Open Access Library Journal
2022, Volume 9, e8331
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Trace Metals Evaluation of Groundwater in the Granito-Basaltic Fractured Rock Aquiferous Formations in Bafoussam, West Region—Cameroon

Jovens Nyangang Aduck, Agbor Ngale Ma-Effeti, Sharon Ntube Ngwese, Richard Ayuk II Akoachere*

Department of Geology, University of Buea, Buea, Cameroon
Email: *r.akoachere@ubuea.cm

How to cite this paper: Aduck, J.N., Ma-Effeti, A.N., Ngwese, S.N. and Akoachere, R.A. II (2022) Trace Metals Evaluation of Groundwater in the Granito-Basaltic Fractured Rock Aquiferous Formations in Bafoussam, West Region—Cameroon. *Open Access Library Journal*, **9**: e8331.
https://doi.org/10.4236/oalib.1108331

Received: December 27, 2021
Accepted: February 25, 2022
Published: February 28, 2022

Abstract

Bafoussam is situated between latitude 5.42N - 5.60N and longitude 10.38E - 10.48E, is the capital and largest city in the Western Region of Cameroon. Increased urbanization and agricultural activities have potentials for trace metal pollution of groundwater. As such, trace metals evaluation of groundwater in Bafoussam is among the most important environmental issues related to contamination from natural and anthropogenic sources. This study investigated the trace metal content of groundwater sources; determined estimates of the health hazard and pollution risk indices; assessed the health hazard and level of risk to trace metal pollution in Bafoussam. Field measurement of physicochemical parameters from 206 Dug-wells and chemical analysis of 10 representative groundwater samples determined their trace metal content using Inductively Coupled Plasma Mass Spectroscopy ICP-MS and R-mode statistical analysis; Hierarchical Cluster Analysis (HCA) and Pearson's correlation analysis (PCA) of the trace metal content with the physico-chemical parameters were carried out. Four pollution hazards were determined: the average daily dose ADD, carcinogenic risks CR, non-carcinogenic risk hazard quotient HQ and hazard index HI. Six pollution risks were determined: the Degree of contamination DC, Enrichment factor EF, Ecological risk factor Er, Ecological risk index RI, Pollution load index PLI, and geo-accumulation index Igeo. The relative abundance of trace metals levels in the sampled groundwater follows the decreasing order: Zn > Ba > Sr > Cu > Mn > Fe > Pb > Cr > Ni > Co > V > Cd > As > Li. HCA distinguishes trace metals into two clusters: cluster one is made up of 2 elements divided into two classes and cluster two is made up of 12 non soluble elements divided into three classes.

The groundwater pollution hazard indices ADD, CR, HQ and HI are less than 1 in the categories of insignificant pollution health hazard and are below the acceptable guideline values. The pollution health risk indices DC, EF, Er, RI, PLI, and Igeo are all below the acceptable guideline values. The enrichment factor EF shows the sources of these metals are geogenic processes. Thus, from the health hazard indices and pollution risk indices, trace metal pollution of groundwater in Bafoussam is within the safe limits for drinking. However, due to an increasing level of environmental pollution that might be imposed by increasing human activity in this region, water sources might become a potential sink of trace metal contaminants; we recommend constant monitoring of groundwater.

Subject Areas

Environmental Sciences, Hydrology

Keywords

Trace-Metal-Evaluation, Pollution, Health-Risks, West-Region-Cameroon

1. Introduction

Bafoussam situates between latitude 5.42N - 5.60N and longitude 10.38E - 10.48E, is the capital, and largest city of the Western Region of Cameroon in the Bamboutous Mountains. Bafoussam has a maximum elevation of about 1450 m a.m.s.l, covering a surface area of about 450 km^2 as in **Figure 1**. Bafoussam is a group of seven villages (Bamendzi, Banengo, Ndiangdam, Ndiangsouoh, Ndiangbou, Toukouop, Ngoueng) and Banengo city, with 46 districts or sub-villages [1]. The main economic activity carried out is agriculture and the inhabitant's plant cash crops such as coffee, cocoa, palm kernel, peanuts, banana and other food crops like tomatoes, beans, corn, Irish potatoes, yam, okra, cassava and cabbage. Poultry farming is also well developed here, with many poultry farmers involved in table birds and egg production.

Trace metals are chemical components found in low concentrations, in mass fractions of ppm or less, in water, organisms and soil [2]. Trace metals are naturally part of the environment and can be found in soils and rocks and also dissolved in rivers, streams and groundwater [3]. Despite the natural occurrence of trace metal in the environment, the main sources of their accumulation in nature are human activities [4]. Trace metals like Fe, Mn, Cu, Zn, Co, and Ni are micronutrient for living system; their deficiency or excess can lead to a number of illnesses in human body [5]. Some trace metals like Cd, Pb and Cr can be lethal to human being even at low concentration because of their tendency to accumulate in the body [6] [7] and have no known physiological activity, but are proven detrimental beyond a certain limit which is very much narrow for some elements like Cd 0.01 mg/l, Pb 0.10 mg/l and Cu 0.050 mg/l [3].

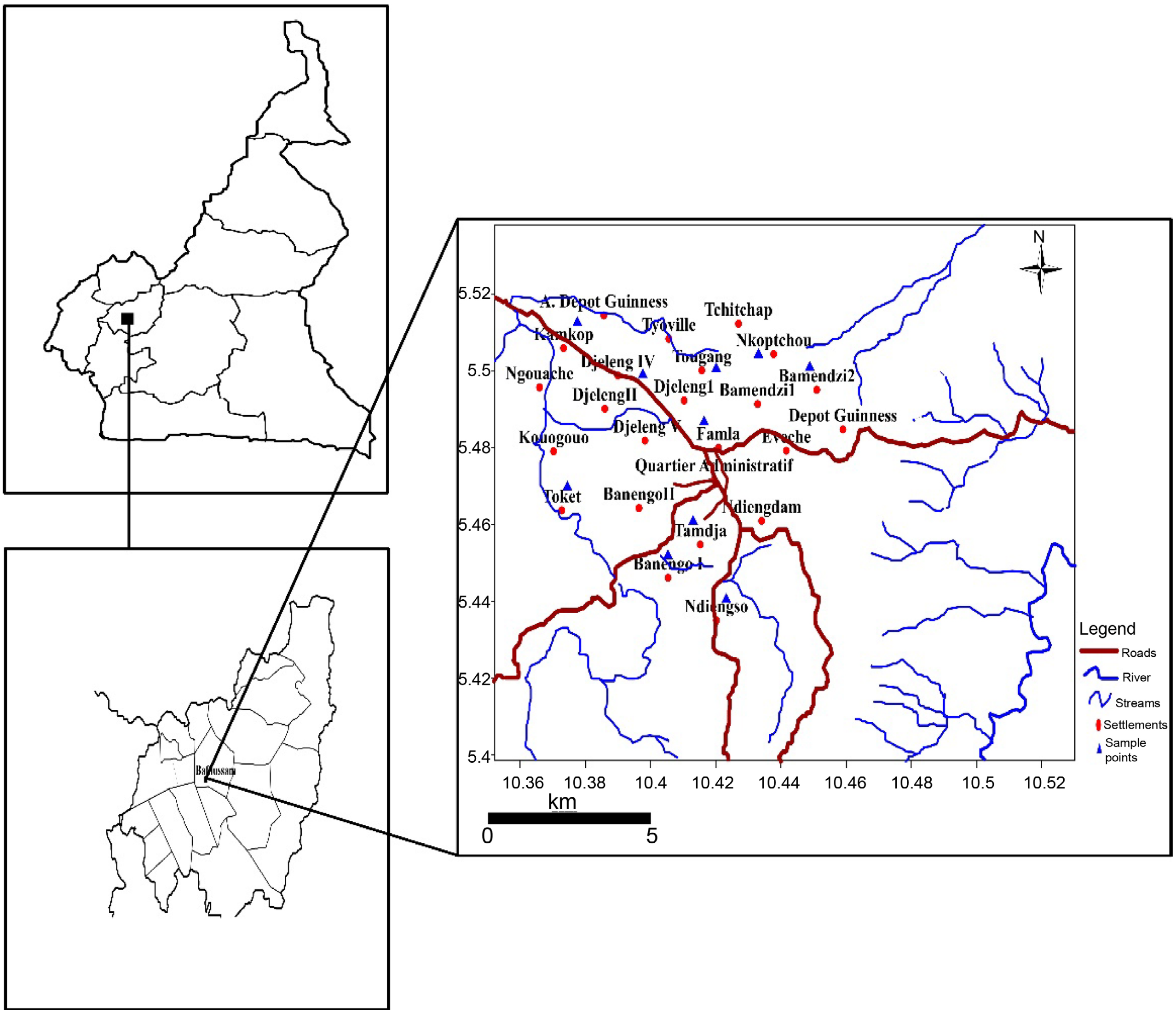

Figure 1. Location of study with sampled and tests sites in Bafoussam.

Trace metals comprising of As, Pb, Sr, Ba, Mn, Co, Ni, Cu, Cd, Fe, Zn, Cr, B, Se, and Al, are categorized according to their place in periodic table and toxic nature as toxic element (Pb, As), alkaline earths (Sr, Ba), transition metals (Mn, Co, Ni), metallic elements (Cu, Cd, Fe, Zn, Cr), and non-metallic elements (B, Se, Al) [8].

Water is the most precious natural resource on earth essential for the existence and survival of life [9] and is generally obtained from surface sources; freshwater lakes, rivers and streams and groundwater; springs and wells. A relatively small fraction (about 2.5%) of earth's water is fresh and suitable for human consumption, with ground water occupying about 13% of this fraction [10] which serve as an important source of drinking water for many people worldwide especially in rural and small communities.

Global water demand has increased by a factor of six over the past 100 years [11] and is currently estimated to increase by about 1% per year, which is as a result of population growth, economic progress, and a change of the main uses of water [12]. For both industrial (20% energy, 70% agriculture) and domestic use (10%), water demand will continue to increase although agricultural water usage will remain the largest [13]. Moreover, demand will increase especially in countries with developing or emerging economies [12].

On the African continent, Cameroon is one of the nations endowed with important, surface and groundwater fresh water resources [14]. Despite its endowment, supply of safe drinking water is uncommon in numerous rural, peri-urban and urban areas of Cameroon. Groundwater appears, therefore, to be the most essential source of water for the population due to ease of access and resistance to climate change variability. As such its vulnerability has been recognized as one of the most important problems in the country [15].

Approximately 70% of the population in Cameroon has access to safe drinking water [14]. On the other hand, the availability of drinking water in rural areas is only about 20% [15]. This implies that rural areas are more vulnerable to diseases related to drinking water. In undeveloped areas, rural water supply programs have enabled the realization of several boreholes to facilitate access to drinking water. Despite the achievement of these water points, the average number of inhabitants in rural areas that does not have access to portable water is still high (approximately 80% [14] [15]. A great portion of the population still uses water from springs, open dug wells and streams, the quality of which is unknown [16]. Moreover, chemical water quality of major ions is rarely determined and trace element content is never considered, even in the case of some rural water infrastructure.

The trace element content of water has now become a major concern in Cameroon and most countries around the world since it has a great potential for a wide variety of diseases and illnesses [1]. There is a vital need to study the quality of groundwater through the determination of groundwater pollution potentials for trace metals in Bafoussam. Trace metals in groundwater are generally dissolved in very minute quantities in most of the cases; its concentration is less than 1 mg/l [17]. Trace elements are distributed in groundwater from a variety of geogenic and anthropogenic sources. Various anthropogenic activities in Bafoussam under the shadow of urbanization and industrial development could result in effluent disposal to the groundwater system with high concentrations of trace metals.

A characteristic feature of most of trace metals is their tendency to form hydrolyzed species in water, and some of them form complex species by combining with inorganic anions such as HCO_3^-, CO_3^{2-}, SO_4^{2-}, Cl^-, F^- and NO_3^- [8]. The sole reason of groundwater contamination is not only the inorganic species, but dissolved organic compounds may also play important roles in it [18].

The present study investigated the trace metal content of groundwater sources, determined the health hazard indices, health hazard, pollution risk indices and level of risk to pollution due to trace elements in Bafoussam.

1.1. Climate

The climate is cool with temperatures oscillating between 15˚C and 22˚C. With climate change in recent years, Bafoussam sometimes reaches 28˚C during the dry season that extends from mid-November to mid-March (four months). The rainy season lasts eight months; mid-March to mid-November. The average amount of precipitation for the year in Bafoussam is about 2000 mm [19].

Based on temperature and rainfall data, the Koppen Climate Classification type is the "A type" (which represents Tropical rainy climates), and particularly the "Aw subtype". This categorizes the climate of Bafoussam as a tropical savannah climate [20].

1.2. Vegetation

The climate and topographic relief of Bafoussam play an important role in determining the type of vegetation found here—mainly forest and savannah grasslands. Most of the primary forest present has been destroyed by the inhabitants for agricultural and pastoral purposes. The savannah grassland is made up of weed and grasses such as *Pennisetum purpureum* and *Impereta venifera*, covering most of the area.

1.3. Soil

The soil is primarily composed of alluvio-colluvium material that resulted from the weathering of volcanic rocks. This large volcanic soil has contributed in making the soils of Bafoussam very fertile. Hence the population of Bafoussam carries out both agricultural and pastoral activities extensively [19]. The soil in Bafoussam exhibits different colors based on the parent material from which they originated. As such, we have soils that range in color from: reddish brown, reddish yellow, light reddish brown, to yellowish red.

1.4. Hydrology

The drainage consists of a dendritic network of several streams as in **Figure 1**, with variable discharge rates depending on the season; flooding occurs during the rainy season and low discharge in the dry season. The main river here is the River Noun, which acts as a boundary with the Kouoptamo municipality [19].

1.5. Geologic Setting of Study Area

Geologically, the Bafoussam area is part of the Cameroon Neoproterozoic Orogenic Belt, located along the southern extension of the Central Cameroon Shear Zone (CCSZ), as well as on the great axis of the Cameroon Volcanic Line (CVL). It is dominated by granitoids which belong to the Pan-African syn- to post-collisional post-650 Ma group [21]. Syenogranites are predominant with alkali-feldspar granite, monzogranite, quartz-monzonite and quartz-monzodiorite. Four granitoid suites, biotite granitoids and deformed biotite granitoids with amphibole, megafeldspar granitoids with megacrysts and two-mica granitoids with primary muscovite and igneous garnet are distinguished. The granites can be assigned to high-K calc-alkalic to shoshonitic series. The partly shoshonitic biotite granitoids are met-aluminous to weakly per-aluminous and can be labeled as a highly fractionated I-type suite. The megafeldspar granitoids are weakly per aluminous with I-type character whereas the two-mica granitoids are weakly to strongly per-aluminous and belong to an S-type suite [21]. As such two distinct rock families are located here: igneous and metamorphic rocks. The CVL is responsible for the vast igneous rock formations found here and the shearing caused by the CCSZ and the displacement of the Cameroon Neoproterozoic Orogenic belt is the main driving force that led to the deformation of the rocks found here [1].

Majority of the study area is covered by tertiary basalts that outcrop in various locations and form structures such as columnar basalts at some outcrops. Columnar basalts are structures formed in basalts that are usually hexagonal in shape and separated by joints and fractures formed when the rock contracted, most often during cooling. These form quarry sites from which rocks are extracted for construction purposes for local construction of houses and stadia.

Granitoid rocks are also abundant in the study area where they occur dominantly on hill slopes or along river cuts in the northwestern parts of the city. Two types are observed in this area: the biotite granitoids and mega feldspar granitoid. Some of these granitoids showed preferred mineral alignment, indicating that they had undergone some deformation after their formation [1] as seen in Figure 2.

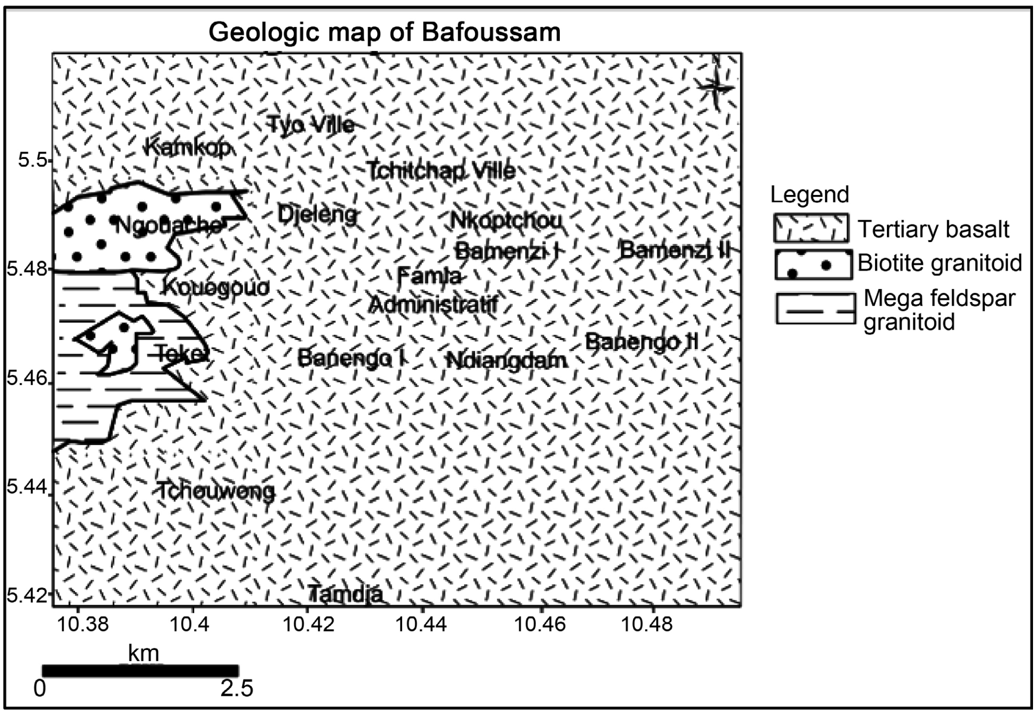

Figure 2. Geology of Bafoussam; composed of tertiary basalts, biotite granitoids and mega feldspar granitoids. The tertiary basalts are columnar with column diameters up to 3.6 meters [1].

2. Materials and Methods

2.1. Sample Collection, Pre-Treatment and Chemical Analysis

Ten samples were collected from pre-selected wells, boreholes and springs. Site selection was based on spatial distribution of the wells, boreholes, springs and population. At each site, groundwater temperature, electrical conductivity, total dissolve solids and pH value were measured *in situ*, using portable field pH, EC and TDS meters as shown in **Table 1**.

Prior to sampling, the pre-cleaned sample bottles were rinsed with the sample water. The well water was withdrawn with the use of a 50 ml syringe, and then filtered through the 0.2 µm mixed cellulose ester filter into 50 ml high-density polyethylene HDPE containers. The sample was preserved by acidifying to pH <2 with nitric acid and sealed using a permanent tape. The filtered groundwater samples were later shipped to the Activation laboratory in Canada for trace metal analysis by Inductive Coupled Plasma Mass Spectrometer ICP-MS.

2.2. Hazard Identification

Hazard identification includes the identification of trace metals of concern; characterization of potential contaminant; their relative mobility and their toxic effects on human beings [22] as shown in **Table 2**.

Table 1. Field equipment, software, their specifications and functions used in the study.

Equipment/Soft wares	Specifications	Functions
Bike	Commercial Bikes	For transport to sites
GPS	GARMIN GPSMAP 60 Csx	For coordinates and elevation of wells
EC Meter	Hanna Hi 98304/Hi98303	To measure Electrical Conductivity
pH Meter	Hanna Hi 98127/Hi98107	To measure pH
Digital Thermometer	Extech 39240	To measure water temperature
Total Dissolved Solid	Hanna HI 96301	To measure Total dissolved solids
Water sampler	Gallenkampf 500 ml	To collect water samples
Syringe	Polystyrene	Acidification and filtration of sample
Nitric acid	98% Pure Nitric Acid	Acidifying to pH < 2
Filter	Cellulose Ester Filter 0.2 µm	Filtration of sample
Sample bottles	Polyethylene (HDPE) 50 ml	To hold sample
Tape/bold marker	Tape and marker	Sealing and labeling of sample bottles
IBM SPSS Statistics	Version 25.0	Statistical analysis for PCA
Global Mapper	Version 11	GIS geolocation of wells
Surfer Golden	Software Version 12	GIS plotting spatial distribution
Aqua	Version 15	To analyze water analysis data
Q GIS	Version 2.1.8	For georefercning and production of map

Table 2. Trace element and their effects [17].

Element	Toxicity effects
Zn	Zinc suppresses copper and iron intake causing peripheral neuropathy.
Co	Active in vitamin B12 and in chemical reactions. Excess causes hearth failures.
Cu	Excess leads to acute gastrointestinal problems.
Cr	Excess may result in renal failures. Excess of Cr+6 is carcinogenic.
Mn	Manganese toxicity result in neurological disorder (manganism) with tremors.
Cd	Cadmium compounds are known human carcinogens.
V	Vanadium causes albumin in urine.
Ni	Nickel is carcinogenic and causes neurological deficits.
As	Arsenic causes cancer of the skin, lungs, liver and bladder.
Sb	Antimony causes gastrointestinal problems, kidney damage or liver damage.
Al.	Aluminum causes neurotoxicity.
Pb	Lead is a carcinogen affecting every organ and system in the body.
Ni	Nickel is carcinogenic and causes neurological deficits.
As	Arsenic causes cancer of the skin, lungs, liver and bladder.
Sb	Antimony causes gastrointestinal problems, kidney damage or liver damage.

2.3. Exposure Assessment

This is the process of estimating the intensity, frequency and duration of human exposures to an environmental agent [23]. The main exposure pathway taken into consideration in this study was intake of the metals through water consumption. The daily environmental exposures to metals were assessed for carcinogenic and non-carcinogenic elements [24].

$$\text{ADD} = \frac{\text{C} \cdot \text{IR} \cdot \text{ED} \cdot \text{EF}}{\text{BW} \cdot \text{AT} \cdot 360} \quad (1)$$

where:

ADDs are Exposure duration (mg/kg-day)—The Average Daily Dose (ADD) of the contaminant through water pathway indicates the quantity of chemical substance ingested per kilogram of body weight per day.

C: Concentration of contaminant in the environmental media (e.g, μg/L, mg/L).

IR: Ingestion rate per unit time (e.g. mg/day or L/day).

EF: Exposure frequency (day/year).

ED: Exposure duration (years).

BW: Body weight of receptor (kg).

AT: Averaging time = life expectancy (years) 365 is the conversion factor from years to days.

For non-carcinogenic effects, AT = ED in days; carcinogenic effect, AT = 70 years or 25,550 days.

2.4. Dose—Response Assessment

This is the quantitative relationship that indicates the contaminants degree of toxicity to exposed species. It also involves the identification of the toxicity criteria used to evaluate human health risk associated with the chemical of concern in the study area. The amount of chemical that can affect human health is estimated. The Reference Dose (RfD) is used for non-carcinogen risk.

2.5. Risk Characterization

This is the final phase of the risk assessment process. In this phase, cumulative exposure and dose-response assessments are integrated to yield probabilities of effects occurring in human beings under specific exposure conditions and time scales. Also incorporated is information from hazard identification, exposure assessment, toxicity assessment and risk estimation to evaluate the potential risk to residents.

2.6. Carcinogenic Risk Assessment

Carcinogenic risks were determined by calculating the potential of an individual to develop cancer as a result of cumulative exposure to each potential carcinogen over a lifetime. Carcinogen was identified by a weight-of-evidence classification of the chemical [25]. The estimated daily dose and the cancer slope factor are multiplied together to find the lifetime cancer risk posed by the chemical. Cancer slope factors are estimates of carcinogenic potency used to relate estimated daily dose of the trace metal over a lifetime exposure to the lifetime probability of excess tumors of Equation (2) [26] [27].

$$\text{CR} = \text{ADD} \cdot \text{SF} \quad (2)$$

where; CR is the excess probability of developing cancer over a lifetime as a result of exposure to a contaminator carcinogenic risk. It is unit less SF is the slope factor of the contaminant $[\text{mg/kg/d}]^{-1}$.

2.7. Non-Carcinogenic Risk Assessment

Non-carcinogenic hazards are characterized by the hazard quotient (HQ). HQ is a unitless number that is expressed as the probability of an individual suffering an adverse effect. To estimate non-carcinogenic risk, the hazard quotient (HQ) was calculated using Equation (3) [5] [28].

$$\text{HQ} = \frac{\text{ADD}}{\text{RfD}} \quad (3)$$

where:

RfD is the reference dose mg/kg/d. It represents a toxicity index of a daily exposure to the population in comparison to a safe level of exposure through oral intake over a lifetime [29].

2.8. Hazard Index

It is the toxic risks due to all the potentially hazardous substances present in the same media simultaneously [30]. Since more than one toxicant is evaluated, the interactions of all the toxicants were considered and assumed to be cumulative. Thus, the HI was calculated by summing all the HQ for all toxicants using Equation (4) [2] [28].

$$\text{HI} = \sum_{i=1}^{n} \text{HQ}_i \tag{4}$$

2.9. Pollution Risk Evaluation Indices

Generally, pollution indices are estimated for a specific use of the water under consideration. The trace metal degree of contamination (DC), Contamination factor (CF), enrichment factor (EF), ecological risk index (Er), potential ecological risk index (RI), pollution load index (PLI) and geo-accumulation index (I_{geo}) were used to evaluate the pollution potential of Bafoussam as in **Table 3**.

3. Results and Discussion

3.1. Chemical Suitability of Groundwater for Drinking

The physicochemical parameters of groundwater in Bafoussam: temperature, pH, EC and TDS were measured *in situ* for 206 wells and springs and summarized in **Table 4**.

3.2. Water Level Fluctuations

The depth-to-static water level ranged from 0.01 - 16.82 m for the wet season, whereas for the dry season was 0.23 - 22.13 m which shows that an increase in temperature affects the aquifer. The static water levels are high and the well depths are shallow which indicates that the dug wells construction is relatively

Table 3. Parameters and formulae of pollution evaluation indices for trace elements.

Trace element pollution indices	Formulae	References
Degree of contamination	$\text{DC} = \sum_{i=1}^{n} C_f^i$	[31]
Enrichment factor	$\text{ER} = \frac{(C_i/C_e)_{\text{sample}}}{(C_i/C_e)_{\text{background}}}$	[32]
Ecological risk factor	$E_r^i = T_r^i \times C_f^i$	[33]
Ecological risk index	$\text{RI}_i = \sum_{i=1}^{n} E_r^i$	[33]
Pollution load index	$\text{PLI} = \sqrt[n]{C_{f1} \times C_{f2} \times \cdots \times C_{fn}}$	[34]
Geo-accumulation index	$I_{\text{geo}} = \log_2\left[C_i/(1.5C_{ri})\right]$	[35]

Table 4. Field determined physicochemical parameters; EC, pH, TDS and temperature of groundwater in Bafoussam.

Parameters	Wet			Dry			WHO (2011)
	Min	Max	Mean	Min	Max	Mean	
T(˚C)	20.7	28.4	23.28	21.5	28.5	24.26	0 - 30
PH	5.01	7.36	6.03	5.03	7.81	6.10	6.5 - 8.5
EC (μs/cm)	01	89	29.38	01	102	30.32	750
TDS (mg/l)	0.67	59.63	19.68	0.67	68.34	20.31	500
SWL	0.01	16.82	5.07	0.23	22.13	7.55	

inexpensive mostly hand which is a reason for the abundance dug wells in Bafoussam.

3.3. Groundwater Flow Direction

The groundwater flows in Bafoussam flows from the outwards from Ndiangdam to low lying areas like Ngouache, Nkoptchou, Tougang and Ancien-Depot-Guinness which is in consonance with the topography.

3.4. Temperature

The temperature values of groundwater in Bafoussam ranged from 20.7 - 28.4 for the wet season and from 21.5 - 28.5 in the dry season. The temperature variation is similar in the different areas, suggesting a single aquifer since groundwater in the same aquifer have similar temperature. This is also indicative of a phreatic aquifer as the temperatures are close to air temperatures.

3.5. pH

The pH value of most of the groundwater samples in the study area ranged from 5.01 - 7.36 for the wet season and 5.03 - 7.81 in the dry season. The values of pH of a water sample are recognized as an index of classifying groundwater as acidic <5.5, slightly acidic 5.5 - 6.5, neutral 6.5 - 7.5, slightly alkaline 7.5 - 8, moderately alkaline 8 - 9 and alkaline >9. This clearly shows that the groundwater in the study area is acidic to slightly alkaline in the dry season and acidic to neutral in the wet season.

3.6. Electrical Conductivity

The EC of groundwater ranged from 01 - 89 μS/cm during the wet season and 01 - 102 μS/cm during the dry season. These low values indicate fresh groundwater. The low electrical conductivity is due to less solute concentration in the groundwater probably due to short contact time with the rocks.

3.7. Total Dissolved Solids

The total dissolved solids ranged from 0.67 - 59.63 mg/l for the wet season and

0.67 - 68.34 mg/l in the dry season. These TDS values are <500 mg/l thus indicating that the water is fresh.

3.8. Trace Metal Concentration

The results for ten samples of trace metal analysis ICP-MS are presented in Table 5. The concentrations of fourteen significant trace metals were evaluated; Li, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr, Cd, Ba and Pb. All concentrations of these trace metals are below the [36] allowable limits.

However, the cumulative effects of long term consumption of these trace metals in the groundwater necessitated a health risk assessment. The trace metal with the highest concentration is Zn with a maximum value of 931.0 μg/L detected at Ndiengso. They occurred in the decreasing order as follows in μg/L: Zn (161.83), Ba (142.65), Sr (108.90), Cu (54.70), Mn (32.68), Fe (26.00), Pb (12.66), Cr (2.83), Ni (2.47), Co (2.26), Li (1.00), V (0.23), Cd (0.17) and As (0.10).

3.9. Pearson's Correlation Analysis PCA between Trace Metals and Physico-Chemical Parameters

Correlation between trace metals in groundwater within the study area was carried out using Pearson's correlation analysis (PCA) as shown in Table 6 to establish the relationships that exist between the variables; trace metals and the physico-chemical parameters.

The correlation analysis establishes the relationships between physicochemical characteristics of water samples, which can reveal the origin of solutes and the process that generated the observed water compositions [37] [38]. r values between 0.5 and 0.6 are considered fairly correlated, 0.6 and 0.8 show strong correlation, 0.8 and 0.99 show very strong correlation. In Table 6 a perfect

Table 5. Trace metal concentration (μg/L) and basic statistics of groundwater in Bafoussam.

S/N	Li	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb
1	<1	0.1	0.7	40.1	40	1.96	12.3	532	931	0.05	6.4	0.67	13.3	56.3
2	<1	0.2	4.4	15.8	40	0.855	1.1	1	23.6	<0.03	15.3	0.09	33.6	27
3	1	0.1	0.7	78.6	30	15.1	2.4	2.4	175	0.37	98.7	0.15	232	1.5
4	<1	0.6	<0.5	0.9	20	0.399	1.1	2.7	44.7	0.07	120	0.12	118	1.38
5	<1	0.2	<0.5	70.1	30	0.754	1.3	1.4	27.9	0.12	134	0.11	212	1.14
6	<1	0.1	5.5	37.7	30	0.569	2.2	1.1	79	0.08	236	0.1	211	34.7
7	<1	0.1	<0.5	15	20	0.399	1	0.9	37.1	0.07	170	0.09	224	0.86
8	<1	<0.1	<0.5	10.7	20	0.575	1	1.5	49.6	0.04	3.17	0.1	15.4	1.28
9	<1	<0.1	<0.5	1.4	10	0.64	0.9	1.2	64.4	0.05	83.4	0.1	41.2	0.98
10	<1	0.4	<0.5	56.5	20	1.37	1.4	2.8	186	0.09	222	0.17	326	1.5
Min	1	0.1	0.7	0.9	10	0.399	0.9	0.9	23.6	0.04	3.17	0.09	13.3	0.86
Max	1	0.6	5.5	78.6	40	15.1	12.3	532	931	0.37	236	0.67	326	56.3
Mean	1	0.23	2.83	32.68	26.00	2.26	2.47	54.70	161.83	0.10	108.90	0.17	142.65	12.66

Table 6. Correlation matrix of r values for trace metals and physicochemical parameters in Bafoussam.

	Li	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb	˚C	pH	EC	TDS
Li	1																	
V	0.47	1																
Cr	−0.14	−0.15	1															
Mn	0.40	−0.11	−0.03	1														
Fe	0.30	−0.15	0.52	0.41	1													
Co	0.64	−0.20	−0.12	0.61	0.20	1												
Ni	0.26	−0.21	−0.05	0.19	0.56	0.08	1											
Cu	0.19	−0.19	−0.11	0.09	0.51	−0.02	0.99	1										
Zn	0.30	−0.17	−0.14	0.22	0.48	0.11	0.99	0.98	1									
As	0.61	−0.11	−0.17	0.71	0.10	0.95	−0.05	−0.16	−0.03	1								
Sr	0.09	0.27	0.16	0.29	−0.31	−0.07	−0.37	−0.42	−0.34	0.16	1							
Cd	0.28	−0.13	−0.16	0.18	0.49	0.05	0.99	0.99	1	−0.08	−0.37	1						
Ba	0.35	0.26	−0.05	0.62	−0.15	0.27	−0.33	−0.40	−0.28	0.48	0.87	−0.31	1					
Pb	0.04	−0.26	0.54	0.03	0.74	−0.13	0.80	0.78	0.74	−0.28	−0.25	0.73	−0.38	1				
Temp	−0.72	−0.60	0.25	−0.08	−0.18	−0.35	−0.25	−0.25	−0.33	−0.22	0.34	−0.33	0.12	−0.03	1			
pH	−0.23	0.11	0.19	−0.59	−0.11	−0.58	0.11	0.15	0.01	−0.52	0.16	0.06	−0.25	0.28	0.38	1		
EC	−0.07	0.21	0.33	0.21	−0.15	−0.28	−0.14	−0.19	−0.14	−0.09	0.92	−0.16	0.69	0.06	0.40	0.30	1	
TDS	−0.07	0.21	0.33	0.21	−0.15	−0.28	−0.14	−0.19	−0.14	−0.09	0.92	−0.16	0.69	0.06	0.40	0.30	1	1

0.5 - 0.6; fair, 0.6 - 0.8: strong, 0.8 - 0.99: very strong, 1.00: perfect and (−) inverse correlation.

correlation exist between Zn and Cd (r = 1.00).

A very strong correlation exist between the following: Ni and Pb (r = 0.80), Co and As (r = 0.95), Ni and Cd (r = 0.99), Ni and Cu (r = 0.99), Cu and Zn (r = 0.98), Cu and Cd (r = 0.99), Sr and Ba (r = 0.87), Sr and EC (r = 0.92), Sr and TDS (r = 0.92) whereas a strong correlation exist between Li and Co (r = 0.64), Li and As (r = 0.62), Li and temp (r = −0.72), V and temp (r = −0.60), Mn and Co (r = 0.61), Mn and As (r = 0.71), Mn and Ba (r = 0.62), Fe and Pb (r = 0.74), Cu and Pb (r = 0.78), Zn and Pb (r = 0.74), Cd and Pb (r = 0.73), Ba and EC (r = 0.69), Ba and TDS (r = 0.69) and a fair correlation can be observed between Cr and Fe (r = 0.52), Fe and Ni (r = 0.56), Fe and Cu (r = 0.51), Cr and Pb (r = 0.54), Mn and pH (r = −0.59), Co and pH (r = −0.58), As and pH (r = −0.52).

3.10. Hierarchical Cluster Analysis HCA

The R-mode Cluster Analysis; hierarchical cluster analysis HCA performed on the groundwater of Bafoussam produced two clusters based on spatial similarities and dissimilarities: cluster one is made up of 2 elements divided into two classes: class one (01) Cu; soluble, class two (01) Zn; enriched. Cluster two is made up of 12 non soluble elements divided into three classes; class one (07) As, Cd, V, Li, Cr, Co, Ni less enriched, class two (03) Fe, Pb, Mn moderately enriched, class three (02) Sr, Ba moderately enriched seen in **Figure 3**.

3.11. Health Risk Assessment

Human health risk assessment is a process used to estimate the health effects that might result from exposure to carcinogenic and non-carcinogenic chemicals [39] [40]. This was done to estimate the intensity, frequency, and duration of human exposures to the trace metals [3] as in **Table 7**. Exposure assessment was carried out by measuring the average daily dose ADD of the selected trace metals from which carcinogenic and non-carcinogenic risk were calculated.

3.12. Average Daily Dose

The trace element for ADD value ranges are; (Li) 1.57×10^{-05} to 3.14×10^{-05}, (V)

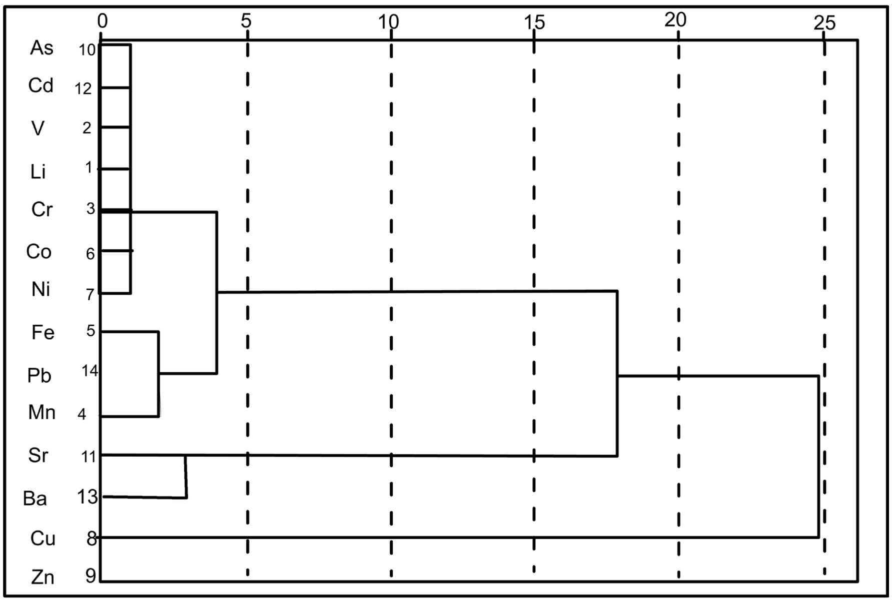

Figure 3. Dendrogram of trace metals in groundwater of Bafoussam made up of two clusters: cluster one is made up of 2 elements divided into two classes. Cluster two is made up of 12 non soluble elements divided into three classes.

Table 7. Parameters used for estimating exposure assessment.

Factor/parameter	Symbol	Units	Residual
Exposure duration	ED	Years	70
Exposure frequency	EF	Days in year	365
Average time	AT	Days	25,550
Body weight	BW	Kg	70
Ingestion rate	IR	L/day	2.2
Contaminant concentration	C	Mg/L	

1.89×10^{-06} to 1.89×10^{-05}, (Cr) 3.14×10^{-06} to 1.73×10^{-04}, (Mn) 2.83×10^{-05} to 2.47×10^{-03} (Fe) 3.14×10^{-04} to 1.26×10^{-03}, (Co) 1.25×10^{-05} to 4.75×10^{-04}, (Ni) 2.83×10^{-05} to 3.87×10^{-04}, (Cu) 2.83×10^{-05} to 1.67×10^{-02}, (Zn) 7.42×10^{-04} to 2.93×10^{-02}, (As) 6.29×10^{-07} to 1.16×10^{-05}, (Sr) 9.96×10^{-05} to 7.42×10^{-03}, (Cd) 2.83×10^{-06} to 2.11×10^{-05}, (Ba) 4.18×10^{-04} to 1.02×10^{-02}, (Pb) 2.70×10^{-05} to 1.77×10^{-03} and all the values are below toxic levels shown in Figure 4.

3.13. Carcinogenic Risk

The carcinogenic risk for the carcinogenic elements: As, Cr, Cd and Ni are; (As) 1.30×10^{-05} to 2.41×10^{-04}, (Cd) 2.38×10^{-05} to 1.77×10^{-04}, (Cr) 1.76×10^{-04} to 9.68×10^{-03}, (Ni) 3.39×10^{-05} to 4.64×10^{-04} as in Figure 5 and all the trace metals are below the permissible limit and will not pose any health issue to inhabitants of the study area if consume over time.

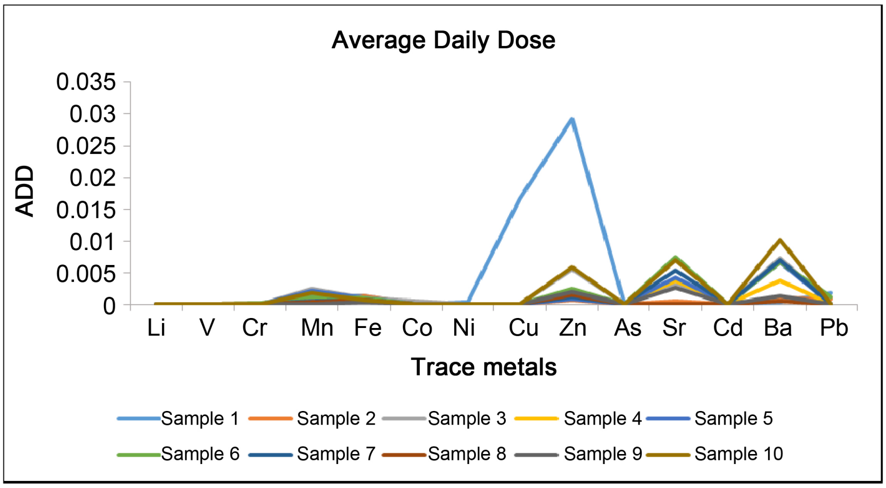

Figure 4. Average Daily Dose (ADD) of trace metals through water intake. All values are below toxic level in Bafoussam.

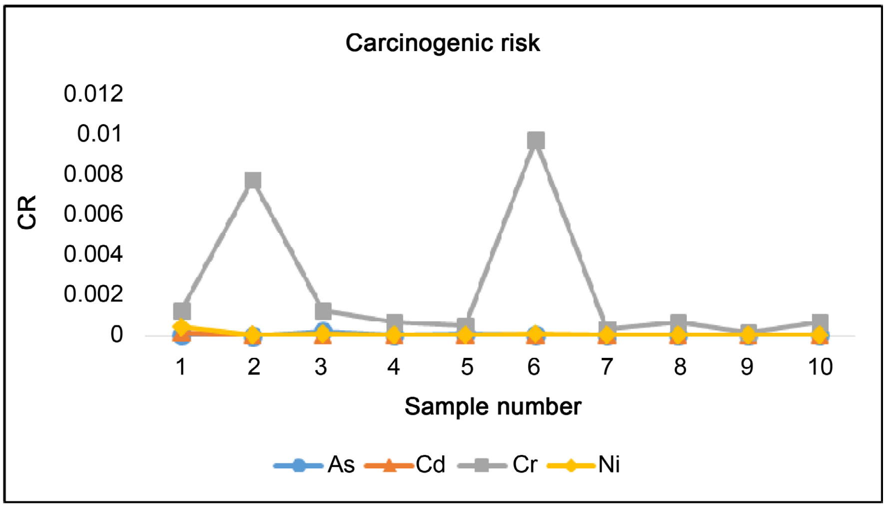

Figure 5. Carcinogenic Risk (CR) of each contaminant. All values are below toxic levels in Bafoussam.

3.14. Hazard Quotient

The elements considered for the calculation of HQ are V, Cu, Pb, Zn, Fe, Mn and their values are as follows; (V) 0.000269 to 0.002694, (Cu) 0.000707 to 0.418000, (Pb) 0.007722 to 0.505551, (Zn) 0.002472 to 0.097533, (Fe) 0.000449 to 0.001796, (Mn) 0.002020 to 0.176449. All these values are <1 hence below permissible limit, seen in Figure 6.

3.15. Hazard Index

The HI is a cumulative sum of the Hazard Quotient. The values ranged between 0.02 and 1.11 for each of the contaminant. Sample 1 has HI values >1 indicating toxicity associated with it as shown in Figure 7 and Table 8.

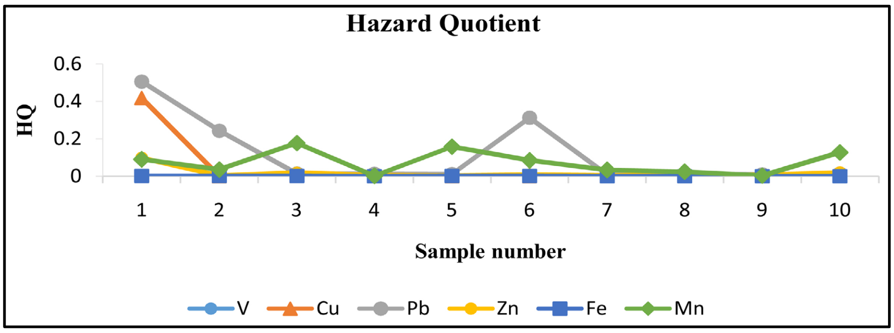

Figure 6. Hazard Quotient (HQ) of trace metals through water intake. All values are below toxic levels in Bafoussam.

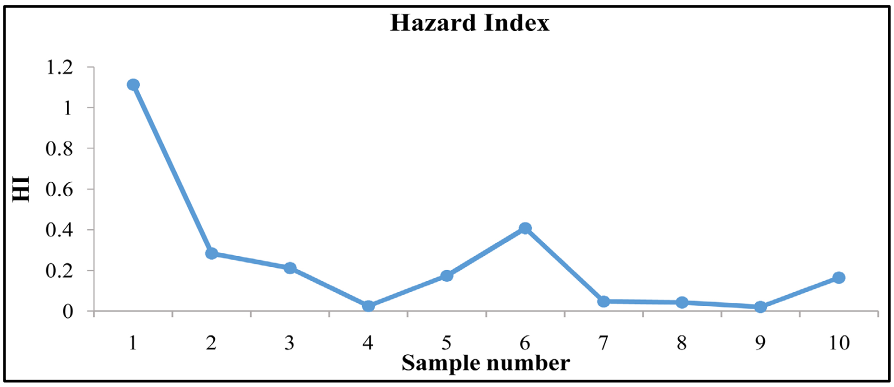

Figure 7. Non carcinogenic toxic risk index or Hazard Index (HI) of trace metals in Bafoussam.

Table 8. Classification of health hazard assessment carcinogenic and non-carcinogenic risk.

Index	Range	Classification	samples	%
CR	$<10^{-6}$	cause no significant health effects	10	100
HQ	<1	Acceptable level (no concern)	10	100
	>1	carcinogenic adverse effects		
HI	<1	Safe	09	90
	>1	Unsafe	01	10

3.16. Pollution Evaluation Indices

3.16.1. Degree of Contamination (DC)

The degree of contamination (DC) is used as reference of estimating the extent of metal pollution. The DC values in the groundwater ranged from 0.52 to 7.44 as shown in **Figure 8**. 100% of the water samples have low degree of contamination according to the classification of Edet and Offiong (2002).

3.16.2. Enrichment Factor

The sequence of EF in the water samples was Fe, Cu > Sr, Mn > Li, V > Ba, Ni > Cr > Pb, As, Co > Cd as Zinc was chosen as a stationary reference element to perform this calculation because of its high concentration. The enrichment factor of trace metals in the water samples ranges from 0.002 - 1.236 which indicates that the source of these metals is entirely from natural processes. Fe and Cu are the most enriched elements in the study area seen in **Figure 9**.

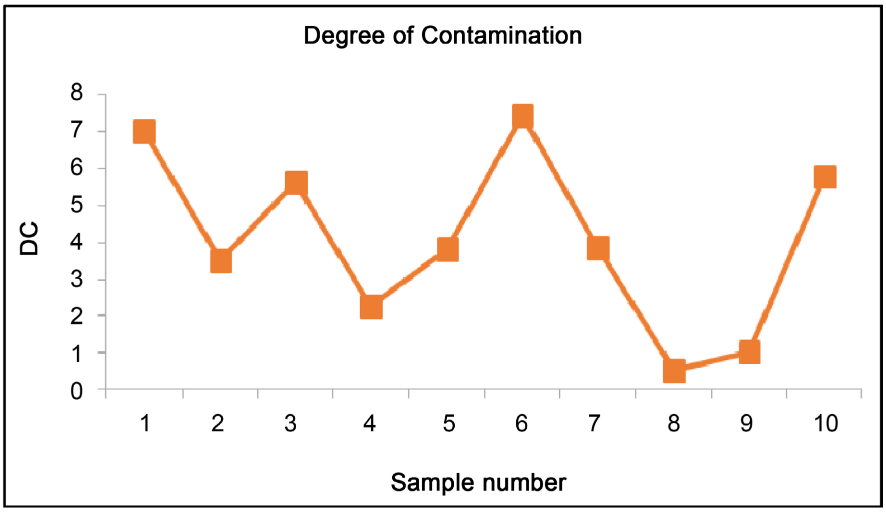

Figure 8. The degree of contamination for trace metals of groundwater in Bafoussam.

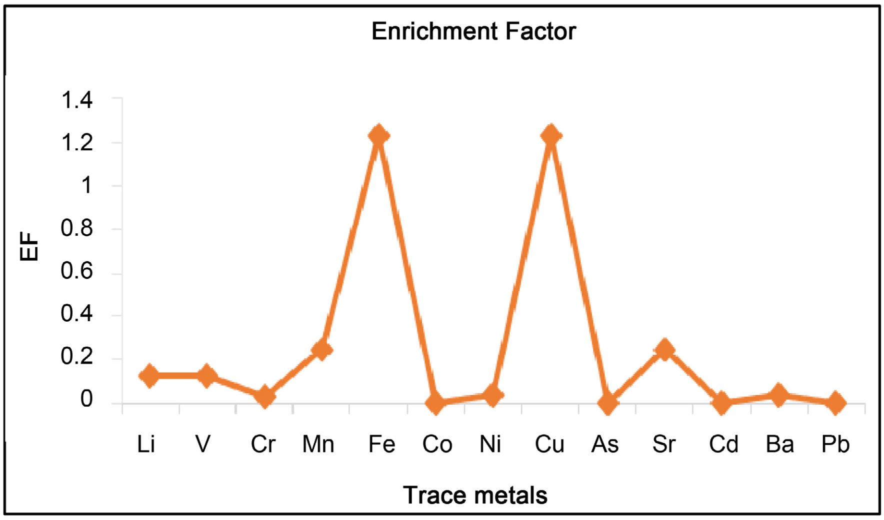

Figure 9. The enrichment factor for trace metals of groundwater in Bafoussam.

3.17. Ecological Risk Assessment

3.17.1. Ecological Risk Factor (Er) and Ecological Risk Index (RI)

Er and RI of the heavy metals in the investigated area are given in Table 10, Figure 10 and Figure 11. All the analyzed trace metals showed low ecological risk factor (Er < 40). RI of the studied trace metals ranges from 1.69 - 38.30. According to Hakanson, 1980 all the samples show low ecological risk index; this indicates low pollution.

3.17.2. Pollution Load Index (PLI)

The Pollution Load Index values for all the analyzed trace metals range from 0.01 - 0.05 which are <1 and is indicative that there is no pollution as shown in Figure 12. These results are attributed principally to natural sources. This index is a quick tool in order to compare the pollution status of different places [40].

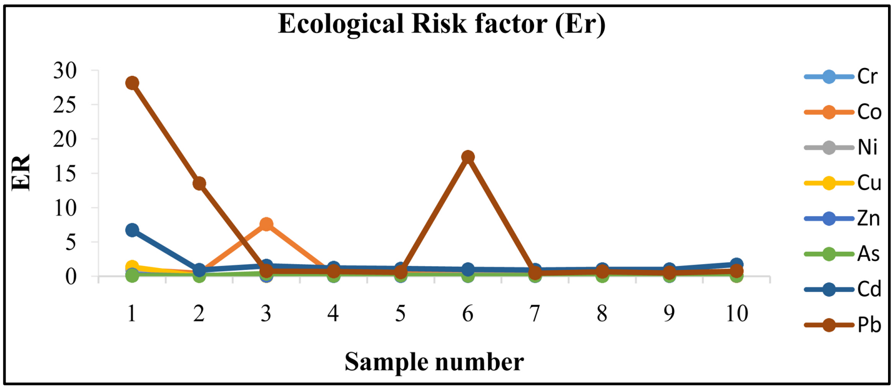

Figure 10. The ecological risk factor (Er) for trace metals of groundwater in Bafoussam.

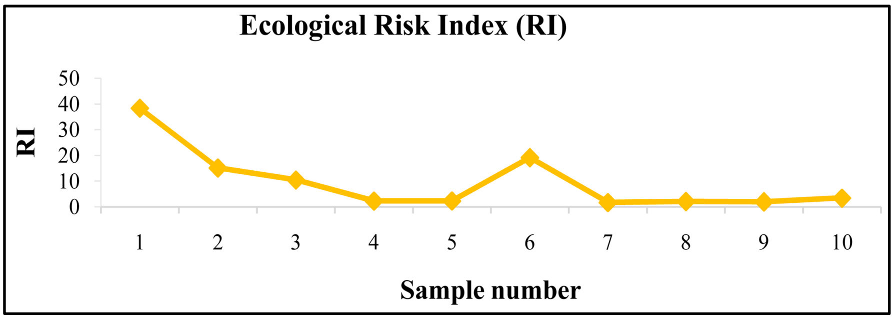

Figure 11. The ecological index (RI) for trace metals of groundwater in Bafoussam.

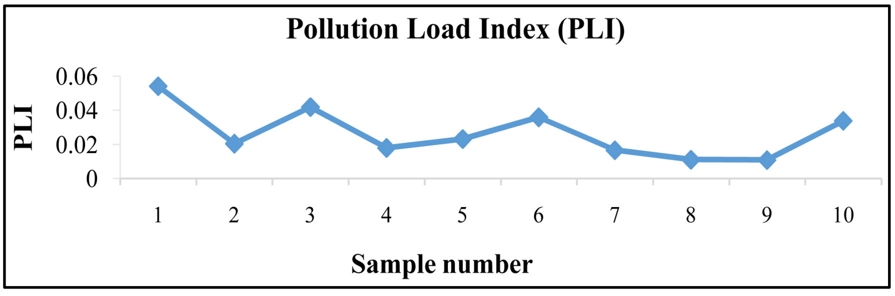

Figure 12. The pollution load index for trace metals of groundwater in Bafoussam.

3.17.3. Geo-Accumulation Index Igeo

Geo-accumulation index Igeo is a quantitative measure of the degree of pollution in groundwater and the values range as shown in Table. Groundwater is unpolluted to moderately polluted by Pb in samples 1, 2 & 6 and also by Ba in samples 3, 4, 5, 6 & 7. The other twelve trace metals are not polluting the groundwater in Bafoussam (Table 9). The results of pollution evaluation indices are presented in Table 10.

Table 9. The Geo-accumulation Index (Igeo) of Bafoussam groundwater.

S/N	Li	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb
1	−8.55	−11.55	−6.74	−3.90	−6.23	−2.94	−3.09	−2.50	−3.01	−8.23	−6.55	−2.75	−2.98	1.91
2	−8.74	−10.55	−4.09	−5.25	−6.23	−4.13	−6.58	−11.55	−8.31	−9.55	−5.29	−5.64	−1.64	0.85
3	−8.23	−11.55	−6.74	−2.93	−6.64	0.01	−5.45	−10.29	−5.42	−5.34	−2.60	−4.91	1.14	−3.32
4	−8.38	−8.97	−7.55	−9.38	−7.23	−5.23	−6.58	−10.12	−7.39	−7.74	−2.32	−5.23	0.17	−3.44
5	−8.97	−10.55	−7.97	−3.10	−6.64	−4.31	−6.34	−11.07	−8.07	−6.97	−2.16	−5.35	1.01	−3.72
6	−8.97	−11.55	−3.77	−3.99	−6.64	−4.72	−5.58	−11.41	−6.57	−7.55	−1.35	−5.49	1.01	1.21
7	−8.74	−11.55	−8.55	−5.32	−7.23	−5.23	−6.71	−11.70	−7.66	−7.74	−1.82	−5.64	1.09	−4.12
8	−9.23	−11.87	−7.55	−5.81	−7.23	−4.71	−6.71	−10.97	−7.24	−8.55	−7.56	−5.49	−2.77	−3.55
9	−9.23	−12.29	−9.55	−8.74	−8.23	−4.55	−6.87	−11.29	−6.86	−8.23	−2.85	−5.49	−1.35	−3.94
10	−8.55	−9.55	−7.55	−3.41	−7.23	−3.45	−6.23	−10.07	−5.33	−7.38	−1.43	−4.73	1.63	−3.32
Max	−8.23	−8.97	−3.77	−2.93	−6.23	0.01	−3.09	−2.50	−3.01	−5.34	−1.35	−2.75	1.63	1.91
Mean	−8.76	−11.00	−7.01	−5.18	−6.95	−3.93	−6.01	−10.10	−6.59	−7.73	−3.39	−5.07	−0.27	−2.14
Min	−9.23	−12.29	−9.55	−9.38	−8.23	−5.23	−6.87	−11.70	−8.31	−9.55	−7.56	−5.64	−2.98	−4.12

Table 10. Summary classification of Bafoussam groundwater pollution evaluation indices.

Index	Range	Classification	Samples	%
DC	<10	Low degree of contamination factor	10	100
EF	≤1	Background contamination	8	80
	1 - 2	Minimal enrichment	2	20
Er	Er < 40	Low potential risk	10	100
RI	RI < 150	Low ecological risk	10	100
PLI	<1	No pollution	10	100
Igeo	≤0	Unpolluted	Li, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr, Cd	
	0 - 1	Unpolluted to moderately polluted	Ba, Pb	

4. Conclusions

There is no trace metal pollution hazard or pollution risk in Bafoussam since trace metal concentrations are below WHO permissible limits.

The relative abundance of trace metals in the groundwater of Bafoussam is as follow: Zn > Ba > Sr > Cu > Mn > Fe > Pb > Cr > Ni > Co > V > Cd > As > Li. The mean values of almost all trace elements in the groundwater were within threshold limits allowable for drinking water except that of Lead (Pb) which was slightly higher than the threshold limits.

The degree of contamination and contamination factors such as the ER, EF, PLI and Igeo had low values of trace metals indicating that, the groundwater is unpolluted with Iron and Copper being the most enriched metals. Thus, from health risk indices and pollution evaluation indices of trace metals, the groundwater in Bafoussam is safe for drinking.

The enrichment factors show that the sources of the trace metals are entirely from geogenic processes.

Also, several factors, such as dose, nutrition, age, and even life style govern the severity of metal toxicity. Therefore, these low trends might not guarantee the complete absence of human health risks. Generally, risk assessment on trace metals using risk indices in the analyzed groundwater samples might not cause any health risk.

However, due to an increase in human activity, the level of environmental pollution might increase in this area as industries discharge their effluents and agro farms apply fertilizers. With time groundwater sources might become a potential sink for trace element contamination. There is a need for constant monitoring of groundwater sources for drinking purposes.

Acknowledgements

The authors acknowledge the reviewers of the manuscript whose corrections improved the paper immensely.

Availability of Data and Material

All data submitted were generated from this study.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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