EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 62 (2024): 35-44
Journal homepage: https://eqa.unibo.it/

published by

Origin of hydrochemicals and trace metal elements in stream waters of the Passi sub-watershed in the Mungo agricultural basin, South West Cameroon

Dibangue Maurice Bienvenu[1,2*], Nkoue Ndondo Gustave Raoul[1], Gloria Eneke Takem Eyong[3], Suzanne Ngo Boum[1], Lawrence Tatanah Nanganoa[2], Ebobisse Marie Estelle Ines[2], Komba David Eric[1], Etame Jacques[1]

[1] Department of Earth Sciences, Faculty of Sciences, University of Douala, Douala 24157, Cameroon
[2] Laboratory of Soil, Plant and Water Analysis, Institute of Agricultural Research for Development, Ekona, Buea, Cameroon
[3] Centre for hydrological Research, Institute for Geological and Mining Research, Yaoundé, Cameroon

* Corresponding author E-mail: mauricedibangue@yahoo.fr

Article info
Received 1/2/2024; received in revised form 16/5/2024; accepted 9/6/2024
DOI: 10.6092/issn.2281-4485/19025

Abstract
Streams of the Passi sub-watershed, a tributary downstream of the Mungo River, are important sources of water for agro-industrial activities, irrigation, drinking and other household activities of the surrounding population. This study was conducted to determine the water quality of the Passi sub-watershed. Seven water samples were collected from different points including the confluence with the Mungo River and analyzed for physicochemical parameters, hydrochemicals and trace metal elements. Descriptive statistical analysis (DSA) and Pearson correlation were performed to show the relationship between samples and access the sources of chemicals in the watershed. pH was acidic and did not fall within the range of the World Health Organization (WHO) limits for drinking water. Fe and PO_4^{3-} in a single site of Mboma were above the WHO permissible limits of the set quality standards for surface water. Pearson correlation analysis showed a significant positive correlation between Na, Ca, Mg, K, P and Cl indicating a common geogenic origin. DSA and chemical ratios revealed a significant difference in water quality of the Mboma stream which exhibited high concentrations of hydrochemicals and trace metals with respect to the other sampling points, highlighting anthropogenic influence from leaching of fertilizers and discharge of effluent from processing of palm oil. The results of this study point out the need for these stream waters to be managed properly for the benefit of the end-users.

Keywords
Stream water, Hydrochemicals, Trace metal elements, Passi sub-watershed, Water quality, agro-industrial activities.

Introduction

Water is a natural resource that is essential and critically needed for sustenance of life and also for economic development (Mobin et al., 2014; Mishra and Kumar, 2021), yet this resource is increasingly in demand and under threat (Jannat et al., 2019).

The earth's surface is made up of 70% water including rivers, beels, lakes, streams, seas, oceans, ground water and all these forms are very important in life cycle (Arimieari et al., 2014; Jannat et al., 2019). Natural freshwater bodies (e.g., rivers, lakes and streams) make up only 3 % of water in the earth surface (Aniyikaiye et al., 2019) and are the major

DOI: 10.6092/issn.2281-4485/19025

sources of water to fulfill the daily water demand for household, agriculture and industrial activities (Mishra and Kumar, 2021). Rivers contain less than 1 % of the world's freshwater (Tawati et al., 2018) and are key in controlling the global water cycle and the most dynamic agents of transport in the hydrological cycle (Otieno et al., 2017). However, they are subjected to increasing pressures from human activities that impair their ecological equilibrium. Due to the formation of large urban zones, industrial zones and intensive development of agriculture, the need for water and the growth of urban and industrial waste discharges to the rivers with no prior treatment have increased (Iwata et al., 2013; Adefemi and Awokunmi, 2010; Otieno et al., 2017). According to Carpenter et al. (1998), river water pollution is directly connected with agriculture and agro-industrial activities, coupled to untreated household sewages (Igbinosa and Okoh, 2019; Jafarabadi et al., 2016). In Cameroon, rivers are vital for the economy as they are used for drinking, domestic activities, agriculture (irrigation), industries, hydroelectricity, mining activities, fishing, tourism and leisure (Rakotondrabe et al., 2017). Due to human activities (urbanization, agriculture, industries and mining activities), the quality of these rivers is increasingly degraded. The fertility of soils in the Mungo basin has promoted the development of agricultural and agro-industrial activities in this area (Ako et al., 2010). At lower altitudes in the Mungo River plain, the Passi sub-watershed host important agro-industrial activities such as the vast expanses of rubber, oil palm and banana plantations operated by companies such as Cameroon Development Corporation (CDC) and Cameroonian oil palm company (SOCAPALM). Agro-industrial activities such as palm oil production, banana processing and rubber pre-processing plants are sources of chemical effluents. These activities have also promoted a pole of attraction for laborers and enhanced the creation of agglomerations. The risks related to the vulnerability of surface water to pollution are quite obvious in this sub-watershed due to agricultural operations and rapid increase in population (Ako et al., 2010). Thus regular water quality monitoring of the water resources are absolutely necessary to assess the quality of water for ecosystem health and hygiene, industrial use, agricultural use, and domestic use (Radeva and Seymenov, 2020). Therefore, the objectives of this work are to (1) determine and compare the hydrochemical properties and trace metals of streams in the Passi sub-watershed with standards limits of WHO (2) access the sources of chemicals in these surface water in relation to the agricultural and agro-industrial activities carried out in this area.

Materials and Methods

The study area

The Passi sub-watershed which is an entity of the Mungo watershed is located in the south-western part of Cameroon between latitudes 4°10' N and 4°25' N and longitudes 9°25'E and 9°30' E (Fig. 1). It has an area of 288 km^2 and represents about 12% in area of the Mungo watershed. This area is 60% covered by the palm groves of the company SOCAPALM. The rest of the sub-basin is covered by secondary forest bordering the streams and wetlands. Meteorological data of the Passi sub-basin were obtained from the

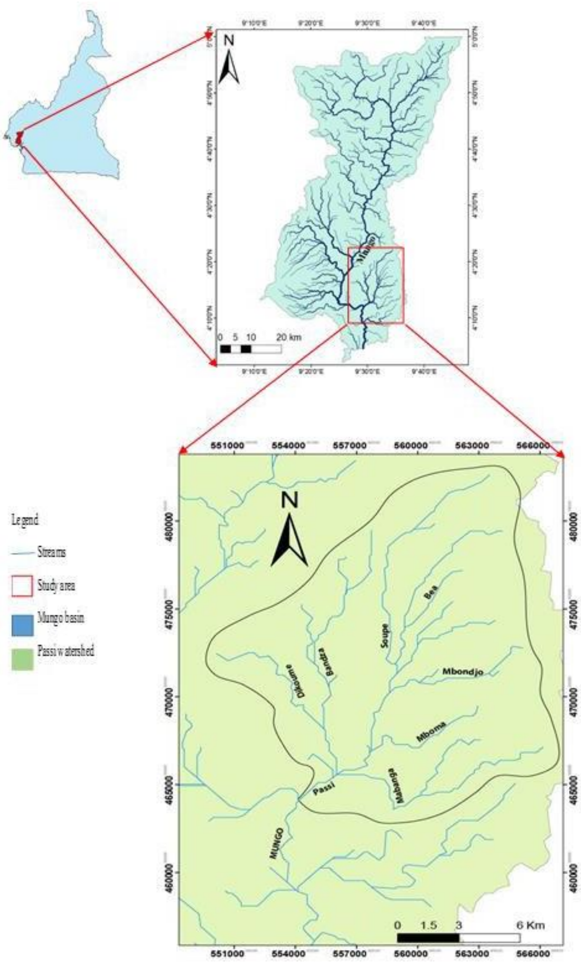

Figure 1. *Map of study area*

DOI: 10.6092/issn.2281-4485/19025

meteorological service of the Cameroon Development Corporation (CDC). This sub-watershed has a coastal tropical climate, characterized by a long rainy season (March to October) and a short dry season (November to February). The regional average annual rainfall in the area is 2140.84 mm (for the 2011 cycle). The wettest months are June, July and August and correspond to the high flow periods while the months of December and January are dry and the temperature vary between 26 and 31°C. The Passi sub-watershed area is located in the coastal plain with lower altitudes less than 70 m made up of essentially sedimentary rocks of Cretaceous to Quaternary age and composed of sands and sandstones (Martin et al., 1996). It is bordered to the north by volcanic deposits of diverse origin which can be divided into old volcanic series (Basalts and andesites), medium age volcanic series (acidic volcanic rocks, trachytes) and young volcanic series (basalts and lapillis) (Geze, 1943; Ako et al., 2010). Southward, the Passi sub-watershed is limited by the coastal mangrove.

Sample Collection

River water samples were collected in May 2012. This period before the wettest months was chosen as it allows a better appreciation of the average chemical composition of the rivers. Six water samples were collected at the middle of the streams (Soupe, Bea, Mbondjo, Mabanga, Passi, Mboma and Passi) from the Passi sub-watershed and one from the Mungo River after its confluence with the Passi stream (Figure 1 and Table 1). Prior to sample collection, all polyethylene and polypropylene bottles were prewashed with concentrated nitric acid, washed with distilled water and MilliQ de-ionized water. The bottles, sterilized syringes and 0.22 µm cellulose acetate filters were rinsed three times with the river water to be collected. Samples for major anions analysis (SO_4^{2-}, Cl^-, NO_3^-, F^-, and PO_4^{3-}), pH, Electrical conductivity (EC), Total dissolved solid (TDS), alkalinity and Temperature measurements were collected in polyethylene bottles while samples intended for major cations (Ca, Mg, Na, and K) and trace elements (V, Cr, Co, Ni, Zn, Cu, As, Rb, Sr, Zr, Ba, Pb, Th, U) were filtered with 0.22 µm cellulose acetate syringes filters before being introduced into polypropylene bottles (Rodier et al., 2009). Two drops of HNO_3^- at $pH<2$ were added in the 30 ml polypropylene bottles to prevent possible chemical changes. The bottles were then stored at 4°C before analysis.

Physicochemical analysis

The physicochemical parameters (pH, TDS, temperature and EC) were measured in the field after sampling with a WTW pH 330 pH meter and a WTW 315i conductivity meter. Alkalinity was determined by titration method (Reimer and Arp, 2011). Elemental analyses of major cations and trace elements were carried out at the laboratory of "Institut de mineralogie et physiques des milieux condenses" (IMPME) of the Pierre and Marie Curie University (Jussieu, Paris France). Cation concentrations were measured with an atomic abso-àrption/emission spectrometer (Perkin Elmer 5100 ZL spectrometer); trace elements were measured with an Inductively Coupled Plasma-Mass Spectrometer (ICP-MS, Perkin Elmer 5000 ZL). Analyses of major anions were performed at the "Laboratoire d'Analyse Géochi-mique des Eaux (LAGE)" of the "Centre de Recherche Hydrologique de Yaoundé", by ion Chromatography (ICS-90 Dionex QUIC).

Statistical analysis

Descriptive statistical analysis (DSA) of physicochemical and chemical parameters: mean values, minimum, maximum, standard deviations, skewness and kurtosis were computed using SPSS-IBM 23. Their Variability were assessed using coefficient of variation (CV). CV less than 20 is regarded as low variability; between 21 and 50 %, CV is considered as moderate variability; while between 51 and 100 %, CV is regarded as high variability. CV above 100 % is considered as very high variability (Phil-Eze, 2010). The hypothesis of data normality was verified by the Shapiro-Wilk and Kolmogorov-Smirnov (K-S) tests.

Results and Discussion

Summary statistics of water parameters

Summary descriptive statistical data (minimum, maximum mean values, standard deviations, skewness and kurtosis) of hydrochemicals and trace elements of the water samples are presented in Tables 1a and b. pH had low variability while the other parameters ranged from high to very high variability. According to Aremu et al. (2011), the quality of raw water normally varies from one site to another depending on its source and its contact with air and environment. Most of the chemical properties showed positive skewness except for Co and Zn. Most of the Kurtosis were greater than 1 or less than -1 (Table 1a and b).
By the Shapiro-Wilk and K-S statistical measurement

DOI: 10.6092/issn.2281-4485/19025

at $P < 0.05$, it was found that most of the properties had non-normal distributions. However, Al, Ti, Mn, Co, Ni, Zn, As, Sr and Zr among the trace elements and F^-, NO_3^- and SO_4^{2-} among the anions had normal distributions (Table 1a and b).

Table 1a. *Descriptive statistical analysis of physical and major cations and anions of river waters at the Passi watershed*

Parameters	Min	Max	Mean	Standard diviation	Skewness	Kurtosis	Shapiro-Wilk	K-S	CV %	WHO standard (mg/L)
pH	5.31	7.21	5.87	0.64	1.89	1.59	0.04	0.12	10.94	6.5- 8.5
EC (μS/cm)	10.00	171.10	50.81	63.28	1.55	1.59	0.01	0.00	124.52	1400
TDS (mg/L)	2.16	59.21	13.95	20.76	2.28	1.59	0.00	0.01	148.75	25-40
TA (ppm)	10.00	120.00	41.43	36.71	2.05	1.59	0.01	0.00	88.61	--
Sodium	0.04	0.74	0.19	0.25	2.37	5.90	0.001	0.00	130.12	200
Magnesium	0.17	5.21	1.67	2.19	1.23	-0.62	0.00	0.00	131.64	125
Aluminium	0.02	0.08	0.03	0.02	1.54	2.59	0.13	0.20*	61.00	0.05-0.2
Potassium	0.07	25.19	4.25	9.28	2.59	6.77	0.000	0.00	218.49	12.0
Calcium	0.30	5.58	1.82	2.00	1.43	1.04	0.03	0.03	110.20	75.0
Phosphorus	0.00	1.64	0.24	0.62	2.64	6.98	0.47	0.48	254.12	--
Fluoride	0.05	0.15	0.08	0.04	1.02	-0.35	0.10	0.07	47.09	1.5
Chloride	0.78	15.90	3.45	5.51	2.60	6.81	0.00	0.00	159.82	250
Nitrate	0.00	0.61	0.18	0.21	1.53	2.51	0.10	0.20*	117.16	50.0
Phosphate	0.00	2.69	0.41	1.01	2.64	6.96	0.00	0.00	246.45	0.1
Sulphate	0.00	3.64	1.41	1.32	1.01	-0.28	0.22	0.15	94.20	250

Table 1b. Descriptive statistical analysis of trace elements of river water at the Passi watershed

Parameters	Min	Max	Mean	Standard	Skewness	Kurtosis	Shapiro -Wilk	K-S	CV (%)	WHO standard (mg/L)
Titanium	0.00	0.00	0.00	0.00	1.49	1.80	0.07	0.12	/	--
Manganese	0.00	0.11	0.05	0.04	0.68	-0.56	0.71	0.20*	78.82	0.4
Iron	0.13	2.75	0.57	0.96	2.62	6.89	0.00	0.00	168.57	0.3
Vanadium	0.05	7.52	1.25	2.77	2.61	6.85	0.00	0.00	221.59	--
Chromium	0.01	1.37	0.29	0.48	2.56	6.66	0.00	0.00	168.17	0.05
Cobalt	0.01	0.81	0.47	0.30	-0.65	-1.14	0.42	0.20*	63.83	
Nickel	0.20	1.21	0.59	0.33	1.08	1.65	0.58	0.20*	55.64	0.07
Zinc	0.00	2.79	1.58	1.07	-0.33	-1.66	0.42	0.20*	67.78	5.0
Copper	0.05	1.75	0.44	0.61	2.18	4.98	0.00	0.04	138.12	2.0
Arsenide	0.05	0.37	0.14	0.11	1.64	2.81	0.06	0.20*	81.62	0.01
Rubidium	0.38	145.24	23.17	53.90	2.63	6.94	0.00	0.00	232.57	--
Strontium	4.03	56.60	21.40	20.04	1.08	0.02	0.14	0.20*	93.62	--
Zirconium	0.02	0.28	0.10	0.09	1.42	1.53	0.12	0.15	94.60	--
Barium	12.28	241.64	53.45	83.69	2.56	6.62	0.00	0.00	156.58	0.7
Lead	0.01	0.20	0.06	0.07	2.08	4.32	0.00	0.00	116.63	0.01
Thorium	0.00	0.02	0.00	0.01	2.03	3.88	0.00	0.00	194.51	
Uranium	0.00	0.05	0.01	0.02	2.57	6.72	0.00	0.00	114.53	0.015

DOI: 10.6092/issn.2281-4485/19025

Variation of hydrochemical characteristics

Physicochemical properties. The results of the variation of physicochemical properties of water samples are given in Table 2. In general, the pH values were relatively homogeneous in the river waters of the Passi sub-watershed. pH was acidic, ranging from 5.3 to 6.1 in comparison with the Mungo River, which has a neutral pH of 7.2. Apart from the Mungo River, all the samples were below the permissible range prescribed by WHO (2011) and FAO (6.5 – 8.5 mg/L). The acidity most probably originated from acidic soils found in this area. Alkalinity in the Passi sub-watershed (between 10 and 40 mg/l) are lower than that measured for the Mungo River (120 mg/L). There is a strong positive correlation (r^2 =0.84) between alkalinity and pH, acidic waters being less alkaline than neutral waters. Except in Mboma River where the total dissolved salt (TDS) were five times higher than the average calculated value. TDS measured for the Passi sub-watershed was among the lowest (between 2 and 6 mg/L) of the world surface waters (Meybeck, 2005; Thorslund and Van Vliet, 2020) and that of the Mungo River was 19 mg/L. The ion balance defined by the normalized inorganic charge balance NICB= (TZ^+ - TZ^-)/ TZ^+ where TZ^+ and TZ^- are respectively the cationic charge (Na^+ + K^+ + $2Mg^{2+}$ +$2Ca^{2+}$ +$3Al^{3+}$ +$2Fe^{2+}$) and the anionic charge (Cl^- + NO^-_3 + $2SO^{2-}_4$) shows anionic deficit, except for the well-buffered Mbondjo and Mabanga streams. The range of TDS fell below the limit of 500 mg/L as prescribed by the US EPA (Verma et al., 1984; US EPA, 1997). Electrical conductivity (EC) was relatively homogeneous in the Passi sub-watershed, varying between 10.0 and 23.2 µS/cm, except at Mboma stream (EC 171.1 µS/cm), higher than the EC for the Mungo river (107.0 µS/cm). This water can be classified as very weakly to weakly mineralize according to the classification of (McNeil and Cox, 2000). These ECs are comparable to those measured in desaturated soils (Braun et al., 2012; Rakotondrabe et al., 2017) and fall below the WHO standard (WHO, 2011).

Table 2 *Physicochemical properties of river waters of the Passi watershed*

Parameters	Soupe	Bea	Mbondjo	Mabanga	Passi	Mboma	Mungo
pH	6.06	5.71	5.31	5.40	5.77	5.60	7.21
TA	40	20	40	10	40	20	120
EC (µS/cm)	23.2	11.5	10.9	10	22	171.1	107
TDS (mg/L)	4.96	3.02	3.57	2.16	5.88	59.21	18.87

Major cations and anions

The major cations and anions were slightly variable with the sampling sites and the Mboma stream having the highest major ions concentration, followed by Mungo (Figure 2). Ca^{2+}, K^+ and Mg^{2+} were the dominant cations in most stream (Soupe, Mbondjo, Mabanga, Bea and Passi) ranging from 0.3 to 1.2 mg/L, 0.08 mg/L and 0.2 to 0.5 mg/L respectively, but lower than those observed in the Mungo River which were 5.57 mg/L, 2.7 mg/L and 4.48 mg/L respectively. Mn^{2+}, Al^{3+}, PO^{3-}_4, Ti^{2+}, Fe^{2+} and Na^+ have very low concentrations in these streams generally below 0.3 mg/L. The Mboma stream had relatively high concentrations of K^+, Mg^{2+}, Ca^{2+}, Fe^{2+} and PO^{3-}_4. Cl^- and SO^{2-}_4 were the dominant anions, with the highest concentrations of 15.9 and 3.64 mg/L respectively for Cl^- and SO^{2-}_4. PO^{2-}_4 had low concentrations below the detection limit (<0.05 mg/L) in the Passi sub-watershed, except at Mboma where maximum value of 2.69 mg/L was recorded, with total phosphorus concentration reaching 4.33 mg/L. F^- and NO^-_3 had concentrations ranging between 0.05 mg/L and 0.15 mg/L and between 0.00 mg/L and 0.61 mg/L respectively. The major pollutant in this area was phosphate at Mboma (2.69 mg/L) and Mungo (0.12 mg/L) sites. These values were above the prescribed limit (0.1 mg/L) for drinking water (USEPA, 1986). Phosphate in Mboma also exceeded the permissible limit for water used for irrigation (FAO, P ≈ 0 – 2 mg/L). This may be due to agro-industrial discharges and anthropogenic activities along the river banks at these sites, especially palm oil processing effluents or from the leaching of fertilizer used in agricultural cultivation of oil palm. This high phosphate level observed at Mboma is associated with high concentrations of Cl, K, Mg, Ca, Fe and SO4 compared to other sites, thus reinforcing the idea of anthropogenic inputs.

Trace elements

Trace elements in the Passi sub-watershed were dominated by Barium, Rubidium and Strontium (Table 1b) which had fairly broad concentration ranges from 12 µg/L to 242 µg/L for Ba; 0.4 µg/L to

DOI: 10.6092/issn.2281-4485/19025

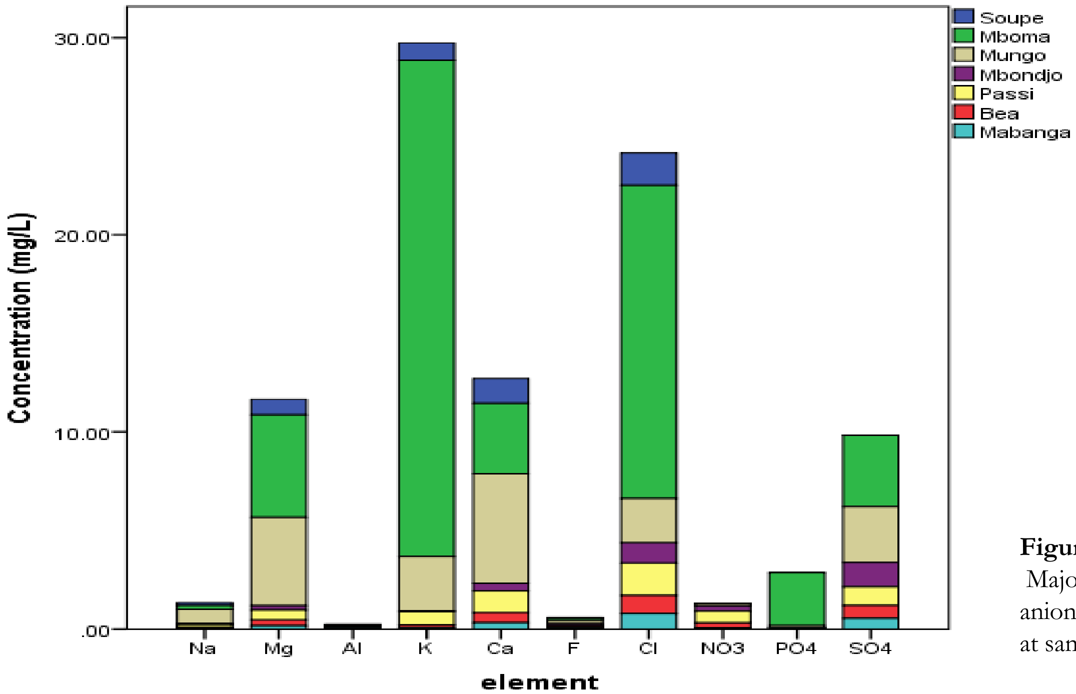

Figure 2
Major cations and anion concerntrations at sampling sites

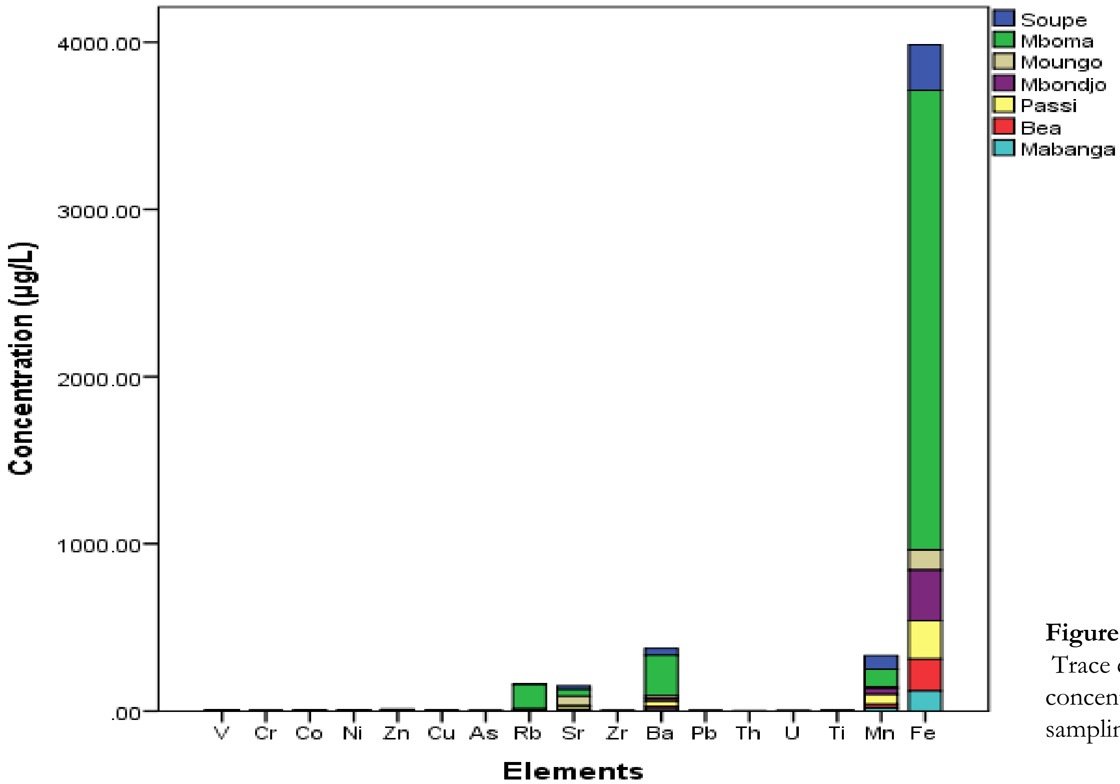

Figure 3
Trace element concentrations at sampling sites

145 µg/L for Rb and 4 µg/l to 40 µg/L for Sr. Other metals have intermediate concentrations from 0.75 µg/L to 2.78 µg/L for Zn; 0.44 µg/L to 1.23 µg/L for V; 0.44 µg/L to 1.12 µg/L for Li; 0.19 µg/L to 1.21 µg/L for Ni. The lowest concentrations were observed for As, Zr, Pb, Th, U with an average below

145 µg/L for Rb and 4 µg/l to 40 µg/L for Sr. Other metals have intermediate concentrations from 0.75 µg/L to 2.78 µg/L for Zn; 0.44 µg/L to 1.23 µg/L for V; 0.44 µg/L to 1.12 µg/L for Li; 0.19 µg/L to 1.21 µg/L for Ni. The lowest concentrations were observed for As, Zr, Pb, Th, U with an average below

DOI: 10.6092/issn.2281-4485/19025

0.1 µg/L. High trace metals concentrations were recorded in Mboma stream, corroborating the observation made for the major ions in this same point. Except for Fe in Mboma and Mbondjo, the concentrations of metals in the study area were noted to be within the recommended limits. However, Fe concentrations were far above the concentrations of other metals (Figure 3), suggesting that the geology is not the only source of Fe in this sites, especially in Mboma stream (Wedepohl, 1991). The high concentrations of Fe observed along with Ni, Cr and Cu (Table 1b) in this sampling point could suggest significant effect of anthropogenic flux into stream, mainly from agro-industrial activities (Zhou et al., 2020).

Inter-element relationships and source of chemicals in streams

In order to determine the pathway and input source of elements in the river water, Pearson correlation analysis was performed. It can be observed a strong correlation between Ca, Mg, Na, K and Cl with each other, indicating their common source rather related to rock weathering and soil. This statement is supported by the ratio Na/Cl, which apart from Mboma stream (Na/Cl= 0.01) is on average Na/Cl= 0.14. This imbalance indicates that rainwater, in which Na/Cl is close to 1 (Wotany et al., 2013), is not the main source of Cl in the Passi sub-watershed. Generally, calcium and magnesium maintain a state of equilibrium with Cl in most natural waters (Chandra et al., 2014; Tawati et al., 2018).

The good correlations r= 0.9 observed between Cl, Ca and Mg show that lithological factor has an influence on the excess of Cl which would arise from the dissolution of sandstones. This is further supported by the Ca/Mg, Ca/Na and Mg/Na ratios, which average 1.7, 8.8 and 5.2 respectively apart from the Mboma stream. These results suggest that the source of these ions results mainly from the weathering of silicate rather than carbonate minerals (Gaillardet et al., 1999; Nkoue et al., 2021). In Mboma stream, Ca/Mg, Ca/Na and Mg/Na ratios of 0.7, 19.8 and 28.9 respectively, were recorded, reflecting additional source, probably due to anthropogenic inputs, since carbonate minerals are rare in this area. Furthermore, there was a strong positive correlation between phosphate and Mg, Ca and K, mainly supported by the high concentrations measured at the Mboma stream. This good correlation reflects the sources of ions related to human activities, particularly through phosphate fertilizers. Aluminium and iron oxyhydroxides are important components of colloids and suspensions, which originate from the precipitation of the secondary minerals of kaolinite, goethite and hematite (Olivia et al., 1999). In this study, although there was weak correlation between these two parameters, by isolating the Mboma stream, the other streams showed negative correlation between Fe and Al that justified the dominance of hematite on kaolinite in the clay fraction in this area. Also, at acid pH observed in these streams, Fe and Al are mainly carried by the particulate phase, which

Table 4. *Pearson correlation for chemical properties*

Parameters	Na	Mg	Al	P	K	Ca	Ti	Mn	Fe	F	Cl	NO_3	PO_4	SO_4	Rb	Sr	Ba
Na	1																
Mg	0.92**	1															
Al	-0.28	-0.17	1														
P	0.74	0.88**	0.00	1													
K	0.89**	0.96**	-0.10	0.88**	1												
Ca	0.96**	0.96**	-0.35	0.85*	0.92**	1											
Ti	0.55	0.74	0.07	0.92**	0.74	0.70	1										
Mn	0.10	0.35	0.14	0.18	0.32	0.14	0.18	1									
Fe	0.21	0.42	0.10	0.29	0.25	0.25	0.29	0.78*	1								
F	0.38	0.34	0.30	0.51	0.29	0.38	0.64	-0.32	0.05	1							
Cl	0.92**	0.92**	-0.14	0.70	0.85*	0.89**	0.59	0.39	0.50	0.40	1						
NO_3	-0.14	-0.43	-0.14	-0.67	-0.54	-0.34	-0.78*	-0.37	-0.14	-0.15	-0.19	1					
PO_4	0.47	0.51	0.45	0.63	0.61	0.47	0.73	0.02	-0.03	0.73	0.51	-0.54	1				
SO_4	0.60	0.53	0.32	0.44	0.42	0.50	0.44	0.03	0.39	0.80*	0.71	0.10	0.61	1			
Rb	-0.26	-0.13	0.75*	0.04	0.04	-0.26	0.23	0.22	-0.13	0.18	-0.13	-0.51	0.63	0.04	1		
Sr	-0.18	0.10	0.65	0.43	0.23	-0.05	0.54	0.30	0.10	0.18	-0.09	-0.81*	0.53	-0.05	0.77*	1	
Ba	-0.51	-0.29	0.25	0.00	-0.11	-0.37	0.07	0.11	-0.29	-0.37	-0.55	-0.63	0.02	-0.70	0.55	0.73	1

**. Correlation is significant at the 0.01 level (2-tailed) - *. Correlation is significant at the 0.05 level (2-tailed).

DOI: 10.6092/issn.2281-4485/19025

could justify the low concentrations in the dissolved fraction. Nevertheless, in the Mboma stream the concentration of Fe is quite high despite a pH that is in the same range to that of the other sampling sites, suggesting iron complexation in this water. Trace elements were dominated by Ba, Rb and Sr. The concentrations of these alkaline and alkaline earth metals in streams are highly influenced by the lithology, depending on whether they drain silicate, carbonate or sulphate substratum (Blum et al., 2001). Overall the relationships between these metals, pH and SO^{2-}_4 are quite significant. When isolating the Mboma stream and the Mungo River, the correlation coefficients become interesting, highlighting the control of these elements in solution by pH and SO_4^{2-}. The balance between barium and sulphates in natural water is such that there is an inverse relationship between the two parameters (Barbier and Chery, 1997). In this study, the high concentrations of Ba correlate well with the low concentrations of SO_4^{2-} which reflects the lithological origin of Ba. Contrary to this prediction of natural equilibrium, the correlation of barium with sulphates is positive in the Mboma stream, indicating an anthropogenic influence. The concentrations of the other trace elements are relatively low in the Passi sub-watershed. The observed concentration ranges are rather characteristic of denatured and highly leached soils, which could thus be attributed to a lithological origin.

Conclusions

This study evaluated the hydrochemical characteristics of surface water in the Passi sub-watershed to access the origin of the water quality in this area. From the results obtained, except for the Mboma stream, the concentrations of hydrochemicals in the Passi sub-watershed reflect the lithological characterristics of the study area. The low concentration of major ions observed in these streams would result to inputs from leached sedimentary soils that characterrize this site, the chemical composition of these waters being mainly related to the dissolution of silicates minerals and sandstones. In the Mboma stream, high concentration of hydrochemicals and trace elements were observed compared to other sampling points, with phosphate and Fe exceeding the permissible limits. The chemical balances in this stream reflected an anthropogenic influence which could result from the leaching of fertilizers used in agricultural practices and discharge effluent from processing of palm oil. Apart from Mboma stream, surface waters analyzed within the period of this study was of good quality with regard to WHO permissible limits for drinking water. The main contaminants of surface water in this sub-watershed come from agro-industrial and agricultural practices. There is need for detailed and continuous monitoring and assessment of chemical species in the area. Furthermore, the population and agro-industries should adopt best management practices for farming and adequate waste management practices to maintain the environmental equilibrium of these streams.

Acknowledgements

This research was carried out at laboratory of the Institut de minéralogie et physiques des milieu condenses (IMPME) of the Pierre and Marie Curie University, Jussieu, Paris – France with the help of Martine Gerard whom we thank greatly for cations and heavy metals analysis. We also thank the Laboratoire d'Analyse Géochimique des Eaux (LAGE) of the Centre de Recherche Hydrologique de Yaoundé – Cameroon, for anions analysis.

References

ADEFEMI S.O., AWOKUNMI E.E. (2010) Determination of physico-chemical parameters and heavy metals in water samples from Itaogbolu area of Ondo State, Nigeria. African Journal of Environmental Science and Technology, 4:145-148. https:/www.academicjournals.org/AJEST

AKO A.A., SHIMADA J., ICHIYANAGI K., KOIKE K., HOSONO T., EYONG G.E.T., ISKANDAR I. (2010) Isotope hydrology and hydrochemistry of water resources in the banana plain (Mungo-division) of the Cameroon volcanic line. Journal of Environmental Hydrology, 18(4):1-3. https:/www.hydroweb.com

ANIYIKAIYE T.E., OLUSEYI T., ODIYO J.O., EDOKPAYI J.N. (2019) Physicochemical analysis of wastewater discharge from selected paint industries in Lagos, Nigeria. International Journal of Environmental Research and Public Health, 16:1235. https://doi.org/10.3390/ijerph16071235

AREMU M.O., OZONYIA G.N., IKOKOH, P.P. (2011) Physicochemical properties of well, borehole and stream waters in Kubwa, Bwari, area council, FCT, Nigeria. Electronic Journal of Environmental, Agricultural and Food Chemistry, 10(6): 2296 – 2304. https:/www.researchgate.net/publication/316605365

DOI: 10.6092/issn.2281-4485/19025

EREOFORIOKUMA N.S. (2014) Assessment of surface water quality in some selected locations in Port Harcourt, Nigeria. International Journal of Engineering and Technology, 3:1146-1151. Technologies and Applications. McGraw- Hill, New York, NY, USA. https:/www.ijert.org

BARBIER J., CHERY L. (1997) Relation entre fond géochimique naturel, teneurs élevées en metaux lourds dans les eaux (antimoine, arsenic, barium, chrome, nickel, plomb, zinc). Application (Auvergne, Limousin), Validation. Pap. BRGM R 39544, 51p.

BLUM A., BARBIER J., CHERY L., PETELET-GIRAUD E. (2001) Contribution à la caractérisation des états de reference géochimique des eaux souterraines. Outils et méthodologie. Rapport BRGM/RP-51093-FR; 2001: p.274.

BRAUN J.J., MARECHAL J.C., RIOTTE J., BOEGLIN, J.L., BEDIMO BEDIMO J.P., NDAM NGOUPAYOU J.R., NYECK B., ROBAIN H., SEKHAR M., AUDRY S., VIERS J. (2012) Elemental weathering fuxes and saprolite production rate in a Central African lateritic terrain (Nsimi, South Cameroun). Geochimica et Cosmochima Acta, 99:243-270. https://doi.org/10.1016/j.gca.2012.09.024

CARPENTER S.R., CARACO N.F., CORRELL D.L., HOWARTH R.W., SHARPLEY A.N., SMITH V.H. (1998) Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, 8559–8568 pp. https://doi.org/10.2307/2641247

CHANDRA S.A., SINGH P.K., TIWARI A.K., PANIGRAHY B., KUMAR A. (2014) Evaluation of hydrogeological factor and their relationship with seasonal water table fluctuation in Dhanbad district, Jharkhand, India. ISH. Journal of Hydraulic Engineering, 21(2): 193-206. https://doi:10.1080/09715010.2014.1002542

ELIKU T., LETA S. (2018) Spatial and seasonal variation in physicochemical parameters and heavy metals in Awash River, Ethiopia. Applied Water Sciences., 8:177. https:// doi. org/ 10.1007/s13201-018-0803-x

GAILLARDET J., DUPRE B., LOUVAT P., ALLEGRE C.J. (1999) Global silicate weathering and CO2 consumption rates deduced from the chemistry of large rivers. Chemical Geology, 159:3-30. https:/doi.org/10. 1016/S0009-2541 (99)00031-5

GEZE B. (1943) Géographie physique et géologie du Cameroun occidental. Mém. Mus. Hist. Nat., XVII. 320.

IGBINOSA E.O., OKOH A.L. (2009) Impact of discharge wastewater effluents on the physico-chemical qualities of a receiving watershed in a typical rural community. International Journal of Environmental Sciences and Technology, 6:175–182. https://doi.org/ 10.1007/BFO3327619

IWATA T., NAKANO S., INOUE M. (2003) Impacts of past riparian deforestation on stream communities in a tropical rain forest in Borneo. Ecological . Application. 13: 461-473. https://doi.org/10.1890/1051-0761(2003)013

JAFARABADI A., MASOODI M., SHIRIfiNIYA M., BAKHTIYAN A. (2016) Integrated River Quality Management by CCMEWQI as an effective tool to characterize surface water source pollution (Case Study: KarunRiver, Iran). Pollution, 2(3):313–330. https://doi. org/10.7508/pj.2016.03.006

JANNAT N., MOTTALIB M.A., ALAM M.N. (2019) Assessment of Physicochemical Properties of Surface Water of Mokeshbeel, Gazipur, Bangladesh. Journal of Environmental Science Current Research, 2:014. https://doi.org/10.24966/ESCR- 5020/100014

MARTIN D., SIEFFERMANN G., VALLERIE M. (1966) Sols rouges du Nord Cameroun. *Cahier ORSTOM. IV* (3) : 3-28.

MCNEIL V.H., COX M.E. (2000) Relationship between conductivity and analyzed composition in a large set of a natural surface-water samples, Queensland, Australia. Environmental Geology. 39:1325-1333. https:/doi.org/ 10.1007/s00254990033

MEYBECK M. (2005) Looking for water quality Hdrological Processes, 19(1):331-338. https:/doi.org /10. 1002/ hyp.5778

MISHRA S., KUMAR A. (2021) Estimation of physicochemical characteristics and associated metal contamination risk in the Narmada River, India. Environmental Engineering Research, 26(1):190521. https://doi.org/10.4491/eer.2019.521

MOBIN M.N., ISLAM M.S., MIA M.Y., BAKALI B. (2014) Analysis of Physicochemical Properties of the Turag River Water, Tongi, Gazipur in Bangladesh. Journal of Environmental Science and Natural Resources, 7(1):27- 33

NKOUE NDONDO G.R., NGO BOUM S., SONG F., TAKEM G.E., KOMBA D.E., NLEND B., ETAME J. (2021) Hydrogeochimical characteristics and Quality Assessment of surface water in an Agricultural Area in Equatorial Africa: The Mungo River Basin, South West Cameroon, Central Africa. Journal of Geoscience and Environment Protection, 9:165-181. https:/doi.org/ 10.4236/gep.2021.93010

OLIVIA P., VIERS J., DUPRÉ B., FORTUNE J.P., MARTIN F., BRAUN J.J., NAHON D., ROBIN H. (1999) The effect of organic matter on chemical weathering: study of small tropical watershed: Nsimi-Zoetele site, Cameroon. Geochimica et Cosmochima Acta, 63:4013-4035. https://doi.org/10.1016/S0016-7037(99)00 (306-3

DOI: 10.6092/issn.2281-4485/19025

OTIENO A.A., KITUR E.L. GATHURU G. (2017) Physico-Chemical Properties of River Kisat, Lake Victoria Catchment, Kisumu County, Kenya. Environment Pollution amd Climate Change, 1(4):4. https://doi.org/10.4172/2573-458X.1000137

PHIL-EZE P.O. (2010) Variability of soil properties related to vegetation cover in a tropical rainforest landscape. Journal of Geography and Regional Planning, 3(7):177-184. https://www.academicjournals.org/JGRP

RADEVA K., SEYMENOV K. (2020) Assessment of Physicochemical Properties and Water Quality of the Lom River (NW Bulgaria). In: Nedkov S., Zhelezov G., Ilieva N., Nikolova M., Koulov B., Naydenov K., Dimitrov S (Eds: Smart Geography, Key Challenges in Geography, Springer Internationnal Published, pp. 129-140.

RAKOTONDRABE F., NGOUPAYOU J.R.N., MFONKA Z., RASOLOMANANA E.H., ABOLO A.J.N., ASONE B. L., AKO A.A., RAKOTONDRABE M.H. (2017) Assessment of Surface Water Quality of Bétaré-Oya Gold Mining Area (East-Cameroon). *Journal of Water Ressource and Protection*. 9 (8), 960-984. https://doi.org/10.4236/jwarp.2017.98064.

REIMER A., ARP G. (2011) Alkalinity In: Reitner, J., Thiel V. (eds) Encyclopedia of Geobiology Encyclopedia of Earth Sciences Series. Springer, Dordrecht. https://doi.org/10.1007/978-1-40420-9212-18

RODIER J., LEGUBE B., MERLET N. (2009) L'Analyse de l'Eau. 9è edition, Dunod Paris, 1579 p.

TAWATI F., RISJANI Y., DJATI M.S., YANUWIADI B., LEKSONO A.S. (2018) The Analysis of the Physical and Chemical Properties of the Water Quality in the Rainy Season in the Sumber Maron River - Kepanjen, Malang – Indonesia, *Resources and Environment*, 8(1):1-5. https://doi.org/10.5923/j.re.20180801.01

THORSLUND J., VAN VLIET M.T.H. (2020) A global dataset of surface water and groundwater salinity measurement from 1980_2019. Scientific Data 7 (1): 1-11. https://doi.org/10.6084/m9.figshare.12455954

VERMA S.R., SHARMA P., TYAGI A., RANI S., GUPTA A.K., DALELA, R.C. (1984) Pollution and saprobic status of eastern Kalinadi, Limnologia, 15, 69–133

U.S. ENVIRONMENTAL PROTECTION AGENCY. (1986) Quality Criteria for Water, Gold Book Quality Criteria, EPA 440/5-86-001, Office of Water, Washington.

U. S. ENVIRONMENTAL PROTECTION AGENCY. (1997) Exposure Factors Handbook (Final Report), EPA/600/P-95/002F a-c, Washington,

WEDEPOHL K.H. (1991) The Composition of the Upper Earth's Crust and the Natural Cycles of Selected Metals in Natural Raw Materials, Natural Resources, in: E. Merian (Ed.), Metals and their Compounds in Environment: Occurrence, Analysis and Biological Relevance, VCH, New York, , pp. 3-17. https://doi:10.1002/9783527619634.ch1

WHO. (2011) Guideline for Drinking Water Quality. Fourth Edition. WHO Technical Report Series, 2:;564.

WOTANY E.R., AYONGHE S., FANTONG W.Y., WIRMVEM M.J., TAKESHI O. (2013) Hydrogeochemical and Anthropogenic Influence on the Quality of Water Sources in the Rio del Rey Basin, South Western, Cameroon, Gulf of Guinea. African Journal of Environmental Science and Technology, 7, 1053-1069. https://doi:10.5897/AJEST2013.1578

ZHOU Q.Q., YANG N., LI Y.Z., REN B., DING X.H., BIAN H.L., YAO X. (2020) Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017. Global Ecology and . Conservation, 22:e00925. https://doi:10.1016/j.gecco.2020.e00925