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Hydro-geochemistry of groundwater and surface water in Dschang town (West Cameroon): Alkali and alkaline-earth elements ascertain lithological and anthropogenic constraints

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Abstract: This study focuses on the sources of alkali and alkaline-earth elements based on the geochemistry of groundwater and surface water in Dschang concerning environmental and anthropogenic constraints. A comprehensive set of 50 samples from groundwater and surface water were analyzed by ICP-MS and processed by spatial interpolation in a GIS environment. The results highlight a geochemical anomaly at the center of the densely inhabited area subject to a profusion of open dumps discharges. This anomaly with the highest spatial contents of Be (Cs, Rb, Mg) suggests an anthropogenic source that demarcates with the lowest alkali and alkaline-earth elements on the peripheral area of Dschang. Other findings include lithological constraints with volcanic rocks being the main source compared to granitoid. The study points out good correlations between Be, Cs, Rb and Mg spatial distributions and physico-chemical parameters of waters (K, EC, TDS), and inversely with the lowest pH. pH is established as the most functioning physico-chemical constraint of alkali and alkaline-earth mobility in Dschang. The pH lowest values within the geochemical anomaly also highlight the impact of human activities on water acidity, which later enhance elements mobility and enrichment. Despite low elements contents relative to WHO standards, our findings point out an example of anthropogenic impact on water geochemistry linked to solid waste pollution; it also demonstrates significant anthropogenic changes of environmental physico-chemical parameters of prime importance in the mobility and distribution of elements in the study area. Similar assessments should be extended in major towns in Cameroon.

Keywords: Alkali/alkaline-earth elements; Groundwater and surface water; Geochemical anomaly; Anthropogenic impact; Dschang-Cameroon

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Introduction

The total dissolved solids (TDS) of groundwater and surface water is an essential factor in defining its quality relative to drinking water guidelines. It mainly originates from the dissolution of rocks, stream mixtures and anthropogenic polluted environments (Bakyayita et al. 2019; Embaby and Redwan, 2019). Chemical elements are enriched in waters due to their greater or less mobility in leaching solutions and abundance in rocks and soils (Liao et al. 2018). Most studies focused on trace metals, namely transitions metals and metalloids, given their harmfulness. Moreover, attention is also paid to other groups of elements such as alkali and alkaline-earth elements. They can also be subject to anthropogenic and health impacts through contributions linked to land use; they can also be sensitive to significant changes of physico-chemical parameters influencing their dynamics. Numerous studies have been carried out on physico-chemical parameters of water in

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Cameroon (Ako Ako et al. 2014; Njueya Kopa et al. 2021), and particularly in Western Cameroon (Tchakam Kamtchueng et al. 2016; Defo et al. 2016; Mofor et al. 2017; Mfonka et al. 2021) in order to highlight the influence of lithological and anthropogenic activities on water quality.

Findings of these issues raised questions related to urban geochemistry in Cameroon, and mainly in cities with rapid and unplanned growth, such as Dschang city. Different aspects of water geochemistry in such a town require indeed renewed interest given the growing insalubrity and its potential effects on the city's drinking water. However, substantial contributions have been made in this geographical area mainly on the bacteriological quality and the physico-chemical parameters of water (Temgoua, 2011; Ntangmo Tsafack et al. 2019; Mba et al. 2019). Hence, to address the geochemical quality of groundwater and surface water in Dschang, the present study stands as a comprehensive issue for determining the sources and dynamics of alkali and alkaline-earth elements in waters in the urban area of Dschang. It aims to ascertain the spatial distribution of alkali and alkaline-earth elements in waters and study the lithological and anthropogenic constraints in their speciation.

1 Study area

Dschang is located on the southern slope of Mount Bambouto, a major geomorphological unit in the western highlands of Cameroon (Fig. 1). It covers about 28 km^2 between latitude 5°24'59"N and 5°28'40"N, and longitude from 10°01'30"E to 10°05'21"E. The population is estimated at 63 838 inhabitants with a 4.7% growth rate (United Councils and Cities of Cameroon, 2021) due to various attractions and rural exodus. The type of settlement, as in major cities of Cameroon, is unstructured with related typical insalubrity. Land use in the city shows a densely populated area at the center of the urban perimeter (Fig. 2a). Other points of high population density are noticed along major roads. The sparsely populated peripheral area is dedicated to agriculture, representing the

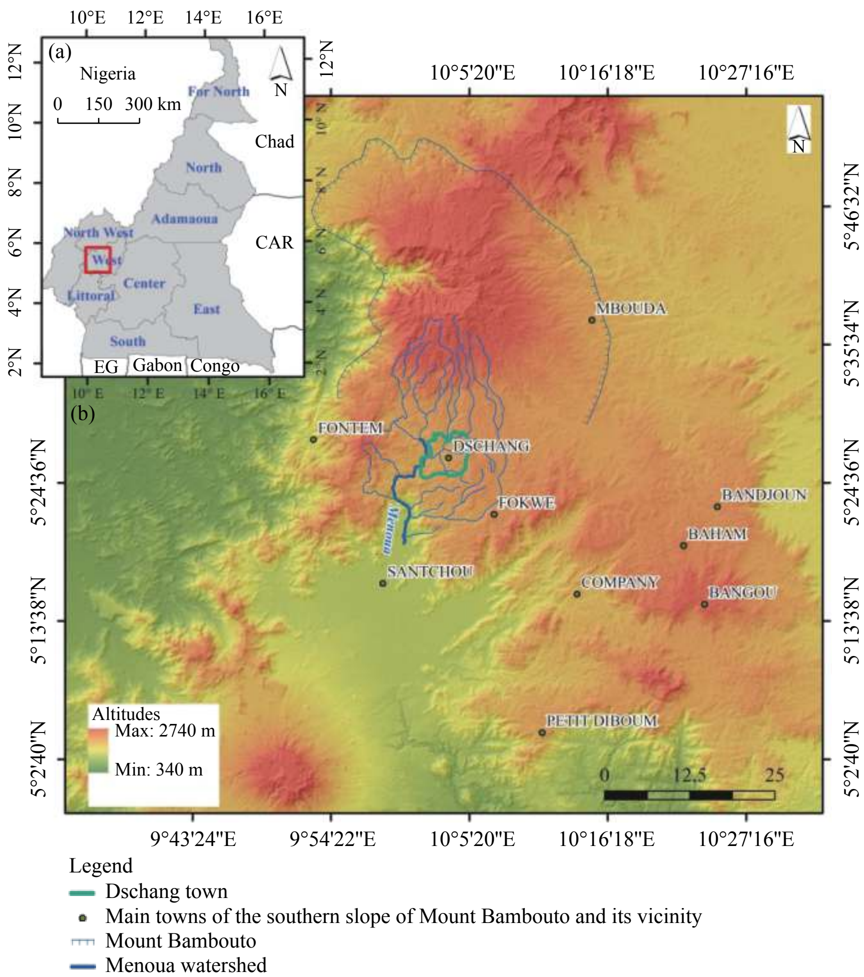


Fig. 1 (a) Localization of Cameroon within nearby countries; (b) Localization of Dschang town on the southern slope of Mount Bambouto

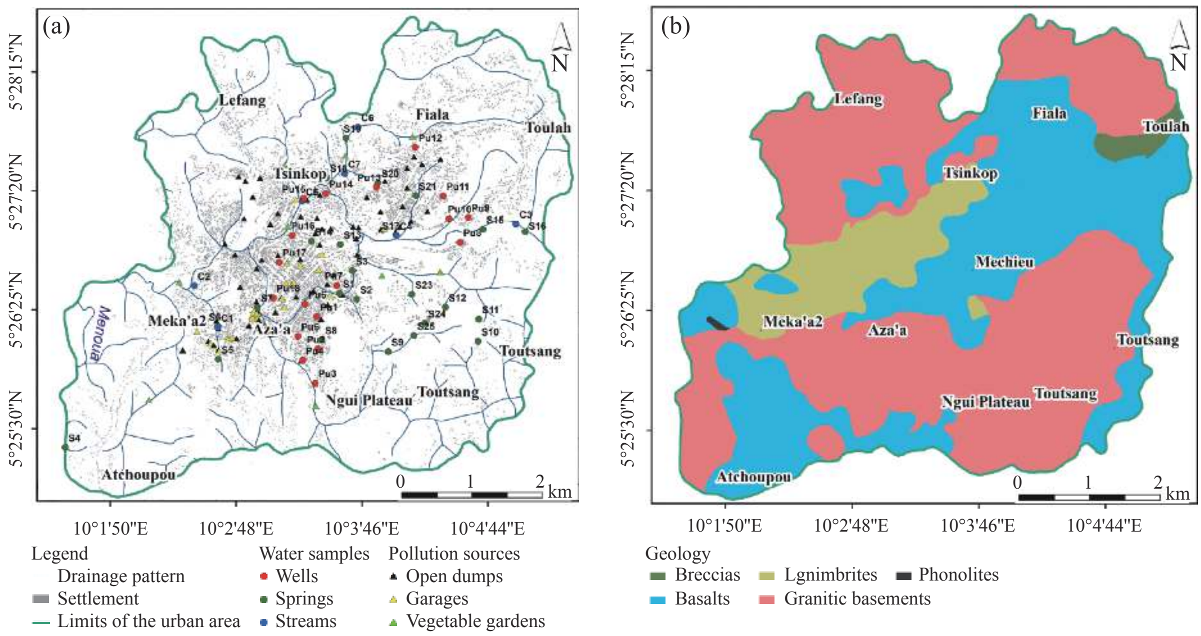


Fig. 2 (a) Settlement and drainage pattern in Dschang. Water samples locations and distribution of anthropogenic pollution sites are shown. Vegetable garden sites are adapted from Ntangmo Tsafack et al. (2012); (b) Geology of Dschang area

major activity through artisanal farming systems (Temgoua et al. 2012).

The city of Dschang is subject to a sub-equatorial climate influenced by altitude, with an average annual rainfall of 1 831 mm, and average annual temperatures of 24.9°C. The landscape is characterized by convex hills on the crystalline basement, while volcanic substrates landscapes highlight rolling surfaces characterized by elongated hills, delimited by deep valleys.

Hydrologically, Dschang is drained by numerous rivers belonging to the Menoua hydrographic watershed. The Menoua river is the mainstream on the southern slope of Mount Bambouto (Fig. 1). Its watershed shows an elongated shape towards the south with a surface area of 655 km^2, a perimeter of 128 km and a compactness index of 1.4 (Ngouffo, 1989). The hydrography in the city of Dschang is dense and describes a network of semi-dendritic streams. Most streams originate from the nearby morphological and lithological environments and flow into the main tributary (Menoua), crossing the town from east to west (Fig. 2a).

Upon field observations, springs as well as well-water originate from a thick and noticeably porous lateritic cover developed on various rocks. This cover thus embodies a main unconfined aquifer in Dschang town supplied by surface infiltration. Furthermore, structurally/lithologically controlled aquifers are also determined in Dschang, e.g. upon deep water drilling and mining of captive water deeply enclosed in rock fissures and unconformities. The runoff coefficient of the overall Menoua watershed is 44.8% and the water balance is 745 mm/a with excess supply (Ngouffo, 1989).

The geological setting on the overall southern slope of Mount Bambouto shows a Pan-African basement covered by Cenozoic volcanic formations (Kwekam et al. 2010). Ananfouet Djeufack (2012) established a detailed mapping showing basalts, ignimbrites, breccias and phonolites extrusions (Fig. 2b). These are outpourings linked to the different phases of volcanic activity on Mount Bambouto, with unaltered layers observable in the deep valleys. The crystalline basement covers almost 50% of the surface of the urban perimeter. Weathering of these different substrates has resulted in thick lateritic coverings. These are essentially highly evolved ferralitic soils with a high clay content on basalt and granitoid (Momo Nouazi et al. 2016), and poorly evolved soils on ignimbrites. Ferralitic soils cover the summits and slopes of interfluves, while lowlands are covered by gleysols formed by detrital debris and organic matter (Ananfouet, 2012).

2 Methods

Preliminary work was carried out in Dschang to identify and map potential pollution sources likely to affect physico-chemical properties of soils, as well as the concentrations of chemical elements in groundwater and surface water. We focused on open dumps, garages and vegetable gardens, which according to the geochemical characterization of Hunyh (2009), constitute potential points of anthropogenic input of chemical elements in Third World countries towns. On this basis, 68 open dumps, 25 garages and 11 vegetable gardens (Fig. 2a) were identified, a total of 95 potential pollution sites, and most of which are located in the densely populated area (Fig. 2a).

A sampling of springs, well-water and streams was then carried out in Dschang during the dry season (January). A total of 50 samples were considered. Their spatial distribution accounts for stratigraphic lithology, types of land-use, and distribution of potentially polluting sites (Fig. 2). The water was collected using "metal-free" syringes and flasks. It was first filtered below 0.22 μm (Fig. 3) and acidified with HNO_3 to limit adsorption on the solid phase, mainly made up of organic matter. The environment in the vicinity of sampling points was described in order to establish further a link with alkali and alkaline earth element contents in waters and types of land-use.

Fig. 3 Water sampling on the field. (a) Spring on densely populated area of Dschang; (b) Spring on peripheral area of Dschang; (c) Sampling kit

The physico-chemical parameters of the waters were measured directly on the field. These are pH, electrical conductivity (EC), temperature (T) and total dissolved solids (TDS). The multipurpose pH-meter was calibrated with three values, namely pH 7.0, 4.0 and 10.0. Values were measured with an accuracy of 0.01 units. For electrical conductivity, the calibration was performed with a standard solution of 1 278 $\mu S \cdot cm^{-1}$.

The geochemical analyzes of waters were carried out at the CEREGE laboratory (Centre Européen de Recherche et d' Enseignement des Géosciences de l' Environnement, Aix Marseille Université-France). Analyzes were carried out using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) Nexion 300X Perkin-Elmer. The results in μg/L are presented in Table 1, along with their limits of quantification.

As a methodological novelty in this context, the data were processed by studying the spatial variation of element contents according to the different geological contexts and types of land-use. Correlation studies between elements and physico-chemical parameters of waters were also undertaken, along with element ratios of hydrogeochemical significances. The study of the spatial distribution was carried out by interpolation using the Inverse Distance Weighting method (Elumalai et al. 2017). This interpolation is a comprehensive approach with more insights on factors affecting element sources and fractionation in a given environment. Here, element contents measured at sampling points are geochemical responses of nearby environments, namely, type of pollution sources, soils, and lithologic basement. Interpolating geochemical data allows to determine the spatial impact of each point, and hereby allows to predict the value of a given element or geochemical parameter within unmeasured springs and wells.

3 Results

3.1 Physico-chemical characteristics of waters in Dschang

Temperature (T)

Groundwater temperatures (springs and well-water) in the city of Dschang range from 16.7°C to 26.5°C (Fig. 4a, 4b, 4c) with an average of 21.8°C. Surface water temperatures range from 17.2°C to 24.0°C (Fig. 4d) with an average of 20.8°C. These different values obtained are below the limit value of 25.0°C prescribed by the WHO (2011) standards, except for S10 spring water at 26.5°C (Table 1). In both cases (groundwater and surface water), temperature ranges are extensive and reflect rapid ambient temperature changes within sampling time in such a high altitude zone.

The interpolated spatial variations of temperature in groundwater (Fig. 5a) highlight areas with the lowest and highest values. The mapped temperature anomalies do not correlate with land-use types (Fig. 2a) and geology (Fig. 2b), thereby indicating no lithological and anthropogenic constraint in temperature distribution.

The hydrogen potential (pH)

Waters in Dschang in January show pH values of 4.25 to 6.62 for groundwater and 4.94 to 6.97 for surface water (Table 1 and Table 2). This indicates that waters are mostly acidic for springs and wells, and around 7 for rivers. In terms of spatial variations, pH highlights two contrasting geochemical distributions. The lowest values are limited within the area of dense settlement and higher density of potentially polluted sites and suggest a link between physico-chemical parameters of

Table 1 Physico-chemical parameters and alkali and alkaline-earth element contents (μg/L) in groundwater and surface water of Dschang

Source	Code	pH	T (°C)	EC (μs/cm)	TDS (μg/L)	Be	Mg	Cs	Rb	Ba	Sr	Rb/Sr
Granitoids	S4	6.62	21.70	19.50	13.80	-	685.00	0.02	1.86	15.63	13.63	0.14
	S5	5.90	25.00	62.60	44.30	-	1 513.00	0.05	6.63	59.34	36.44	0.18
	S6	5.02	22.20	104.60	74.20	0.03	1 921.00	0.20	7.46	34.28	38.84	0.19
	S8	6.32	22.80	132.60	93.80	-	5 574.00	0.13	16.68	66.28	116.00	0.14
	S9	5.61	21.70	32.50	23.10	0.03	1 239.00	0.03	1.54	26.71	19.89	0.08
	S10	6.14	26.50	25.20	17.90	-	548.00	0.00	1.26	10.49	19.93	0.06
	S11	6.42	18.70	46.70	33.20	-	1 225.00	0.00	3.16	35.23	29.99	0.11
	S12	5.75	21.00	43.00	30.60	0.02	1 153.00	0.00	1.17	23.29	60.53	0.02
	S18	5.75	23.40	50.60	36.10	0.07	692.00	0.11	6.39	23.10	13.92	0.46
	S19	5.49	22.00	35.10	25.10	0.06	1 113.00	0.07	2.37	34.21	42.66	0.06
	S22	6.21	18.30	68.00	48.30	-	3 091.00	0.04	3.63	40.12	75.44	0.05
	S23	6.42	24.50	45.20	32.00	-	1 316.00	0.06	3.19	22.34	31.28	0.10
	S24	6.00	22.40	32.30	22.20	-	1 143.00	0.01	1.90	33.52	37.79	0.05
	S25	6.35	20.80	68.20	48.40	-	2 397.00	0.03	4.10	29.41	51.46	0.08
	Pu1	4.94	20.80	73.00	51.60	0.42	1 030.00	0.28	5.52	65.37	18.31	0.30
	Pu2	5.70	21.20	88.20	62.60	0.06	4 554.00	0.12	4.86	68.29	79.75	0.06
	Pu3	6.26	19.40	94.20	66.80	-	2 951.00	0.16	8.37	26.27	34.54	0.24
	Pu4	5.59	21.70	79.00	56.00	-	2 772.00	0.14	10.06	51.14	51.56	0.20
	Pu5	5.50	21.80	77.00	54.70	0.03	2 563.00	0.16	6.37	24.19	33.72	0.19
	Pu8	6.08	22.90	117.00	82.70	0.01	10 515.00	0.02	7.07	15.84	442.00	0.02
Basalts	S1	5.80	23.60	112.50	86.70	0.06	3 417.00	0.16	7.41	100.00	79.31	0.09
	S3	6.02	23.20	85.40	60.60	0.03	2 433.00	0.08	4.36	42.66	52.27	0.08
	S7	5.21	23.50	107.50	76.20	0.04	2 244.00	0.18	6.54	57.05	48.93	0.13
	S13	5.66	22.00	60.70	43.10	0.02	2 664.00	0.03	1.75	22.61	40.69	0.04
	S15	6.17	16.70	20.10	14.10	-	959.00	0.01	0.75	13.56	15.68	0.05
	S16	6.25	19.20	22.90	16.20	-	780.00	0.01	1.29	20.60	20.11	0.06
	S17	5.87	21.10	70.80	50.30	-	3 771.00	0.01	1.38	28.68	99.22	0.01
	S20	5.68	22.10	101.90	72.40	0.06	2 216.00	0.25	9.71	187.00	54.40	0.18
	S21	5.17	21.10	93.00	66.00	0.07	2 759.00	0.18	7.51	127.00	89.21	0.08
	Pu6	6.24	22.20	152.80	109.00	-	9 420.00	0.82	36.39	92.56	210.00	0.17
	Pu7	5.41	22.00	140.30	99.40	0.28	8 198.00	0.34	11.12	343.00	234.00	0.05
	Pu9	5.94	21.60	54.80	38.60	-	2 142.00	0.10	3.19	40.55	18.80	0.17
	Pu10	6.18	22.00	54.90	39.10	-	2 107.00	0.05	2.90	19.71	58.68	0.05
	Pu11	6.34	22.30	94.30	66.90	-	1 693.00	0.11	6.19	30.46	83.85	0.07
	Pu12	5.90	21.40	172.80	123.00	-	10 056.00	0.64	14.20	276.00	194.00	0.07
	Pu13	5.49	21.80	112.50	79.70	0.08	3 935.00	0.19	8.61	275.00	128.00	0.07
	Pu18	5.69	21.50	127.30	91.00	-	6 162.00	0.27	15.88	192.00	120.00	0.13
Ignimbrites	S2	5.29	22.20	85.20	60.20	0.02	3 010.00	0.15	4.13	119.00	84.48	0.05
	S14	5.27	22.20	78.30	55.60	0.09	2 033.00	0.08	3.66	68.92	52.69	0.07
	Pu14	4.50	21.80	105.50	74.50	1.23	3 722.00	0.29	8.93	130.00	79.00	0.11
	Pu15	5.66	22.30	61.50	43.80	0.03	1 434.00	0.22	6.38	26.35	30.32	0.21
	Pu16	4.51	21.30	111.20	78.90	2.65	3 564.00	0.33	28.02	179.00	97.24	0.29
	Pu17	4.25	22.40	148.50	105.00	2.67	4 910.00	0.74	13.95	155.00	109.00	0.13
Streams	C1	6.26	22.60	110.60	78.50	-	2 789.00	0.13	14.65	39.95	64.64	0.23
	C2	6.76	24.00	113.40	80.40	-	2 741.00	0.18	16.19	37.85	62.95	0.26
	C3	6.86	17.20	37.60	26.70	-	1 777.00	0.04	3.39	13.34	31.20	0.11
	C4	6.91	22.60	44.80	32.20	-	1 866.00	0.03	4.14	11.71	32.62	0.13
	C5	6.77	19.70	52.40	37.10	-	2 123.00	0.04	4.69	16.27	42.58	0.11
	C6	6.54	19.70	55.50	39.50	-	2 176.00	0.05	4.24	31.89	54.55	0.08
	C7	6.97	21.40	97.40	69.20	-	3 041.00	0.05	8.71	38.84	72.23	0.12

Note: Quantification limits of elements in μg/L: LQ_{Be}=0.013; LQ_{Mg}=0.043; LQ_{Cs}=0.000 3; LQ_{Rb}=0.004; LQ_{Ba}=0.005; LQ_{Sr}=0.003. (-)=elements below quantification limits.

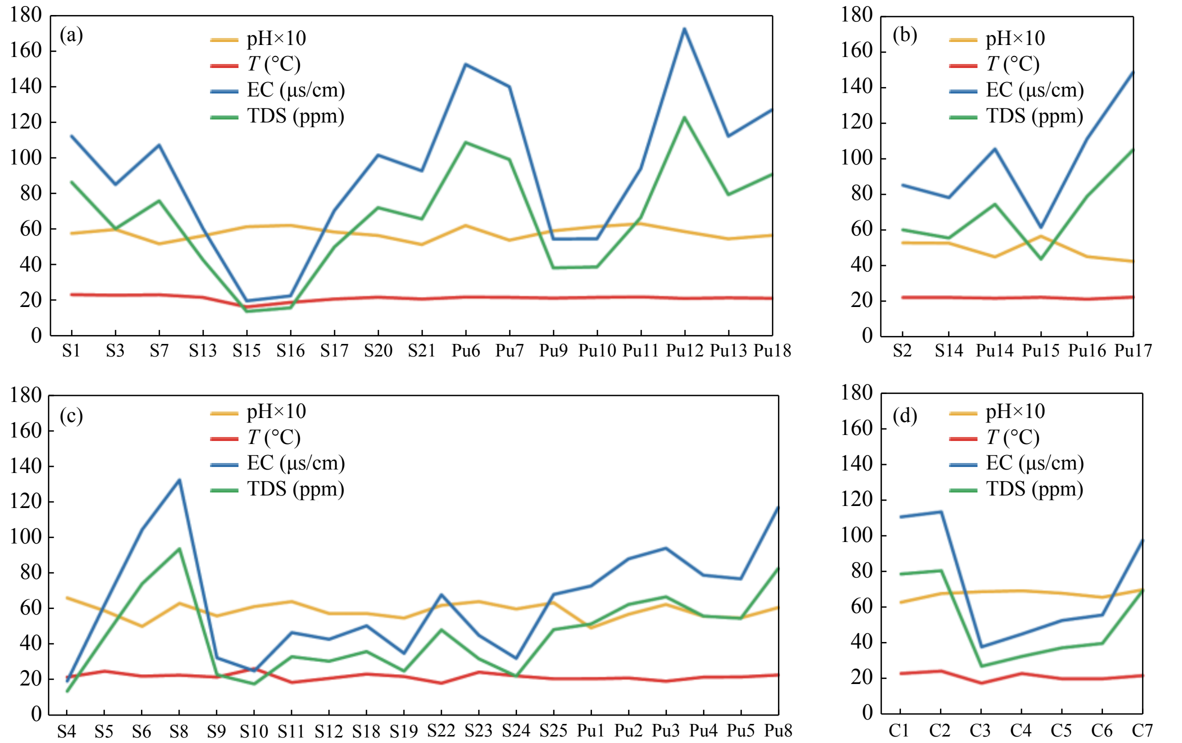


Fig. 4 Relationship scatters diagram of EC, pH, TDS and T. pH values are magnified with a 10 factor. (a) Groundwater on basalts; (b) Groundwater on ignimbrites; (c) Groundwater on granitoids; d) Rivers

waters and anthropisation (Fig. 5b). Maximum values are observed in most areas with less or no potential polluted sites and the lowest density of settlement on the periphery of the town. The areas of higher values indicate that the geological environment has not been affected by human activities.

Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

EC values of groundwater and surface water for the city of Dschang are presented in Table 1 and 2, and Fig. 4.

The EC ranges from 19.5 µS/cm to 172.8 µS/cm with an average of 80.7 µS/cm for groundwater, and from 37.6 µS/cm to 113.4 µS/cm with an average of 67.7 µS/cm for surface water. The comparison of these values with the classification of Rodier et al. (1976) allows setting surface and groundwater of Dschang as weakly mineralized. This mineralization is variable according to the lithology; Fig. 4 shows the highest electrical conductivity values on springs and wells on volcanic rocks (basalts and ignimbrites) than on granitoids.

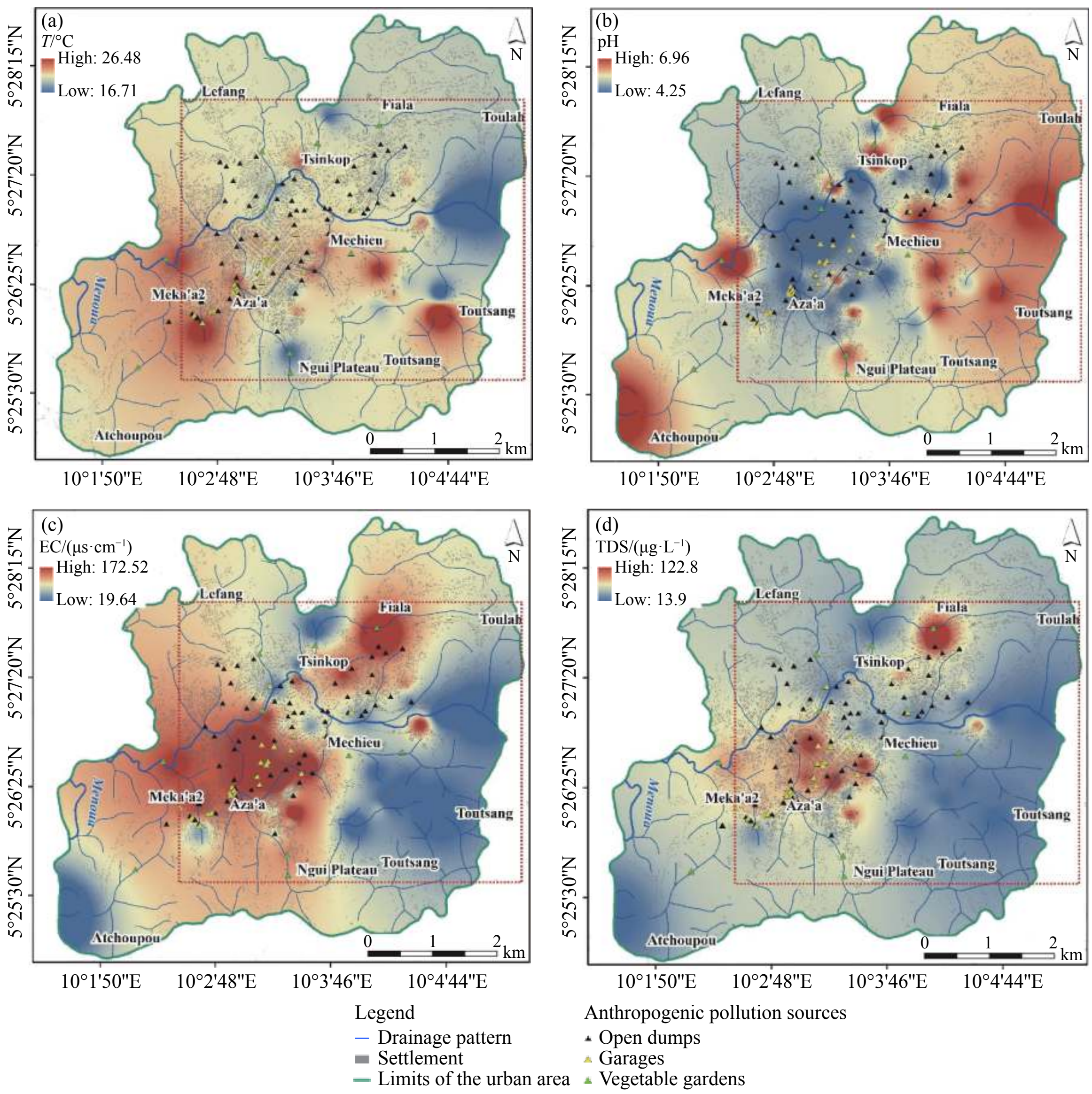
Spatially, the electrical conductivity map has a distribution generally opposite to that of the pH with a Spearman correlation coefficient $r^2_{K\text{-}pH}$= −0.5. This implies maximum EC values in dense settlements and highly polluted sites, and minimum values in sparsely populated areas and on the periphery of the urban area to some extent (Fig. 5c).

The total dissolved solid varies from 13.80 µg/L to 123.00 µg/L with an average of 57.39 µg/L for groundwater, and from 26.70 µg/L to 80.40 µg/L with an average of 51.94 µg/L for surface water (Table 1 and Table 2; Fig. 5d). This shows that groundwater is more charged with dissolved ions and, therefore, more conductive. The TDS also shows high values in springs and wells on volcanic rocks compared to crystalline basement (Fig. 4). In terms of spatial distribution, the total dissolved solid also shows an opposite distribution to the pH (Fig. 5d). This is ascertained by a Spearman correlation coefficient $r^2_{TDS\text{-}pH}$=−0.5.

3.2 Alkali and alkaline-earth element contents and distribution in waters of Dschang

The alkali and alkaline-earth elements analyzed in this study are Be, Mg, Cs, Rb, Ba and Sr. These elements were considered given their reliability in differentiating between industrial effluents and other sources (Rb/Sr ratio), and their potential effects on crop performance, stock farming and thus, on human life for decades (e.g. Be) (Noor Shah et al. 2016).

They were also selected given their direct heath impact upon anthropogenic exposure (e.g. Ba)



Note: Dashed insert shows the area of optimal distribution of sampling points

Fig. 5 Spatial interpolated distribution maps of (a) temperature; (b) the hydrogen potential (pH); (c) electrical conductivity (EC); (d) total dissolved solids in Dschang

(Kravchenko et al. 2014). These elements represent a major concern in Dschang given a combination of a huge solid waste issue surrounded by artisanal farming systems.

Our target elements (Be, Mg, Cs, Rb, Ba and Sr) present variable proportions are ranging from a minimum content (quantification limit of the different elements) to maximum values of 130 μg/L (Ba) and 10 515 μg/L (Mg) (Table 2). Alkali and alkaline-earth elements are strongly correlated with the physical parameters of waters, especially EC and TDS (Fig. 6a-6e), reflecting their essential contributions in the TDS both in groundwater ($r^2_{Rb\text{-}TDS}$=0.73) and rivers ($r^2_{Rb\text{-}TDS}$=0.95) of Dschang.

Alkali and alkaline-earth elements are highly soluble elements during weathering processes and are the most enriched in percolating solutions. They are also correlated with each other (Fig. 6f) in various waters, i.e. springs, well-water and rivers (e.g. $r^2_{Ba\text{-}Rb}$=0.5 in springs and well-water; $r^2_{Ba\text{-}Rb}$=0.78 in rivers).

The distribution of contents according to rock types generally shows the highest values of alkali and alkaline-earth elements in waters from springs and wells on volcanic rocks. These are Rb, Be, Mg, Cs, and Ba (Fig. 6; Table 1). The highly alkaline geochemistry of these rocks (basalts), and their high alterability/dissolution (ignimbrites) are lithological factors controlling alkali and alkaline-earth elements availability in aquifers and waters.

The Rb/Sr (Fig. 7) ratio of Nirel and Revaclier (1999) is a tracer of the origin of the chemical

Table 2 Descriptive statistics on physico-chemical parameters and alkali and alkaline-earth element contents in waters of Dschang (CV=Coefficient of variation)

Springs and wells	Min	Max	Mean	Standard deviation	CV
pH	4.25	6.62	5.73	0.55	0.10
T (°C)	16.70	26.50	21.82	1.69	0.08
EC (µs/cm)	19.50	172.80	80.68	38.48	0.48
TDS (µg/L)	13.80	123.00	57.39	27.50	0.48
Be	-	2.67	0.19	0.59	3.13
Mg	548.00	10 515.00	3 061.02	2 492.79	0.81
Cs	0.00	0.82	0.16	0.19	1.17
Rb	0.75	36.39	7.16	6.96	0.97
Ba	10.49	343.00	75.62	79.20	1.05
Sr	13.63	442.00	75.52	76.74	1.02
Streams	**Min**	**Max**	**Mean**	**Standard deviation**	**CV**
pH	26.70	6.97	6.72	0.25	0.04
T (°C)	17.20	24.00	21.03	2.31	0.11
EC (µs/cm)	37.60	113.40	73.10	32.71	0.45
TDS (µg/L)	26.70	80.40	51.94	23.15	0.45
Be	-	-	0.00	0.00	-
Mg	1 777.00	3 041.00	2 359.00	494.45	0.21
Cs	0.03	0.18	0.07	0.06	0.82
Rb	3.39	16.19	8.00	5.37	0.67
Ba	11.71	39.95	27.12	12.81	0.47
Sr	31.20	72.23	51.54	16.28	0.32

elements in waters; it then makes it possible to infer potential industrial pollution effluent inputs (e.g. mine and smelt) in which Rb is generally highly enriched compared to natural systems. In the waters analyzed in this study, Sr is highly enriched compared to Rb. Indeed, Sr ranges from 13.63 µg/L to 442 µg/L in groundwater and 31.2 µg/L to 72.23 µg/L in rivers. Rb ranges from 1.17 µg/L to 28.02 µg/L in groundwater and 3.39 µg/L to 16.19 µg/L in rivers (Table 1).

Moreover, the Rb/Sr ratio (Table 1) does not show any particular constraint lithology or even groundwater and surface water (Fig. 7). It varies from 0.01 to 0.28 in groundwater, and from 0.07 to 0.25 in rivers (Table 1). These data indicate no influence of industrial pollution (enriched in Rb) in the distribution of alkali and alkaline-earth elements in groundwater and surface water in Dschang area.

3.3 Spatial distribution of alkaline and alkanine earth elements

In terms of spatial variations, alkali and alkaline-earth data were interpolated for Be, Cs, Rb and Mg contents. The result shows a distinct geochemical anomaly in the center of the densely inhabited area for Be, Cs, Rb and Mg highlight scattered geochemical anomalies with most of the highest values also covering the densely inhabited area (Fig. 8), corresponding to the highest concentration of potentially polluted sites. The Be positive anomaly matches the pH lowest spatial values and evidences no or little correlation with other physico-chemical parameters (Fig. 5b and Fig. 8a), while the Cs, Rb and Mg anomalies instead correlate with EC and TDS spatial distributions (Fig. 5 and Fig. 8).

Hence, upon spatial interpolation, positive alkali and alkaline-earth anomalies reflect optimal physico-chemical conditions of their mobility, especially the lowest pH values. Acidic conditions are indeed catalysts for the solid-fluid interaction and are instrumental in element enrichments in groundwater and surface water.

4 Discussion

4.1 Lithology and physico-chemical parameters constraints on alkali and alkaline-earth elements contents

The analysis of physico-chemical parameters of

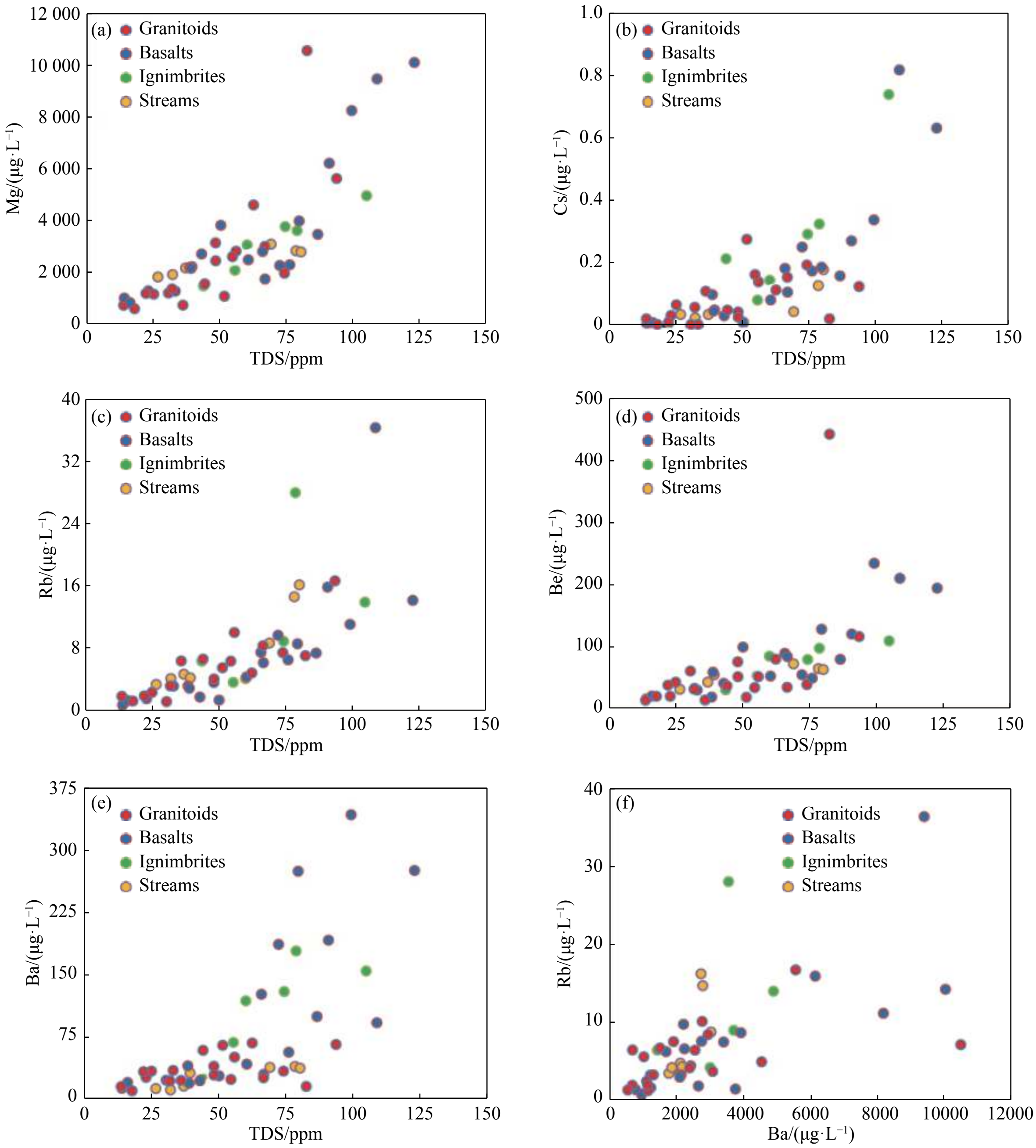


Fig. 6 Binary diagrams of the correlation between alkaline and alkaline earth elements and physico-chemical parameters of waters in Dschang (a) Mg *vs* TDS; (b) Cs *vs* TDS; (c) Rb *vs* TDS; (d) Be *vs* TDS; (e) Ba *vs* TDS; (f) Ba *vs* Rb. Colors represent the different lithological origins of groundwater samples, and surface water

waters in Dschang reveals significant variations in groundwater and surface water, lithology and type of land-use. Spring and well-water are acidic compared to rivers and streams, as already established by Ntangmo Tsafack et al. (2012), and have the highest total dissolved solids (TDS) and electrical conductivities (EC). The water mineralization in groundwater and surface water varies according to the geological context with the highest values from wells and springs predominantly on volcanic rocks compared to granitoids and ignimbrites. The interpolation of these physico-chemical parameters deciphers strong correlations and important anomalies in the densely populated area with the highest density of polluted sites (open dumps, garages and vegetable gardens). This anomaly highlights the highest TDS, EC, and lowest pH, and thus corroborates with changes in physico-chemical parameters of groundwater and surface water with increasing anthropogenic activities.

The study further focused on geochemical

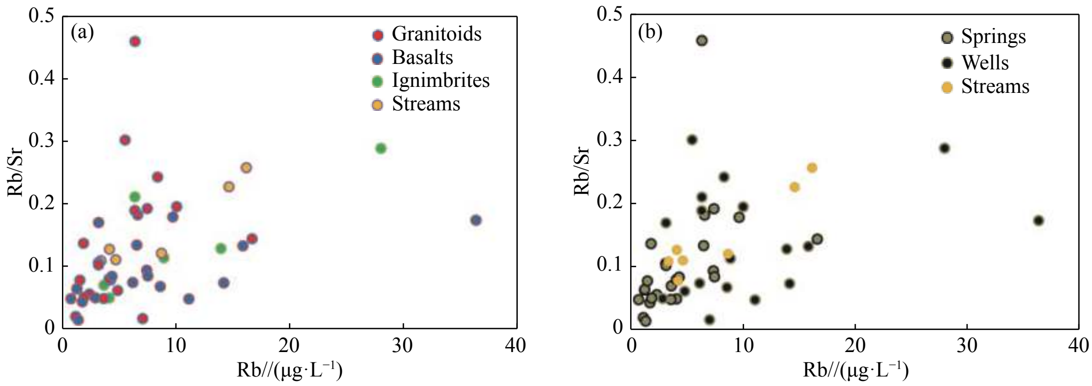
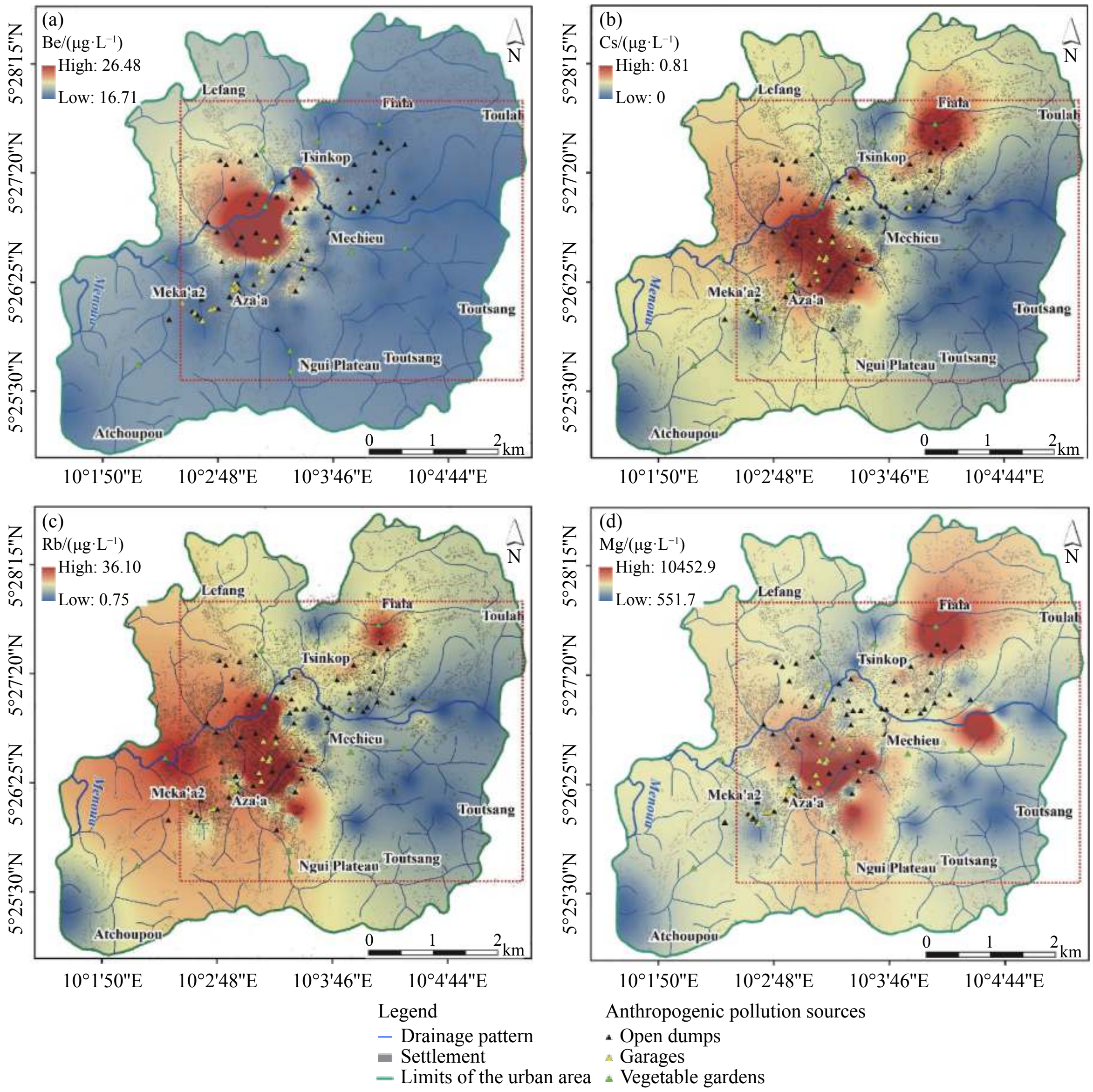


Fig. 7 Rb/Sr ratio relative to lithology and types of waters



Note: Dashed insert shows the area of optimal distribution of sampling points

Fig. 8 Interpolated maps of the spatial distribution of alkaline and alkaline earth elements in Dschang. Settlements and anthropogenic sources of elements distribution are superimposed for a comprehensive analysis

analysis factors constraining alkali and alkaline-earth elements and dynamics in groundwater and surface water in Dschang. These elements are strongly correlated with each other and with physical parameters such as TDS and EC. Their distribution according to lithology shows higher contents on volcanic rocks (basalts and ignimbrites) relative to granitoids. Moreover, the Rb/Sr ratio highlights no significant effluents of industrial origin acting as an external source of alkali and alkaline-earth elements enrichment in Dschang.

These elements are thus likely first controlled mainly by water table components (soils and rocks geochemical components) and released in groundwater and surface water upon dissolution. Indeed, Be, Mg, Cs, Rb, Ba and Sr are highly enriched in mafic rocks (Nkouathio et al. 2008) as opposed to acidic rocks (granitoids). On Mount Bambouto in general and nearby environments, they are found in basalts and basanites in which their proportions reach 16% (Nkouathio et al. 2008), compared to 3% in granitoids (Kwékam et al. 2010). These are the essential components of Fe-Mg minerals, namely olivines and pyroxenes, and Fe-Ti oxides. In rocks evolving under similar weathering conditions in Dschang, the differential abundance of alkaline and alkaline earth elements in groundwater and surface water relative to lithology points out the availability of rocks and related soils. Such a lithological constraint has also been established by Ako et al. (2014), Li et al. (2014), and Njoyim et al. (2020).

4.2 Anthropogenic impact on alkali and alkaline-earth element distribution

Data analysis highlighted a geochemical anomaly of anthropogenic origin. It thereby ascertains awareness of the sanitary risk that should be addressed concerning trace metals (harmful elements) or other elements of significance for water quality. Hence although alkali and alkaline-earth contents remain below WHO standards for drinking water, they demarcate an area of anthropogenic significance within the center of urban area. The circumscribed geochemical anomalies well distinct for Be (Cs, Rb and Mg) correlate with the highest density of polluted sites and dense settlements, and are opposed to lowest values in areas of no or less anthropogenic activities. The interpolated spatial distribution here stands as a modern asset allowing to demarcate a geochemical impact on waters clearly. It corroborates with numerous findings based on classical approaches (Ako et al. 2014; Njoyim et al. 2020) and better links the concentration of the geochemical contaminant in towns of Cameroon to insalubrity and solid wastes distribution.

Physico-chemical constraints with influence on elements mobility favored the enhancement of the anthropogenic impacts in Dschang. The hydrogen potential (pH) here with geochemical anomalies (high correlation with Be) highlights its lowest values in the contaminated area of Dschang. It can be assumed as instrumental for high mobility and alkali and alkaline-earth element enrichment of waters in this area. pH is indeed known as the main factor affecting element mobility in natural environments (Ge et al. 2000; Adamczyk et al. 2016; Benessam et al. 2019). This study thus stands as an instigating factor for alkali and alkaline-earth element distribution after their anthropogenic sources are poured in open dumps, fertilizers, and other human-made and decaying materials. The correlation between densely inhabited zones, open discharges distribution and pH is indeed linked to organic matter decay in open discharges, leading to soluble organic acids that are instrumental for pH decrease (Morris, 2004), thereby enhancing element mobility and enrichment in soils and waters.

5 Conclusions

This research demonstrates the influence of lithology, anthropogenic activities and environmental physico-chemical parameters on abundance and speciation of alkali and alkaline-earth elements in waters in Dschang. The main findings can be summarized as follows:

Alkali and alkaline-earth elements in groundwater and surface water in Dschang naturally originate from rock dissolution. Various lithologies provide differential enrichments in waters with the highest contents from volcanic rocks.

Aside from this natural speciation, these elements are subject to an anthropogenic influence. They are enriched in a contaminated area at the center of the town where geochemical anomalies are evidenced upon geostatistical interpolation.

Anthropogenic alkali and alkaline-earth elements originate from various human activities and mainly from open dumps, which highlight their highest concentration within the broad geochemical anomaly.

Alkali and alkaline-earth elements are strongly correlated with physico-chemical parameters, and the geochemical speciation within the contaminated area is also constrained by the lowest pH, which enhances elements mobility from different sources and their enrichment in groundwater and surface water.

Caution should be made to inhibit anthropogenic geochemical inputs in towns in Cameroon, given the awareness highlighted in this study.

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