Hydrogeochemical Characteristics and Quality Assessment of Surface Water in an Agricultural Area in Equatorial Africa: The Mungo River Basin, South West Cameroon, Central Africa

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Abstract

The Mungo River and its tributaries represent the major sources of water supply for agriculture and drinking purposes for the Douala city and the south western agricultural region of Cameroon. In this study, the surface water hydrochemistry was investigated at 12 locations to determine the hydrochemical and heavy metals characteristics and to assess the suitability for drinking and irrigational purposes. Results of water samples collected along the main channel and tributaries showed that the major ions were dominated by $Ca^{2+} > Na^+ > Mg^{2+} > K^+ > NH_4^+$ and $HCO_3^- > NO_3^- > SO_4^{2-} > Cl^- > F^- > PO_4^{3-}$, with concentrations varying between 0 to 60 mg/l. Heavy metal concentrations were relatively weak, dominated by Fe > Mn > As > Cd > Zn > Se. The main hydrochemical facies types revealed primarily 52% Ca-Na-HCO$_3$ and 48% Ca-Mg-HCO$_3$. Base on Gibbs diagram and relative ion ratios, the hydrochemical characteristics are derived from weathering of silicate rocks and atmospheric source. The influence of anthropogenic factors including agro-industrial activities on the hydrochemical characteristics was less marked. The chemical composition of the water samples was compared with the drinking water standards and only the concentration of Fe was above the WHO guide limits in a single sample at Passi. The evaluation of the water quality for irrigation showed that 95% of water samples are suitable for irrigation in almost all soil types. According to the water quality index (HPI, HEI and Cd), this water is considered of excellent quality for consumption. The results provide a preliminary database for sustainable management of water resource in the Mungo River basin.

1. Introduction

Rivers, streams and lakes, have long been important sources of water for drinking and agricultural uses. The proportion of drinking-water supplies relying on surface water is extremely variable regionally, but globally, surface water is estimated to cover about 50% of drinking water needs. As population pressures increase in many parts of the world, protecting surface water sources and preventing deterioration of their quality are becoming a fundamental requirement. Surface water interacts hydrochemically with environment in the area where they flow. The degree of these interactions significantly depends on hydro-meteorological, fluvial, anthropogenic, and geological processes (Winter et al., 1998), and affects the hydrochemical composition of water bodies on the local and regional scales (Ako et al., 2012; Sanga et al., 2020). Consequently, surface water quality is subjected to hydrochemical changes that are indicative of the climate and environment changes such as increased precipitation, evaporation, domestic and industrial activities, agriculture and breeding, human and animal consumption (Zhang et al., 2019). The hydrochemical characteristics represent an important factor determining the multi-purpose use of water (Khatri & Tyagi. 2014; Huang et al., 2014). To better identify the basic processes affecting the chemical composition of the surface water, an understanding of the main factors controlling the ion and metal composition is required (Güler & Thyne, 2004; Huang et al., 2014). Since anthropogenic influences (domestic and industrial uses, agrochemical loadings, irrigation and increasing exploitation of water resources), reduces the suitability of surface water and induces costly water treatment, hydrochemical investigations can help to assess the water quality for drinking and for agricultural uses.

The evaluation of water quality in most developing countries has become a relevant issue in recent years, especially due to concerns that freshwater will be a scarce resource in the future (Aminiyan et al., 2016). Measuring the concentration of heavy metals (Zn, Ni, Pb, Cd, Cr, As and Cu) and determining the Water Quality Indices (WQI: the heavy metal pollution index and heavy metal evaluation index) are essential in monitoring drinking water quality (Ghaderpoori et al., 2018). Permissible limits for various ions in drinking water are given by WHO (1993). From an agricultural perspective, the suitability of water for irrigation use can be determined by sodium percent (Na %), magnesium hazard (MH), residual sodium carbonate (RSC), sodium adsorption ratio (SAR), permeability index (PI), salinity index (Brindha & Kavitha, 2015).

The Mungo River basin (MRB) is located in a volcanic area where the fast

weathering nature of volcanic materials would be an important process controlling the concentration of ions in surface and groundwater (Bartarya, 1993; Endeley et al., 2001; Ako et al., 2012). Volcanic mountains slopes are known to possess soils that are amongst the best for agriculture (Driessen& Dudal, 1991). The fertility of soils in the MRB has promoted the development of vast industrial plantations and pre-processing factories for agricultural products. At lower altitudes in the Mungo River plain, many economic activities such as extensive plantations and agro-industries of bananas, palms, rubber have enhanced the creation of agglomerations. Throughout the course of the river, sand quarries have developed, often constituting a risk of contamination for stream water. The quality of the waters of the Mungo River and its tributaries are thus subject to the influence of discharges from domestic and agro-industrial activities and natural processes of inputs from runoff and groundwater discharges from slopes springs. To these influences, one can add the in-stream remobilization of deposited sediments, which create a strong turbidity likely to promote the transport of precipitated metals. The MRB is intensively exploited downstream, both for agricultural and agro-industrial purposes and pumping for drinking water supply. It is the main water resource for almost 6 million people, including drinking water supplies for the towns of Kumba, Muyuka, Buea, Mbanga and the megapolis of Douala and its environs. Despite the fact that water from the river is needed to maintain the productivity and daily life of the residents and the ecological balance, catchment-based hydrochemical studies of surface water in the MRB are few (Ako et al., 2012; Tabot et al., 2016). Therefore, the hydrochemichal characterization of the surface water in the MRB is significantly important to check the risk of water pollution and managing surface water resources. Early studies of the hydrochemical characteristics of surface flows, springs and groundwater in South Western Cameroon (Ako et al., 2012; Wotany et al., 2013; Ako et al., 2014, Tabot et al., 2016) showed controls of silicate minerals weathering on major ions (Ca^{2+}, Mg^{2+}, Na^+ and K^+) while NO_3^- and Cl^- were of anthropogenic origin. Oceanic monsoon chloride-rich/sulfate-rich rainwater seems to affect spring water chemistry at low-altitude toward the coastal part of the basin. Nitrate contamination were attributed to N-fertilizers, sewerage, animal waste, organic manure, pit latrines (Ako et al., 2014). The discharging of such groundwater to surface freshwater of the Mungo River and tributaries could alter their quality. The anthropogenic risk pollution reported by Tabot et al. (2016) for the Lake Barombi Bo, which is an important source of fresh water for the Kumba population and its surroundings (more than half a million people), could be a warning signal for the assessment and protection of surface water of the MRB.

This study aims to analyze the hydrochemical characteristics of the Mungo River Basin (MRB) to access: 1) the sources of chemical composition and 2) the suitability for drinking and irrigational purposes of surface water in the Mungo River and tributaries.

2. Site Description

The MRB extends from 4˚05' - 5˚30'N; 9˚20' - 9˚40'E is located both in the South West and Littoral Regions of Cameroun (Central Africa). It covers a surface area of 4200 km² and spreads over altitudes between the coastal plain and the mountain ranges (Figure 1), shaped into four geomorphological units: 1) the coastal plains (altitude < 150 m); 2) undulating low hills (200 m < altitude < 500 m); 3) high hills dotted with valleys and interfluves (500 m < altitude < 1500 m) and 4) mountain massifs of Mount Rumpi, Mount Bakossi and Mount Cameroon (altitude > 1500 m).
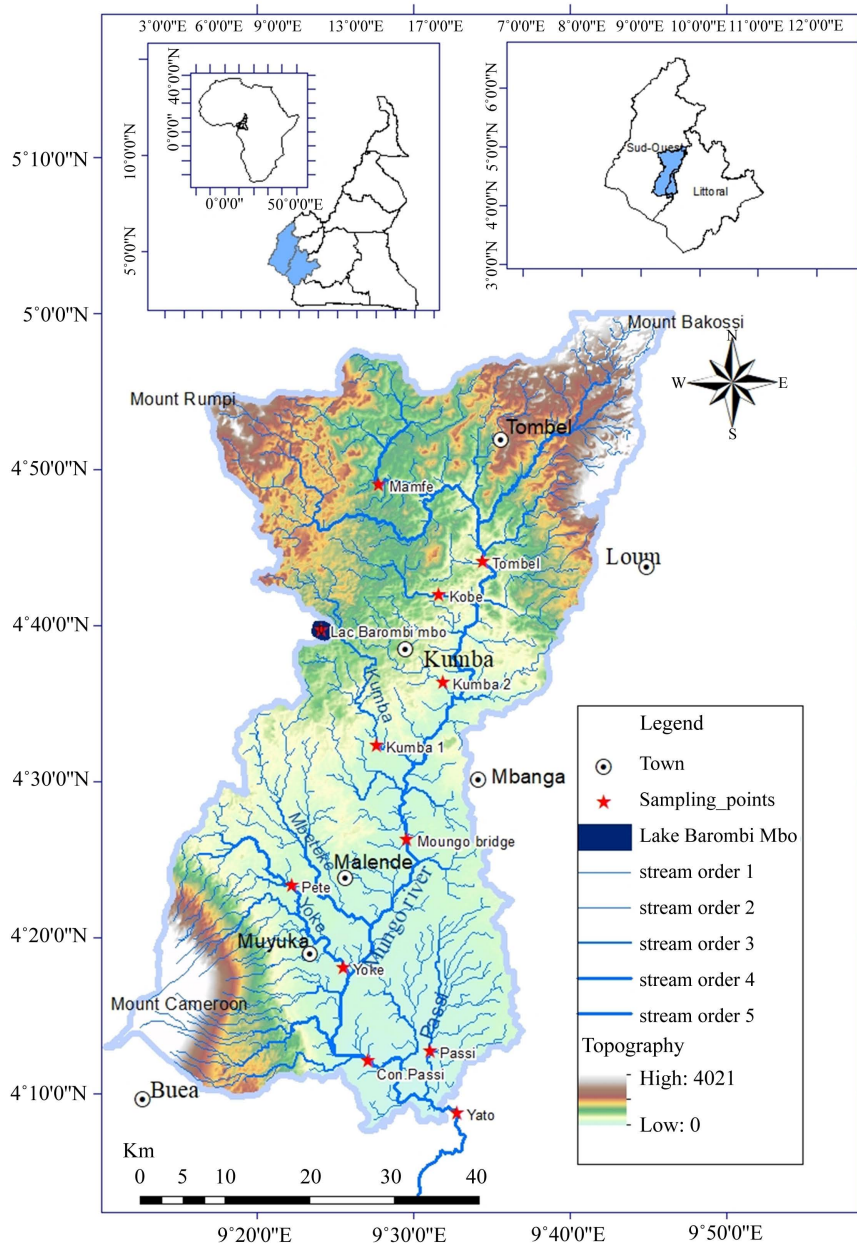
Figure 1. Map showing the location of the settlements within the Moungo River basin and the sampling stations.

The Mungo River and its tributaries drain large agricultural areas as well as semi-urban and urban areas where the population density reach up to 150 inhabitants/km² (Ako et al., 2014). Its hydrographic network extends from the Rumpi and Bakossi mountains and is joined on the right bank by Kobe, Kumba, Mbeteke, Yoke streams as well as numerous torrents that run down the slopes of the mountains. On the left bank, the MRB network is sparsely densified, mainly made up of the upstream torrents from Mont Bakossi and the Passi stream in the coastal plain. The Mungo River flows southward through the upstream valley of volcanic materials. At lower altitudes downstream, it flows through sedimentary deposits of the coastal plain, before entering the mangrove swamps at the Wouri estuary, after a course of 150 km (Olivry, 1986). West of the MRB, there is a large natural volcanic lake, the Barombi Mbo, which is the source of Kumba stream and an important reservoir of fresh water for the Kumba town and its surrounding.

The climate is of equatorial type with two quite distinct seasons. A rainy season extending from June to October is influenced by humid monsoon summer with maximum rainfall in September. The dry season extends from November to May. Ten-year (from 2003-2013) meteorological data from local stations (Malende, Meandja, Mukondje, Kompina, Penda Mboko, Matouke, Missellele and Sonne) show that the mean annual air temperature was 28°C in the southern coastal plain, and lower than 21°C at the northern mountainous area. About 185 rainfall days are recorded per year with annual rainfall varying from one station to another between a minimum of 1571 mm and a maximum of 3432 mm, of which 70% occurs during the period from June to October.

The MRB lies on a Pre-Cambrian basement made of crystalline schist, gneiss and intrusive granites which constitute the northern edge of the Congo craton. In the south of the basin there is a coastal plain of 20 m altitude and hills with altitude less than 60 m where the crystalline basement is covered with essentially sedimentary rocks of Cretaceous to Cenozoic age, made up of sands and sandstones (Martin & Sieffermann, 1966), above which are found recent volcanic rocks (basaltic lava and deposits volcanoclastic) (Tamen et al., 2007). Thick alluvia are found downstream in the coastal border of the basin, where sedimentary series dominate. The north of the coastal plain is characterized by volcanic rocks of diverse origin, which according to Gèze (1943) are made up of old volcanic series (basalts and andesites), medium age volcanic series (acidic volcanic rocks and trachytes) and young volcanic series (basalts and lapillis).

Three types of soil are developed in the MRB area, 1) yellow and red ferralitic soil in the coastal plain (60%), developed on sandstone bedrock Sieffermann (1973); 2) hydromorphic soil (30%), founded in the mangrove at coastal border and in the swampy wetland; and 3) brown young soil on the slopes of the mountains (10%), derived from basalts and lapillis of the young volcanic series. Well preserved volcanic cones provide gently sloping lava flows covered by ash and pumice deposits, from which soils have developed to produce fertile arable lands devoted to intensive agriculture. The main types of land covers are green

rainforest in the north (40%), Atlantic littoral forest in the south (11%), farm-land (45%) and water area (4%). The MRB is one of the greatest agricultural area of the southern Cameroon, including a large proportion of surface watering to support banana production and other crops in the region.

3. Sampling

Sampling was done during the rainy season in August 2016. Surface water samples were collected at 12 locations, distributed as follows: 5 samples along the main course of the Mungo river (Manfe bridge, Tombel bridge, Mungo bridge, Passi confluent, and Yato bridge); 6 samples in the main tributaries (Kobe, Kumba 1 and 2, Pete, Yoke and Passi) and 1 sample in the lake Barombi Mbo (Figure 1). The sampling polyethylene bottles (PET) were pre-washed by soaking in 15 N nitric acid for six hours and then thoroughly rinsed with deionized water and finally dried in an electric oven. A multi-parameter instrument (YSI. Inc) was used to measure the pH, temperature, total dissolved solid (TDS) and electrical conductivity (EC). The water samples were filtered using a 0.45 μm cellulose acetate membrane syringe filter. The syringe filters were rinsed with the sampling water before the collection of the water sample. Sample for cations and heavy metals analysis were collected into an 80 ml pre-cleaned PET bottle and acidified with two drops of 15 N nitric acid. An aliquot of non-acidified water was collected in a 125 ml PET bottle for the alkalinity titration and anion analysis. The sampled bottles were carefully sealed using Parafilm® film and stored in a refrigerator at 4°C.

4. Analytical Methods

Concentrations of major cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and major anions (F^-, Cl^-, NO_3^-, PO_4^{3-}, SO_4^{2-}) were measured by ionic chromatography (HPLC - DIONEX Ics-90) with a precision of ±2% at the Laboratory of Water Analysis (LAGE) of the Institute of Geological and Mining Research (IRGM). HCO_3^- was derived from headline volumetric titration of alkalinity with hydrochloric acid using Grant method, with an analytical error of <3%. The charge balance error (CBE = (Σcations − Σanions)/(Σcations + Σanions) ×100) was calculated to validate the quality of major ion analysis, which was within <4%. The analysis of heavy metals (Cu, Cr, Zn, Ni, Cd, Se, As, Fe and Mn) was conducted at the Laboratory of Plants, Soils, Water and Fertilizer Analysis (LAPSEE) of the Agricultural Research Institute for Development (IRAD) thanks to ICP-OES (Perkin's Elmer 8200). The quality control of the analysis was done using the laboratory reagent blanks as a continuing check on performance. The determined mean concentration from three analyses of the reagent blanks was ±3% of the stated values.

5. Data Processing

The hydrochemical classification of water using the Piper diagram was per-

formed by the software DIAGAMMES 6.5. The chemical indices used in the evaluation of surface quality for irrigation in the MRB include; Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP or %Na), Magnesium Ratio (MAR) and Kelly Ratio (KR).

Sposito & Mattigod (1977) proposed the calculation of the SAR as follows:

$$SAR = \frac{Na^+}{\left[\left(Ca^{2+} + Mg^{2+}\right)/2\right]^{1/2}} \tag{1}$$

Todd (1980) defined the soluble sodium percentage (SSP), or Na%, as follows:

$$SSP \text{ or } \%Na = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \tag{2}$$

Paliwal (1972) proposed an index for computing the MAR using the following equation:

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \tag{3}$$

(Kelly, 1963) defined Kelly's Ratio (KR) which derived from sodium measured against calcium and magnesium as follows:

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \tag{4}$$

In these equations, all the concentrations of ions are expressed in mg/l.

Heavy Metal Pollution Index (HPI) that was proposed by Mohan et al., (1996) is used to access the influence of natural and anthropogenic activities based on the important parameters on water chemistry (Ghaderpoori et al., 2018). The HPI calculation provides a simple indicator of water quality and is based on some very significant heavy metals elements. The relative HPI is computed from the equation below:

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \tag{5}$$

where n is the number of samples considered, W_i is the unit weight age of the ith parameter and Q_i is the sub-index of the ith metallic element. Q_i is determined by Equation (2).

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{S_i - I_i} \times 100 \tag{6}$$

where M_i is the average concentration of element i in a given sample. I_i is the maximum ideal concentration for element i. S_i is the standard value of the ith metallic element. The critical value for HPI is 100 (Prasad & Bose 2001).

The contamination index (Cd) summarizes the combined effects of several quality parameters considered harmful to domestic water (Backman et al. 1997). It is calculated from equation below:

$$Cd = \sum_{i=1}^{n} C_{fi} \tag{7}$$

where C_{fi} represents the contamination factor.

$$C_{fi} = \frac{C_{Ai}}{C_{N1}} - 1 \tag{8}$$

C_{Ni} and C_{Ai} represent analytical value and upper permissible concentration of the ith component, respectively.

The Heavy Metal Evaluation Index (HEI) method gives an overall quality of the water with respect to heavy metals (Edet & Offiong, 2002). The HEI is computed as:

$$HEI = \sum_{i=1}^{n} C_i / H_{max} \tag{9}$$

where C_i is the monitored value of the ith parameter and H_{max} the maximum permissible concentration of the ith metal parameter.

6. Results and Discussion

6.1. General Hydrochemical Characteristics

Descriptive statistics were used for the hydrochemical characteristics of surface water sampled in the MRB as shown in Table 1. The pH values of the study area ranged from 5.45 - 7.07, with the mean of 6.67 ± 0.42, indicating that the water

Table 1. Hydrochemical parameters and descriptive statistics of the Mungo River and tributaries (major cations and anions, dissolved oxygen (DO) and alkalinity are expressed in mg/l, total suspended sediments (TSS) in g/l, electrical conductivity (EC) in µs/cm).

|	Mamfe	Tombel	Bridge	Con. Passi	Yato	Kobe	LBM	Kumba 1	Kumba 2	Pete	Yoke	Passi	Min	Max	Mean	SD	VC	Skewness
pH	6.98	6.72	6.78	6.9	6.85	6.56	6.91	6.51	6.74	6.57	7.07	5.45	5.45	7.07	6.67	0.42	0.06	−2.47
EC	29.1	30.0	35.5	53.2	54.1	31.5	54.3	39.3	44.5	40.2	167.8	16.8	16.8	167.8	49.69	38.91	0.78	2.93
TSS	41.2	8.0	31.2	37.8	31.2	9.6	10.0	34.6	38.4	35.6	0.2	14.2	0.2	41.2	24.33	14.66	0.6	−0.43
D.O	91.4	97.2	95.3	75.3	86.8	97.6	88.0	72.3	93.4	75.1	88.1	73.02	72.3	97.6	86.13	9.67	0.11	−0.40
T˚C	21.8	25.0	23.2	24.6	24.2	23.2	26.7	24.1	24.7	23.7	23.4	23.7	21.8	26.7	24.0	1.19	0.05	0.43
Alc	239	197	216	194	150	239	300	199	228	190	983	100	100	983	269.58	229.96	0.85	3.18
Ca	2.22	2.18	3.25	2.20	2.22	2.33	2.55	3.18	3.60	3.19	4.70	3.27	2.18	4.70	2.91	0.77	0.27	1.10
Mg	0.48	0.94	1.42	1.63	1.64	1.55	0.83	2.79	1.39	1.29	1.84	2.12	0.48	2.79	1.49	0.61	0.41	0.47
Na	1.27	1.65	1.99	2.83	3.04	1.09	1.48	2.28	1.75	1.79	1.29	2.92	1.09	3.04	1.95	0.68	0.35	0.55
K	0.80	0.94	1.29	0.87	0.77	0.56	0.87	1.01	0.9	1.09	1.55	1.44	0.56	1.55	1.01	0.29	0.29	0.65
NH$_4$	0.00	0.00	0.00	0.00	0.12	0.00	0.07	0.00	0.00	0.22	0.25	0.00	0.00	0.25	0.06	0.09	1.68	1.50
HCO$_3$	2.5	0.5	1.9	1.9	2.3	0.6	18.3	12.1	13.9	11.6	60.0	6.1	0.5	60.0	10.98	16.57	1.51	2.71
SO$_4$	0.36	0.43	0.56	1.12	1.13	0.19	0.31	0.80	1.02	1.65	6.15	0.43	0.19	6.15	1.18	1.62	1.38	3.05
PO$_4$	0.08	0.14	0.02	0.00	0.05	0.01	0.03	0.03	0.06	0.03	0.02	0.00	0.00	0.14	0.04	0.04	1.01	1.65
NO$_3$	0.00	1.30	1.15	1.21	1.43	0.99	0.34	2.87	3.44	2.08	1.49	0.53	0.00	3.44	1.4	1.00	0.71	0.80
Cl	0.22	0.25	0.40	0.68	0.69	0.44	0.63	1.23	1.45	0.86	2.78	0.89	0.22	2.78	0.88	0.7	0.8	1.99
F	0.04	0.05	0.05	0.05	0.03	0.04	0.04	0.04	0.04	0.05	0.10	0.01	0.01	0.1	0.05	0.02	0.46	1.48

were slightly acidic. The Electrical Conductivity (EC) measured in all samples ranged between 16.80 - 167.78 µs/cm, with an average of 48.90 ± 38.91 µs/cm. In the main course of the Mungo River, the EC values increase downstream after the confluence of the Yoke tributary where the highest EC value was obtained. These EC of surface water were basically lower than the WHO permissible limits (1000 µs/cm). From the average ion concentrations, the relative abundance of cations and anions were as follows: Ca^{2+} 39.2% > Na^+ 26.3% > Mg^{2+} 20.1% > K^+ 13.6% and HCO_3^- 75.6% > NO_3^- 9.7% > SO_4^{2-} 8.1% > Cl^- 6.0%. The concentration of total suspended sediments (TSS) was higher in the main course of the Mungo River and in urban tributaries, which could result from sand quarry activities and urban runoff, generating high turbidity.

In general low concentrations of ions were obtained for all the water samples. Ca^{2+}, Na^+, Mg^{2+} and K^+ have normal distributions, with skewness values lower than 2 and VCs lower than 0.5. However, skewness values of HCO_3^-, SO_4^{2-} and Cl^- were ≥2 and their VCs, including NO_3^- were >0.5, showing heterogeneous distribution that would result from the highest concentration of observed in Yoke stream. A positive correlation were observed between Ca^{2+} vs. Cl^- + SO_4^{2-} + NO_3^- and Cl^- vs. SO_4^{2-} + NO_3^- (**Figure 2**), indicating that these species are belonging to the same geogenic sources and may be affected by the same processes. The highest concentrations and VCs recorded at Yoke and Kumba could suggest additional influences in this sampling sites.

The Piper diagram is suited for graphical presentation of the major ions to quickly determine the hydrochemical facies of the surface water (Zhang et al., 2019; Jiang et al., 2020). The hydrochemical types in the MRB are presented in **Figure 3**. It can be seen from the anion distribution that the dispersion of HCO_3^- dominated the waters, while some sampling points were controlled by NO_3^- and SO_4^{2-}. From the cation distribution, all water sample points fell in the center of the triangle, which is the mixing zone. The Ca-HCO₃ water type occur in all the water samples. The dominant hydrochemical type of the surface water of the MRB was Ca–Na-HCO₃-NO₃, followed by Ca-Mg-HCO₃-SO₄. The hydrochemical type of the Lake Barumbi Mbo was Ca-Na-HCO₃, shifting downstream in Kumba stream to Ca-Mg-HCO₃-NO₃ or Ca-Na-HCO₃-NO₃ type.

(a)   (b)
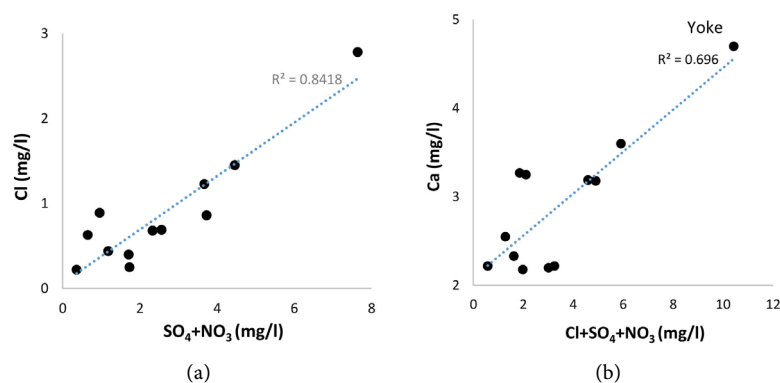
Figure 2. Linear correlation of water quality parameters.
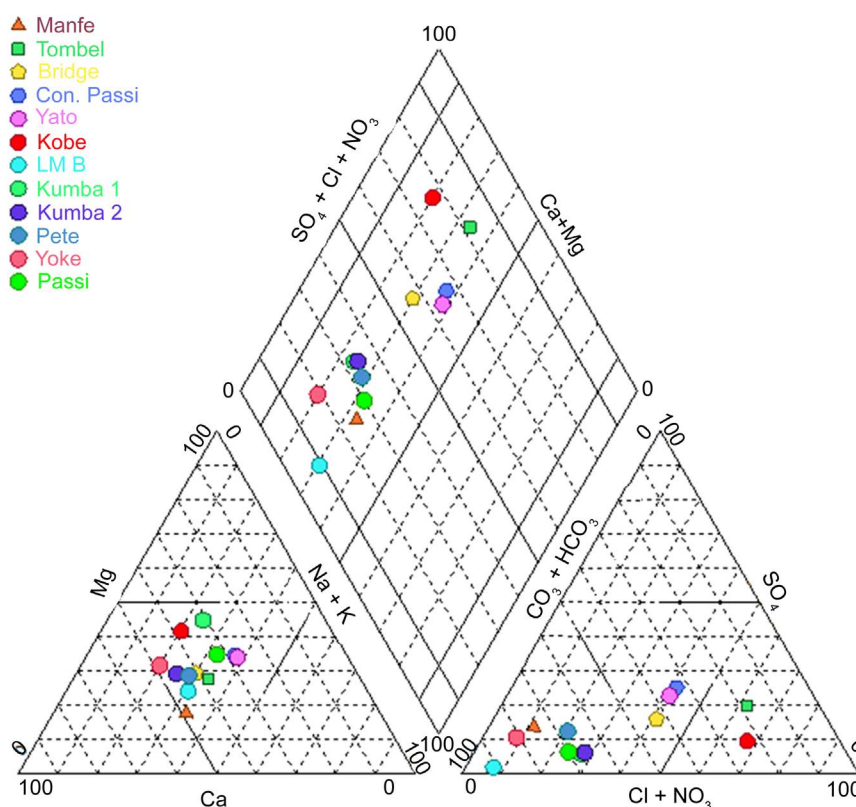
Figure 3. Piper plot of analyzed surface water characteristics in the MRB.

6.2. Origin of Major Ions

Gibbs diagram (**Figure 4(a)**) which shows the relative fractions for ions plotted against the total dissolved solids (TDS) on a logarithmic axis, indicates that the samples are mainly in the atmospheric control area, extending toward the rock-weathering control area. The Ca^{2+}/Na^+ versus Mg^{2+}/Na^+ and HCO_3^-/Na^+ ratios (**Figure 4(b)** and **Figure 4(c)**) were analyzed to determine the type of rock weathering source associated with the surface water chemistry characteristics (Isidoro & Aragüés, 2007). The results indicate that the source of chemical components in surface water of the study area is dominated by the weathering of silicate rock. This is consistent with the results in the Gibbs diagram, in which the samples get closer to atmospheric with a trend towards rock-weathering control areas. This suggests that rock weathering is apparently the dominant process influencing surface water hydrochemistry in the study area. Ako et al. (2012) studied spring water chemistry in the area of mount Cameroon in which the downstream river system of the MRB originates and observed that two main water types (Ca-Mg-HCO₃ and Ca-Na-HCO₃) represent spring waters in this area. This is consistent with the results obtained in the present study. In another study Benedetti et al. (2003) have found that there are no significant carbonate minerals in the soils and aquifers in this area implying that the dominance of bicarbonate water type could therefore be the result of the weathering of volcanic rocks. We therefore conclude that the weathering of volcanic rocks is the major
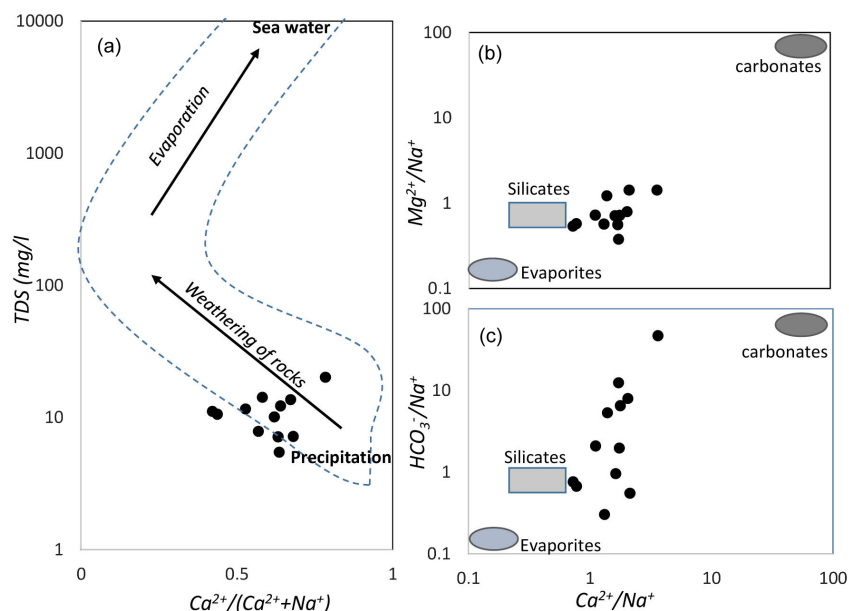
Figure 4. Gibbs (1970) plot for cations (a); end-member diagrams of ionic ratios in surface water ((b) and (c)).

control on the stream and spring water compositions. This assertion is consolidated by Ako et al. (2012) who indicated that cations and bicarbonate ions are derived from weathering of the basaltic minerals, and this occurs primarily within the aquifer where waters are in contact with fresh basaltic minerals. Although Cl^-, SO_4^{2-} and NO_3^- concentrations were low, relatively significant concentration were founded in Yoke and Kumba, indicating additional sources for these species. Ako et al. (2012) found that oceanic monsoon chloride-rich/sulfate-rich rainwater seems to affect spring water chemistry at low-altitude, what could be the case for Yoke where high Cl^-, SO_4^{2-} concentrations were observed. Elsewhere, leaching through urban leaching may contribute nitrates to Kumba stream.
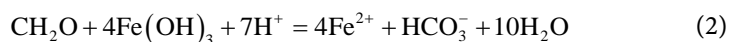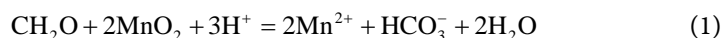
6.3. Heavy Metal Composition

Results of heavy metal analysis for the MRB are given in Table 2. Cu, Cr and Ni were below the detection limit in all the sampling points, while Zn and Se were detected in only two sites (*Manfe and Tombel*), with concentrations not exceeding 0.005 and 0.03 µg/l respectively. Cd was found downstream of the Mungo River at Con. Passi and Yato and in all the tributaries, with concentrations varying between 0.06 and 0.74 µg/l, with an average of 0.31 ± 0.27 µg/l. As was found in all the sampling points, with concentrations between 0.01 and 0.96 µg/l, with a mean of 0.21 ± 0.30 µg/l. Although Fe was not found in all samples, it appears in a wide range, from 1 to 364 mg/l, significant concentrations been observed in the Mungo River at Manfe (40 mg/l) and Yoke stream (100 mg/l) and the highest concentration of 364 mg/l exceeding the WHO (2011) limit observed in Passi stream. Mn appeared only associated with high Fe concentration at Yoke and Passi, where it had concentrations of 6 and 21 mg/l respectively. The correlation

Table 2. The concentrations of heavy metals (in μg/l) in the Mungo River Basin (Fe and Mn are expressed in mg/l) and applied standards for calculation of HPI and HEI.

	Mamfe	Tombel	Con, Passi	Yato	LMB	Kumba2	Yoke	Passi	MCL	Wi	Ii	Si
Fe	40	bdl	bdl	1	bdl	1	100	364	200	0.005	200	300
Mn	bdl	1	bdl	bdl	bdl	bdl	6	21	50	0.02	500	100
Cu	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	1000	0.001	2000	1000
Zn	0.005	0.003	bdl	bdl	0.17	bdl	bdl	bdl	5000	0.0002	3000	5000
Ni	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl				
Cd	bdl	bdl	0.066	0.059	0.45	0.41	0.74	0.116	3	0.3	3	5
Se	0.027	0.018	bdl	bdl	bdl	bdl	bdl	bdl				
As	0.108	0.106	0.104	0.097	0.109	0.109	0.1	0.96	50	0.02	10	50
Cr	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	50	0.02	50	1
Pb	na	na	na	na	na	na	na	na	1.5	0.7	10	100

bdl (below the detection limit); na (not analyzed).

among the physico-chemical properties (pH and EC) and significant heavy metals (Cd and As) concentrations were studied to characterize the origin of heavy metals in the MRB. High As concentration was correlated with lower pH and high Cd concentration with high CE (Figure 5). This pattern of As and Cd could suggest natural source controlling these heavy metals in the study area. Indeed, the low concentrations of heavy metal observed in the MRB could be related to the pedo-geochemical background of the studied area. This observation can be justified by the positive correlation observed between CE and Cd, almost related to silicate weathering. The high concentrations of Fe and Mn observed at Passi were associated to low pH and may be released from the soil and the aquifer. Ngon Ngon et al. (2015) found that the lithology of this coastal plain is made up of clayey materials, generally ferruginous, in which iron and manganese nodules can be found. Dissolution of iron and manganese nodules in clay soil can be considered through chemical reactions of Fe and Mn oxides in the aquifer:

$$CH_2O + 2MnO_2 + 3H^+ = 2Mn^{2+} + HCO_3^- + 2H_2O \tag{1}$$

$$CH_2O + 4Fe(OH)_3 + 7H^+ = 4Fe^{2+} + HCO_3^- + 10H_2O \tag{2}$$

According to Rawson et al. (2017), this dissolution of Fe and Mn minerals causes As adsorbed on them to be released into the water system. This may explain the relatively high concentration of As (0.96 μg/l) associated with high concentration of Fe and Mn recorded in Passi stream. The low concentration of heavy metals could be the results of dilution since sampling was done during the rainy season (Yi et al., 2020). In addition, within the observed pH range, some metals such as As, Cd, Cu, Cr and Ni would precipitate, lowering the concentration of the dissolved fraction (El Bouraie et al., 2010). This process may explain the absence of these metals in some sampling points.
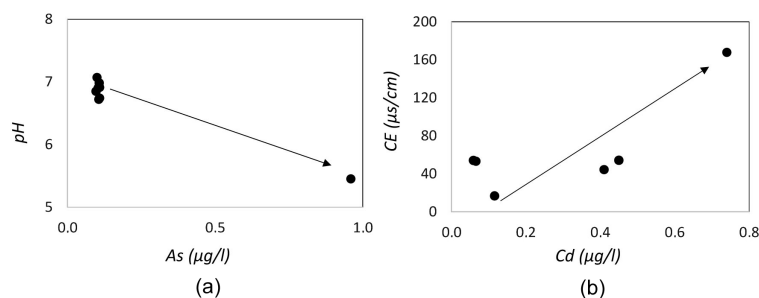
Figure 5. Relationship between pH vs. As (a) and CE vs. Cd (b).

## 6.4. Water Quality Assessment for the Study Area

6.4.1. Suitability of Surface Water for Agriculture

The calculations of four indices of sodium related parameters (SAR, SSP, MAR and KR) were performed to analyze the irrigation suitability of surface water in the study area (Table 3). SAR represents the relative activity of Na^+ in soil exchange reactions and is used to evaluate the degree of alkalization of water. From the classification of irrigation suitability made by Richards (1954) four types of water can be distinguished as excellent (<10), good (10 - 18), doubtful (19 - 26) and unsuitable (>26). As shown in Figure 6(a), all samples in the study area are suitable for agricultural irrigation based on SAR values. The suitability for irrigation based on SSP was classified as excellent (<20%), good (20% - 40%), doubtful (40% - 60%) or unsuitable (60% - 80%). In the study area, approximately 58% of water samples were found as doubtful with regard to SSP, while 42% was good for irrigation (Figure 6(b)). According to Szabolcs and Darab (1964), the safe limit for MAR is 50 above which the water is not suitable for irrigation. As shown in Figure 6(c), all the water samples were within the safe limit and do not pose threat due to magnesium. When classifying the suitability of irrigation water based on KR, a value more than 1 means that there is too much sodium in water for irrigation and a value less than 1 means the water is suitable for irrigation. In the study area, all the water samples were suitable for irrigation with regard to KR (Figure 6(d)).

The irrigation suitability evaluation of surface water in the MRB based on SAR, SSP, MAR and KR showed that all the surface water is suitable for irrigation. Although the SSP showed 58% of doubtful samples, the influence of Na concentration on irrigation suitability can be minimized because these samples are not in a critical state (Table 4). In fact carbonate and bicarbonate are in very low concentrations to form precipitates with calcium and magnesium that reduces the permeability. Nevertheless, the high SSP observed downstream of the Mungo River may be indicative of an early marine salt rise at these points which are located in the areas where the river water is pumped for drinking and irrigation purposes.

6.4.2. Suitability of Surface Water for Drinking Purpose

The calculated heavy metal pollution index (HPI), contamination index (Cd) and heavy metal evaluation index (HEI) for surface water, based on monitored
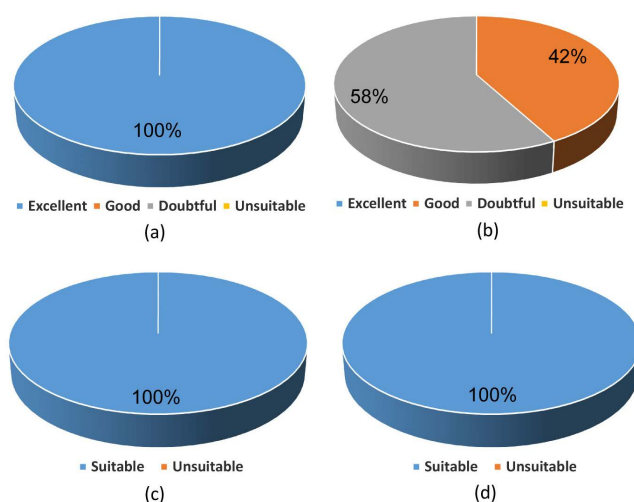
Figure 6. Water suitability based on SAR, Na%, MAR and KR. (a) SAR; (b) SSR or NA%; (c) MAR; (d) KR.

Table 3. The calculated indexes of sodium related parameters at the sampling points.

	Mamfe	Tombel	Bridge	Con. Passi	Yato	Kobe	LBM	Kumba 1	Kumba 2	Pete	Yoke	Passi
SSP (Na%)	43.4	45.4	41.3	49.1	49.7	29.8	41.0	35.5	34.7	39.1	30.3	44.7
SAR	1.1	1.3	1.3	2.0	2.2	0.8	1.1	1.3	1.1	1.2	0.7	1.8
KR	0.5	0.5	0.4	0.7	0.8	0.3	0.4	0.4	0.4	0.4	0.2	0.5
MAR	17.8	30.1	30.4	42.6	42.5	39.9	24.6	46.7	27.9	28.8	28.1	39.3

Table 4. The calculated indices, HPI and HEI, at the sampling points for heavy metals.

	Mamfe	Tombel	Con. Passi	Yato	LBM	Kumba2	Yoke	Passi
Cd	−7.80	−7.98	−7.98	−7.97	−7.85	−7.86	−7.13	−5.70
HPI	55.45	55.63	54.71	54.80	49.28	49.84	44.68	53.69
HEI	0.20	0.02	0.02	0.03	0.15	0.14	0.87	2.30

values of heavy metal and the used constants of Mn, Cu, Zn, Cd, As, Cr and Pb are presented in Table 4. Pb was not analyzed in this study and its concentration was assumed to 0 μg/l, the same applied to other metals whose concentration was below the detection limit (bdl). The threshold risk for water quality based on HPI is 100 (Prasad & Bose, 2001; Ghaderpoori et al., 2018). If HPI is more than 100, water cannot be used for drinking. Measured values of HPI index for this study was below 100 (44.68 - 55.63), indicating that all the surface waters of the study area was suitable for drinking purpose with regard to heavy metals. The contamination index (Cd) was used as reference to estimate the extent of metal pollution. According to Al-Ami et al. (1987), Cd may be grouped into three categories as follows: low (Cd < 1), medium (Cd = 1 - 3) and high (Cd > 3). The range of value of Cd in this study was −7.98 to −5.70, suggesting the absence of

pollution for these waters. Edet and Offiong (2002) proposed the classifications of the HEI index as follows: low (less than10), medium (between 10 and 20) and high (more than 20). The level of HEI in surface water of the MRB (between 0.02 and 2.3) shows that the water quality falls within the zone of water suitable for drinking.

7. Conclusion

Based on the data of stream hydrochemistry and heavy metals, the surface water quality of the Mungo River Basin, one of the most important agricultural basins in Cameroon, has been evaluated for multipurpose uses, aiming to understand the processes controlling the regional hydrochemistry and to assess the suitability of surface water for irrigation and drinking purposes.

Low content of ions was recorded in this study area and normal distribution was found for cations. Heterogeneous distribution was observed for HCO_3^-, SO_4^{2-}, Cl^- and NO_3^- due to relatively high concentrations observed in Yoke and Kumba streams. The hydrochemistry was dominated by two types, the Ca-Na-HCO_3-NO_3 and Ca-Mg-HCO_3-SO_4. The chemical composition was mainly affected by silicate weathering; there is a partial influence of atmospheric input from chloride-rich/sulfate-rich rainwater at Yoke stream. Despite the agro-industrial and agricultural activities and the inflow of urban/suburban sewage, the effects of anthropogenic source pollution were less marked in the hydrochemistry of the surface water, significant concentration of NO_3^- recorded in Kumba stream has been attributed to urban leaching. Very low concentrations of heavy metals were found in the study area, far below the WHO permissible limits for drinking water, except Fe at Passi stream, which concentration exceeded the permissible limit and might be due to the release from soil and aquifer following the dissolution of iron minerals of ferruginous nodules in clayey soil.

Despite the fact that 58% of water samples were found doubtful with regard to SSP, carbonate and bicarbonate were in very low concentrations to form precipitates that affect permeability. Hence, the evaluation of surface water for irrigation and drinking purposes based on SAR, SSP, MAR and KR showed that all the surface water was below the critical limits and then suitable human uses.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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