *Comptes Rendus Géosciences* 337: pp 551-562.

Tanyileke G. Z., Kusakabe M., Evans W. C., 1996. Chemical and isotopic characteristics of fluids along the CVL, *Cameroon J. African Earth Sciences* 22(4): pp 433-441.

Tay CK., 2012. Hydrochemistry of groundwater in the Savelugu-Nanton District, Northern Ghana. Environ. *Earth Sci*. 67: pp 2077-2087.

Tchuimegnie N.N.B., Kamgang P., Chazot G., Agranier A., Bellon H. and Nonnotte P., 2015. Age, geochemical characteristics and petrogenesis of the Cenozoic intraplate alkaline volcanic rocks in the Bafang region, West Cameroon. *J. African Earth Sciences* 102: pp 218-232.

Tietenberg T., 1996. Environmental and Natural Resource Economics. 4th edition. *Harper Collins*, U.K. 376p.

Tita M. A., Kamgang K. V. B. and Tsala G. N., 2009. Microbial Pollution of surface water and its health impact in the Nkoup River basin in Foumbot, West Cameroon. *Revue CAMES-Serie A* 8: pp 56-61.

Tita M. A., Magha A. and Kamgang K. V.B., 2013. Micorobial pollution of the Mezam River system and its health impacts in Bamenda (North West Cameroon), *African J. Microbiology Research* 7(42): pp 4940-4948.

Tita M. A., Tsala G.N., Kamgang K.V.B., Parisot J.C. and Ndjama J., 2007. Macrophytes and Water Quality of the Nkoup River system. *J. the Cameroon Academy of Sciences7*(2): pp 59-69.

Todd D.K.,1980. Groundwater hydrology. New York. *Wiley*.

Toteu S.F., Deloule E., Penaye J. and Tchamani R., 2004. Preliminary U-Pb ionic microprobe data on zircons from Poli and Lom volcano-sedimentary basins (Cameroon): Evidence for a late-Mesoproterozoic to Early Neoproterozoic (1100-950) magmatic activity in Central African Fold Belt. The IGCP-470 Second annual field Conference 5-10 January 2004, Garoua-Cameroun.

UK EPA., 1990. National Water Inventory Report. In: Porteous, A. 2001. Dictionary of Environmental Science and Technology. 3rd edition. *John Wiley and Sons*, New York. 368p.

UN., 2016. Briefing on the 2016 UN World Water Development Report, "Water and Jobs".

UN-HABITAT., 2012. Water for sustainable urban human settlements. Briefing note. WWAP.

UNICEF., 2015. Water a family affair: Safe Drinking Water and Sanitation.

Wegelin M., 1991. Water Treatment: Information and Training for Low Cost Water Supply and Sanitation. World Bank, Washington D.C. 575p.

WHO., 2004. Guidelines for drinking water quality. Vol 3. Control and Surveillance of Community Supplies. 2nd edition. Geneva, Switzerland.

WHO/UNICEF., 2012. Joined monitoring programme for water supply and sanitation. Coverage estimates: Improved sanitation, Cameroon.

Wirmvem M. J., Takeshi O. Fantong W. Y., Ayonghe S. N. Suila J. Y., Asobo N.E., Tanyileke G. and Hell J. V., 2013. Hydrochemistry of shallow groundwater and surface water in the Ndop plain, North West Cameroon. *African J. Environmental protection and Technology*. 7(6): pp 518-530.

Wotchoko P., Djoukam J.F.T., Kouankap G.D., Kouske P.A., Nkouathio D.G.and Atenkia F.S., 2015., Petrographic and Geochemical Characterization of Basalts in Bangangte Area (West Cameroon): Implications on Their Source. *Earth Sciences* 4(6): 266-274.

Yokoyama T., Aka F.T., Kusakabe M. and Nakamura E., 2007. Plume-lithosphere interaction beneath Mt. Cameroon volcano, West Africa: constraints from 238U-230Th-226Ra and Sr-Nd-Pb isotopic systematics. *Geochimica et Cosmochimica Acta*71: pp 1835-1854.

APPENDICES

Articles published from this study are:

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-**Alice Magha**, Margaret Tita Awah, Gus Djibril Kouankap Nono, Pierre Wotchoko, Mispa Ayuk Tabot, Véronique Kamgang Kabeyene, 2015. Physico-chemical and bacteriological characterization of spring and Well Water in Bamenda III (NW Region, Cameroon). American Journal of Environmental Protection. *Vol. 4, No. 3, 2015, pp. 163-173. doi:10.11648/j.ajep.20150403.17.*

ANNEXES

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Physico-Chemical and Bacteriological Characterization of Spring and Well Water in Bamenda III (NW Region, Cameroon)

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Abstract: Bamenda is a major town in the NW Region of Cameroon and constitutes part of the Cameroon Volcanic line. In the frame of this work, four springs and three wells in the Bamenda III council area were investigated to evaluate the physico-chemical and bacteriological characteristics of their waters. All the water points yielded pH values below 6.5 and were classified as acidic water. Electrical conductivity ranged between 0.04-2.38µm/cm. The relative abundance of major ions (meq/l) was Ca2+ > Mg2+ > K+>Na+ for cations and HCO3⁻ > SO42⁻ > NO3⁻ > PO43⁻ for anions. Major ion concentrations were within the WHO guidelines for drinking water, but Ca2+ (110-1770mg/l) and Mg2+ (97.05-236.85mg/l) concentrations were much higher and above WHO limits. Main water types in the dry season were Ca-Mg-HCO3 while in rainy season the main water types were Ca-Mg-HCO3 and a mixed Ca-Mg-SO4. Bacterial analysis revealed that the water samples were highly polluted and classified B, C and D according to Cheesbrough classification. The spring and well waters analysed are not suitable for drinking and domestic purposes therefore the population of Bamenda III which depends on the mentioned water for drinking and domestic purposes may face serious health problems if appropriate actions are not taken to prevent and mitigate the problems.

Keywords: Bamenda III, Faecal Bacterial Analysis, Physico-Chemical Analysis, Water Quality

1. Introduction

Cameroon is endowed with numerous water sources [1,2]. It is a country with the second highest volume of available water in Africa [3]. Groundwater constitutes 21.5% (57 billion m3) of this resource and plays a very important role in the socio-economic life of the country.

The setting and evolution of most forms and pattern of settlements is linked to the availability of reliable and substantial water sources, and the fertility of volcanic soils have brought through ancient times the intense settlement and agricultural exploitation of the lower flanks of volcanoes [4]. This is the case of Bamenda town, a rapidly growing town which belongs to the Cameroon Volcanic Line (CVL) the principal watershed of the country [5]. Many thermal and mineral springs typified by the Fe - Mg - Ca –HCO3- or Na – HCO3- compositions are found along the CVL [6]. The chemical composition of surface and groundwater is controlled by many factors that include composition of precipitation, mineralogy of watershed and aquifers, climate and topography as well as anthropogenic influence such as urban, industrial and agricultural activites. These factors combine to create diverse water types that change spacially and temporally [3]. When water perculates through formations, it comes in contact with geologic formations and ions are exchanged especially during the process of weathering and alteration. These rocks release minerals whose ions enter aquifers and alter the chemical composition.

Geochemical studies from groundwater and surface water can provide a better understanding of potential water quality variations due to geology and land use practices [7-9]. Knowledge of the levels of microorganisms in water is also important for indexing the health harzard associated with its use, adopting meaningful interventions and improving bacterial water quality [10]. The Bamenda III Council Area is made up of many springs and wells on which about 80% of the population depends for both drinking and domestic purposes. Characterizing the mentioned water is of great importance to determine if the population is at risk. In this paper we present the evaluation of the physico-chemical and bacteriological quality of some springs and wells in Bamenda III.

2. Natural Setting of the Study Area

Bamenda III is found in Mezam Division in the North West Region of Cameroon between latitudes 06°00'N and 06°89'N and longitudes 10°13'E and 10°28'E (Figure 1). This town is located at the central part of the Cameroon Volcanic Line, and is implanted below the high lava plateau, at an altitude of about 1500m. Bamenda III Subdivision is made up of two villages: Nkwen and Ndzah with about 250,000 inhabitants and a surface area of 74.61km2.

The climate is mainly of the equatorial type with two main seasons, the rainy season (April to October) and the dry season (November to March). Absolute annual average precipitation ranges from 1700mm to 2824mm and exhibits fluctuations [11].

The study area forms part of the Bamenda Mountains which lie along the Cameroon Volcanic Line. It is made up of a basement rock which is mainly composed of leucogranites of Precambrian age [12]. The basement rock is overlain by volcanic materials composed of mafic and felsic lavas. The mafic lavas include basalts which outcrop as lava flows and pyroclastic deposits respectively, while the felsic lavas include trachytes and rhyolites [13].

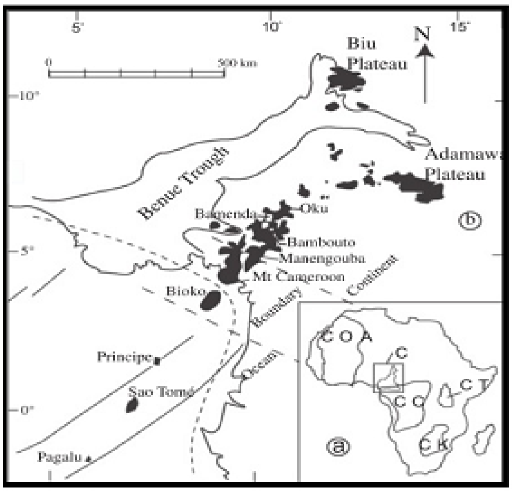


Figure 1. Location of Bamenda along the Cameroon Volcanic Line. From [14].

3. Methods

3.1. Field Work

Field studies were carried out in two phases and at different seasons of the year; the first phase took place in the rainy season (September) and the second phase in the dry season (February). Water samples were collected from 4 springs and 3 wells and at each sampling point, two sets of samples were collected and in one of the sets of samples 5ml of HCl were added to stabilise the heavy metal concentration. Sampling points were chosen in relation to their uses by the population.

3.2. Laboratory Analysis

Physico-chemical and bacteriological analyses were performed in the laboratory of the Faculty of Agronomy and Agricultural Sciences (FASA) in the University of Dschang, Cameroon.

3.3. Physical Analysis

For physical analysis, Total Dissolved Solids was determined. An NTU Turbidimeter (DRT 100B HF model type) was used to measure turbidity. Electrical Conductivity was determined using a Conductivity meter (WTW LF 521 model type).

3.4. Chemical Analysis

3.5. Major Cations

Sodium (Na^+) and potassium (K^+) were determined by flame photometry. The analysis of Calcium (Ca^{2+}) was done by titration with 0.02M solution of Ca- EDTA together with 1ml of TEA and 1ml of 5% KCN. The determination of magnesium (Mg^{2+}) was done in a similar manner; ammonium (NH_4^+) was analysed using the colorimetric method.

3.6. Major Anions

Chloride (Cl^-) was analysed by titration. Nitrates ($NO32^-$) and phosphate ($PO43^-$) were determined using colorimetry. Sulphates ($SO42^-$) were determined by turbidimetry and Bicarbonates (HCO_3^-) concentrations by titration.

3.7. Bacteriological Analysis

This was done on three set of samples (two springs and one well) to determine the presence of faecal streptococcus, Escherichia coli, faecal and total coliform using the membrane filter procedure. 1ml of water sample was added to 9ml of distilled water. Each sample was diluted three times. A membrane was placed on a sterilized Wheaton Filtration funnel used to filter 20ml of undiluted sample. The funnel was sterilized after each filtration to avoid interferences. Several diluted samples were then processed so as to get filter plates with appropriate range of colonies. These filter plates were placed in an incubator at different temperature conditions for different bacteria. These were: 44oC for E-coli and feacal coliform, 35oC for streptococcus and total coliform.

4. Results

The physico-chemical characteristics of the studied water were similar, whether it was from well or from spring but significant differences were noted with the different seasons.

4.1. Physical Characteristics

Water temperatures were higher during the dry season and lowest in the rainy season for all sampling point with the average of 22.6°C in the rainy season and of 26.31°C in the dry season (Figure 2). The average pH value was higher in the rainy season (5.71) than in the dry season (5.47) as shown in Figure 2, but all water points yielded acidic to barely acidic water (Table 1).

The value for EC was very low regardless of the sampling point and season but in the dry season a highest value (2.38µS/cm) was recorded in AMW3.

Turbidity was higher in the rainy season than in the dry season with the respective average value recorded of 8.14 and 2.40 (Table 1).

***Table 1.** Variation of Temperature, PH, Electrical Conductivity, and Turbidity in the rainy season and dry season.*

	Temperature (T°)		pH		Electrical conductivity (EC)		Turbidity	
Sampling points	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season
AMS_1	24.7	27.7	5.4	6.5	0.03	0.05	7.3	2.8
AMS_2	21.6	26.4	5.8	6	0.04	0.04	5.6	2.2
AMS_3	21.2	24	6.0	5.4	0.03	0.05	9.6	2
AMS_4	22.4	26.2	5.2	6.3	0.20	0.03	7.6	4.4
AMW_1	24	27.9	6.7	6.2	0.29	0.11	13.5	1.9
AMW_2	22.3	27	5.3	5.4	0.16	0.13	6.9	1.8
AMW_3	22	25	5.6	2.5	0.05	4.7	6.5	1.7
Average	22,60	26,31	5.71	5.47	0.11	0.73	8.14	2.40

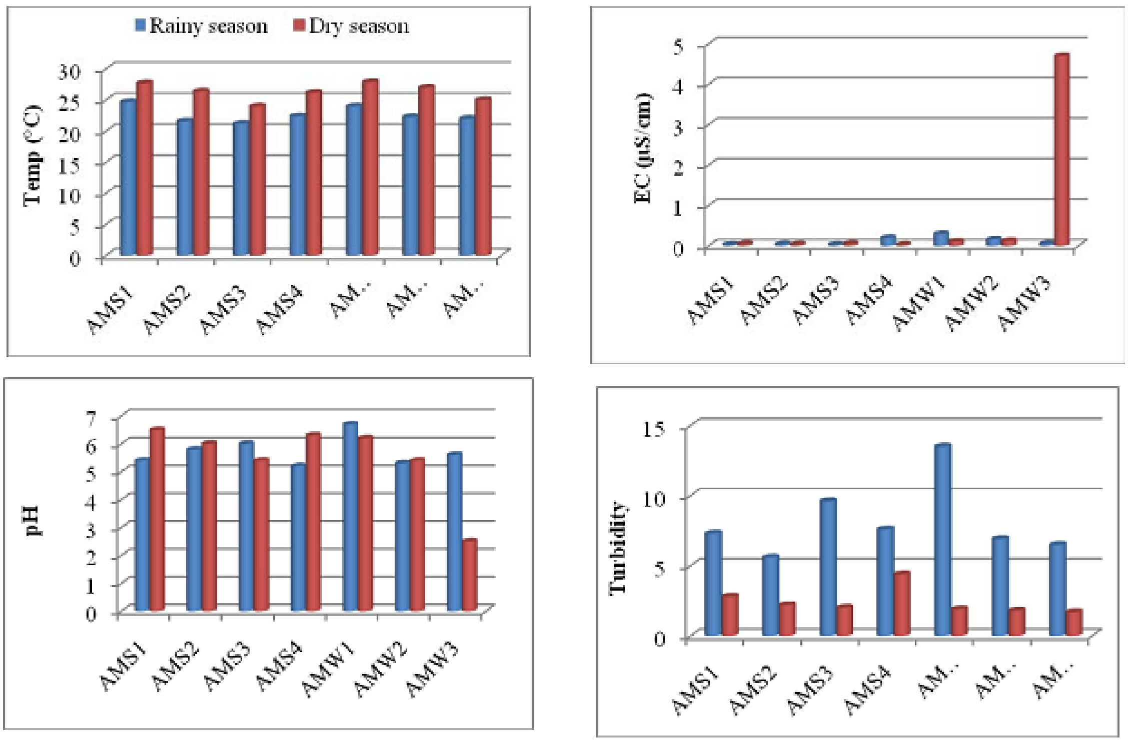


***Figure 2.** Seasonal variation of physical parameters (Temperature, pH, Electrical conductivity, Turbidity).*

4.2. Chemical Characteristics of Cations

K^+ and Na^+ concentration were high in the dry season and just barely detectable in the rainy season. There were not differences for the different sampling points, their respective average values for the rainy season were 0.39mg/l and 0.30mg/l, these values for dry season were 24.72mg/l and 11.37mg/l.

Regarding the average concentration in the dry season, Ca^{2+} was the most abundant cations in all the water samples with an average value above 500 mg/l (Table 2). Ca^{2+} was also higher in the dry season than in the rainy season for all samples.

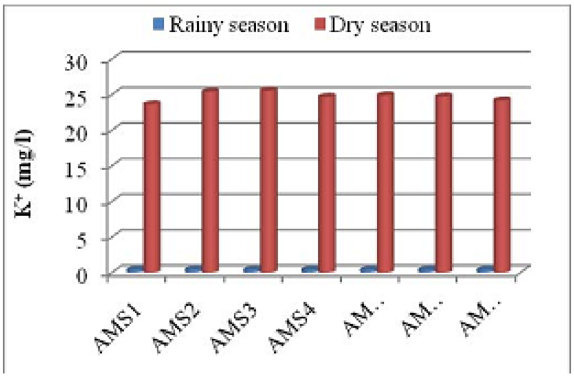
Mg^{2+} was the second abundant cations present in the analysed water with an average of 232.3 mg/l in the rainy season and 126.57 mg/l in the dry season.

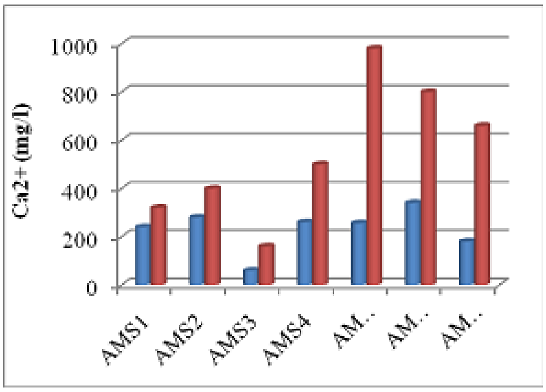
The NH_4^+ values were higher in the rainy season and barely detectable in the dry season (Figure 3) with average values ranging of 12.06 mg/l in the rainy season to 0.0073mg/l in the dry season.

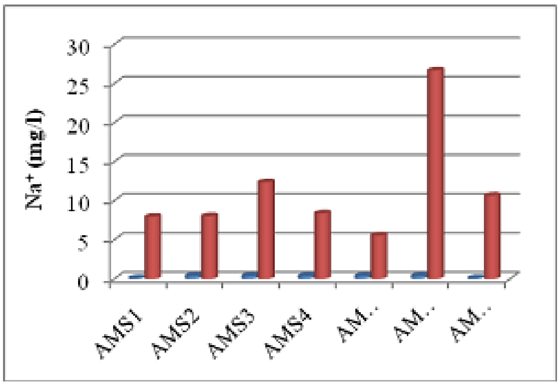
Fe^{2+} was the least abundant cation in the water samples with the highest concentration of 1.14 mg/l in AMW_2 during the dry season. In the rainy season Fe^{2+} was not detected in AMS_3, AMS_4, AMW_1, AMW_2 and AMW_3 while in the dry season it was not detected in AMS_1 and AMS_2 (Table 2).

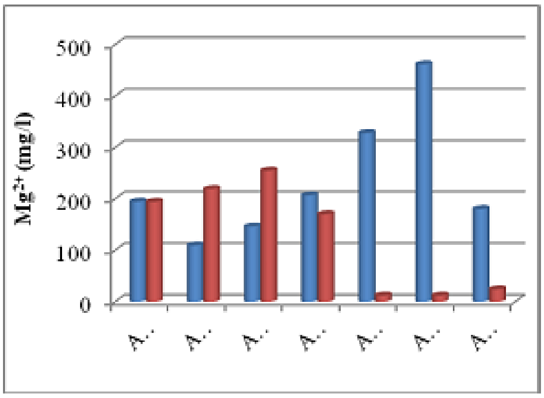
Table 2. *Variation of Cations in the rainy season and dry season.*

	K+		Na+		Ca2+		Mg2+		NH4+		Fe2+	
Sampling points	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**
AMS_1	0.39	23.64	0.11	7.94	240	320	194.4	194	8.40	0.0062	0.89	-
AMS_2	0.40	25.39	0.37	8.01	280	400	109.4	219	12.88	0.0048	0.83	-
AMS_3	0.39	25.55	0.37	12.38	60	160	145.8	255	14	0.0070	-	0.39
AMS_4	0.40	24.68	0.37	8.38	260	500	206.6	170	16.80	0.0083	-	0.05
AMW_1	0.39	24.89	0.37	5.54	256	980	328.1	12	10.36	0.0084	-	0.05
AMW_2	0.39	24.72	0.37	26.67	340	800	461.7	12	12.77	0.0076	-	1.14
AMW_3	0.39	24.18	0.11	10.64	180	660	180	24	9.24	0.0087	-	0.18
Average	0.39	24.72	0.30	11.37	230.9	545.7	232.3	126.57	12.06	0.0073	0.25	0.26









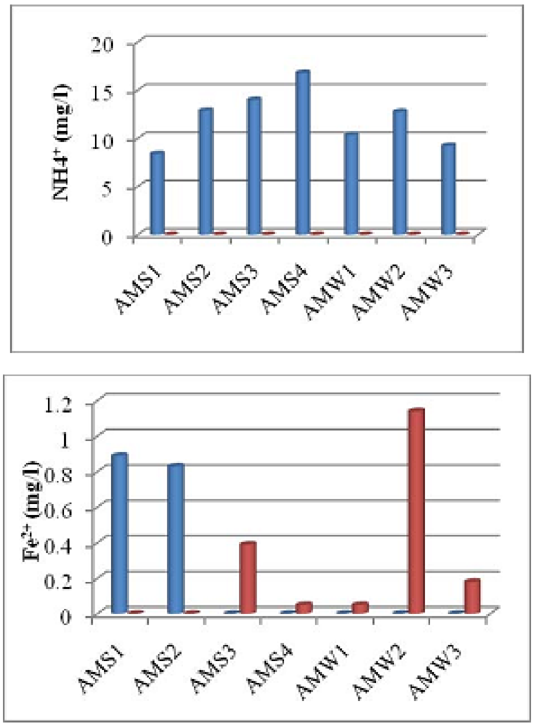


Figure 3. *Seasonal variation of cations (K^+, Na^+, Ca^{2+}, Mg^{2+}, NH_4^+, Fe^{2+}).*

4.2.1. Anions

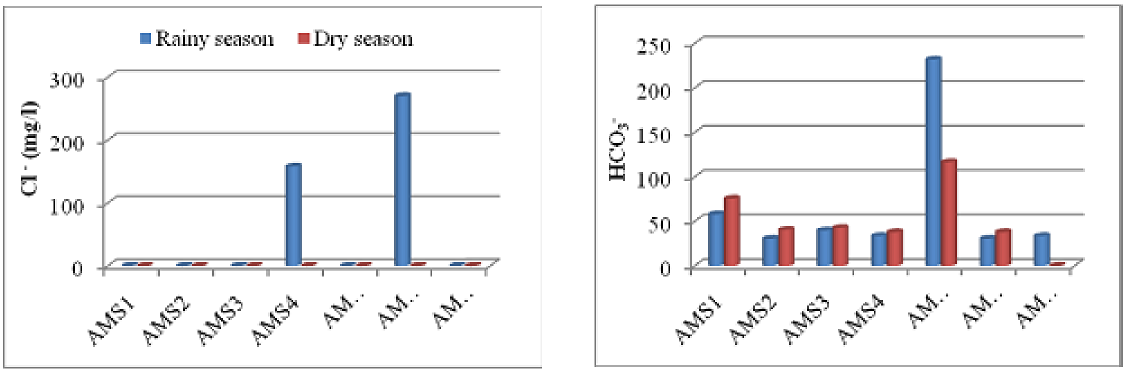
Cl^- was completely absent in all the samples in the dry season. In the rainy season, high Cl^- values were recorded only in AMS_4 (158mg/l) and AMW_2 (270mg/l) as shown in Table 3.

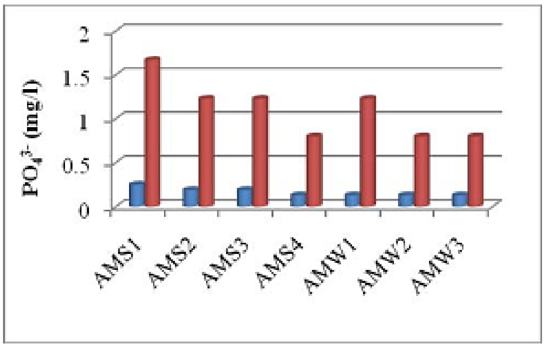
Average values for HCO_3^- were higher in the rainy season (65.36mg/l) than in the dry season (50.13mg/l).

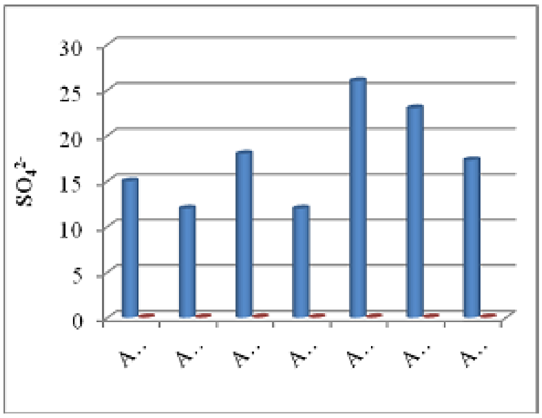
The values of PO_4^{3-} were higher in the dry season than in the rainy season but all the values were less than 2mg/l with an average of 0.16mg/l in the dry season and of 1.11mg/l in the rainy season (Table 3). NO_3^{2-} and SO_4^{2-}were barely detectable in the dry season with the respective average value of 0.0033mg/l and 0.05mg/l. In the rainy season for each cation there were just minor differences in the sampling points, NO_3^{2-} concentration yields an average of 7.68mg/l and SO_4^{2-} an average of 17.61mg/l in the rainy season as presented in table 3 and Figure 4.

Table 3. *Variation of Anions in the rainy season and dry season.*

	Cl^-		HCO_3^-		PO_4^{3-}		NO_3^-		SO_4^{2-}	
Sampling points	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**
AMS_1	-	-	57.95	75.6	0.25	1.67	11.20	0.0028	15	0.05
AMS_2	-	-	30.50	40.32	0.19	1.23	8.40	0.0006	12	0.05
AMS_3	-	-	39.65	42.84	0.19	1.23	5.60	0.0022	18	0.06
AMS_4	158	-	33.55	37.8	0.13	0.80	7.28	0.0034	12	0.05
AMW_1	-	-	231.80	116.55	0.13	1.23	5.88	0.0048	26	0.06
AMW_2	270	-	30.50	37.8	0.13	0.80	7.00	0.0045	23	0.05
AMW_3	-	-	33.55	-	0.13	0.80	8.40	0.0048	17.3	0.05
Average	*61.14*	*0.00*	*65.36*	*50.13*	*0.16*	*1.11*	*7.68*	*0.0033*	*17.61*	*0.05*







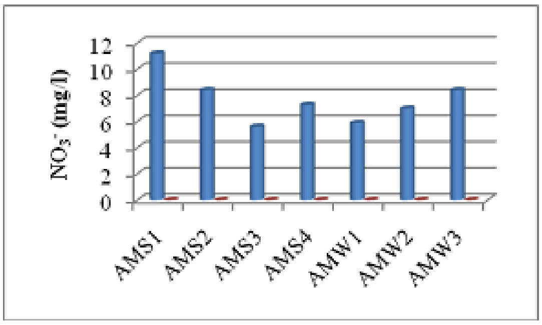
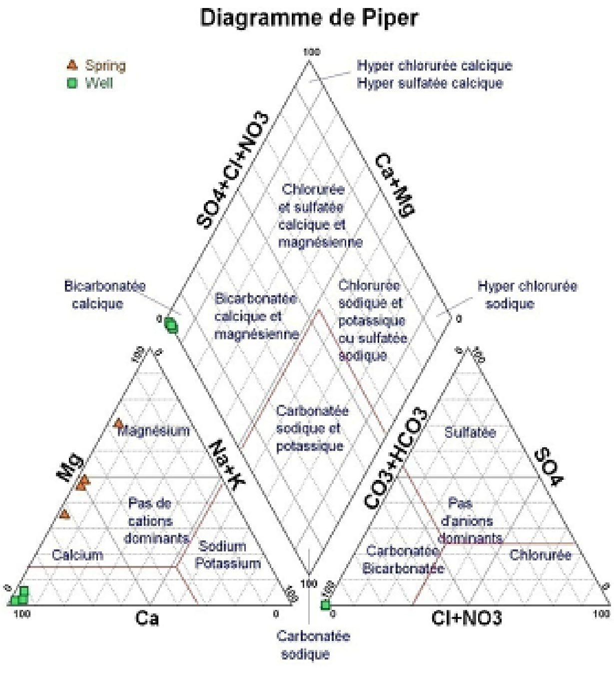


Figure 4. *Seasonal variation of anions (Cl^-, HCO_3^-, PO_4^{3-}, NO_3^-, SO_4^{2-}).*

4.2.2. Hydrochemical Facies

The piper diagram provides information on the different chemical facies of the analysed water.



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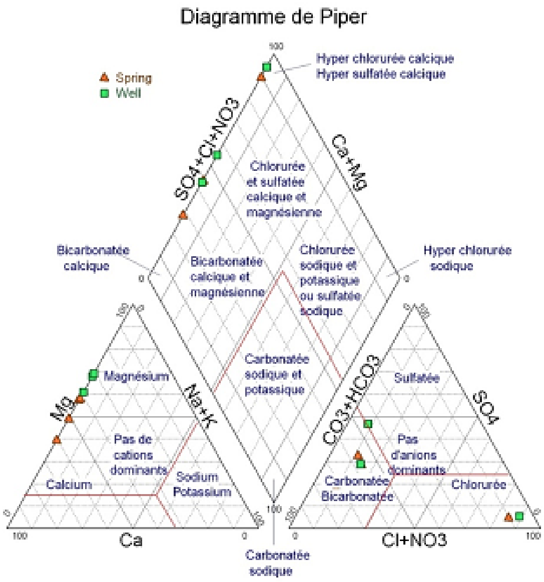

b

Figure 5. *Piper's diagram [15], showing the water types in Bamenda III, a) dry season b) for rainy season.*

In the dry season, the major cations and anions presented one facies of the Ca- Mg-HCO3 type (Figure 5a) whereas in the rainy season the major cations and anions presented two facies of Ca-Mg-HCO3 type and Ca-Mg-SO4 type (Figure 5b). This significant difference may be due to the hydrochemical processes taking place within the aquifer systems in different seasons. The mineralization process is more homogeneous in the dry season while in the rainy season mineralization is heterogeneous and influenced by the weathering of rocks.

4.3. Bacteriological Characteristics

Three (03) water points (AMS1, AMS2 and AMW2) were analysed for bacteria indicators of pollution as well as for specific microbes (Table 4).

Table 4. *Bacterial counts of specific microbes isolated in springs and well in the rainy and dry seasons.*

	Enterobacteria (cfu/100ml)		E. coli (cfu/100ml)		Streptococcus (cfu/100ml)		Salmonella (cfu/100ml)		Proteus (cfu/100ml)	
	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season
AMS_1	50	100	20	30	200	50	00	00	00	10
AMS_2	20	200	10	20	100	70	00	10	00	50
AMW_2	200	300	100	200	300	200	60	15	10	00
Average	90	200	43,33	83,33	200	106,67	20	8,33	3,33	20

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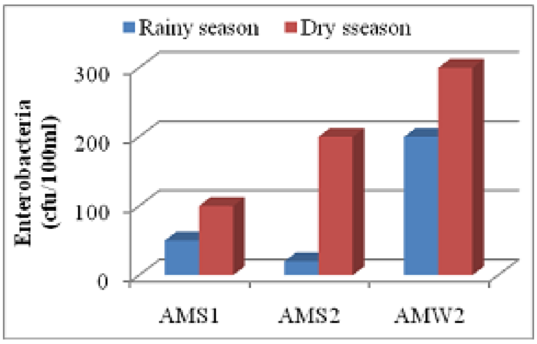

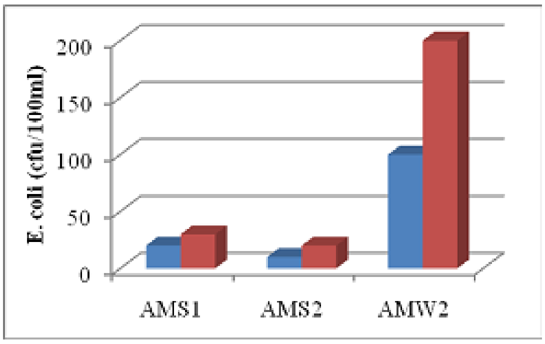

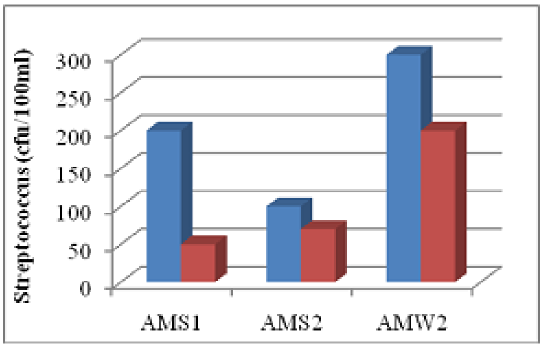

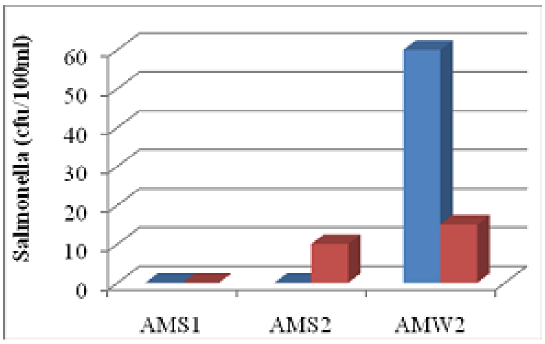

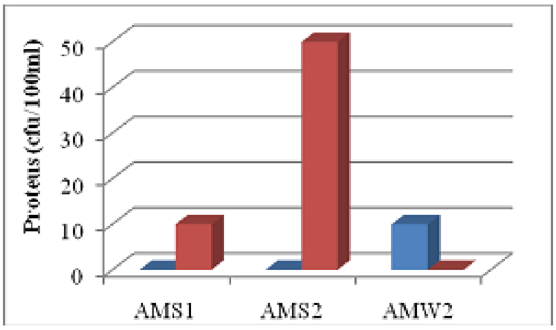

***Figure 6.** Seasonal variation of bacteria indicators of pollution and specific microbes.*

Enterobacteria, Escherichia coli, Streptococcus, Salmonella and Proteus were detected in the water samples and the species richness varied from one water point to another: Enterobacteria, Escherichia coli and Streptococcus were present in all the sampling points whereas Salmonella and Proteus were present only in some sampling points. High counts were recorded in the dry season than in the rainy season with Streptococcus presenting an exception with higher counts in the rainy season (100 to 300 cfu/100ml) than in the dry season (50 to 200 cfu/100ml). Enterobacteria levels were particularly high during the rainy season (20 to 200 cfu/100ml) but increased greatly during the dry season (100 to 300cfu/100ml). On the other hand Salmonella and Proteus were absent in springs (AMS1 and AMS2) in the rainy season but registered an increase in the dry season.

5. Discussion

The major ions chemistry of groundwater and compositional relations among ionic species can reveal the origin of solutes and processes that generate water composition [16-18].

The acidic to barely acidic water may be an indication that the dissolve carbonates were predominantly in the form of HCO3; In Ghana [19] and in Nigeria [20] low pH has also been reported from granitic basement complex aquifers and were related to the same processes.

5.1. Cations

The relative abundance of the cations was as follows $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$, this shows that

Ca^{2+} is the most abundant cation followed by Mg^{2+} in the springs and wells of the study area. Their main source may be from the weathering of calco-sodico feldspaths and hornblende in the basic rock. [21] explains that these minerals are found in basic rocks.

2 Hornblende + $30H^{+}$ + $9H_2O$ → Kaolinite + $12H_4SiO_4$ + $4Ca^{2+}$ + $10Mg^{2+}$ + $2Na^{+}$.

The most common source of K^{+} is the silicate minerals:

orthoclase, nepheline, leucite and biotite [22]. The basement rock of the study area is composed of granite and the K+ is probably from the dissolution of orthoclase (KAlSi3O8)) and Fe Mg minerals like biotite (K (Mg Fe)3 (AlSi3)O10 (OH, Fe)2 present in the granites.

2 Orthoclase +2H++9H2O → Kaolinite + 4H4SiO4 + 2K+

2 Biotite + 13H+ + CO2 + 2H2O → Kaolinite + 4H4SiO4 + 6Fe2++6Fe3 + + HCO3-+2K+

Albite in the granites is the probable source of the Na+

2 Albite +2H+9H2O→ kaolinite + 4H4SiO4 + 2 Na+

Meanwhile the main source of NH4 is probably from fertilizers used in farms which is being leached into the water while natural sources such as organic (metabolic processes) and inorganic (rock weathering and hydrothermal activity) could also contribute to the presence of NH4.

The source of Fe2+ is from the hydrolysis of Fe Mg rich minerals such as biotite in the granite and diorite of the study area. The low concentration of Fe2+ is due to its being retained in the soil for the formation of clays, oxides and hydroxides during weathering [23,24].

5.2. Anions

The relative abundances of anions (mg/l) in different samples were as follows: HCO3¯ > SO42¯ > NO3¯ > PO43¯ > Cl¯.

HCO¯3 concentrations were high with average values ranging from 16.78 – 174.18mg/l. All the samples had values below the WHO value (200mg/l). The dorminance of HCO3¯ is consistent with most natural waters along the CVL [25]. The primary source is the dissolved CO2 in rain water and the decay of organic matter at the surface which may release CO2 for dissolution [22]. Weathering, precipitation and organic decay probably account for the dominance of this ion, CO2 + H2O → H+ + HCO3- or CO2 + H2O + CO2 → 2HCO3-.

SO42¯ could derive from natural source such as sulphate minerals common in igneous rocks [22]. It can also be from the oxidation of pyrite; Fe S2 + 2O2 + H2O → 2 SO42- + H2. The low concentrations may be a consequence of gradual dissolution [26].

The presence of PO43¯ probably indicates leaching of phosphate fertilizers from nearby farmlands.

Low concentrations of NO3¯ in the dry season suggest their adsorption in organic colloids [27]. The potential source may also be shallow pit toilets and oxidation of organic matters in biochemical processes as well as the oxidation of ammonia by Nitrosomonas and Nitrobacter bacteria.

Cl¯ was absent in the rainy season and according to [28], at high altitude the decrease in Cl¯ concentration is due to smaller rainfall inputs caused by rapid decrease of the absolute humidity and temperature with elevation resulting in a smaller condensation. An anormalous Cl¯ concentration of 158mg/l and 270mg/l were obtained in the rainy season which might have been due to disinfection through chlorination.

6. Groundwater Suitability for Drinking and Domestic use in Bamenda III

The analytical results were evaluated to ascertain the suitability of groundwater in the study area for drinking and domestic purposes based on the WHO, 2004 standard (Table 5) and the [28, 29] classification (Table 6).

Table 5. *Groundwater quality in Bamenda III in compliance with WHO (2004) drinking water standard.*

Parameter	Range in study area	WHO limit (2004)
pH	4.1 – 6.5*	6.5 – 8.5
T (C°)	20.7 – 25.9*	15
EC (μs/cm)	0.04 – 2.38	750
Ca2+ (mg/l)	110 – 1770*	75
Mg2+ (mg/l)	97.05 – 236.85*	30
Na+ (mg/l)	4.02 – 13.52	200
K+ (mg/l)	12.02 – 12.97	100
Cl- (mg/l)	0 – 270*	250
NO3¯ (mg/l)	2.801 – 5.601	10
SO42¯ (mg/l)	6.025 – 11.525	250
HCO3- (mg/l)	16.78 – 174.18	200

* values above WHO limit

EC, Na^+, K^+, NO_3^-, SO_4^{2-}, and HCO_3^- concentrations of the analysed water were under the limits required by the WHO (2004) drinking water norms whereas pH and T (C°) values, Ca^+, Mg^+, and Cl^- concentration values were above the WHO limits.

pH values for the study area ranged from 4.1 to 6.5 and were below the WHO guideline limit (Table 6). Even though pH has no effect on human health, it is closely related to other chemical constituents of water [3].

The temperature values were high which favour bacterial growth and may increase taste, odour, colour and corrosion problems.

Ca^+ and Mg^+ values were much higher than the WHO norms. The presence of these alkaline earth metals determines water hardness. [30] expresses Hardness of water as Total Hardness (TH) and is given by TH = 2.5Ca + 4.1Mg. Though hardness has no adverse effect on human health, there is an esthetic concern because of the unpleasant taste that it impacts. It can prevent formation of lather with soap, increase the boiling point of water and may cause encrustation in water supply distribution system. According to [31], there is some suggestive evidence that long term comsumption of extremely hard water might lead to increase urolithiasis, ancephaly, parental mortality and some kind of cancer and cardiovascular disorders. On the other hand water softness (low in Ca^{2+} and Mg^{2+}) could be a health problem since soft water has been linked to cardiovascular ailments [32].

WHO limit for Cl^- is 250mg/l and sample AMW_2 exceed this limit in the rainy season. Higher concentration may cause gastrointestinal irritation when associated with Na^+ and Mg^{2+} [33].

According to the [29] classification of drinking water, two of the sampling points (AMS_1 and AMW_2) could be placed in category C and one (AMS_2) under category B in the rainy season (Table 5). In the dry season, AMS_1 and AMS_2 fell under category C and AMW_2 under category D (Table 5).

Table 6. *Category of water samples according to Cheesbrough classification of drinking water.*

Sampling points	Seasons	Mean count	Category
AMS_1	Rainy	30	C
	Dry	35	C
AMS_2	Rainy	10	B
	Dry	30	C
AMW_2	Rainy	40	C
	Dry	90	D

These bacterial loads indicate an excessive level of pollution of the water samples [01]. Feacal coliforms such as E. coli are prevalent in the digestive tracts of warm – blooded animals and their presence in water is definite evidence of feacal contamination.

Contaminations of water points are much higher in the dry season than in the rainy season. This may be feacal bacteria accumulate and settle as a result of greater contact between water and sediments which enables significant sediment–water exchange [34].

7. Conclusion

Bamenda III, which is petrographicaly made up of two units, plutonic (granite) and volcanic (Rhyolite, basalte and trachyte), was subjected to physico-chemical and bacteriological analyses of its 7 water points: 03 wells and 04 springs.

All water samples had pH range between 4.1 and 6.5 which is below the WHO standard for drinking water. The low EC and TDS classified the water as low-mineralised and freshwater. The relative abundance of major cations and anions in the water (mg//l) was $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ and $HCO_3^- > SO_4^{2-} > NO_3^- > PO_3^-$ respectively. Major ion concentrations were low, and below maximum values of the WHO standards for drinking water, except for Ca^{2+} and Mg^{2+} which were higher classifying the water as hardwater.

The variety and level of faecal bacteria recorded indicate that this area is under anthropogenic influence and receives feacal contamination. None of the water points are suitable for drinking. For this reason, the population of Bamenda III, 80% of which depends on the well and spring water for drinking and domestic purposes, may face serious health problems if appropriate actions are not taken to prevent and mitigate the problems.

References

[1] Katte V.Y., Fonteh M.F., Guemuh G.N. (2003): Domestic water quality in urban centres in Cameroon: A case study of Dschang in the West Province. Afr. Water. J. Pilot ed.: 43-54.

[2] Molua E.L., Lambi C.M. (2006) : Climate hydrology and water resources in Cameroon. CEEPA.

[3] Ako A.A. (2011): Hydrogeological study on groundwater in the Banana Plain and Mount Cameroon area – Cameroon Volcanic Line. Kumamoto University.

[4] Auippa A., Bellomoa S., Bruscab L., Alessandrolo W., Federico C. (2003): Natural and Anthropogenic factors affecting ground water quality of an Active volcano (Mt. Etna, Italy): Applied Geochemistry 18: 863-882.

[5] Mafany G.T., Fantong W.Y., Nkeng G.E. (2006): groundwater quality in Cameroon and its vulnerability to pollution. In Groundwater pollution in Africa. Edited by Yongxin Xu and Brent Usher. Taylor and Francis London

[6] Ako A.A., Shimada J., Hosono T., Kagabu M., Akoachere R.A., Nkeng G.E., Eneke G.T., Fouepe Appelo C., Postma D. (2005): Geochemistry, groundwater, and pollution (2nd ed.). Balkema, Amsterdam p. 635.

[7] Edmunds W.M., Smedley P.L. (1996) : Groundwater geochemistry and health: An overview. In: Appleton JD, Fuge R, McCall GJH (eds.) Environmental geochemistry and health with special reference to developing countries. Geological Society Special Publication No.113, pp. 91-105.

[8] Deutsch W.J. (1997): Groundwater geochemistry: Fundamentals and applications to contamination. CRC Press, Florida p. 221

[9] Ramesh K., Elango L. (2012) : Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. Environ. Monit. Assess. 184:3887-3899.

[10] Entry J.A., Farmer N. (2001): Movement of coliform bacteria and nutrients in groundwater flowing through basalt and sand aquifers. J. Environ. Q. 30: 1533 – 1539.

[11] Acho C. (1998): Human interface and environmental instability: Addressing the environmental problems of rapid urban growth. In: Environment and urbanisation. Vol. 10. No. 2. London. P.415.

[12] Nzenti J.P., Abaga B., Suh E.C., Nzolang C., (2010): Petrogenesis of peraluminous magmas from the Akum-Bamenda massifs, Pan-African Fold Belt.International Geology Review. 1-29p.

[13] Njilah I.K., (1991): Geochemistry and petrogenesis of the Tertiary-Quaternary volcanic rocks from Oku Ndu area, North West Cameroon. PhD Thesis, Leeds University, 350pp+1map.

[14] Kamgang P., Njonfang E., Nono A., Gountie D.M., Tchoua F. (2010):Petrogenesis of a silicic magma system: geochemical evidence from Bamenda Mountains, NW Cameroon, Cameroon Volcanic Line; Journal of African Earth Sciences 58: 285–304

[15] Piper A.M. (1944): A graphic procedure in the geochemical interpretation of water analyses. Transactions American Geophysicists Un. Papers, Hydrology, 914-929.

[16] Hounslow A.W. (1995): Water quality data: Analysis and interpretation. Lewis Publishers, Boca Raton.

[17] Demlie M., Wohnlich S., Wisotzky F., Gizaw B. (2007) : Groundwater recharge, flow and hydrogeochemical evolution in a complex volcanic aquifer system, central Ethiopia. Hydrogeol. J. 15: 1169-1181.

[18] Tay C.K. (2012) : Hydrochemistry of groundwater in the Savelugu-Nanton District, Northern Ghana. Environ. Earth Sci. 67: 2077-2087.

[19] Adomako D., Osae S., Akiti T.T., Faye S., Maloszewski P.

(2011): Geochemical and isotopic studies of groundwater conditions in the Densu River Basin of Ghana. Environ. Earth Sci. 62:1071–1084.

[20] Edet A., Nganje T.N., Ukpong A.L., Ekwere A.S. (2011) : Groundwater chemistry and quality of Nigeria: A status review. Afr. J. Environ. Sci Technol. 5 (13): 1152-1169.

[21] Marzoli A., Piccirillo E.M., Renne P.R., Bellien G., Facumin G.M., Nyobe J., Tongwa A.T. (2000): The CVL Revisited: petrogenesis of continental Basaltic mangmas form lithospheric and Asthenospheric Mantle sources; Journal of petrology; 41(1): 87-109.

[22] Karanth K.R. (1987): Groundwater Assessment: Development and management; Tatamc Grawl Hill publishing company limited; 7 west patel Nagar, New Delhi; 488pp.

[23] Goldschmidt (1954) : Geochemistry. A Muir (éd) clarendo press, Oxford 730p

[24] Millot G. (1964): Geologie des argiles Masson et Cie (ed) Paris , 499 p

[25] Tanyileke G. Z., Kusakabe M., Evans W. C., (1996): Chemical and isotopic characteristics of fluids along the CVL, Cameroon – Journal of African Earth Sciences, 22. (4): 433-441.

[26] Ngwa M. (2013): Hydrochemical variation of groundwater in Bafut Subdivision (North West Region, Cameroon).

[27] Fonge B.A., Egbe E.A., Fongod A.N., Tening A.S., Achu R.M., Yinda G.S., Mvondo Z. (2012): Effects of land use on macrophyte communities and water quality in the Ndop wetland plain, Cameroon. J. Agric. Soc. Sci. 12: 41-49.

[28] Benedetti M.F., Dia A., Riotte J., Chabaux F., Gerald M. Boulegue J., Fritz B., Chauvel C., Bulourde M., Deruelle B., Ildefonse P. (2003): Chemical weathering of basaltic lava flows undergoing extreme climatic conditions: the water geochemistry record. Chemical geology 2011- 17.

[29] Cheesbrough M. (1991). Medical Laboratory manual for tropical countries. Low priced edition, Daddington, Cambridgshire.

[30] Todd D. k. (1980): Goundwater Hydrogeology. New York : Wiley.

[31] Durvey V.S., Sharma L.L., Saini V.P., Shama B.K. (1991): Handbook on the methodology of water quality assessment in India: Rajasthan Agriculture University.

[32] Kozisek F. (2005): Health risks from drinking demineralised water. In: Nutrients in drinking water. World Health Organization, Geneva. pp. 148-163.

[33] Garg V.K., Suthar S., Singh S., Sheoran A., Garima M., Jain S. (2009) : Drinking water quality of Southwestern Hanyana India : Assessing human health risks associated with hydrochemistry. Environmental Geology. Dio: 10. 1007/s00254 – 008 1636 – y.

[34] Mitsch W.J., Gosselink J.G. (2000): Wetlands. 920 p. wiley, New York, USA.

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Full Length Research Paper

Microbial pollution of the Mezam river system and its health impact in Bamenda (North-West Cameroon)

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A two-year study was carried out from June 2009 to May 2011 to investigate the microbial quality of the Mezam river system in Bamenda and its health impact, given the prevalence of waterborne diseases among the population who use the river water for various purposes, notably domestic and agricultural activities. River, spring and tap water samples were collected monthly and analysed quantitatively for faecal bacteria indicators of pollution and qualitatively for specific pathogens. The study shows that most of the sites were heavily polluted with faecal bacteria (12 to 2822 cfu/100 ml) that consistently exceeded the WHO recommended range for potability. These bacteria often comprised the pathogens *Salmonella* and *Shigella* which seemed to be endemic. They all tended to be highest in the dry season and at the onset of the rainy season. The incidence of waterborne diseases showed a seasonal pattern similar to the seasonality of the causative agents in water samples. The most impaired segments were the Ayaba and Mughed tributaries which receive inputs from urban and domestic activities, as well as the Nkimefeu tributary which receives direct waste discharge from the dressing of carcasses at the town slaughter house. The population which is dependent on the river water are thus exposed to health risks which could be reduced by minimizing the discharge of both liquid and solid wastes into water channels.

Key words: Faecal bacteria, market gardening, pathogens, river pollution, wastewater.

INTRODUCTION

Surface water plays an important role in the transmission of pathogenic agents discharged through human and animal faeces. These agents may find their way into the water via domestic wastewater, surface runoff from agricultural land and pastures during rainfall, or by direct deposition of faecal matter with access to stream channels (Eyles et al., 2003; Collins et al., 2005). They can transfer to humans by various routes, like recreation, irrigation of fruits and vegetables and drinking water (Davies-Colley et al., 2004). An understanding of the nature and dynamics of the microbial community in such surface waters is a necessity, since the indiscriminate increase in pollution factors has made natural purification capacities insufficient. In particular, knowledge of the levels of microorganisms in water is important for indexing the health hazard associated with its use, adopting meaningful interventions and improving bacterial water quality (Entry and Farmer, 2001).

The Mezam river sub-basin in Bamenda, West Cameroon, harbours a growing urban community that relies on the Mezam river for household chores, irrigation of market gardens and as a source for public watersupply (Tita et al., 2012). It also serves as recreational swimming pool for small children from nearby homes and

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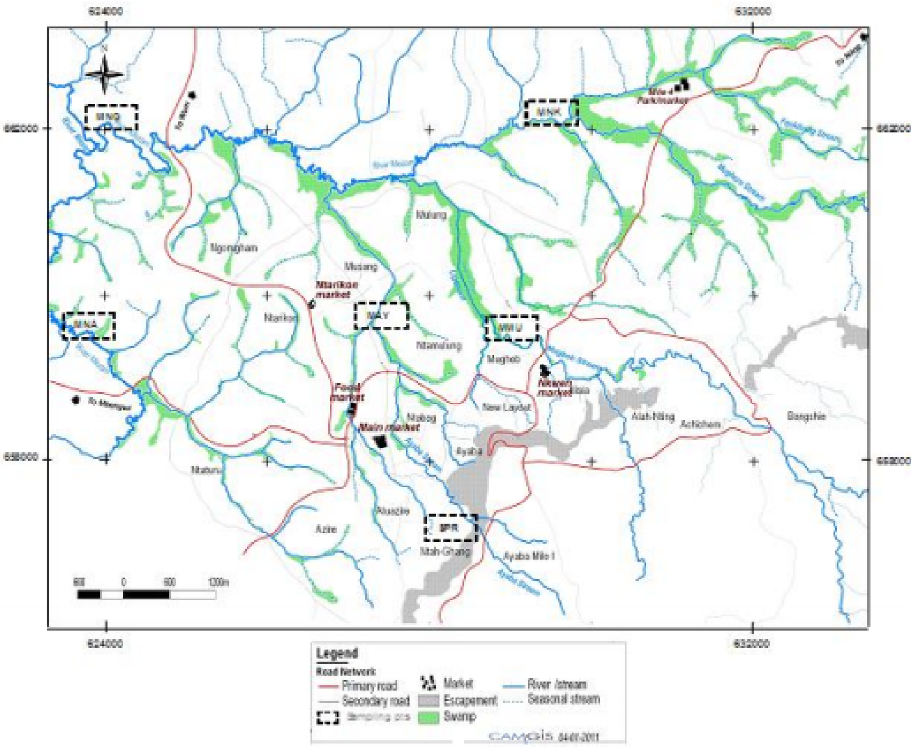

Figure 1. Map of Mezam river system in Bamenda showing sampling points.

schools. The increasing demand on this water resource and the resultant contamination from human activities generate a number of pollution problems thus increasing the risk of outbreaks from waterborne diseases. Katte et al. (2003) and Kuitcha et al. (2010) have illustrated that serious public health problems prevail in Dschang and Yaoundé (Cameroon), respectively, due to the biological pollution of wells, backwaters and rivers resulting from poor domestic and industrial waste management.

In fact, a number of studies have highlighted the great threat to public health in urban centres in many developing countries caused by microbial contamination and associated increase in waterborne enteric diseases (Ilorin, Nigeria: Kolawole et al., 2011; Abidjan, Ivory Coast: Coulibaly et al., 2004; Blantyre, Malawi: Palamuleni, 2001).

Hospital records from the Bamenda Health District show a high prevalence of waterborne diseases in Bamenda, and isolated cases of cholera occur from time to time. There is, however, a complete lack of scientific information on bacteriological water quality in this locality for appropriate intervention.

The main objective of this study was to evaluate the microbial status of the Mezam river system in Bamenda and its health impact on the population. Specifically, the study aimed to determine the types and levels of faecal bacteria and to identify the factors responsible for the degradation of the water resources. Such a study is important as it shall provide a framework for practical measures to guide water management in the sub-basin and, through this, mitigate and control the impact of pollution on the population.

MATERIALS AND METHODS

Study area

The study area is the Mezam river sub-basin in Bamenda (North West Cameroon), situated between latitudes 5°43' and 7°10' N and longitudes 9°35' and 11°12' E. The Mezam River is a second order perennial stream fed by several small streams and springs which take their rise from the Bamenda Escarpment. Water samples were collected for bacteriological analyses at six sites (SPR, MNA, MAY, MMU, MNK and MNG) in the Mezam river system (Figure 1). Details of the sites are given in Table 1.

Table 1. Location and characteristics of sampling sites in the Mezam river system in Bamenda.

Site N°	Code	Location	Characteristic
1	SPR	Spring situated at the foots of the escarpment and constitutes reference point.	Presence of a few farm and grazing lands.
2	MNA	Naaka stream, western boundary of Bamenda town.	Rural tributary for the most part. Water drains in from the Mbatu plain, an intensive agricultural area in the basin.
3	MAY	Ayaba tributary	Urban tributary. Drains through thickly populated commercial centre and residential area.
4	MMU	Mugheb tributary	Urban tributary. Drains waste from the Nkwen market and its neighbourhood.
5	MNK	Nkimefeu tributary, northern boundary of Bamenda town.	Receives waste successively from fish farms, carwash, market gardens, soap factory and town slaughter house.
6	MNG	Mezam river at Ngomgham Situated at the outlet of the Mezam River from Bamenda.	Drains the Municipal open waste discharge at Mile 8.
7	MTW	Tapwater	Treated water from Mezam River distributed to population.

Water sampling

Sampling was carried out monthly from June 2009 to May 2011 for bacteriological analyses. On each sampling occasion, 1-l samples of water were collected from a well-mixed, flowing section of the river using sterile glass bottles and transported in an ice bucket to the Centre Pasteur Laboratory in Yaoundé, where they were analysed quantitatively for bacteria indicators of faecal contamination within 24 h. Every other month, qualitative analyses for specific indicators and pathogens were also carried out. During these occasions, tap water (MTW) was simultaneously sampled for both quantitative analysis of faecal bacteria and qualitative determination of pathogens.

Quantitative analysis of bacteria indicators of pollution

Heterotrophic bacteria and *Clostridium* were quantified by incurporation in plate count agar and beef liver agar, respectively, and incubated at 37°C for 24 h. Total coliforms, faecal coliforms, faecal streptococci and *Pseudomonas* were enumerated using the membrane filter technique (APHA, 1998). After filtration, the membrane was placed over lactose agar and cultured for 24 h at 37°C (total coliforms) or 44°C (faecal coliforms). To estimate faecal streptococci, the membranes were cultured over Slanetz medium for 48 h at 37°C. *Pseudomonas* was estimated on Cetrimide agar for 24 to 48 h at 37°C. The results are expressed in colony forming units (cfu) per 100 ml.

Qualitative analysis of specific indicators and pathogens

Escherichia coli were identified by inoculating characteristic total coliform colonies in MacConkey broth. Growth characteristics together with reaction to indole methyl red confirmed the presence of *E. coli* (Marchal et al., 1991). Meanwhile, Enterococci were detected by incubating faecal streptococci colonies on Enterococci specific agar and confirmed by negative catalase test. The pathogens *Salmonella*, *Shigella* and *Vibrio* were identified on Hectoen agar after enrichment on Rappaport (APHA, 1998), and presumptive colonies were confirmed biochemically (search for galactosidase, urease and indole oxydase, respectively) (Marchal et al., 1991).

Waterborne diseases

Data on waterborne diseases were obtained from the Mezam Health District Service and through structured interviews involving 500 households randomly selected from all the quarters in the city of Bamenda. Respondents were required to furnish information on their sources of water for domestic chores and the occurrence of waterborne diseases in their respective families.

Statistical analysis

The Duncan test was used to evaluate significant differences among sampling sites and the probability for significance set at $p \leq 0.01$. All calculations (mean, standard deviation and t-tests) were performed using Microsoft EXCEL statistical package for win XP-2002 and SPSS version 10.1 statistical calculation program (SPSS Inc., Chicaco IL).

RESULTS

Distribution of faecal indicator bacteria in the Mezam river system

The microbial survey carried out on water samples from the Mezam river system showed that apart from tap water, all the sites sampled contained all the indicator bacteria analysed, and each exceeded the WHO (2001) recommended limits for potable water (Table 2). They were dominated by coliforms and *Clostridium* spores. Further analysis of the coliforms revealed the presence of faecal coliforms in all the samples. Faecal streptococci were also numerous while *Pseudomonas* sp was generally the least represented.

Statistical analysis indicated that faecal indicator bacteria counts were significantly different among sites ($p \leq 0.01$). The highest mean coliform counts (>1600 cfu/100 ml) were recorded downstream at MNG and MNK, as well as MAY and MMU located on the urban tributaries (Table 2). Faecal coliforms and streptococci were also most prolific at these urban sites, whereas upstream at MNA, bacteria counts were less than 100 cfu/100 ml. *Pseudomonas* and *Clostridium* also presented a similar trend. All the indicators were much

Table 2. Geometric mean of bacteria counts in water samples from the Mezam river system in Bamenda (n = 24 except at MTW where n = 12).

Indicator bacteria	Sites in the Mezam river system							*DWQ
	SPR	MNA	MAY	MBA	MMU	MNG	MTW	
Heterotrophic bacteria (cfu/100 ml)	1485[a]	23951[b]	123721[c]	143363[c]	130054[c]	169633[c]	31	<20
Total coliforms (cfu/100 ml)	82[a]	994[b]	1750[c]	1648[c]	1904[c]	2468[c]	<1	<1
Faecal coliforms (cfu/100 ml)	21[a]	68[b]	201[c]	281[d]	175[c]	382[d]	<1	<1
Faecal streptococci (cfu/100 ml)	12[a]	122[b]	168[b]	231[c]	335[d]	311[d]	<1	<1
Pseudomonas sp (cfu/100 ml)	20[a]	25[a]	59[b]	146[c]	41[b]	165[c]	>10	<1
Clostridium spores (cfu/100 ml)	13[a]	432[b]	1753[c]	1521[c]	511[b]	2822[c]	>10	<1

Values in the same row followed by the same letter are not significantly different at p ≤ 0.01; *Drinking water quality (WHO, 2001).

fewer but nonetheless present in spring water (SPR) at the river source. In tap water (MTW), total coliform, faecal coliform and faecal streptococcus counts were within the recommended limit for drinking water (<1 cfu/100 ml) but heterotrophic bacteria, *Pseudomonas* and *Clostridium* spores exceeded their respective limits.

Temporal variations in faecal indicator bacteria in the Mezam river system

The faecal bacteria exhibited great temporal variations at all the sites: high counts were recorded during periods of low and rising water levels (February to May), corresponding to the dry season and the onset of the rainy season, respectively (Figure 2). The counts were much lower in periods of high and falling water levels (August to November). *Clostridium* levels were particularly high and more or less constant (1000 to 1200 cfu/100 ml) but increased two to four fold between February and April. On its part, *Pseudomonas,* which was almost absent during high discharges, registered a sharp increase between January and March.

Occurrence of specific indicators and pathogens in the Mezam river system

E. coli and Enterococci were present in all the water samples analysed except tap water. The pathogens *Salmonella* and *Shigella* were detected at various sites and at different times. *Salmonella* was more frequently (63.3%) detected than *Shigella,* and *Vibrio* sp. was detected only once at MNK (7.69%) (Table 3). None of the pathogens was identified in tap water. Analysis of the isolation frequency of *Salmonella* showed that more than 65% of the *Salmonella*-positive samples were recorded between January and May which corresponds to the dry season and the onset of rains, respectively (Figure 3).

Incidence of waterborne diseases in Bamenda

Household interviews conducted in Bamenda town showed that in most households, the inhabitants repeatedly suffer from various waterborne diseases, and records from the Bamenda Health District Service indicated that between 2008 and 2010, 29695 patients consulted for diarrhoeal diseases, while 8544 were diagnosed for dysentery and 9166 for typhoid fever (Figure 4). Many more people suffered from diarrhoea between December and May while dysentery and typhoid infections were more common from March to June. Meanwhile, less than 20% of the respondents use tap water for drinking while more than 60% use either spring, well and/or river water for domestic activities that include cooking, washing, bathing and even drinking (data not shown). River water is also extensively used for the irrigation of market vegetables.

DISCUSSION

Total coliforms and heterotrophic bacteria are used to evaluate the hygienic status of water and any presence of the coliform group in water indicates contact with sewage (Markosova and Jezek, 1994). Faecal coliforms such as *E. coli* are prevalent in the digestive tracts of warm-blooded animals and it is believed that there is a correlation between their presence and pathogenic organisms since they have very similar survival characteristics to those of the well-known pathogenic members of the family, *Salmonella* and *Shigella* (Van Kessel et al., 2004). They thus serve as indicators for these pathogens and associated animal wastes that enter a water body, and their presence is definite evidence of faecal contamination and the potential risk of zoonotic pathogens (Entry and Farmer, 2001). Faecal streptococci, particularly *Enterococcus* spp, and *Clostridium* spores also show faecal contamination, the former indicating recent contamination as they do not multiply in the environment, and the latter representing more ancient contamination (Payment and Franco, 1993).

Spatial distribution of faecal indicator bacteria in the Mezam river system

The distribution of faecal bacteria in the Mezam river

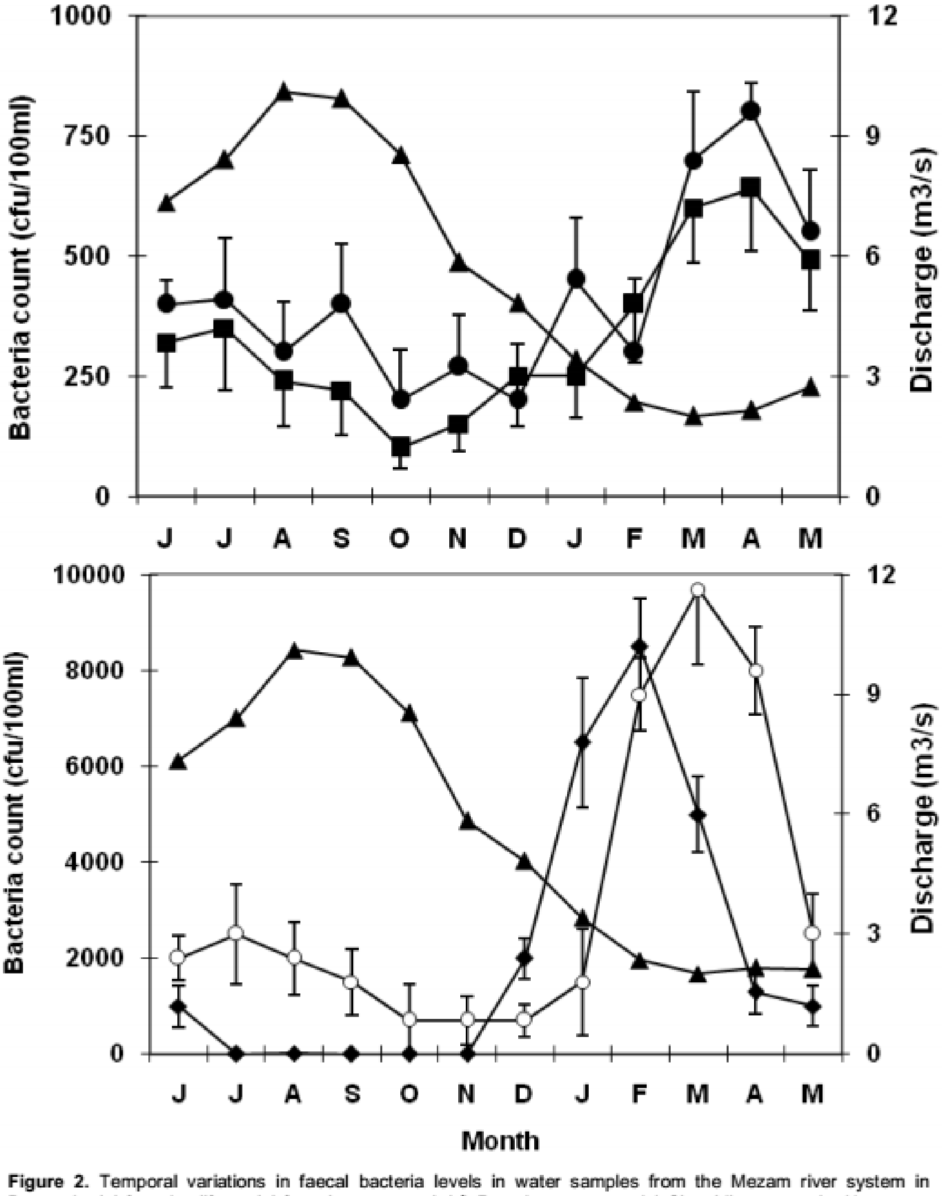

Figure 2. Temporal variations in faecal bacteria levels in water samples from the Mezam river system in Bamenda: (■) faecal coliform, (●) faecal streptococci, (♦ *Pseudomonas* spp, (o) Clostridium spores) with respect to river discharge (▲(n = 12).

system seemed to reflect input from the surrounding land. The lowest counts were measured in SPR, whereas the highest concentrations were obtained at MAY, MMU, MNK and MNG. Bacteria levels at MNA were low to moderate depending on the type of bacteria and the season. MNA is situated downstream of a flood plain where riparian vegetation provides a significant buffer zone such that inputs from human wastes and grazing stock are likely to be reduced (Eyles et al., 2003). Besides, the river gradient is low in this section and this, together with the in-stream vegetation that is almost unique to the segment, may favour the settling of faecal

Table 3. % positive samples for pathogens identified in water samples from the Mezam river system in Bamenda (n = 12).

Pathogen	Sites in the Mezam river system						
	MRS	MNA	MAY	MMU	MNK	MNG	MTW
Salmonella sp.	7.69	23.07	61.53	71.42	76.92	84.61	0
Shigella sp.	0	7.69	15.38	28.57	15.38	23.07	0
Vibrio cholerae	0	0	0	0	7.69	0	0

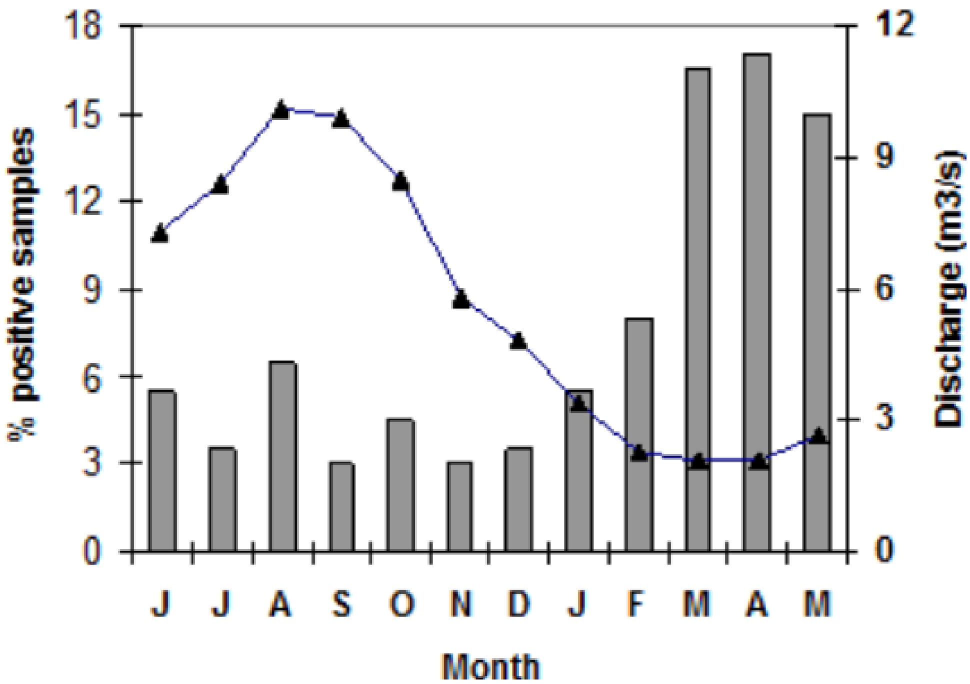

Figure 3. Temporal distribution of *Salmonella*-positive samples (▮) in the Mezam river system in Bamenda with respect to river discharge (▲(n = 12).

indicator bacteria and so reduce water column levels (Tita et al., 2012; Mitsch and Gosselink, 2000).

MAY and MMU are urban sites and receive numerous direct sewage inputs from residential areas along the watercourses as there is no central treatment system for Bamenda town (> 350 000 inhabitants). In fact, many homes do not have latrines and the stream simply serves this purpose. Just upstream from the MMU sampling point, pipes can be seen discharging from some homes, while huge quantities of garbage are deposited either near the river or directly into the river channel. MNK is situated downstream from the town slaughter house whose wastes are discharged directly into the river channel. Furthermore, a number of small animal farms are found in the back yards of many homes, while the presence of a carwash and soap factories attracts a concentration of people for whom sewage facilities are generally not available. Finally, MNG located at about 7 km downstream from MMU, receives not only the bacteria loaded water from the latter, but also input from the urban tributaries, as well as that from the Municipal open waste discharge that extends into the river channel.

Temporal variations in faecal indicator bacteria in the Mezam river system

Faecal contamination of the river was generally higher

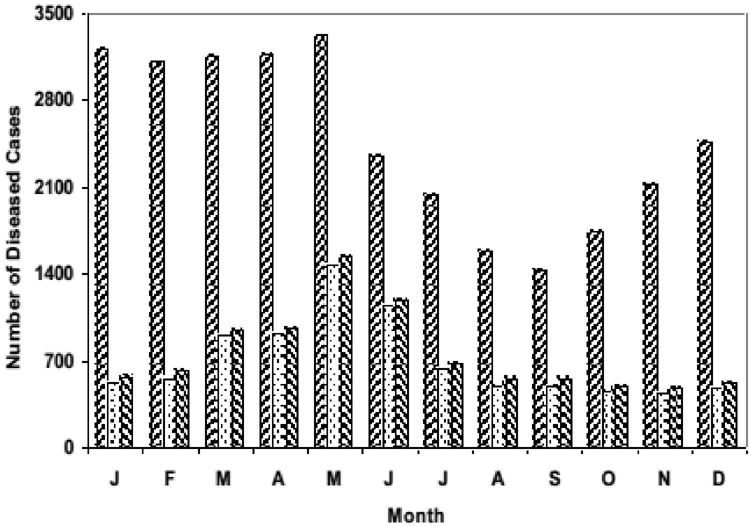

Figure 4. Incidence of waterborne diseases in the Bamenda Health District (2008-2010): (▨) diarrhoea; (□) dysentery; (▤) typhoid fever.

during low and rising water levels and tended to reduce under high and falling discharge rates, corresponding to the dry season/onset of rains and rainy season/end of rains, respectively. In the dry season, water levels are much reduced and bank vegetations cleared for the cultivation of market vegetables using river water for irrigation. This makes the streams more accessible to both humans and animals. This may increase faecal bacteria levels in the water column through direct deposition of faecal matter and re-suspension from sediments, compounded by minimum dilution due to low river flow (Castillo et al., 2004). It is also possible that as the water velocity reduces in the dry season, faecal bacteria accumulate and settle as a result of greater contact between water and sediment which enables significant sediment-water exchange (Mitsch and Gosselink, 2000). Moreover, a lot of faecal matter and associated wastes accumulate on land due to the lack of rainfall. The first rains wash them into surface water and the upsurge in bacteria counts at this time could thus be a combination of contributions from such land stores and those re-suspended from sediments.

On the other hand, regular rainfall flushes faecal matter from land as they are deposited, and with the increased volume of water in river channels, there is maximum dilution resulting in lower counts (Castillo et al., 2004). However, storm events typically resulted in elevated bacteria counts, whether during low or high discharge regime. Storm events are characterised by turbulent rolling waves that result in channel mixing and entrainment of particles in the wave front (Wilkinson et al., 2006).

Besides, the large volumes of water generated may lead to ingress of the stream water into encroaching garbage and waste dumps, as well as the overflow of poorly maintained septic tanks. Faecal bacteria levels are therefore greatly increased by re-suspension from the streambed and allocthonous inputs from runoff and dissolution of actively decomposing waste matter from far afield. As the rainy season dwindles to an end, there is reduced input from land stores through runoff and, with decreasing flow, settling out of sediment particles with associated bacteria is enhanced. The sediments thus gradually switch from being in-channel sources of faecal bacteria to serving as sinks. Consequently, the water column bacteria counts remain low during this phase of the hydrograph.

Implications for public health

Freshwater quality criteria for domestic supply require that faecal bacteria levels should not exceed a geometric mean value of 100 cfu/100 ml while the drinking water criterion is <1 cfu/100 ml (WHO, 2001). Many segments of the Mezam river system are thus highly polluted and either unacceptable for public water supply, or require fairly expensive treatment before use. The presence of *Clostridium* spores in tap water suggests that highly persistent micro-organisms like protozoan cysts may have survived during treatment, while high counts of heterotrophic bacteria are indicative of the availability of nutrients in the water, which may result in aesthetic problems or in the presence of opportunistic pathogens (Payment et al., 2003). Indeed, heterotrophic bacteria are used to assess the suitability of water for use in the manufacture of food and drink products, where high counts may lead to spoilage. This is of particular concern in the present study area where local homemade beverages such as "foléré", "ginger", "Alaska", "kossam" and corn beer are very common. On the other hand, the presence of *Pseudomonas* spp. in high concentrations should be of great concern today with the increasing number of HIV/AIDS patients as it causes opportunistic infections in debilitated patients (Baron and Hollander, 1993).

The pathogens *Salmonella*, *Shigella* and, to a much lesser extent, *Vibrio* were identified at the studied sites. A few significant correlations ($p \leq 0.01$) existed between the presence of *Salmonella* and the levels of some of the faecal indicator bacteria but generally, no direct relationship could be established between the presence of pathogens and levels of faecal indicators. However, it is worth noting that the pathogens were more frequently detected at the urban sites that were also quite remarkable for their chronically elevated levels of faecal bacteria.

The prevalence of waterborne diseases in Bamenda is similar to the situation described by Djuikom et al. (2006) and Katte et al. (2003) in some urban and precarious quarters of Yaoundé and Dschang, respectively. Diarrhoeal diseases are waterborne and common in communities where living standards are low, and wastewater and excreta disposal facilities inadequate. Typhoid is caused by *Samonella* spp. and bacillary dysentery by *Shigella dystentriae*. *Salmonella* was shown in this study to be the most prevalent and endemic of the three classic bacterial agents of intestinal infections investigated. The incidence of the diseases seemed to follow a seasonal pattern that was almost reflected in the seasonality of the agents in water samples. Although the Bamenda Health District lacks the technical facilities to identify many diarrhoea agents and their serogroups, there seems to be strong circumstantial evidence that the enteric diseases in general and typhoid fever in particular, could be transmitted, at least in part, through the use of contaminated water from the Mezam river system.

Conclusion

The high levels and variety of faecal bacteria recorded in this study as well as the presence of pathogens in both river and spring waters clearly show that the Mezam River in Bamenda receives faecal contaminants on a continual basis. The urban tributaries are highly impacted by commercial and domestic activities but the Nkimefeu tributary is the most impacted due to direct waste discharge from the dressing of carcasses at the town slaughter house. The implications of these findings are that people who are dependent on the river water for domestic or agricultural uses may be exposed to public health risks. The evidence of the data and processes discussed indicate that the risk could be reduced by minimising the discharge of both liquid and solid wastes into water channels. This may be achieved by encouraging the establishment of thick and perennial bank vegetations to limit direct access to the river channel, accompanied by the provision of waste collection and disposal facilities by the Municipality. This should be reinforced with the periodic inspection of homes to ensure the effective and proper installation of latrines and individual sewage evacuation systems.

REFERENCES

APHA (1998). Standard Methods for the Examination of Water and Wastewater. 20th Ed. American Public Health Association, Washington DC.

Baron AD, Hollander H (1993). *Pseudomonas aeroginosa* bronchopulmonary infection in late immunodeficiency virus disease. Am. Rev. Resp. Dis. 148:992-996.

Castillo MA, Allan JD, Sinsabaugh RL, Kling GW (2004). Seasonal and interannual variation of bacterial production in lowland rivers of the Orinoco basin. Freshw. Biol. 49:1400-1414.

Collins R, Elliott S, Adams R (2005). Overland flow delivery of faecal bacteria to a headwater pastoral stream. J. Appl. Microbiol. 99:126-132.

Coulibaly LD, Diomandé DA, Coulibaly AG, Gourène G (2004). Utilisation des eaux, assainissement et risques sanitaitres dans les quartiers précaires de la commune de Port-Bouét (Abidjan, Cote d'Ivoire). Vertigo 3 (5). Online December 1 2004. URL:http://www.vertigo.revues.org/3299.

Davies-Colley RJ, Nagels JW, Smith AR, Young RG, Phillips CJ (2004). Water quality impact of a dairy cow herd crossing a stream. New Zealand J. Mar. Freshw. Res. 38:569-576.

Djuikom E, Njine T, Nola M, Sikati V, Jugnia LB (2006). Microbiological water quality of the Mfoundi at Yaounde, Cameroon, as inferred from indicator bacteria of faecal contamination. Envron. Monitor. Assess. 122:171-183.

Entry JA, Farmer N (2001). Movement of coliform bacteria and nutrients in ground water flowing through basalt and sand aquifers. J. Environ. Qual. 30:1533-1539.

Eyles R, Niyogi D, Townsend C, Benwell G, Weinstein P (2003). Spatial and temporal patterns of Campylobacter contamination underlying public health risk in the Taieri river, New Zealand. J. Environ. Qual. 32:1820-1828.

Katte VY, Fonteh MF, Guemuh GN 2003. Domestic water quality in urban centres in Cameroon:a case study of Dschang in the West Province. Afr. Water J. 10:43-54.

Kolawole OM, Ajayi KT, Olayemi AB, Okoh AI (2011). Assessment of water quality in Asa River (Nigeria) and its indigenous Clarias gariepinus fish. Int. J. Environ. Res. Public Health 8 (11):4332-4352.

Kuitcha D, Ndjama J, Tita MA, Lienou G, Kamgang KBV, Ateba BH, Ekodeck GE (2010). Bacterial contamination of water points of the Upper Mfoundi Watershed, Yaoundé, Cameroon. Afr. J. Microbiol. Res. 4(7):568-574.

Marchal N, Bourcho JP, Richard CL (1991). Les milieux de cultures pour l'isolement et identification biochimique des bactéries. Doin Ed., Paris. pp 225-226.

Markosova R, Jezek J (1994). Indicator bacteria and limnological parameters in fish ponds. Water Res. 12:2477-2485.

Mitsch WJ, Gosselink JG (2000). Wetlands. 920 p. Wiley, New York, USA.

Palamuleni LG (2001). Effect of sanitation facilities, domestic solid waste disposal and hygiene practices on water quality in Malawi's urban poor areas. 2nd WARFSA/waterNet Symposium on Integrated Water Resources Management:Theory, Practice, Cases. 30-31 October, 2001, Cape Town, pp 283-290.

Payment P, Franco E (1993). *Clostridium perfringens* and somatic coliphages as indicators of the efficiency of drinking water treatment for viruses and protozoan cysts. Appl. Environ. Microbiol. 8:2418-2424.

Payment P, Waite M, Dufour A (2003). Introducing parameters for the assessment of drinking water quality. *In*:Assessing Microbial Safety of Drinking Water:Improving Approaches and Methods. WHO Drinking Water Quality Series: OEC-WHO Paris, France, pp 47-787.

Tita MA, Kuitcha D, Magha A, Ndjama J, Kamgang KBV (2012). Occurrence of macrophytes in the Mezam river system in Bamenda (Cameroon) and their role in nutrient retention. Syllabus Rev. 3:1-10.

Van Kessel JS, Karns JS, Gorski L, McCluskey BJ, Perdue ML (2004). Prevalence of *Salmonellae*, *Listeria monocytogenes* and faecal coliforms in Bulk Tank Milk on US Dairies. J. Dairy Sci. 87:2822-2830.

WHO (2001). Guidelines for drinking water quality: Addendum: Microbiological agents in drinking water. World Health Organisation, Geneva, Switzerland. 188 p.

Wilkinson J, Kay D, Wyer M, Jenkins A (2006). Processes driving the episodic flux of faecal indicator organisms in streams impacting on recreational and shellfish harvesting waters. Water Res. 40:153-161.