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Research Paper

Hydrochemistry of springs in the bambui-sabga volcanic area (north west region, Cameroon volcanic line)

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Abstract

This study was carried out in the Bambui-Sabga volcanic area in Tubah Sub-Division, North West Region, Cameroon. This research was aimed at carrying out a hydrochemical characterization of springs in the area. Chemical analysis were done using a DR 2010 Hach Spectrophotometer. The analysed spring samples were close to neutral (pH 6.9-7.6) with a high electrical conductivity ranging from 1,400 - 11,400 µS/cm and TDS from 750 - 7,960 mg/l. The FS01 spring recorded the highest average temperature of 34oC, yellowish-brown in colour and rusty odour, while the FS02 spring had a salty taste and soapy feel. The FS02 spring recorded the highest Na+ concentration of 128 mg/l. The analyzed springs can be classified into: thermal spring (FS01), salt spring (FS02) and normal (mineral) spring (FS03). The spring waters showed a (Na+K)-Cl (SO4) facies and are stable with Na-montmorillonite and zeolites, with their mineralisation from evaporation, salt water intrusion and leaching. Physical parameter were enriched in the dry season except for pH, and deficient in cations and anions except NO3- in FS02. In the rainy season, chemical enrichment was higher. The spring waters were not suitable for drinking and should be treated before human consumption.

Keywords: *Bambui-Sabga; Groundwater; Hydrochemical; Chemical Analysis; Spring.*

1. Introduction

Numerous thermal, salt and mineral springs are located in active volcanic regions all over the world, as a result of eruptive events, as well as obvious manifestations of long-lived hydrothermal systems. These springs are frequently developed as spas, improving social and economic well-being (Cruz & França 2005. Siebe et al. 2007). The Cameroon Volcanic Line (CVL) is characterized by more than 26 thermal springs (in the Adamawa and West Regions), most of which are fed by the magma chamber with temperatures ranging from 26-74°C (Le Maréchal 1974, Kling et al. 1989, Chakam et al. 2005). Several attractive geologic features (volcanoes, crater lakes, rock outcrops and salt, mineral and thermal springs) characterize this area. The quality of groundwater can be greatly affected by natural factors (Fehdi et al. 2009) and anthropogenic activities (Njueya et al. 2012). The aim of this paper is to characterize the springs and rocks in terms of hydrochemistry and petrography in the Bambui-Sabga area.

1.1. Geographic and geologic setting

The Bambui-Sabga area is situated between the Bamenda Volcano (2621m) and Mount Oku (3011m). It lies between longitudes 10°15′ and 10°20′30″E, and latitudes 6°00′ and 6°05′N (Fig. 1). The study area forms part of the Western Highlands of Cameroon and is characterized by numerous interfluves, steep hill slopes culminating in V-shaped and U-shaped valleys, domes, plugs and several craters. The climate of the area is the Equatorial (humid tropical) type characterised by two seasons: a short dry season (November-March) and a long rainy season (March-October). The mean annual temperature is 21.9°C, while its mean annual rainfall is 1670 mm.

The Bambui-Sabga area separates Mt Bamenda from Mount Oku. These mountains constitute parts of the Western Cameroon Highlands along the CVL. The massifs lie on a granitic Pan-African basement (Toteu et al. 2001, Nzolang et al. 2003). Mt Bamenda culminates at 2621m (Bambili Lake borders) and are characterized by two elliptic calderas (Gountié Dedzo et al. 2009) Mt Oku culminates at 3011m (Njilah 2007). According to Kamgang et al. (2007, 2008), felsic and intermediate lavas (27.40–18.98 Ma) of Mt Bamenda are made of mugearites, benmoreites, trachytes, rhyolites. Mafic lavas (basanites, basalts, and hawaiites) are dated from 17.4 Ma to the present; rhyolitic ignimbrite flow deposits are inserted between the granito-gneissic basement at their floor and the lateritized old basalts on top.

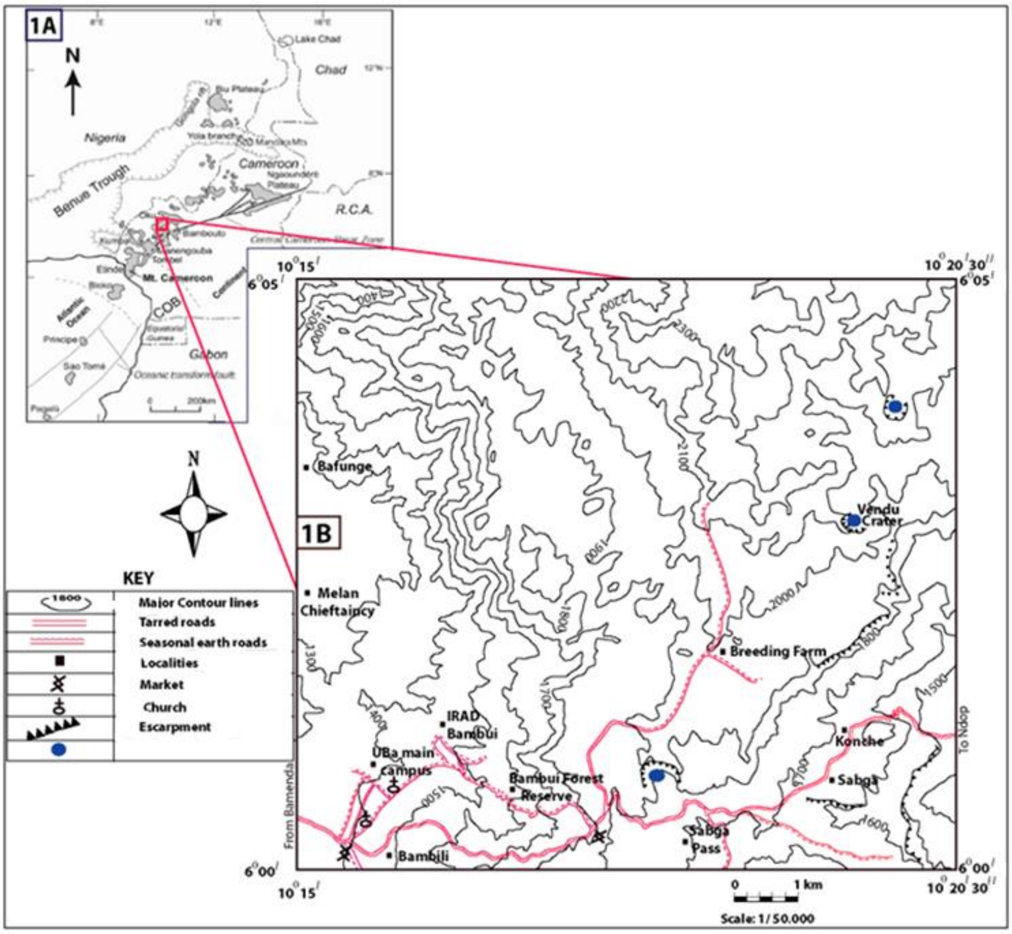

Fig. 1: Location Map of Bambui-Sabga Area.

2. Methodology

2.1. Rock and water sampling

Thirty five fresh rock samples were collected in the field and eight fresh representative samples were selected for thin section preparation. Water was sampled from springs, one on basalt (FS01) and two on ignimbrite (FS02 and FS03). Five water samples were collected from the study area (Fig 3), three during the dry season (18^{th} October 2013) and two during the rainy season (28^{th} February 2014) since one of the springs dried up. At the spring sites, careful observations such as; weather conditions, sampling time, sampling method and coordinates were recorded. Clean sterilized 0.35L polyethylene bottles were used to collect samples and each sample was duplicated; one acidified with 2ml of 1M HCl to preempt any further acidity prior to analysis, which generally dissolves any colloidal material that might be present and minimizes adsorption of cations on the container walls. Each sample bottle was codified and then transported in an ice cool container to the laboratory within 24 hours. The acidified samples were used for the analysis of cations, while the non-acidified samples were used for the analysis of anions.

2.2. Petrographic and Hydrochemical analyses

Thin sections were prepared at the Institute of Geologic Research and Mining (IGRM) Laboratory Yaounde using the protocol proposed by Head (1929). These thin sections were coated with vinyl analyzed using the petrographic light microscope at the Geology Laboratory of the University of Bamenda.

For the spring water samples, physical parameters like colour, odour, taste pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), discharge (Q), and temperature were determined in situ in the field. Taste, odour, colour, and turbidity determined through tasting, smelling and naked eye observation while pH, EC, TDS and temperature were determined using a Hanna pH-EC meter, respectively.

The chemical parameters of the sampled waters were determined at the Wastewater Research Unit of the Faculty of Sciences (WRUFS) of the University of Yaounde I using a DR 2010 Hach Spectrophotometer. Each sample was properly agitated and filtered before analyses using the following laboratory techniques: Tetraphenylborate for Na^+ and K^+; Colorimetry for Ca^{2+} and Mg^{2+}; Phenanthio-line 1.10 method for Fe^{2+}; Heteropolyblue for SiO_2; SulfaVer 4 for SO_4^{2-}; Mercury Thiocyanate for Cl^-; Cadmium Reduction and Direct binary complex for NO_3^- and NH_4^- respectively, and pH titration for CO_2-HCO_3^-.

3. Results and discussion

3.1. Petrography

The Bambui-Sabga area is characterised by effusive, explosive (strombolian) and extrusive dynamisms. The rocks formed in this area include: rhyolite, basalt, ignimbrite, scoria and trachyte, together with salt and carbonate precipitates.

Rhyolite occupies 5% of the area and are aphyric and porphyritic, with macro crystals which are mostly feldspars that measure between 0.1mm x 0.5mm long and averagely 0.3mm wide. The basalts are aphanitic and olivine basalt. Aphanitic basalts occupy 35% of the study area and show few phenocrysts of olivine, clinopyroxenes (Fig. 2a) and plagioclases in a mafic groundmass of oxides, plagioclase, olivines and clinopyroxenes. Porphyritic olivine basalt occupies 10% of the study area with numerous phenocrysts of olivine, pyroxenes, xenoliths of the basement rock and voids of escaped gases in a fine grained groundmass (Fig. 2b). Vesicular basalts occupy about 6% of the total surface area. Their mineralogical composition is very close to that of porphyritic olivine basalt (Fig. 2c). Scoria occupies about 5% of the study area, and is highly vesicular. Some of the voids are occupied by secondary minerals (e.g. calcite and quartz) and xenoliths of peridotite, while some primary minerals like olivines, plagioclases and clinopyroxenes are still visible (Fig 2d). Trachyte occupies about 20% of the study area. The phenocrysts comprise principally, extra-large crystals of sanidine measuring 1-2mm x 4.5-8mm (fig 2e) which are tabular in shape, with some having pointed edges. Pitchstone results from the recrystallization of silica, and occupies about 4% of the study area; it has irregular-curved fracture planes and rounded crystals (fig 2f). Ignimbrite occupies about 10% of the study area and is highly coherent but weathered. They show fragments of pyroxenes, quartz, feldspars, organic matter, micas, olivines and fiammes, embedded in a rhyolitic vitrified groundmass (fig 2g and h).

Granite occupies about 4% of the area and is highly weathered. Carbonate precipitation occurs in two caves at Bambui and at Sabga. Stalactites are well developed compared to stalagmites. The evaporites on the other hand occur as whitish precipitates on rocks in the Down-Sabga area, especially in the dry season. The geologic map of the area indicating all the sampling points are shown in Fig. 3.

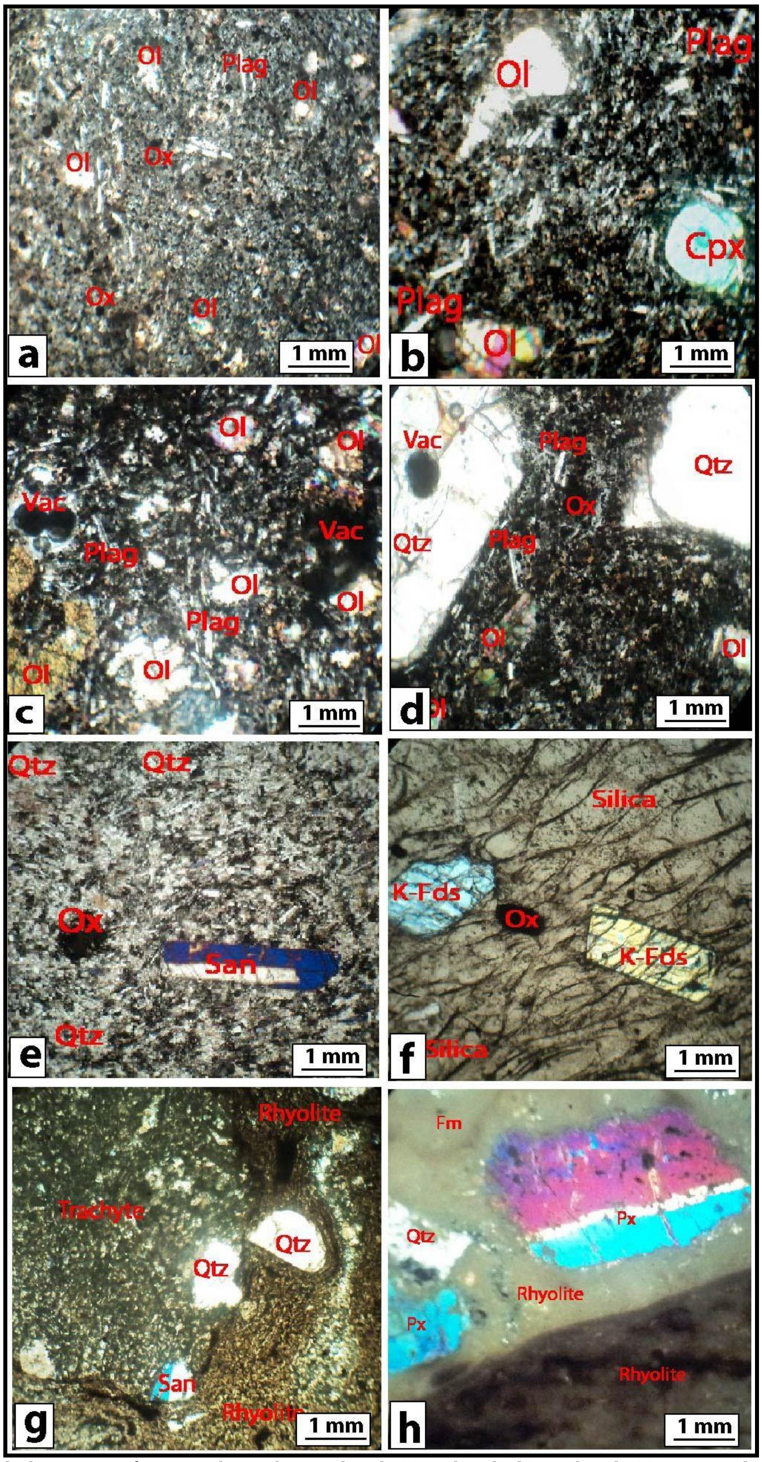

Fig. 2: Microphotography of rock thin section from Bambui-Sabga: A-basalt (a); P-basalt (b); V. basalt (c); Scoria (d); Trachyte (e); Pitchstone (f); Ignimbrite (g &h).NB: Ol = Olivine; Plag = Plagioclase; Ox = Oxide; Cpx = Clinopyroxene; Px = Pyroxene; San = Sanidine, Bt = Biotite; Vac = Vacuole; Ryo = Rhyolite; Fm = Fiammes; Qtz = Quartz.

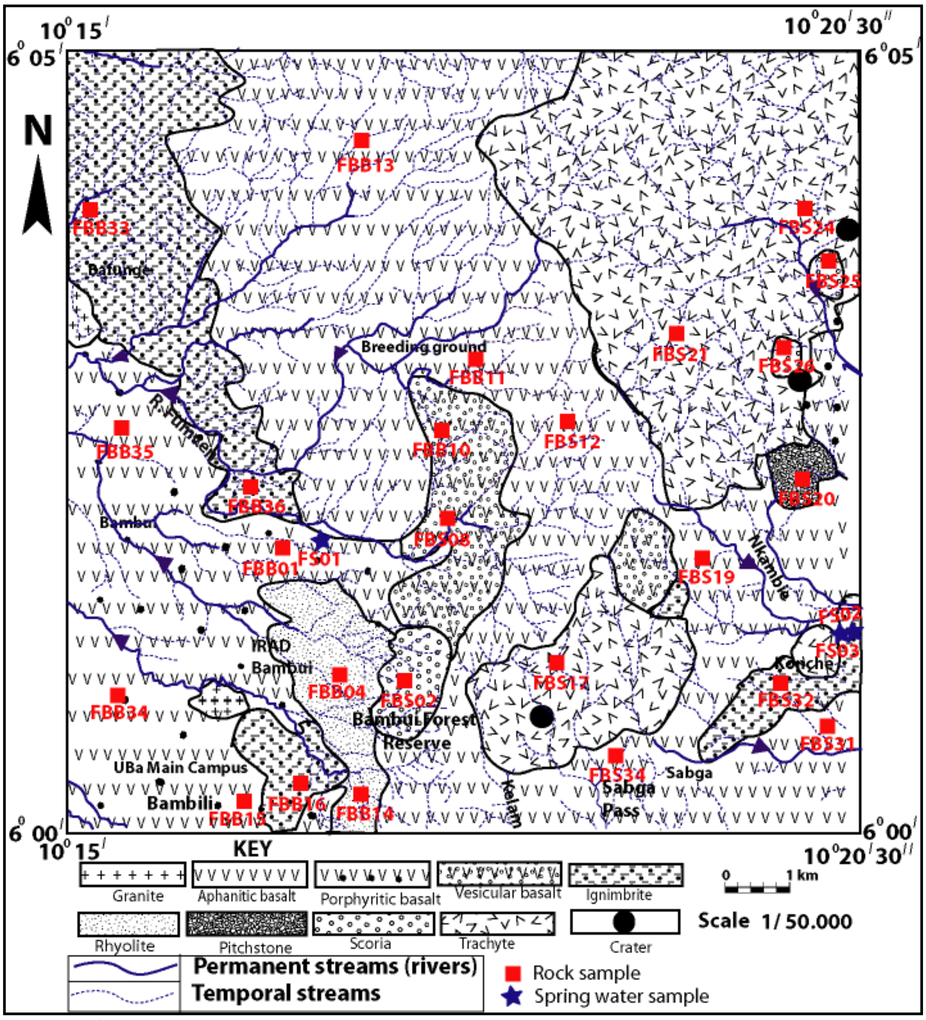

Fig. 3: Geologic / Sample Map of the Bambui-Sagba Area (Fosap, 2013).NB: FS01, FSO2 and FSO3=Spring Water Samples 1, 2 1 and 3; FBB34=P. (Olivine) Basalt; FBS08=V. Basalt; FBS31=A. Basalt; FBS21=Trachyte; FBS02=Scoria; FBS20= Pitchstone; FBS32=Ignimbrite 1; FBB33=Ignimbrite 2; FBS34=A. Basalt; FBB35 =P. Basalt; FBB36=Ignimbrite; FBS17=Trachyte; FBS19=A. Basalt; FBB10=V. Basalt; FB; FBB15=P. Basalt; FBS25 & 26=Scorias; FBB11 & 13=A. Basalts.

3.2. Physico-chemical characteristics of springs

The physical and chemical parameters of the studied springs in the Bambui-Sabga are presented in table 1.

3.2.1. Physical parameters

Spring FS01 in Bambui had a reddish brown colour and a rusty smell. Sample FS02 spring in Sabga was clear, tasted salty and was soapy to feel (Table 1). Both springs remained rusty and salty, respectively, in both seasons due to Fe^{3+} precipitation in FS01 and saline water intrusion in FS02.

The mean annual pH of the springs ranged from 6.91-7.52, and falls within the WHO standard of 6.5-8.5 for drinkable water. The pH of all the springs reduced from the rainy season to the dry season.

The average temperature of the springs ranged from 19.2 to 34.0°C, the hottest (34.0°C) being FS01. The FS02 spring showed a rise in temperature of +3.2°C, following the evolution of the atmospheric temperature during the dry season. However, the FS01 spring showed a temperature drop of -1.3°C from rainy to dry season.

The average electrical conductivity of the springs ranged from 1,428-11,330 µS/cm, while TDS ranged from 753-6,875 mg/l. Spring FS02 had the highest EC and TDS concentrations, while FS01 had the lowest. Generally, the EC and TDS increased from rainy to dry seasons.

3.2.2. Chemical parameters

Alkali earth metals (Na^+ and K^+): The Na^+ concentrations ranged from 33-128 mg/l. Samples FS01 and FS02 showed a deficit in Na^+ from the rainy season to the dry season. The highest K^+ concentration ranged from 0.00 to 2.4mg/l. K^+ showed an increase of +4.8 mg/l in the FS01 spring from the rainy to dry season. However, Na^+ and K^+ concentrations are within the WHO (2004) allowable limits of 200mg/l and 20mg/l respectively.

Alkaline metals (Ca^+ and Mg^+): All the springs had a low dissolved Ca^+ content that ranged from 1.88 mg/l in FS02 on ignimbrites to 2.34 mg/l in FS01 on basalt. The Ca^+ contents reduced by -3.72 mg/l in FS01 to -1.64 mg/l in FS02 in the dry season. Mg^{2+} content was also very low in the springs, ranging between 0.00 mg/l in FS03 and 4.3 mg/l in FS02 in the rainy season. However, in the dry season Mg^{2+} increased from 0.0 to 1.22mg/l. The alkaline metal contents of the springs are acceptable according to the WHO standard which is 100mg/l for Ca^{2+} and 50 mg/l for Mg^{2+}. There is a general deficit in alkaline metals in the springs in the dry season

Fe^{2+} is high in all the three water samples, ranging from 0.31mg/l in FS02 on ignimbrites to 0.92 mg/l in FS01 on basalts in the rainy season, which exceeds WHO standard of 0.30 mg/l. However, the Fe^{2+} concentration reduced from the rainy season to the dry season probably because of constant transformation (oxidation) of Fe^{2+} to Fe^{3+} as temperature increases, as shown in the thermal spring (Fig. 4).

Table 1: Physico-Chemical Parameters of the Bambui-Sabga Springs

Parameters		Samples											WHO Standard (2004)
		Rainy season			Dry season			Average			Difference		
		FS01	FS02	FS03	FS01′	FS02′	FS03′	FS01	FS02	FS03	FS01	FS02	
Physical	Colour	Rusty	Clear	Clear	Rusty	Clear	u.d	Rusty	Clear	Clear	Rusty	Clear	Colourless
	Taste	-	Salty	-	-	Salty	u.d	-	salty	-	-	Salty	Tasteless
	Odour	Rusty	-	-	Rusty	-	u.d	Rusty	-	-	Rusty	-	Odourless
	Feel	-	Soapy	-	-	Soapy	u.d	-	Soapy	-	-	Soapy	No feel
	pH	7.36	7.51	7.52	6.46	7.45	u.d	6.91	7.48	7.52	-0.90	-0.06	6.5 – 8.5
	EC (µS/cm)	486	10710	2550	2370	11950	u.d	1428	11330	2550	+1884	+1240	< 1000 µS/cm
	TDS (mg/l)	316	7790	1270	1190	8130	u.d	753	7960	1270	+874	+340	500-1000 mg/l
	Temp. (°C)	34.6	20	19.2	33.3	23.2	u.d	34.0	21.6	19.2	-1.3	+3.2	30 - 40o`C
Chemical	K^+ (mg/l)	0	traces	traces	4.8	0	u.d	2.40	0.00	traces	+4.8	0	20 mg/l
	Na^+ (mg/l)	63	153	33	53	103	u.d	58	128	33	-10	-50	200 mg/l
	Ca^{2+} (mg/l)	4.2	2.7	2	0.48	1.06	u.d	2.34	1.88	2	-3.72	-1.64	100 mg/l
	Mg^{2+} (mg/l)	0	7.2	0	1.22	1.40	u.d	0.61	4.30	0	+1.22	-5.8	50 mg/l
	Fe^{2+} (mg/l)	1.70	0.58	0.32	0.14	0.04	u.d	0.92	0.31	0.32	-1.56	-0.62	0.30 mg/l
	SiO_2 (mg/l)	1.40	0.64	1.46	1.81	0.53	u.d	1.61	0.35	1.46	+0.41	-0.11	-
	NH_4^+ (mg/l)	0.05	0.20	0.2	0.71	0.41	u.d	0.38	0.31	0.2	+0.66	+0.21	1.50 mg/l
	NO_3^- (mg/l)	9.72	8.60	8.97	1.2	11	u.d	5.46	9.80	8.97	-8.52	+2.4	50 mg/l
	CO_2- HCO_3^- (mg/l)	0.00	traces	0.00	0.00	0.20	u.d	-	0.20	-	0.00	-0.20	125-350 mg/l
	SO_4^{2-} (mg/l)	18	7	12	8	0	u.d	13	3.5	12	-10	-7	250 mg/l
	Cl^- (mg/l)	82.12	75.02	99.66	35	75	u.d	47.12	75.01	99.66	-51.12	-0.02	200-600 mg/l

EC=Electrical Conductivity, TDS=Total Dissolved Solids, Temp=Temperature, pH=Hydrogen ion concentration, u.d=undetermined,+= enrichment, -=deficit

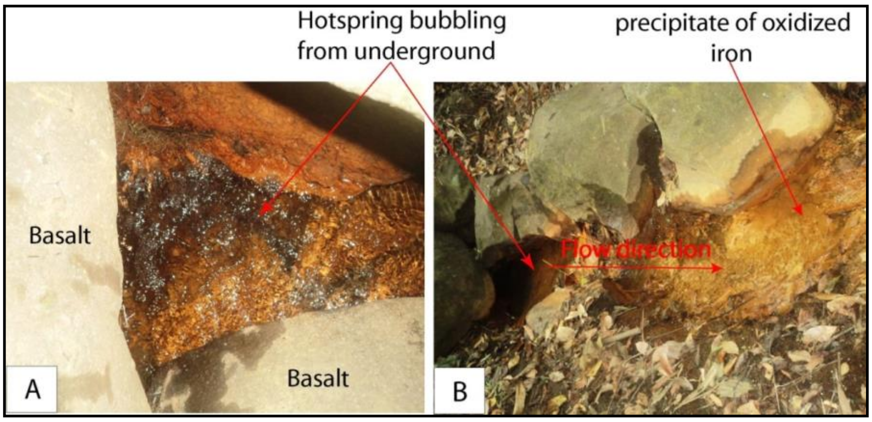

Fig. 4: Thermal Spring in Bambui. A: Thermal Spring Bubbling from Underground; B: Precipitate of Oxidized Iron at Its Outlet.

SiO_2 in the spring waters ranged from 0.35 mg/l in FS02 on ignimbrites to 1.61 mg/l FS01 on basalts. Its concentration reduced from the rainy to dry season

NH^{4+} levels are acceptable in all the samples, averaging 0.38 mg/l in FS01, 0.31 mg/l in FS02 and 0.2 mg/l in FS03. NH^{4+} showed an increase in FS01 and FS02 from the rainy to the dry season.

NO_3^- concentration in the water is significant, although within WHO acceptable limits of 50 mg/l. The highest concentration was recorded in FS02 followed by FS03 (9.8 mg/l and 8.97 mg/l respectively), while the lowest concentration was 5.46 mg/l found in FS01

CO_2-HCO_3- concentration was minimal in the samples, occurring only as traces (0.2 mg/l) in FS02.

SO_4^{2-} concentration was also acceptable for WHO drinking water standards (400 mg/l), with average concentrations being 13 mg/l in FS01, 12 mg/l in FS03 and 3.5 mg/l in FS02. The SO_4^{2-} concentration reduced from the rainy to the dry season indicating a deficit.

Cl^- concentration is high in all the three samples, though within WHO acceptable limits of 200-600mg/l. The highest concentration (99.66 mg/l) was recorded in FS03, followed by FS02 (75.01) and lastly by FS01 (58.56 mg/l). In the dry season chloride showed a drop of -51.12 mg/l and -0.02 mg/l for samples FS01 and FS02, respectively.

Overall, there is enrichment in the physical parameters except for pH, a deficit in cations and anions except NO_3^- in FS02 in the dry season (Fig. 5).

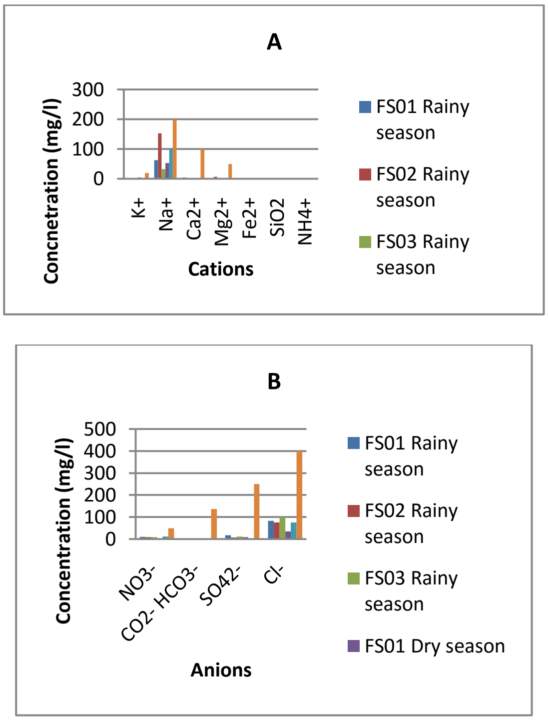

Fig. 5: General Evolution of Chemical Parameters from Rainy to Dry Season of springs in the Bambui-Sabga Area. A: Cations; B: Anions

3.3. Origin of TDS in Solution and nature of secondary minerals

To determine the mechanism controlling the spring water chemistry in the Bambui-Sabga area, the average of (Na+K) / (Na + Ca) was plotted against TDS for both seasons (Fig 6). The three studied springs waters plotted in the Gibbs diagram indicated that the spring got their dissolved solids from the evaporation of evaporites or salty water.

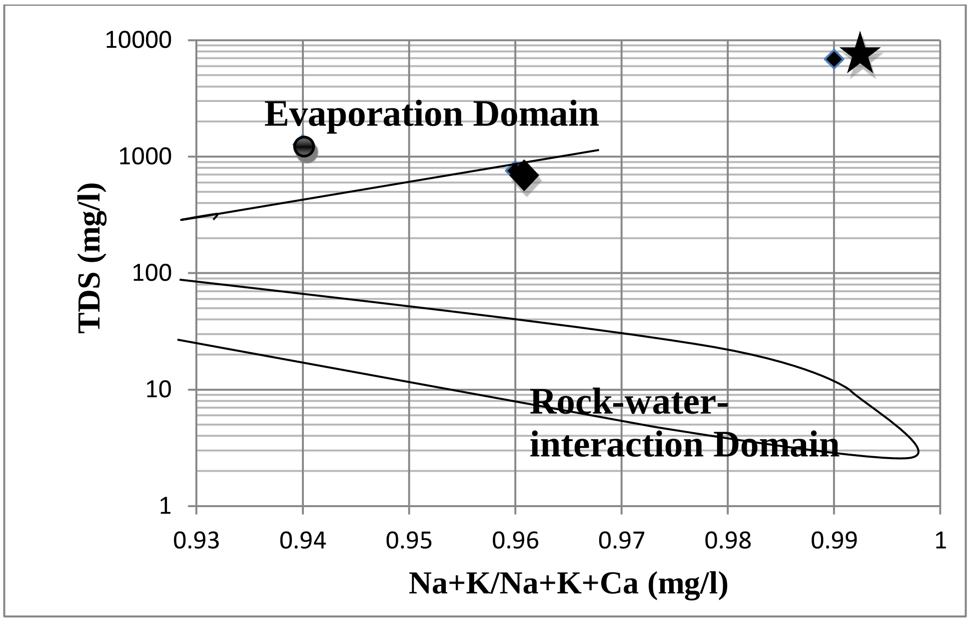

Fig. 6: Variation of the Weight Ratio (Na+ K)/ (Na+K+Ca) as a Function of TDS of springs (Gibbs 1970).

The activity diagram of alkaline earth metals and that of Bluth and Kump (1994) were used to determine the nature of secondary minerals (Fig. 7). The logarithm concentrations of pH, Ca, Mg and Na were simplified using the following equations (Fosap 2012).

Log $[Ca^{2+}/ (H^{+})^{2}] = \log [Ca^{2+}] - \log [H^{+}]^{2} = \log [Ca^{2+}] - 2[H^{+}]$

Since $-\log [H^{+}] = pH$,

Log $[Ca^{2+}/ (H^{+})^{2}] = \log [Ca^{2+}] + 2 (pH)$

Log $[Mg^{2+}/H^{+}]^{2} = 2(\log [Mg^{2+}] + (pH)$

Log $[Na^{+}/ (H^{+})] = \log [Na^{+}] + pH$

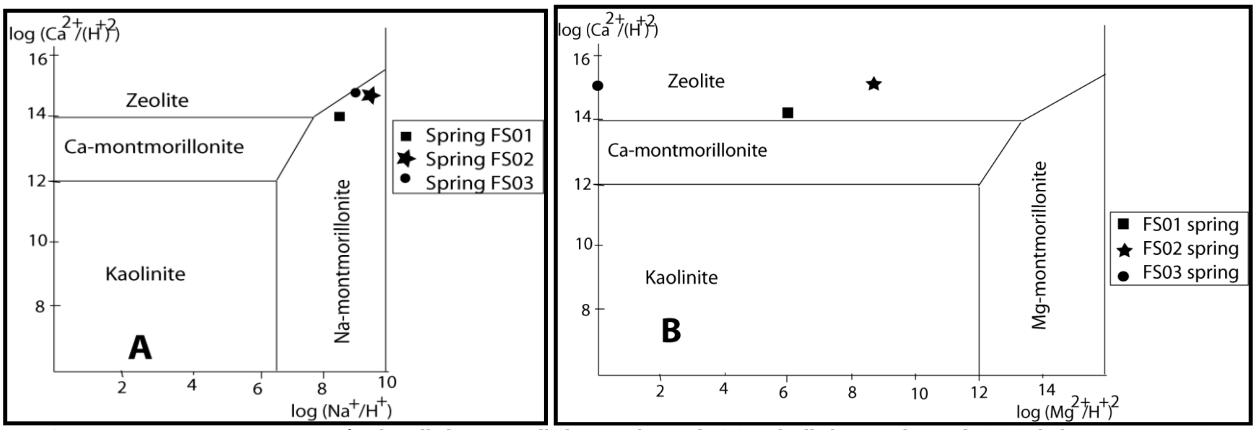

Fig. 7: Activity-Activity Diagrams for the Alkali versus Alkaline Earth Metals (A) and Alkaline Earth Metals (B) (Bluth & Kump, 1994).

The activity diagram for the alkaline earth metals versus alkali metals (Fig 7A) showed that all the spring water samples occur at equilibrium with Na-montmorillonite while the alkaline earth metal activity diagram (Fig 7B) on its part clearly shows that the springs occur at equilibrium with the zeolite.

3.4. Hydrochemical facies of the springs

The piper diagram provides information on the different chemical facies of the analysed water. From the pipers diagram, the major cations and anions for both the rainy and dry season waters present the [(Na-K) Cl- (SO4)] facies (Fig. 8A and B) indicating that there is no change in the chemical facies with the change in season.

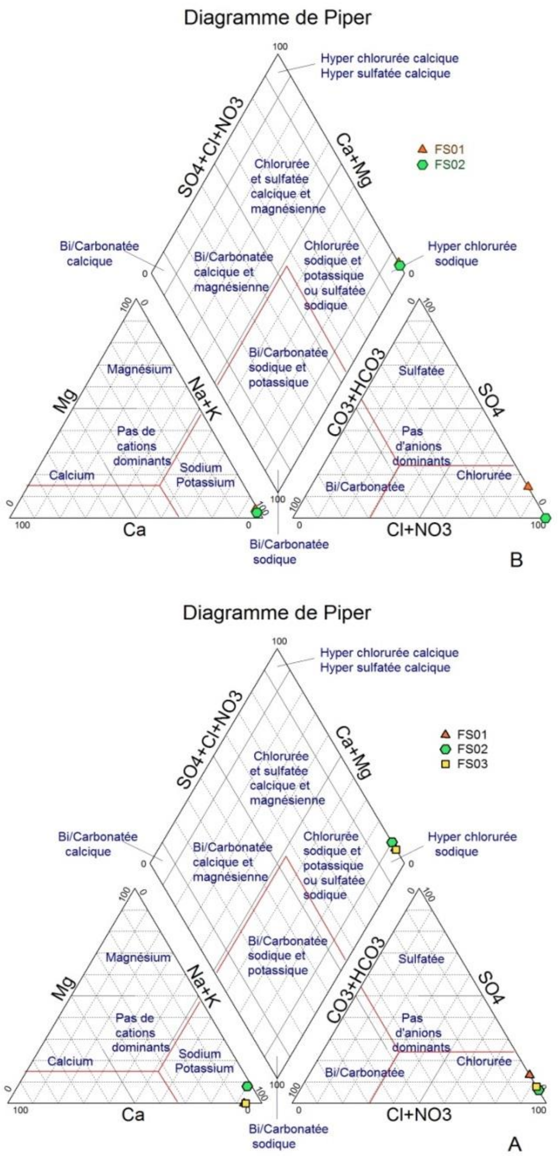

Fig. 8: Piper's Diagram (Piper, 1944), Showing the Water Types in Bambui-Sabga Area. A: Dry Season; B: Rainy Season.

4. Discussion

The mean annual temperature of the FS01 spring is 34°C and considered as a hot spring which may have therapeutic properties (Bunnell et al. 2007). This spring as in other volcanically-active regions, evidences post volcanic manifestations (Chakam et al. 2005). Deep fracturing of the basalts linked the surface and the perched aquifer underground in this area, which is steam heated by a SO_2 and H_2S-rich vapour from a deep-seated magmatic body (Fig 9). Chenyi (2012) also reported similar results about the spring as having a temperature of 33.1°C.

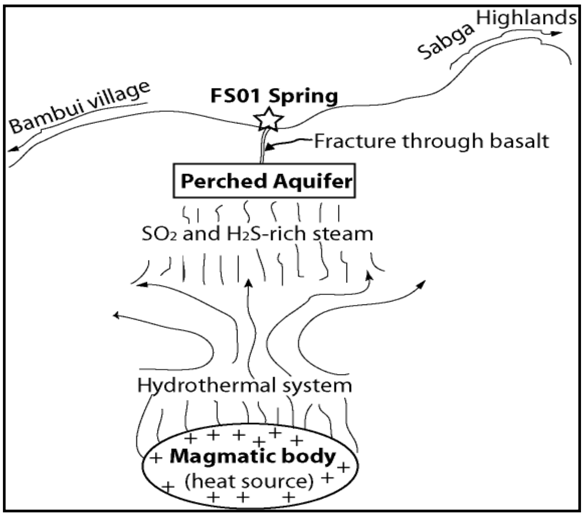

Fig. 9: Conceptual Model for the Na-SO_4 Type Thermal Spring (FS01) Discharging from A Steam-Heated Perched-Water Body.

The spring at Sabga is salty in nature, as revealed by its high sodium content of 128 mg/l. The spring's high EC (11,330 µS/cm) and TDS (7,960 mg/l) are probably due to enrichment from the surrounding topography and atmosphere (Fig 9). Some of the Na^+ and Cl^- in FS02 and FS03 springs may also results from the leaching of secondary salts and salt water intrusion (Fig 10). The high content of sodium in the spring samples may be due to the abundance of Na-bearing minerals in the surrounding rocks. Chenyi (2012) carried out a similar study and discovered similar high concentrations in the dry season. The presence of sodium in drinking water is beneficial for electrolyte balance in the body.

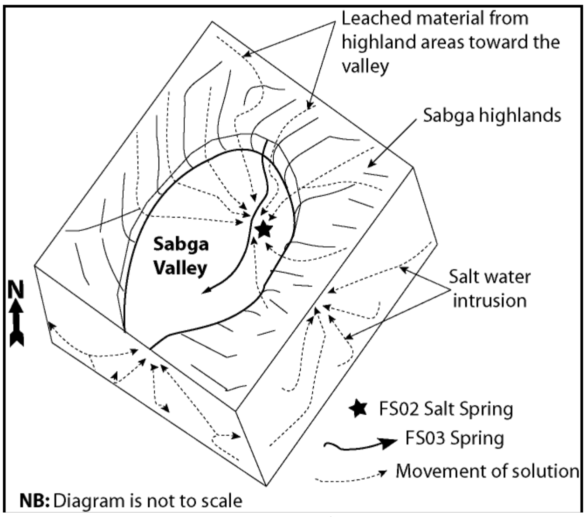

Fig. 10: Conceptual Diagram of the Sabga Salt Spring.

Sample FS01 in Bambui has a reddish brown colour and a rusty smell. The colour and odour of this spring may be due its high iron content that precipitates at the outlet of the spring. Sample FS02 spring in Sabga tastes salty (saline) and soapy to feel.

The pH of the two springs reduces from the rainy season to the dry season probably due to increasing atmospheric temperatures and reduced alkalinity toward the dry season. According to Idoko & Oklo (2010), this reduction in pH is implied because during the wet season, rainfall combines with carbon dioxide and can influence the water toward acidity.

The average temperature of the springs ranges from 19.2 to 34.0°C, the hottest (34.0°C) being FS01. Spring FS02 has the highest EC and TDS concentrations, while FS01 has the lowest probably due to low residence time of the groundwater within the rock. The high concentration in FS02 is obvious because of its altitude and the surrounding topography. Generally, EC and TDS increase from rainy to dry seasons. This increase in conductivity may be due to the concentration of salts dissolved by percolating water during the preceding rainy season. This means that as time goes on, the concentration of dissolved salts is supposed to increase in groundwater. These results are consistent with the findings of Bowell et al. (1996, Efe et al. (2005) and Idoko & Oklo (2010). Chlorine in ground water mostly comes from evaporation and other anthropogenic sources. The high concentrations of NO_3^- in FS02 and FS03 are obviously due to their positions with respect to the surrounding topography.

The sources of dissolved chemical constituents in water were explained using the following equation (the biota part was ignored).

Rock + atmospheric input = weathered rock + solution

The atmospheric input consists of H_2O, CO_2, O_2, and various species dissolved in the water, as well as dry deposition of soluble material from the atmosphere, most of which will dissolve rapidly in rain. Na^+ and K^+ are soluble in water. During the hydrolysis of albite or K-feldspar, gibbsite, kaolinite or smectite (Na-beidellite) through allitisation and monosiallitisation, Na^+, K^+, HCO_3^- and H_4SiO_4 are released into solution, together with some other secondary minerals (Anazawa and Ohmori, 2005). Ca^{2+} and Mg^{2+}, because of their large ionic sizes, remain soluble in water. Ca^{2+} in water could come from the dissolution of calcite, anorthite, smectite (Ca-beidellite), gypsum, pyroxenes, and from NPK fertilizers which usually contain 5% CaO. Mg^{2+} could be derived from the dissolution of olivine (forsterite), serpentine, talc, magnesite, pyroxene, dolomite and Mg-chlorite. Fe^{2+} in groundwater could come from the hydrolysis of iron-rich silicate minerals such as olivines, augite, and magnetite in basalts, trachytes and ignimbrites. NH_4^+ in water could be from the solubility of nitrogenous fertilisers from farmlands and other nitrogenous wastes on land. NO_3^- in water could come from the atmosphere, legumes, plant debris synthetic fertilisers such as Ammonia, ammonium nitrate and other nitrogen compounds, and animal excrement. SO_4^{2-} could result from the dissolution of SO_2 and H_2S from magma, oxidation of sulphide ores, gypsum and anhydrite Karanth (1987). Cl^- could come from the dissolution of feldspathoids; sodalite, apatite, halite or precipitation. However, minerals in which chlorine is an essential component are not very common, and Cl^- is more likely to be present as an impurity.

5. Conclusion

The Bambui-Sabga area is made up of basalt, scoria, trachyte, ignimbrite, pitchstone, rhyolite and granite. From the analysed waters, three different classes of spring were revealed: one thermal spring (FS01), one salt spring (FS02) and one normal (mineral) spring (FS03). These spring waters are considered soft and not acceptable for drinking according to WHO standards. The springs in the area need to be treated before human consumption.

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