

# Nitrate contamination of groundwater in two areas of the Cameroon Volcanic Line (Banana Plain and Mount Cameroon area)

Andrew Ako Ako · Gloria Eneke Takem Eyong · Jun Shimada · Katsuaki Koike · Takahiro Hosono · Kimpei Ichiyangi · Akoachere Richard · Beatrice Ketchemen Tandia · George Elambo Nkeng · Ntankouo Njila Roger

Received: 27 June 2012 / Accepted: 11 October 2013 / Published online: 1 November 2013  
© The Author(s) 2013. This article is published with open access at Springerlink.com

**Abstract** Water containing high concentrations of nitrate is unfit for human consumption and, if discharging to freshwater or marine habitats, can contribute to algal blooms and eutrophication. The level of nitrate contamination in groundwater of two densely populated, agro-industrial areas of the Cameroon Volcanic Line (CVL) (Banana Plain and Mount Cameroon area) was evaluated. A total of 100 samples from boreholes, open wells and springs (67 from the Banana Plain; 33 from springs only, in the Mount Cameroon area) were collected in April 2009 and January 2010 and analyzed for chemical constituents, including nitrates. The average groundwater nitrate concentrations for the studied areas are: 17.28 mg/l for the Banana Plain and 2.90 mg/l for the Mount Cameroon area. Overall, groundwaters are relatively free from excessive nitrate contamination, with nitrate concentrations in only 6 % of groundwater resources in the Banana Plain exceeding the maximum admissible concentration for

drinking water (50 mg/l). Sources of  $\text{NO}_3^-$  in groundwater of this region may be mainly anthropogenic (N-fertilizers, sewerage, animal waste, organic manure, pit latrines, etc.). Multivariate statistical analyses of the hydrochemical data revealed that three factors were responsible for the groundwater chemistry (especially, degree of nitrate contamination): (1) a geogenic factor; (2) nitrate contamination factor; (3) ionic enrichment factor. The impact of anthropogenic activities, especially groundwater nitrate contamination, is more accentuated in the Banana Plain than in the Mount Cameroon area. This study also demonstrates the usefulness of multivariate statistical analysis in groundwater study as a supplementary tool for interpretation of complex hydrochemical data sets.

**Keywords** Nitrate contamination · Groundwater · Banana Plain · Mount Cameroon area · Cameroon Volcanic Line

A. A. Ako (✉) · G. E. T. Eyong  
Hydrological Research Centre Yaoundé, P.O. Box 4110,  
Yaoundé, Cameroon  
e-mail: akoandrewako@yahoo.com; akoandy@gmail.com

J. Shimada · K. Ichiyangi  
Graduate School of Science and Technology, Kumamoto  
University, Kurokami 2-29-1, Kumamoto 860-8555, Japan

K. Koike  
Laboratory of Environmental Geosphere Engineering,  
Department of Urban Management, Graduate School of  
Engineering, Kyoto University, Katsura C1- 2-215,  
Kyoto 615-8560, Japan

T. Hosono  
Priority Organization for Innovation and Excellence, Kumamoto  
University, Kurokami 2-29-1, Kumamoto 860-8555, Japan

A. Richard  
Department of Geology, University of Buea, P.O. Box 63, Buea,  
Cameroon

B. K. Tandia  
Department of Earth Sciences, University of Douala, P.O. Box  
12407, Douala, Cameroon

G. E. Nkeng  
National Advanced School of Public Works Yaoundé, P.O. Box  
510, Yaoundé, Cameroon

N. N. Roger  
Water Resources Management Laboratory, Department of Agric  
Engineering, University of Dschang, P.O. Box 222, Dschang,  
Cameroon

## Introduction

Nitrate contamination in groundwater is a common problem in many part of the world arising from diffuse reasons, e.g., intensive agriculture, unsewered sanitation in densely populated areas or from non-point sources such as irrigation of land by sewage effluents. Nevertheless, the heavy use of nitrogenous fertilizers in cropping system is the largest contributor to anthropogenic nitrogen in groundwater worldwide (Suthar et al. 2009). In particular, shallow aquifers in agricultural fields are highly vulnerable to nitrate contamination, due to the widespread application of fertilizers and manure (Böhlke 2002; Kyoung-Ho et al. 2009).

In many groundwater basins, urbanization has created a growing demand for drinking water, while long histories of agricultural activity have left aquifers potentially at risk from  $\text{NO}_3^-$  (Moore et al. 2006). Some of the major concerns of nitrate contamination/loading to both groundwater and surface water systems include health risks to humans through drinking water (i.e., methemoglobinemia and potential carcinogenic effects) and degradation of the local ecosystems (i.e., excessive plant and algal growth) (Murgulet and Tick 2008).

Extensive research has indicated that agricultural practices may cause nitrate contamination to be high so as to exceed the maximum acceptable level for drinking water (Böhlke 2002). The maximum admissible concentration (MAC) in most countries is within the range of 45–50 mg/l, which is equivalent to 10–11 mg/l nitrate as nitrogen. Also, the World Health Organization (WHO) indicates a guideline value (GV) of 50 mg/l (11 mg/l nitrate as nitrogen) for drinking water (WHO 2004), which has been integrated into Cameroon Water Quality Norms for mineral and drinking waters (ANOR 2001, 2003). Various authors have studied the issue of nitrate contamination of groundwater resources in Cameroon, especially in the north of Cameroon (Njitchoua and Ngounou Ngatcha 1997; Djoret 2000; Ngounou Ngatcha and Djoret 2010), which is the main agro-pastoral zone of Cameroon. Ako et al. (2011) also reported about nitrate contamination of groundwater and surface water resources in the Banana Plain. Endeley et al. (2001) in a study of water sources around Mount Cameroon made up of weathered volcanic and sedimentary rocks like the Banana Plain showed that these waters did contain trace elements and a dominance of  $\text{Na}^+$  and  $\text{K}^+$  as major cations closely associated with nitrates.

Currently, there is a lack of information and understanding of  $\text{NO}_3^-$  input and its effect on the quality of groundwater resources and ecosystem health within these densely populated, agro-industrial areas of the Cameroon Volcanic Line (CVL). Therefore, it is essential to conduct

detailed assessments of the degree of nitrate contamination of their groundwater resources.

The objective of this research was to apply hydro-chemistry and principal component/factor analysis for the identification of factors responsible for nitrate contamination of groundwater in the Banana Plain and Mount Cameroon area, two important areas of the Cameroon Volcanic Line. Research on these areas can contribute to the understanding of nitrate contamination of groundwater in active and dormant volcanic areas under both intense urban development and agro-industrial activities.

## Materials and methods

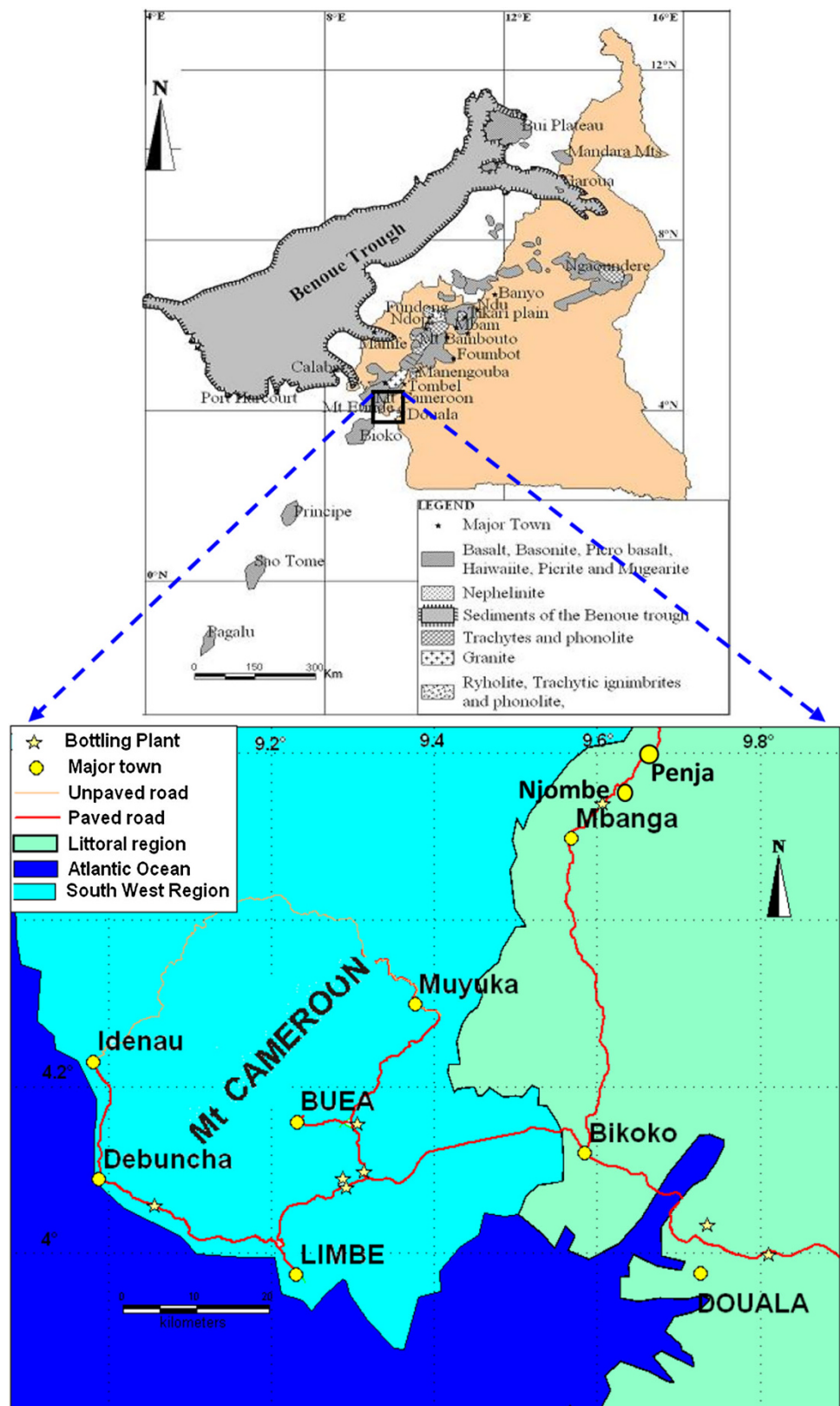
### Study areas

The study areas are located along the Cameroon Volcanic Line, with the Banana Plain located in Mbanga, Njombe-Penja, ( $4^{\circ}30'–4^{\circ}53'N$ ;  $9^{\circ}37'–9^{\circ}50'E$ ) in the Mungo Division, 70 km north of Douala, economic capital of Cameroon. The Mount Cameroon area is located between  $4^{\circ}09'–4^{\circ}13'N$  and  $9^{\circ}16'–9^{\circ}21'E$ . These areas will be referred to as Banana Plain and Mount Cameroon, respectively (Fig. 1).

The development of plantation agriculture and the fertility of the soils in the Banana Plain and the Mount Cameroon area have created dense human settlements. In the Banana Plain, the towns of Mbanga, Njombe and Penja are all flourishing because of plantation agriculture. Mbanga town has a population of about 140,000 and covers a surface area of about 544 km<sup>2</sup> (population density of 257 inhabitants/km<sup>2</sup>), while Njombe and Penja have about 50,800 inhabitants with a surface area of about 260 km<sup>2</sup> (195 inhabitants/km<sup>2</sup>) (Mbanga Rural Council 2008). The populations of these towns have witnessed rapid increases between 1987 and 2006 (the population of Njombe and Penja increased from 33,000 to 50,000 inhabitants). The population in the Mount Cameroon area is estimated at about 450,000 people of whom two-thirds live in urban and semi-urban areas, while the rest live in villages. The population density in the Mount Cameroon area is about 150 inhabitants/km<sup>2</sup>. The settlement pattern forms a closed ring around the foot of the mountain with no permanent settlements on altitudes above 1,500 m. At lower altitudes, extensive plantations of bananas, palms, rubber and the creation of agglomeration have totally replaced the primary forest. Mount Cameroon is unique for having a relatively unbroken sequence of natural vegetation from lowland evergreen forest almost at sea level right up to about 2,000 m then to subalpine prairies near its summit.

Geologically, the CVL is a 1,600 km-long Tertiary–Recent intraplate alkaline volcanic province that trends NE–SW, from the Atlantic Ocean through the Gulf of

**Fig. 1** Location and geology of Banana Plain (Mbanga, Njombe and Penja) and the Mount Cameroon area. Inset shows a map of the CVL modified after Fitton and Dunlop (1985); Déruelle et al. (1987); Marzoli et al. (1999); Oyebog et al. (2012)



Guinea onto African continental lithosphere (Fitton and Dunlop 1985). Recent isotope (K/Ar and Ar/Ar) ages have shown that the Cameroon Line volcanism is essentially Cenozoic (Marzoli et al. 1999; Aka et al. 2004). Geologic settings in the two areas are quite contrasting, with Mount Cameroon being an active volcano made up of younger basaltic rocks (<3 Ma). The Banana Plain is composed of older volcanic rocks (~3 Ma) mixed with sedimentary rocks.

Rapid increase in population in these two areas was not accompanied by the development of basic infrastructure (water supply and sanitation). In the Banana Plain, <10 % of the population is connected to the potable water network of CAMWATER (the national potable water utility) and <5 % have adequate sanitation facilities (GTZ 2006). Only about 35 % of the population in the Mount Cameroon area have access to the potable water network (Folifac et al. 2009). Thus, many people rely on bottled water for safety purposes for infants (for formula preparation, drinking water and reconstitution of food), health reasons and for drinking water. Most of the bottled water plants are located on the volcanics along the CVL (Fig. 1) and they obtain bottled mineral water from springs and boreholes (Oyebog et al. 2012). There are also many springs, boreholes and wells from which the local people fetch drinking water and for other domestic purposes. Groundwater (springs) is also the main source of irrigation water supply in these important agro-industrial zones.

In the Banana Plain, the climate is equatorial type influenced by monsoon winds (July to September) during the rainy season with maximum rainfall in September with about 175–200 rainfall days per year. There are two distinct seasons, a dry season from November to June and rainy season from July to October. Ten-year (1985–1994) metrological data indicate that in Mbanga, the annual average rainfall is 1,626 mm, 3,197 mm in Njombe and 2,769 mm in Penja. Temperatures vary between 19 and 32 °C with an average of 25 °C (National Metrological Service 2008). The climate is humid tropical in the Mount Cameroon area characterized by extreme rainfalls and elevated temperatures all year long. The combination of high relief (4,095 m) and proximity of the sea leads to strong local climatic contrast. Mean annual temperature decreases from 26–29 °C at sea level to 0 °C at the top of the edifice and this large temperature drop is associated with a decrease in rainfall. The highest rainfall is recorded on the southwest flank of Mount Cameroon where rainfall can reach 12 m/year. Lower rainfalls occur on the opposite flank because it is partially sheltered from the oceanic influence (for example, rainfall at Ekona is 1,800 mm/year) (Fraser et al. 1998).

## Methods

### *Sampling and chemical analysis*

A total of 100 samples from boreholes, open wells and springs (67 from the Banana Plain; 33 from springs only, in the Mount Cameroon area) were collected in April 2009 and January 2010. Available water resources in the study areas were randomly sampled with emphasis laid on uniform spatial distribution. Locations and altitudes of selected sample sites were determined on the field using a Garmin GPS. All the samples, collected in tightly capped high-quality polyethylene bottles, were immediately transported under low temperature conditions in ice box and stored at 4 °C until analysis. Water from most of the springs sampled was pumped to the surface using a peristaltic pump equipped with a tubing. The end of the tubing was placed as near as possible to the spring vent. Some spring samples were collected without the use of the pump when sampling containers could easily be placed directly in the spring outflow. Water was collected from open wells using drawing buckets tied with ropes, while boreholes were pumped for 5–15 min before sampling. These waters were poured into 500-ml-capacity plastic bottles after rinsing with the sample and preserved airtight to avoid evaporation. Physico-chemical parameters like pH, electrical conductivity (EC), water temperature, oxygen reduction potential (ORP) and dissolved oxygen (DO) of sampled springs were measured in situ using pH/EC/temperature TOA-DKK meter, TOA-DKK ORP meter and a TOA-DKK DO meter, respectively.

Major ion analyses were done at the Isotope Hydrology Laboratory of Kumamoto University, Japan, for major ions, while dissolved silica (SiO<sub>2</sub>) was analyzed at the National Agriculture Center for Kyushu-Okinawa Region, Kumamoto. The major ions that were analyzed included Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub><sup>-</sup>. Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub><sup>-</sup> concentrations were determined by ion chromatography and dissolved silica using an ICP Dionex 3000 Spectrometer. Bicarbonate (HCO<sub>3</sub><sup>-</sup>) ion concentrations were determined by acid titration of 0.02 N H<sub>2</sub>SO<sub>4</sub>. Samples with EC >200 μS/cm were subjected to 20 times dilution using distilled water before analyzing for major ions and dissolved SiO<sub>2</sub>. No dilution was done for samples with EC <200 μS/cm. Both the diluted and undiluted samples were filtered through 0.2 μm filters, prior to major ions and dissolved silica determination. The analytical precision of cations (Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>) and anions (Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub><sup>-</sup>) was verified using ionic balance error (IBE) on the basis of ions expressed in meq/l (Appelo and Postma 1999). IBE was observed to be within a limit of ±5 % for all the investigated samples.



For quality control purposes, duplicate samples were taken in the field for 10 % of the total samples. These were treated as completely separate samples, receiving their own sample number. The duplicates were thus not recognizable in the laboratory. Also, for quality control of the chemical measurements, standards (used for not more than 3 days after preparation) and blanks were used in between runs to provide a measure of background noise, accuracy and precision. The equipment and instruments were tested and calibrated with calibration blanks and a series of calibration standards as per specifications outlined in standard methods of water and wastewater (APHA 1998). Total dissolved salts (TDS) were calculated by summing the main ionic species ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$ ) and dissolved silica. PHREEQC program (Parkhurst and Appelo 1999) was used to calculate saturation indices, partial pressure of  $\text{CO}_2$  ( $P_{\text{CO}_2}$ ) and the activities of aqueous species in the groundwaters.

After all sample analyses were completed, descriptive statistics, correlation matrix of variables and multivariate statistical analysis [principal component analysis (PCA) and factor analysis (FA) were done using the computer package, Statistical Package for Social Sciences (SPSS) (SPSS 19.0) software on 16 hydrochemical variables (pH, EC, temperature, ORP, DO,  $\text{SiO}_2$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ , TDS,  $P_{\text{CO}_2}$ ].

#### Principal component analysis (PCA) and factor analysis (FA)

Among multivariate techniques, R-mode FA has been widely employed for understanding hydrogeochemical associations and processes controlling them (Drever 1988; Razack and Dazy 1990; Melloul and Collin 1992; Brizkishore and Murali 1992; Ballukraya and Ravi 1999). As a first step, correlation analysis which reveals the relationship between two variables is calculated for the major ion chemical data from the study area. Since correlation analysis reveals similarities or differences in the behavior of pairs of ions, and does not conveniently identify groups of ions that behave similarly, FA is carried out for the chemical data from the study area to help in hydrogeochemical interpretation. For factor analysis, first principal components are calculated, which give the eigenvalue and the percentage of the variance explained by each factor.

Principal component analysis gives communality of unity for each component. Only those factors having eigenvalues greater than unity (Kaiser 1958) are considered for final analysis. Though FA reduces the dimensionality of the problem, the meaning of these factors may sometimes be difficult to deduce (Davis 1986). The interpretation can be simplified using certain rotational procedures. For the present study, Kaiser's varimax rotation was applied to

obtain a simple structure. A set has been taken to rotate the factors (varimax rotated) in such a way that all their components are closer to +1, 0 and -1, representing the contributions of corresponding variables to the total variance as a positive contribution, a no contribution and a negative contribution, respectively. The factor loadings depict the influence of a factor on a variable and vice versa. Thus, Factor 1 gives the largest eigenvalue and explains the greatest amount of variance in the data set. Factor 2 represents low eigenvalue and explains the greatest of the remaining variance and so forth.

The final step of the FA is to project the data on the rotated significant factors. The scores obtained by this projection are called factor scores, which are used to understand the nature of variables. Dalton and Upchurch (1978) have stated that the factor scores are related to the intensity of the chemical process described by each factor. Negative numbers reflect areas unaffected by the process, positive numbers indicate areas most affected and near-zero numbers affect to an average degree (Lawrence and Upchurch 1983).

## Results and discussion

### Descriptive statistical analysis and major water types

Table 1 shows the descriptive statistics (minimum, maximum and average values) of chemical constituents (pH, EC, temperature, Eh, TDS, DO,  $\text{SiO}_2$ ,  $P_{\text{CO}_2}$ , nitrate and major ion concentrations) of groundwater samples (67 in the Banana Plain and 33 in the Mount Cameroon area). Groundwaters in the Banana Plain are moderately acidic to mildly alkaline with pH values varying between 4.30 and 7.85, while in the Mount Cameroon area groundwaters are neutral to mildly alkaline (pH 6.97–7.98). TDS, DO, EC, Eh and  $\text{SiO}_2$  vary in a similar manner in both study sites, but they are generally enhanced in the Mount Cameroon area.

Average cation concentrations occur in the order  $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$  in the Banana Plain, while in the Mount Cameroon area the order is  $\text{Ca} > \text{Na} > \text{K} > \text{Mg}$ . For the anions, the order is  $\text{HCO}_3^- > \text{NO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$  in the Banana Plain and  $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$  in the Mount Cameroon area.

Sulfate and chloride are major constituents of natural water and are generally good tracers of the sources of salinity.

Natural sources of sulfate and chloride are seawater and the dissolution of evaporitic rocks, and the main anthropogenic sources are urban, industrial and agricultural wastewater. Different origins of these contaminants have often been distinguished on the basis of their bromide-to-

**Table 1** Descriptive statistics of groundwater physico-chemical and chemical parameters in the study areas

Constituents	Area	No. samples	Min.	Max.	Average	Standard deviation
pH	Banana Plain	67	4.30	7.85	5.79	0.87
	Mount Cameroon	33	6.97	7.98	7.57	0.29
EC ( $\mu\text{S}/\text{cm}$ )	Banana Plain	67	33.10	530.00	170.33	123.74
	Mount Cameroon	33	70	500	209.36	109.49
Temp ( $^{\circ}\text{C}$ )	Banana Plain	67	25.00	30.40	27.60	1.31
	Mount Cameroon	33	16.20	27.90	22.60	2.33
DO (mg/l)	Banana Plain	67	2.70	48.99	14.06	11.90
	Mount Cameroon	33	5.50	27.50	13.62	5.59
Eh (mV)	Banana Plain	67	-58.00	280.00	190.08	65.38
	Mount Cameroon	33	82	246	189.59	32.81
$\text{SiO}_2$ (mg/l)	Banana Plain	67	5.11	27.73	12.26	7.00
	Mount Cameroon	33	7.60	18.12	13.29	2.96
$\text{Ca}^{2+}$ (mg/l)	Banana Plain	67	1.53	46.31	11.40	8.60
	Mount Cameroon	33	3.87	20.64	12.18	4.42
$\text{Mg}^{2+}$ (mg/l)	Banana Plain	67	0.57	18.79	5.53	3.45
	Mount Cameroon	33	2.55	15.25	8.33	3.43
$\text{Na}^+$ (mg/l)	Banana Plain	67	1.03	43.01	6.81	6.33
	Mount Cameroon	33	5.69	64.90	14.07	11.30
$\text{K}^+$ (mg/l)	Banana Plain	67	0.88	26.46	5.47	4.32
	Mount Cameroon	33	2.60	16.75	6.50	3.05
$\text{HCO}_3^-$ (mg/l)	Banana Plain	67	7.76	377.76	75.56	80.47
	Mount Cameroon	33	44.15	203.60	122.51	41.64
$\text{SO}_4^{2-}$ (mg/l)	Banana Plain	67	0.23	171.59	8.00	26.74
	Mount Cameroon	33	0.27	325.39	15.31	57.12
$\text{Cl}^-$ (mg/l)	Banana Plain	67	0.53	65.08	5.65	8.09
	Mount Cameroon	33	0.52	104.42	6.07	18.16
$\text{NO}_3^-$ (mg/l)	Banana Plain	67	0.05	146.61	17.28	21.54
	Mount Cameroon	33	0.29	12.37	2.90	2.69
TDS (mg/l)	Banana Plain	67	43.18	493.48	147.63	108.05
	Mount Cameroon	33	75.99	503.06	201.16	80.60

chloride and bromide-to-sulfate ratios. No health-based GV has been proposed by the WHO for sulfate and chloride in drinking water (WHO 2004). However, concentrations in excess of about 200 mg/l for both anions can give rise to detectable taste in water. At higher concentration,  $\text{SO}_4^{2-}$  may cause gastrointestinal irritation, particularly when  $\text{Mg}^{2+}$  and  $\text{Na}^+$  are also present in drinking water resources (Suthar et al. 2009). In this study, sulfate (as  $\text{SO}_4^{2-}$ ) concentration ranged from 0.23 to 171.56 mg/l (average 8.00 mg/l) in the Banana Plain and 0.27–325.39 mg/l (average 15.31 mg/l) in the Mount Cameroon area (Table 1). Thirty percent of Mount Cameroon groundwater resources are not suitable for drinking according to the WHO drinking water sulfate concentration limit of 200 mg/l (WHO 2004). Chloride concentrations ranged from 0.53 to 65.08 mg/l (average 5.65 mg/l) in the Banana Plain and 0.52–104.42 mg/l (average 6.07 mg/l) in the Mount Cameroon area (Table 1).

The Chadha diagram (Chadha 1999) was used to define the major water types in the areas. It is a modified version of the Piper (1944) diagram and plots the difference in milliequivalent percentage between alkaline earths ( $\text{Ca} + \text{Mg}$ ) and alkali metals ( $\text{Na} + \text{K}$ ) expressed as percentage and plotted on the  $x$ -axis. The difference in milliequivalent percentage between weak acidic anions ( $\text{CO}_3 + \text{HCO}_3$ ) and strong acidic anions ( $\text{Cl} + \text{SO}_4$ ) is plotted on the  $y$ -axis. The rectangular field resulting from this is similar to the diamond-shaped field in the Piper diagram and describes the overall character of the water. Thus, there are eight fields in the rectangular plot which represent eight different water types as in the case of Piper diagram. Those eight water types are: (1) alkaline earths exceed alkali metals; (2) alkali metals exceed alkaline earths; (3) weak acidic anions exceed strong acidic anions; (4) strong acidic anions exceed weak acidic anions; (5) alkaline earths and weak acidic anions exceed both alkali

metals and strong acidic anions, respectively (such water has temporary hardness); (6) alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions (such water has permanent hardness); (7) alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions; (8) alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions (Chadha 1999).

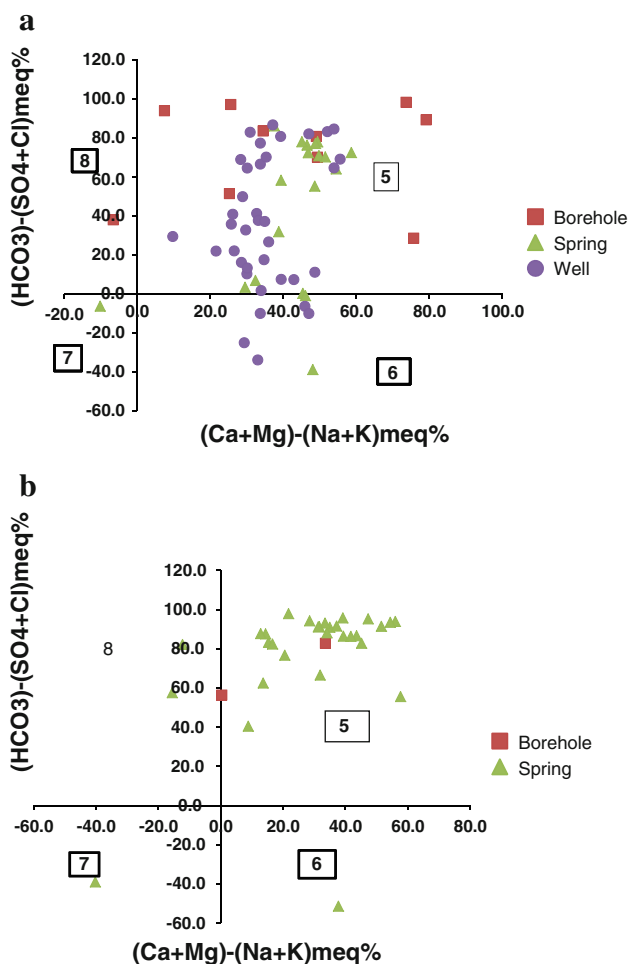
Figure 2a, b shows the Chadha diagrams for groundwater samples from the study areas. This diagram shows that 89.6 % of the groundwater samples from the Banana Plain (Fig. 2a) fall in the subfield 5-(Ca–Mg–HCO<sub>3</sub>), 9 % samples in subfield 6-(Ca–Mg–Cl) and 1.4 % in the subfields 7-(Na–K–Cl) and 8-(Na–K–HCO<sub>3</sub>). For Mount Cameroon groundwaters (Fig. 2b), 87.5 % fall in the subfield 5-(Ca–Mg–HCO<sub>3</sub>), 6.3 % in subfield 8-(Na–K–HCO<sub>3</sub>) and 3.1 % in the subfields 6-(Ca–Mg–Cl) and 7-(Na–K–Cl). The dominance of Ca–Mg–HCO<sub>3</sub> water type in both study areas may represent groundwaters that either contain

waters at the early stages of geochemical evolution (recent recharge) or rapidly circulating groundwaters which have not undergone significant water–rock interactions (Kebede et al. 2005; Marghade et al. 2011). Water groups represented by Ca–Mg–HCO<sub>3</sub> and Na–K–HCO<sub>3</sub> are weakly mineralized waters circulating within the basaltic and scoriaceous aquifers of the Banana Plain and the Mount Cameroon area. Ca–Mg–Cl and Na–K–Cl water types are symptomatic of anthropogenic pollution. In groundwaters, the source of Cl, SO<sub>4</sub>, NO<sub>3</sub> and Na ions are mostly agricultural fertilizers, animal wastes and industrial and municipal sewage. This indicates the influence of human activities on water chemistry (Jalali 2009).

#### Nitrate contamination of groundwaters

The average groundwater nitrate concentration for the study areas is 17.28 mg/l in the Banana Plain and 2.90 mg/l in the Mount Cameroon area. All 100 % of the wells, springs and boreholes had detectable nitrate (Table 2) and about 6 % (in Banana Plain) and 0 % (in Mount Cameroon) of the groundwater resources were not suitable for drinking without treatment, according to the WHO and Cameroon Water Quality Norms drinking water nitrate concentration limit of 50 mg/l (WHO 2004; ANOR 2003). A high nitrate concentration is always related to anthropogenic contamination, the main sources being fertilizers and human or animal bodily waste (Spalding and Exner 1993). Nitrate can be the main anionic species in both agricultural and urban areas. In the Banana Plain, it is the second most abundant anionic species, while in the Mount Cameroon area, it occupies the last position. Thus, it is suggested that the impact of anthropogenic activities, especially groundwater nitrate contamination, is more accentuated in the Banana Plain than in the Mount Cameroon area.

A large majority of nitrate sources are of anthropogenic origin and are commonly confined to the same watershed and groundwater basin. In aquifer systems more prone to nitrate contamination, surficial aquifers are more likely to be contaminated and at a greater extent compared to deeper, confined or unconfined aquifers. Inverse relationships between nitrate concentration and aquifer depth have been noticed in previous studies (Spalding and Exner 1993; Ray and Schock 1996; Ako et al. 2011). The contaminants coming from these various sources can be transported to surface waters by surface runoff and groundwater discharge. Several studies indicate that rural land uses, especially agricultural practices, can cause nitrate contamination of underlying groundwater. In addition, regions experiencing significant population growth may be substantially contributing to the groundwater nitrate contamination (Ako et al. 2011). In some instances, it has been



**Fig. 2** a Chadha diagram for Banana Plain groundwaters. b Chadha diagram for Mount Cameroon area groundwaters

**Table 2** Nitrate concentration and percentage distribution in groundwater of the study areas

Area	No. samples	Number of samples with NO <sub>3</sub> concentration of:			Percentage of samples with NO <sub>3</sub> concentration of:		
		0–10 mg/l	10–45 mg/l	>45 mg/l	0–10 mg/l	10–45 mg/l	>45 mg/l
Banana Plain	67	24	39	4	36.0	58.00	6
Mount Cameroon	33	32	1	0	96.97	3.03	0

observed that elevated nitrate concentrations are accompanied by increased chloride concentrations. In places where fertilizers are applied to the land surface, there is an increased potential for groundwater contamination due to the direct downward infiltration of nitrate to the aquifer system. These sources, however, do not necessarily coincide with increased concentrations of chloride in groundwater. Alternative sources such as sewer breakthrough and animal waste can cause a significant increase of both nitrate and chloride concentrations (Hudak and Blanchard 1997). Ako et al. 2011 observed a very strong positive correlation

between NO<sub>3</sub><sup>-</sup> and Cl<sup>-</sup> ( $R^2 = 0.83$ ) in the Banana Plain and postulated that this was a diagnostic indicator of anthropogenic activity on groundwater quality in the area.

Principal component analysis (PCA) and factor analysis (FA)

The first step in multivariate statistical analysis is to establish relationships between variables for the physico-chemical and chemical data of the study area. Table 3a, b presents the matrix of Spearman's correlation coefficient

**Table 3** Matrix of correlation between 12 variables in (a) Banana Plain and (b) Mount Cameroon area

	pH	EC	Eh	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Cl <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	TDS
(a) Banana Plain												
pH												
EC	0.4											
Eh	-0.02	-0.41										
Ca <sup>2+</sup>	0.2	0.49	<b>-0.64</b>									
Mg <sup>2+</sup>	0.16	0.13	-0.25	<b>0.68</b>								
Na <sup>+</sup>	-0.03	0.31	-0.42	<b>0.68</b>	<b>0.6</b>							
K <sup>+</sup>	0.04	0.00	-0.09	<b>0.5</b>	<b>0.5</b>	0.29						
Cl <sup>-</sup>	-0.19	-0.18	-0.03	0.34	<b>0.51</b>	0.48	0.22					
NO <sub>3</sub> <sup>-</sup>	-0.27	-0.28	0.03	0.2	0.45	0.38	0.14	<b>0.91</b>				
SO <sub>4</sub> <sup>2-</sup>	0.1	0.23	-0.22	0.11	0.03	-0.01	-0.04	-0.06	-0.09			
HCO <sub>3</sub> <sup>-</sup>	0.4	<b>0.76</b>	<b>-0.58</b>	<b>0.76</b>	0.35	<b>0.56</b>	0.25	-0.07	-0.21	0.23		
TDS	0.31	<b>0.64</b>	<b>-0.6</b>	<b>0.86</b>	<b>0.56</b>	<b>0.7</b>	0.33	0.27	0.14	0.4	<b>0.9</b>	
log (P <sub>CO2</sub> )	-0.43	0.08	-0.25	0.19	0.26	0.18	0.16	0.00	0.01	0.05	0.13	0.15
(b) Mount Cameroon area												
pH												
EC	-0.02											
Eh	0.17	0.04										
Ca <sup>2+</sup>	0.30	-0.01	0.04									
Mg <sup>2+</sup>	0.30	0.42	-0.02	<b>0.79</b>								
Na <sup>+</sup>	-0.05	<b>0.70</b>	0.03	0.09	0.42							
K <sup>+</sup>	-0.04	0.36	0.18	0.35	<b>0.53</b>	<b>0.68</b>						
Cl <sup>-</sup>	-0.13	<b>0.53</b>	-0.07	-0.05	0.14	<b>0.86</b>	0.39					
NO <sub>3</sub> <sup>-</sup>	-0.03	-0.12	0.05	0.28	0.13	-0.17	-0.16	-0.06				
SO <sub>4</sub> <sup>2-</sup>	-0.15	0.09	0.23	-0.22	-0.17	-0.06	-0.17	0.02	0.32			
HCO <sub>3</sub> <sup>-</sup>	0.10	<b>0.63</b>	0.04	0.33	<b>0.57</b>	0.11	0.08	-0.12	-0.08	0.08		
TDS	-0.05	<b>0.64</b>	0.19	0.14	0.39	0.39	0.18	0.30	0.19	<b>0.72</b>	<b>0.62</b>	
log (P <sub>CO2</sub> )	0.31	-0.30	0.16	0.04	0.00	-0.20	-0.02	-0.19	-0.20	-0.19	-0.17	-0.29

Correlation coefficients >0.5 are marked in bold font



for physico-chemical and chemical data of the study areas; most of the physico-chemical and chemical parameters were not normally distributed. EC and TDS showed a strong positive correlation with the major cations (calcium, magnesium and sodium and the bicarbonate anion) in both study areas. Very strong correlation exists between chloride and nitrate in the Banana Plain ( $R^2 = 0.91$ ). In the Mount Cameroon area, very strong positive correlation exists between calcium and magnesium and also between sodium and chloride. In both areas, the main contributor to ionic content is bicarbonate deriving from the titration of magmatic carbon dioxide within the aquifers and to metals (mainly alkaline and alkaline earth elements) released by water–rock interaction processes (Aiuppa et al. 2003). Demlie et al. (2007) illustrated that a positive correlation of  $\text{NO}_3^-$  and  $\text{Cl}^-$  was a diagnostic indicator of anthropogenic activity. The very strong correlation between chloride and nitrate in the Banana Plain is a diagnostic indicator of anthropogenic activity on groundwater quality. The high salinity values in Mount Cameroon area are probably due to the presence of seawater or from dissolution of evaporate rocks in the active volcanic area of Mt. Cameroon. According to Vengosh and Rosenthal (1994), the Na/Cl ratio during mixing between groundwater and seawater is 0.86 and for fresh groundwater  $\text{Na/Cl} > 1$ , while  $\text{Na/Cl} = 1$  indicates dissolution of halite minerals. Na/Cl ratios of Mount Cameroon groundwaters vary between 0.1 and 64.1 (median value 0.4) with only 4 % of samples having Na/Cl ratios less than that of seawater (0.86). Ninety-six percent of Mount Cameroon groundwaters have high Na/Cl ratio ( $>1$ ) which is typical of anthropogenic sources like domestic wastewaters and distinguishable from the low ratio of seawater intrusion (El Moujabber et al. 2006). Thus, the coastal aquifers of the Mount Cameroon area are not much subject to saltwater intrusion. In the Banana Plain, Na/Cl ratios vary between 0.7 and 24.4 (median value 2.1) with 85 % of samples having Na/Cl ratios greater than that of seawater (0.86) and 81 % having Na/Cl ratios  $>1$ . Equally, the Banana Plain aquifer is not much subjected to seawater intrusion, but more of the influence of anthropogenic activities. Saturation indices (SI) for groundwater in the Mount Cameroon area have been calculated with respect to carbonate, halite and sulfate minerals (Ako et al. 2012). SI values suggest that all the groundwaters are undersaturated with respect to carbonate, halite and sulfate minerals. SI also suggests that the dissolution of carbonate, sulfate and halite minerals is insignificant in the aquifer of the Banana Plain (Ako et al. 2011). Thus, evaporate mineral phases are minor or absent in the host rocks despite the presence of  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  ions in the groundwaters. Local contamination by septic tanks, sewage systems and agricultural fertilizers may contribute sulfates and chlorides to the groundwaters of the

Banana Plain and Mount Cameroon area (Ako et al. 2011, 2012).

Ako et al. (2012) also established an inverse relationship between  $\text{Cl}^-$  concentrations in spring water and altitude in the Mount Cameroon area. Benedetti et al. (2003) also reported the same findings, and this reflects the input of the oceanic monsoon chloride-rich rainwater at low altitudes. At higher altitudes, the decrease in  $\text{Cl}^-$  concentrations is due to smaller rainfall inputs caused by the rapid decrease in the absolute humidity and temperature with elevation resulting in a smaller condensation. However, chloride ions can also result from a variety of human activities (domestic sewage, fertilizers, etc.). Enrichment of TDS, Na and Cl is also possible, because of the effect of urban wastewaters (Subba Rao and Krishna Rao 1990; Somasundaram et al. 1993). This strong positive correlation between  $\text{Na}^+$  and  $\text{Cl}^-$  is typically observed in wet environments like the Banana Plain and Mount Cameroon area where precipitation inputs dominate evapotranspiration (Appelo and Postma 1999).

Since correlation analysis reveals similarities or differences in the behavior of pairs of ions and does not conveniently identify groups of ions that behave similarly, PCA/FA is carried out on the data set for better hydrogeochemical interpretation. For PCA/FA, first principal components are calculated which give the eigenvalues and the percentage of the variance explained by each factor. The principal components were extracted in the decreasing order of importance, so that the first PC accounts for as much of the variation as possible and each successive component, a little less. As the first PC accounts for the co-variation shared by all the attributes, this may be a better estimate than the simple or weighted averages of the original variables (Mahloch 1974). Eigenvalues and eigenvectors were thus calculated for the covariance matrix. Then, the data were transformed into factors. Table 4 presents the eigenvalues, percent of variance, cumulative eigenvalue and cumulative percent of variance associated with each factor or component. These values are summed to express as a cumulative eigenvalue and percentage of variance, respectively. The number of factors extracted is to be determined. This study retains only factors with eigenvalues that exceed one. This criterion was proposed by Kaiser (1958) and is probably the one most widely used (Matalas and Reihner 1967; Davis 1973; Reymont and Joreskog 1993; Miller and Miller 2000). In the Banana Plain from the 17 variables, 5 explain 77.48 % of the total variance. For the Mount Cameroon data set, from the 15 variables 6 explain 80.78 % of the total variance.

Though FA reduces the dimensionality of the problem, the meaning of these factors may sometimes be difficult to deduce. The interpretation can be simplified using certain rotational procedures. The five components, which

**Table 4** Eigenvalues, percent of variance, cumulative eigenvalue, cumulative percent of variance for the factor analysis of hydrochemical data in the Banana Plain and the Mount Cameroon area

Component	Initial eigenvalues			Total variance explained					
				Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
(a) Banana Plain									
1	6.121	36.006	36.006	6.121	36.006	36.006	5.557	32.686	32.686
2	2.978	17.519	53.525	2.978	17.519	53.525	2.787	16.394	49.08
3	1.698	9.987	63.512	1.698	9.987	63.512	1.971	11.595	60.675
4	1.332	7.833	71.345	1.332	7.833	71.345	1.483	8.722	69.397
5	1.043	6.134	77.478	1.043	6.134	77.478	1.374	8.082	77.478
6	0.971	5.714	83.193						
7	0.775	4.559	87.751						
8	0.642	3.778	91.530						
9	0.387	2.278	93.807						
10	0.358	2.104	95.911						
11	0.263	1.549	97.461						
12	0.147	0.835	98.325						
13	0.142	0.835	99.160						
14	0.081	0.479	99.639						
15	0.058	0.344	99.982						
16	0.002	0.012	99.995						
17	0.001	0.005	100.000						
(b) Mount Cameroon area									
1	3.949	24.679	24.679	3.949	24.679	24.679	2.936	18.348	18.348
2	2.743	17.142	41.821	2.743	17.142	41.821	2.896	18.803	36.451
3	2.149	13.431	55.252	2.149	13.431	55.252	2.608	16.297	52.749
4	1.587	9.92	65.172	1.587	9.92	65.172	1.64	10.297	63.002
5	1.358	8.485	73.657	1.358	8.485	73.657	1.577	9.854	72.856
6	1.14	7.124	80.782	1.14	7.124	80.782	1.268	7.926	80.782
7	0.75	4.688	85.47						
8	0.637	3.98	89.45						
9	0.632	3.953	93.403						
10	0.44	2.75	96.153						
11	0.291	1.819	97.972						
12	0.201	1.255	99.227						
13	0.058	0.362	99.589						
14	0.048	0.299	99.889						
15	0.018	0.111	100.000						

explained 77.47 % of the total variance of the Banana Plain data set and the six components which explained 80.78 % of the total variance in the Mount Cameroon area, were rotated by the varimax method to make interpretation in terms of the original variables easier by adjusting the loadings so that they were either near  $\pm 1$  or near 0 (Davis 1973). Table 5 lists the PCA/FA results after varimax rotation.

The terms ‘strong’, ‘moderate’ and ‘weak’ as applied to factor loadings refer to absolute loading values of  $>0.75$ ,

0.75–0.5 and 0.5–0.3, respectively (Liu et al. 2003). For the Banana Plain, Factor 1 which explains 36.00 % of the total variance has strong positive loadings on TDS,  $\text{HCO}_3$ , Ca and TH, moderate loading on EC, Eh (negative), Na, Mg and  $\text{SiO}_2$  and weak loading on  $\text{SO}_4$ . This PC can be ascribed to natural hydrogeochemical evolution of groundwater by groundwater–geological medium interactions and hence a geogenic factor. Factor 2 accounts for 17.52 % of the variance of the data set. It has strong positive loadings on  $\text{NO}_3$  and Cl and weak loadings on Mg

**Table 5** Results of the factor analysis after varimax rotation

Parameter	Rotated component matrix					
	Component					
	1	2	3	4	5	
<b>(a) Banana Plain</b>						
TDS	<b>0.960</b>	0.18				
HCO <sub>3</sub>	<b>0.925</b>	-0.186				
Ca	<b>0.836</b>	0.257		0.111	0.308	
TH	<b>0.792</b>	0.384	-0.192	0.198	0.308	
EC	<b>0.742</b>	-0.305	0.199		-0.104	
Eh	<b>-0.696</b>				0.112	
Na	<b>0.645</b>	<b>0.474</b>		0.102	0.145	
Mg	<b>0.516</b>	<b>0.493</b>	<b>-0.424</b>	0.262	0.323	
NO <sub>3</sub>		<b>0.955</b>				
Cl		<b>0.949</b>				
Temp			<b>0.774</b>	0.21		
Ph	0.3	-0.294	<b>0.682</b>	0.228		
P <sub>CO2</sub>	0.132	-0.131	<b>-0.617</b>	0.15	0.125	
DO			0.21	<b>0.898</b>		
SiO <sub>2</sub>	<b>0.548</b>		<b>-0.439</b>	<b>0.555</b>	-0.134	
K	0.306	0.125		-0.17	<b>0.807</b>	
SO <sub>4</sub>	<b>0.408</b>			-0.292	<b>-0.574</b>	
Parameter	Rotated Component Matrix					
	Component					
	1	2	3	4	5	6
<b>(b) Mount Cameroon area</b>						
Na	<b>0.96</b>	0.089	0.158	-0.075	-0.009	0.059
Cl	<b>0.882</b>	-0.147	0.048	0.052	-0.014	0.074
K	<b>0.705</b>	<b>0.414</b>	-0.021	-0.059	0.15	-0.208
Ca	0.052	<b>0.889</b>	-0.056	0.283	-0.068	0.09
Mg	0.325	<b>0.868</b>	0.207	0.062	-0.062	0.036
SiO <sub>2</sub>	-0.216	<b>0.684</b>	0.185	<b>-0.452</b>	0.098	-0.131
TDS	0.248	0.121	<b>0.836</b>	0.189	0.129	0.107
HCO <sub>3</sub>	-0.047	<b>0.457</b>	<b>0.75</b>	-0.248	-0.227	0.084
SO <sub>4</sub>	-0.129	-0.321	<b>0.651</b>	<b>0.407</b>	0.346	0.062
EC	<b>0.603</b>	0.108	<b>0.638</b>	-0.224	-0.087	0.09
NO <sub>3</sub>	-0.166	0.181	0.069	<b>0.854</b>	0.074	0.038
ORP	-0.024	0.083	0.198	-0.047	<b>0.759</b>	0.027
DO	0.175	-0.236	-0.119	0.23	<b>0.666</b>	-0.046
PCO <sub>2</sub>	-0.201	0.167	0.187	-0.387	<b>0.483</b>	0.041
Temp	0.125	-0.122	0.271	0.184	-0.109	<b>0.848</b>
pH	-0.158	<b>0.457</b>	-0.146	-0.261	0.261	<b>0.659</b>

Factor loadings >0.4 are marked in bold font and blanks represent very insignificant loadings

and Na. This PC indicates anthropogenic contamination from domestic and agricultural sources and thus can be termed ‘the anthropogenic factor’ (Esteller and Andreu

2005). Factor 3 which accounts for 9.99 % of the total variance has strong positive loading on temperature only, moderate loadings on pH and P<sub>CO2</sub> (negative) and weak loading on SiO<sub>2</sub> (negative). PC3 seems to represent recharge water because of positive loadings on temperature and pH which could be acquired during infiltration of rainwater through soil zones. The loadings on P<sub>CO2</sub> and SiO<sub>2</sub> represent the interaction between CO<sub>2</sub>-charged recharge water and basaltic rocks. Factor 4 has strong positive loading on DO and weak loading on SiO<sub>2</sub> and accounts for 7.83 % of the total variance of the data set. Factor 5 accounts for 6.13 % of the total variance and has a strong positive loading on K with weak (negative) loading on SiO<sub>2</sub>. Major cations including Ca, Na and Mg have positive correlations with alkalinity (HCO<sub>3</sub>) and EC (Table 3). This can be explained by acidic hydrolysis of mafic minerals in basaltic rocks. This hydrolysis reaction consumes water and acid that might have originated from CO<sub>2</sub> and increased the pH, alkalinity and cation concentration of groundwater.

In the Mount Cameroon area, Factor 1, which explains 24.68 % of the total variance, has strong positive loadings on Na and Cl and moderate loadings on K and EC. This association strongly suggests that PC1 may represent an ionic enrichment factor: gentle slope and sluggish drainage conditions supporting longer residence time of groundwater, more water–rock interaction and higher solubility of minerals together with saline water leading to enrichment of Na and Cl (UNESCO 1984; Subba Rao et al. 1997). Enrichment of EC, Na, Cl and K is also possible, because of the effect of urban wastewaters (Subba Rao and Rao 1990; Somasundaram et al. 1993) and high rate of evapotranspiration (Drever 1988; Karanth 1991). Factor 2 has strong positive loadings on Ca and Mg, moderate loading on SiO<sub>2</sub> and weak loadings on HCO<sub>3</sub> and pH. It accounts for 17.14 % of the total variance of the data set. PC2 represents the natural process by which water acquires its chemical characteristics through rock–water interactions, and hence a geogenic factor. Factor 3 which accounts for 13.43 % of the total variance has strong positive loadings on TDS and HCO<sub>3</sub> and moderate loadings on SO<sub>4</sub> and EC. PC3 also seems to represent a geogenic factor. Factor 4 accounts for 9.92 % with strong positive loading on NO<sub>3</sub> only and weak loadings on SO<sub>4</sub> and SiO<sub>2</sub> (negative). PC4 can be considered an anthropogenic factor. Factor 5 has strong loading on ORP, moderate loadings on DO, weak loading on P<sub>CO2</sub> and accounts for 8.49 % of the total variance. Factor 6 accounts for 7.12 % of variance of the data set having strong loading on temperature and moderate loading on pH. PC5 and PC6 can be attributed to the physico-chemical properties of recharge water.

Figure 3a, b illustrates a plot of component scores for PC1 against PC2 in the two study areas. As stated above, in the Banana Plain, PC1 is a geogenic factor, while PC2 is an

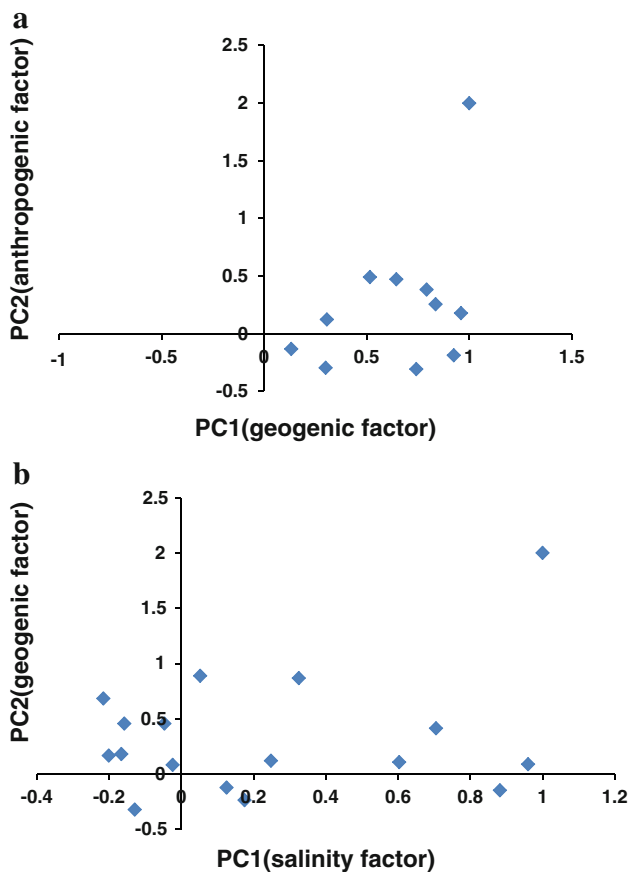
anthropogenic factor. It is obvious from Fig. 3a that in the Banana Plain, samples lean more closely toward PC1 than PC2, suggesting that groundwaters from its aquifers are predominantly under the effects of anthropogenic activities than weathering. Groundwater samples from the Mount Cameroon area (Fig. 3b) are high on the ionic enrichment side and have very significant contributions from the two components, PC1 and PC2.

The result of the principal component analysis/FA suggests that although two areas are part of the CVL, there are differences in their water chemistry that are very apparent. The major differences in the composition of groundwater from the two sampled areas are in the concentrations of nitrate, bicarbonate and sulfate. It can be concluded that three factors are responsible for the groundwater chemistry of the selected areas. The first factor represents the natural hydrogeochemical processes by which the groundwaters acquire their chemical characteristics by interaction with aquifer material and hence a geogenic factor. ‘Anthropogenic factor’ due to anthropogenic contamination from domestic and agricultural sources represents the second factor. Ionic enrichment due to the input of oceanic

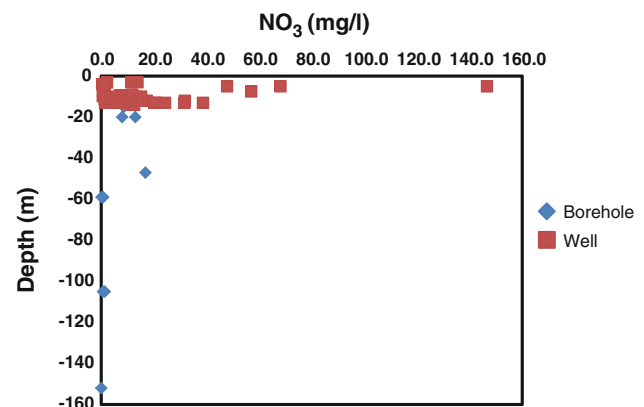
monsoon chloride-rich rainwater and the enrichment of Na and Cl from urban wastewaters is the third factor. In the Banana Plain, the geogenic and anthropogenic factors are the most preponderant, while in the Mount Cameroon area, the ionic enrichment and geogenic factors are the most important.

Kross et al. (1993) indicated that the depth of a well was an important determinant of nitrate contamination. In the Banana Plain, a correlation ( $R = 0.44$ ) was observed between well and borehole depths and nitrate concentrations (Fig. 4). It can be seen that the amount of nitrates are significantly higher in the first 20 m of the aquifers and decreases with depth. Such a distribution clearly indicates that nitrate species in most of the considered groundwaters are of superficial origin (anthropogenic). The significant concentrations of  $\text{NO}_3^-$  in groundwater are indicative of the unconfined nature of the system. Shallow groundwater resources (open wells and springs) are more vulnerable to nitrate contamination due to natural N-fixing under aerobic conditions, while denitrification in reducing conditions is the probable cause of low nitrate concentrations in waters from deep boreholes of the Banana Plain.

The following point and non-point sources could have contributed nitrates to the groundwater of the Banana Plain and the Mount Cameroon area—(1) Fertilizer use: the fertilizer consumption rate is relatively higher in these areas due to well-established agro-industrial farming system of bananas. Commonly used fertilizers in the banana plantations are NPK, urea and potash which are applied on a monthly basis, whereas lime amendments are applied on a 2-year basis and rotation with other crops (pineapple) is sometimes used (Opfergelt 2008). (2) Freely drained, well-aerated, deep, fertile loam soils: the soil of these areas is typically ash and pumice deposits from volcanic cones and sandy or sandy clay with high coarse texture. Such soils have high water filtration rate and possibly contribute in



**Fig. 3** a Plot of the loadings of PC1 against PC2 in the Banana Plain. b Plot of the loadings of PC1 against PC2 in the Mount Cameroon area



**Fig. 4** Plot of depth of wells and boreholes versus nitrate concentrations of groundwaters in the Banana Plain

nitrate leaching to underground waters. (3) Irrigation mechanisms: the two areas are rich in agro-industrial production of banana and other export crops (rubber and palm oil) based on a well-developed system of sprinkler irrigation. High irrigation rate may contribute to nitrate leaching in soils of these areas. Due to intensive agro-industrial activities, nitrogenous fertilizer consumption rate is comparatively higher in these areas than in other agro-zones of the country (Jayne et al. 2003). These nitrogenous fertilizers are easily converted to  $\text{NO}_3^-$  when applied to the soil. Nitrates are highly soluble and easily leachable on irrigation (Kundu et al. 2008). It is therefore concluded that heavy fertilizer consumption, highly coarse soils, high irrigation rates and well-developed sprinkler irrigation network are some factors responsible for  $\text{NO}_3^-$  leaching to groundwater of the studied areas alongside the infiltration of wastewater from sanitation facilities into groundwater.

Apart from non-point sources, some other point sources also contribute to groundwater  $\text{NO}_3^-$  pollution. Wakida and Lerner (2005) reviewed the non-agriculture sources of groundwater nitrate and suggested that waste disposal network, animal wastes including livestock and human excreta, industry, river–aquifer interactions, house building, etc. are some important factors indirectly enriching nitrate in groundwater. It has been observed that open dumping (in heaps) is the common practice to dispose garbage in the two areas. Due to weathering and open dumping, a considerable amount of soluble forms of nitrogen could be leached into deep soil layers especially during the wet months of the year. Other sources such as human excreta may contribute to nitrate leaching in the areas. Pit latrines may enhance  $\text{NO}_3^-$  in groundwater, but further detailed study on groundwater microbiology is needed to support the hypothesis (Suthar et al. 2009).

Continuous urbanization in the selected areas is expected to increase concentrations of contaminants including nitrates in groundwater. The consequence of urban expansion and population growth is that water tables are lowered and contamination of shallow groundwater occurs through indiscriminate disposal of domestic and industrial wastes. In the Banana Plain, a series of cholera epidemics have been recorded in the last few years (222 cases in 2004; 1,112 cases in 2005; 255 cases in 2006) (GTZ 2006). Folifac et al. (2009) revealed that in the Buea municipality of the Mount Cameroon area, anthropogenic activities around the six major drinking water sources are potential threats and pathways for contamination and that source water protection has not been given adequate attention in the planning and development of Buea. Most water sources around the Buea area are not potable with respect to total coliform counts with values ranging from 3 CFU/100 ml to >4,800 CFU/100 ml during the dry and rainy seasons, respectively (Azah 2009). Poor sanitation and hygiene

conditions in the studied areas lead not only to nitrate contamination of groundwaters, but also to outbreak of diseases. High prevalence of waterborne and water-related diseases is a direct manifestation of this situation.

## Conclusions

Principal component analysis (PCA)/factor analysis (FA) is an effective means of manipulating, interpreting and representing data concerning groundwater pollutants. PCA/FA was applied to groundwater samples for the assessment of nitrate contamination of groundwater in two agro-industrial areas of the CVL. The results showed that three factors describe the main processes affecting the groundwater chemistry of the studied areas: (1) Factor 1 ('geogenic') marked by high loadings on TDS,  $\text{HCO}_3^-$ , Ca, Mg and TH. This factor reflects the natural ('geogenic') hydrogeochemical processes, connected mainly with interaction between  $\text{CO}_2$ -charged recharge water and basaltic rocks of the aquifers; (2) Factor 2 ('anthropogenic') marked by high loadings on  $\text{NO}_3^-$  and Cl. The concentrations of these elements have mostly an 'anthropogenic' origin and are associated with the influence of pollution from land use activities in the study area; (3) Factor 3 ('ionic enrichment') marked by high loadings on Na and Cl. The input of oceanic monsoon chloride-rich rainwater and/or the effects of urban wastewaters are responsible for this factor. The discovery of the human activity influence on groundwater chemistry in the densely populated and agro-industrialized areas of the CVL is the main contribution of this research. Based on the results obtained it can be concluded that the impact of anthropogenic activities, especially groundwater nitrate contamination, is more accentuated in the Banana Plain than in the Mount Cameroon area. This study clearly demonstrates that PCA/FA is an effective and reliable method for differentiating natural and anthropogenic processes affecting groundwater quality.

**Acknowledgments** This write up constitutes part of data generated during the PhD study of the corresponding author at Kumamoto University, Japan, who was supported by Monbukagakusho Scholarship from MEXT (The Japanese Ministry of Education, Science, Sports and Culture). Material support was also provided by Grant-in-aid for scientific research No. 21–606 from SASAGAWA Foundation, Japan (Japan Science Society). We thank the Ministry of Scientific Research and Innovation (MINRESI) of Cameroon and the Institute for Geological and Mining Research (IRGM) Yaoundé-Cameroon for putting the corresponding author on study leave during his PhD studies. Thanks are due to the anonymous referees of the journal, who helped immensely in rewriting the paper in terms of content and language.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution License which permits any use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.



## References

- Aiuppa A, Bellomo S, Brusca L, D'Alessandro W, Federico WC (2003) Natural and anthropogenic factors affecting groundwater quality of an active volcano (Mt. Etna, Italy). *Appl Geochem* 18:863–882
- Aka FT, Nagao K, Kusakabe M, Sumino H, Tanyileke G, Ateba B, Hell J (2004) Symmetrical helium isotope distribution on the Cameroon Volcanic Line, West Africa. *Chem Geo* 203(3–4): 205–223
- Ako AA, Jun S, Takahiro H, Kimpei I, Nkeng GE, Fantong WY, Eyong GET, Ntankouo NR (2011) Evaluation of groundwater quality and its suitability for drinking, domestic, and agricultural uses in the Banana Plain (Mbanga, Njombe, Penja) of the Cameroon Volcanic. *Environ Geochem Health* 33:559–575
- Ako AA, Jun S, Takahiro H, Makoto K, Akoachere RA, George EN, Gloria ETE, Alain LFT (2012) Spring water quality and usability in the Mount Cameroon area revealed by hydrogeochemistry. *Environ Geochem Health* 34:615–639
- ANOR (2001) Cameroon mineral water quality norms (NC 05: 2001-02) Agence Nationale des Normes et Qualité, Yaoundé
- ANOR (2003) Cameroon drinking water quality norms (NC 207: 2003-02) Agence Nationale des Normes et Qualité, Yaoundé
- APHA (1998) Standard methods for the examination of water and wastewater, 20th edn. American Public Health Association, Washington DC
- Appelo CAJ, Postma D (1999) Chemical analysis of groundwater, geochemistry, groundwater and pollution. Balkema, Rotterdam
- Azah LA (2009) A physico-chemical and microbiological analysis of some drinking water sources in Buea. MSc Thesis, Department of Geology and Environmental Science. University of Buea, Cameroon
- Ballukraya PN, Ravi R (1999) Characterization of groundwater in the unconfined aquifers of Chennai City, India. *J Geol Soc India* 54:13–22
- Benedetti MF, Dia A, Riotte J, Chabaux F, Gerald M, Boule'gue J et al (2003) Chemical weathering of basaltic lava flows undergoing extreme climatic conditions: the water geochemistry record. *Chem Geol* 201:1–17
- Böhlike JK (2002) Groundwater recharge and agricultural contamination. *Hydrogeol J* 10:153–179
- Briz-kishore BH, Murali G (1992) Factor analysis for revealing hydrogeochemical characteristics of a watershed. *Environ Geol* 19:3–9
- Chadha DK (1999) A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. *Hydrogeo J* 7:431–439
- Dalton MG, Upchurch SB (1978) Interpretations of hydrogeochemical facies by factor analysis. *Groundwater* 10:228–233
- Davis JC (1973) Statistics and data analysis in geology. John Wiley and Sons, New York
- Davis JC (1986) Statistics and data analysis in geology. John Wiley and Sons, New York
- Demlie M, Wohnlich S, Wisotzky F, Gizaw B (2007) Groundwater recharge, flow and hydrogeochemical evolution in a complex volcanic aquifer system, central Ethiopia. *J Hydrogeo* 15:1169–1181
- Déruelle B, N'ni J, Kambou R (1987) Mount Cameroon: an active volcano of the Cameroon line. *J Afr Earth Sci* 6:197–214
- Djoret D (2000) Etude de la recharge de la nappe du Chari Barguimi (Tchad) par les méthodes chimiques et isotopiques. Thèse Doctorat, Université d'Avignon et les pays de Vaucluse
- Drever JI (1988) The geochemistry of natural waters. Prentice-Hill Inc., New York
- El Moujabber M, Bou Samra B, Darwish T, Atallah T (2006) Comparison of different indicators for groundwater contamination by seawater intrusion on the Lebanese coast. *Water Resour Manage* 20:161–180
- Endeley RE, Ayonghe SN, Tchuenteu F (2001) A preliminary hydrogeochemical baseline study of water sources around the Mount Cameroon. *J Cameroon Acad Sc* 1(3)
- Esteller MV, Andreu JM (2005) Anthropogenic effects on hydrochemical characteristics of the Valle de Toluca aquifer (Central Mexico). *Hydrogeo J* 13(2):378–390
- Fitton JG, Dunlop HM (1985) The Cameroon Line, West-Africa, and its bearing on the origin of oceanic and continental alkali basalt. *Earth Planetary Sc Lett* 72(1):23–38
- Folifac F, Lifongo L, Nkeng G, Gaskin S (2009) Municipal drinking water source protection in low income countries: case of Buea municipality—Cameroon. *J Ecolo Nat Env* 1(4):073–084
- Fraser PJ, Hall JB, Healey JR (1998) Climate of the Mount Cameroon region: long and medium term rainfall, temperature and sunshine data. University Wales, Bangor; Mount Cameroon Project and Cameroon Development Corporation. School of Agricultural and Forest Sciences Publication Number 16
- GTZ (German Technical Cooperation) (2006) Projet pour l' Amélioration de l'accès à l'eau potable et de l'assainissement de base dans les trois communes rurales de Manjo, Loum et Penja/ Njombe, Province de Littoral-Cameroun. German Technical Cooperation, Douala-Cameroon
- Hudak PF, Blanchard S (1997) Land use and groundwater quality in the Trinity Group outcrop of north-central Texas, USA. *Environ Int* 23(4):507–517
- Jalali M (2009) Geochemistry characterisation of groundwater in an agricultural area of Razan, Hamadan, Iran. *Environ Geol* 56:1479–1488
- Jayne TS, Valerie K, Eric C (2003) Fertilizer consumption trends in Sub-Saharan Africa. <http://www.msu.edu/agecon/fs2/psynindx.htm>. Accessed 25 August 2010
- Kaiser HF (1958) The varimax criteria for analytical rotation in factor analysis. *Psychometrika* 23(3):187–200
- Karant K (1991) Impact of human activities on hydrogeological environment. *J Geol Soc India* 38:195–206
- Kebede S, Travi Y, Alemayehu T, Ayenew T (2005) Groundwater recharge, circulation and geochemical evolution in the source region of the Blue Nile River, Ethiopia. *Appl Geochem* 20(9):1658–1676
- Kross BC, Hallberg GR, Bruner DR, Sherry Holmes K, Johnson JK (1993) The nitrate contamination of private well water in Iowa. *American J Public Health* 83(2):270–272
- Kundu MC, Mandal B, Sarkar D (2008) Assessment of the potential hazardous of nitrate contamination in surface and groundwater in a heavily fertilized and intensively cultivated district of India. *Environ Monit Assess* 146:183–189
- Kyoung-Ho K, Seong-Taek Y, Byoung-Young C, Gi-Tak C, Yong-sung J, Kangjoo K, Hyung-Soo K (2009) Hydrochemical and multivariate statistical interpretations of spatial controls of nitrate concentrations in a shallow alluvial aquifer around oxbow lakes (Osong area, central Korea). *J Contam Hydrol* 107:114–127
- Lawrence FW, Upchurch SB (1983) Identification of recharge areas using geochemical factor analysis. *Groundwater* 20:680–687
- Liu CW, Lin KH, Kuo YM (2003) Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. *Sci Tot Environ*. doi:10.1016/S0048-9697(02)00683-6
- Mahloch JL (1974) Graphical interpretation of water quality data. *Water Air Soil Pollut* 3:217–236

- Marghade D, Malpe DB, Zade AB (2011) Major ion chemistry of shallow groundwater of a fast growing city of Central India. *Environ Monit Assess*. doi:[10.1007/s10661-011-2126-3](https://doi.org/10.1007/s10661-011-2126-3)
- Marzoli A, Renne PR, Piccirillo EM, Francesca C, Bellieni G, Melfi AJ, Nyobe JB, N'ni JN (1999) Silicic magmas from the continental Cameroon Volcanic Line (Oku, Bambouto and Ngaoundere): Ar-40-Ar-39 dates, petrology, Sr-Nd O isotopes and their petrogenetic significance. *Contribs Mineral Petrol* 135(2–3):133–150
- Matalas CN, Reihel JB (1967) Some comments on the use of factor analysis. *Water Resour Res* 3(1):213–223
- Mbanga Rural Council (2008) Monographie de la Commune de Mbanga. Mbanga Rural Council
- Melloul A, Collin M (1992) The principal component statistical method as a complementary approach to geochemical methods in water quality factor identification: application to coastal plain aquifer of Israel. *J Hydrol* 140:49–73
- Miller NJ, Miller JC (2000) *Statistics and chemometrics for analytical chemistry*. Pearson Education, Englewood Cliff
- Moore KB, Ekwurzel B, Esser BK (2006) Sources of groundwater nitrate revealed using residence time and isotope methods. *Appl Geochem* 21:1016–1029
- Murgulet D, Tick GR (2008) Assessing the extent and sources of nitrate contamination in the aquifer system of southern Baldwin County, Alabama. *Environ Geol*. doi:[10.1007/s00254-008-1585-5](https://doi.org/10.1007/s00254-008-1585-5)
- National Metrological Service (2008) Metrological data for Mbanga. Njombe and Penja, National Metrological Service
- Ngounou Ngatcha B, Djoret D (2010) Nitrate pollution in groundwater in two selected areas from Cameroon and Chad in the Lake Chad basin. *Water Policy* 12(5):722–733
- Njitchoua R, Ngounou Ngatcha B (1997) Hydrogeochemistry and environmental isotope investigations of the North Diamare Plain, northern Cameroon. *J Afr Earth Sci* 25(2):307–316
- Opfergelt S (2008) Silicon cycle in the soil–plant system: biogeochemical tracing using Si isotopes. Dissertation. Catholic University of Louvain, Belgium
- Oyebog SA, Ako AA, Nkeng GE, Suh EC (2012) Hydrogeochemical characteristics of some Cameroon bottled waters, investigated by multivariate statistical analyses. *J Geochem Explor* 112:118–130
- Parkhurst DL, Appelo CAJ (1999) PHREEQC for windows version 1.4.07. A hydrogeochemical transport model. US Geological Survey software
- Piper AM (1944) A graphic procedure in geochemical interpretation of water analysis. *Trans-Am Geophys Union* 25(6):914–928
- Ray C, Schock SC (1996) Comparability of large-scale studies of agricultural chemical contamination of rural private wells. *Ground Water Monit Remed* 16(2):92–102
- Razack M, Dazy J (1990) Hydrogeochemical characterization of groundwater mixing in sedimentary and metamorphic reservoirs with combined use of Piper's principle and factor analysis. *J Hydrol* 114:371–393
- Reyment RA, Joreskog KH (1993) *Applied factor analysis in the natural sciences*. Cambridge University Press, New York
- Somasundaram MV, Ravindran G, Tellam JH (1993) Groundwater pollution of the Madras urban aquifer, India. *Groundwater* 31:4–11
- Spalding RF, Exner ME (1993) Occurrence of nitrate in groundwater—a review. *J Environ Qual* 22(3):392–402
- Subba Rao NG, Rao Krishna (1990) Intensity of pollution of groundwater in Visakhapatnam area, Andhra Pradesh. *J Geol Soc India* 36:670–673
- Subba Rao N, Prakasa Rao J, Chandra Rao P, Niranjana Babu PG, Rao Krishna (1997) Hydrogeochemical zoning in crystalline terrain and its significance to water quality. *J Geol Soc India* 49:715–719
- Suthar S, Preeti B, Sushma S, Pravin KM, Arvind KN, Nagraj SP (2009) Nitrate contamination in groundwater of some rural areas of Rajasthan, India. *J Hazard Mater*. doi:[10.1016/j.jhazmat.2009.05.111](https://doi.org/10.1016/j.jhazmat.2009.05.111)
- UNESCO 1984. *Groundwater in hard rock, studies and reports in hydrology*, 32, Paris, pp 228
- Vengosh A, Rosenthal E (1994) Saline groundwater in Israel: it's bearing on the water crisis in the country. *J Hydrol* 156:389–430
- Wakida FD, Lerner DN (2005) Non-agriculture sources of groundwater nitrogen: a review and case study. *Water Res* 39:3–16
- WHO (2004) *Guidelines for drinking water quality (vol 2). Health criteria and other supporting information*, WHO