

Evaluation of Groundwater Suitability for Domestic and Irrigational Purposes: A Case Study from Mingoa River Basin, Yaounde, Cameroon

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ABSTRACT

A baseline study involving analyses of subsurface water samples from the Mingoa river basin (longitude: 11°30'E; latitude: 3°52'N) in migmatitic complex in Yaounde Cameroon (central Africa) was carried out to assess their suitability for drinking, domestic and agricultural purposes. Study results show that pH is ranged between $5.1 \leq \text{pH} \leq 5.8$ and then, induces acidic waters. Groundwater samples are generally characterized by low conductivity values, of which 100% are within the range ($55 \leq \text{EC} \leq 1500 \mu\text{S}/\text{cm}$). The mean values of the major cations ($\text{Ca}^{2+}, \text{Mg}^{2+}, \text{Na}^+, \text{K}^+$) and anions ($\text{SO}_4^{2-}, \text{Cl}^-, \text{HCO}_3^-$) are all within the World Health Organization (WHO) standards. Two of the springs sampled have nitrate (NO_3^-) contamination. Even though NO_3^- contamination and acidic waters exist in some of the springs, the majority of the springs are excellent for agricultural and domestic purposes. Assessment of the groundwater for agricultural irrigation revealed two main categories. These are low salinity-low sodicity (C1-S1) and medium salinity-low sodicity (C2-S1), using the US Salinity Laboratory (USSL) classification scheme. As much as all of the samples plotted in the "excellent to good" and "good to permissible" categories on the Wilcox diagram. The groundwater in the study area may therefore be regarded as good for irrigation activities. The major identifiable geochemical processes responsible for the evolution of the various ions are mineral weathering, chemical reactions and anthropogenic activities.

Keywords: Groundwater; Suitability; Mingoa Watershed; Yaounde; Cameroon; Central Africa

1. Introduction

Groundwater is a valuable natural resource; it occurs almost in all geological formations beneath the earth surface not in a single widespread aquifer but in thousands of local aquifer systems with similar characteristics [1]. The presence of dissolved minerals coupled with some special characteristics of groundwater as compared to surface water makes it a preferred choice for many purposes [2,3]. The chemical quality of groundwater depends on the characteristics of the soil and rock media through which it passes to the groundwater zone of saturation [4-7]. It is also dependent on the length of time the water is stored in the ground (residence time) [8]. Various researchers carried out the hydrochemical characteristics of groundwater and quality of groundwater in different basins as well in urban areas [9-13].

Groundwater has become the major source of water supply for domestic, industrial and agricultural sectors of

many countries. In recent years, many cities of developing countries as Yaounde are experiencing rapid demographic growth due to rural exodus. Actually, more than 48% of Cameroon population lives in town [14] and 39% still remain in monetary poverty [14]. Majority of the people in our country depend on agriculture (that is cultivators and agricultural laborers). More than 7.5% of the Yaounde population practices the urban and peri-urban agriculture in the swampy area to produce leaf vegetables for commercialization and consumption [15]. In this area, both for drinking as well as irrigation purposes substantial amount of groundwater is being used. Hence, evaluation of groundwater resources for development requires an understanding of the hydrogeologic and hydrochemical properties of the aquifers [5].

This study was conducted to determine physical and chemical quality of spring's water from the Mingoa watershed located in urban area of Yaounde and to evaluate its suitability for domestic and agricultural uses.

2. Characteristics of Mingoa Watershed

The Mingoa watershed (**Figure 1**) is one of 16 basins that make up city of Yaounde which is located within the Mfoundi catchment. This Mingoa watershed in which the outlet is found at the entrance of the “municipal lake” covers an area of 129 ha between longitude $11^{\circ}29'50''$ and $11^{\circ}30'34''$ East and between latitude $3^{\circ}51'47''$ and $3^{\circ}52'23''$ North. It is drained by the Mingoa’s river supplied by the springs “Tap Tap” and “Commando” and its tributary the “Ntougou” and constitutes the principal source of the municipal lake. The rugged landform shows interfluves in form of stairs. The average altitude is 734 metres.

The equatorial climate of Guinean type with 4 seasons governs the region. The average annual pluviometry registered on a period of 77 years (1926-2006) is of 1561 ± 223 mm. The annual temperature varies from 22.3°C to $24.6^{\circ}\text{C} \pm 2.3^{\circ}\text{C}$. The relative humidity is about 72% and remains constantly high all through during the year. The bedrock is formed of migmatitic gneiss [16] on which are found on reddish and yellowish ferrallitic soil and hydro-morphic soil [17]. These geological formations composed by quartz (25% - 30%), K-feldspar (15% - 20%), plagioclase An_{30-38} (20% - 30%), garnet (15% - 20%), biotite (5% - 10%) and disthene (2% - 5%) [16], constitute potential water zones more or less solicited.

The total population is valued at about 21,500¹ inhabitants in 2003 [18]. In this study area, a diversified and heterogeneous settlement is developed and characterised by the existence of accommodation and trade zones coupled by the agricultural fields. In this agricultural field which is situated in the lowland area, women and youth without employment develop vegetables crops and horticulture for consumption and commercialization to increase household’s income. These vegetables crops are generally developed during the dry season and consist to fresh vegetables, lettuces, tomatoes and carrots. By cons, horticulture concerns the production of flowers solicited by populations and beautification projects in city.

3. Data and Method

Seven springs were identified and plotted on map using Global Positioning System (**Figure 2**). In the hydrological year period, discharge was monthly measure such as collecting discharge in a known volume of the bucket over a specific period of time.

Dry, clean and sterilized plastic bottles were used to get fresh aquifer water for sampling. At first the bottles were rinsed by the spring’s waters and then collect the water. The collected samples were carefully sealed with proper labeling which preserved in a refrigerator at a

¹The actual population which is about 35,000 inhabitants is estimated by using the growth rate of Cameroon (5%).

temperature of about 4°C until laboratory analyses. For all samples, temperature, pH and electrical conductivity (EC) were determined in the field with standard field equipment (WTW/LF 91 temperature/conductivity meter and WTW/pH 90 meter). Samples were then collected and stored in 50 ml preconditioned high-density polythene bottles. Samples were analyzed in the laboratory of wastewater research unit of university of Yaounde I for the major ions chemistry employing standard method [19]. The absolute error of the measurements is estimated at 0.02 mg/l.

The analytical data obtained were processed for detailed geochemical and statistical analysis.

Diagramme software package was used for graphical, numerical and modeling studies. It features a fully customizable database of physical and chemical parameters and it provides a comprehensive selection of analysis tools, calculations and graphs for interpreting water quality data. Basic parametric statistical parameters such as min, max, median, standard deviation (SD) and average were computed along with correlation analysis and factor analysis was carried out by using XLSTAT version 7.5.2.

The sodium adsorption ratios (SAR) of the samples were determined using Equation (3). These values were then plotted against the corresponding EC values on a semi-log plot in accordance with the US Salinity Laboratory [20] scheme. Wilcox diagrams [21] were also plotted to determine the suitability of the groundwater for irrigation activities in the area. The parameters such as SAR and percent sodium (Na%) were calculated to evaluate the suitability of the water quality for agricultural purposes.

4. Results and Discussion

4.1. Physicochemical Parameters of Groundwater

A summary of the physico chemical analysis of the groundwater samples is presented in **Table 1**.

The pH values of the groundwater varied from 5.06 to 5.77 with an average value 5.41, indicating an acid type of water. All the groundwater samples are out of the permissible limit prescribed by WHO. EC values ranges from 111.4 to 401.0 $\mu\text{s}/\text{cm}$ with an average value of 232.4 $\mu\text{s}/\text{cm}$. The maximum limit of EC in drinking water is prescribed as 833 $\mu\text{s}/\text{cm}$ according to WHO standard. All the samples are lower than the permissible limit. When we compare these EC values with the values (< 100 $\mu\text{s}/\text{cm}$) generally observed in superficial aquifer of crystalline zone [22-24], it appears that spring’s water in Mingoa watershed are polluted due to the presence of nutrients such as NH_4^+ with concentrations ranged between 1.50 and 53.25 mg/l.

The mean concentration of cation (in meq/l) is in order $\text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$ while for the anion (in meq/l) it is $\text{Cl}^- > \text{HCO}_3^- > \text{NO}_3^- > \text{SO}_4^{2-}$.

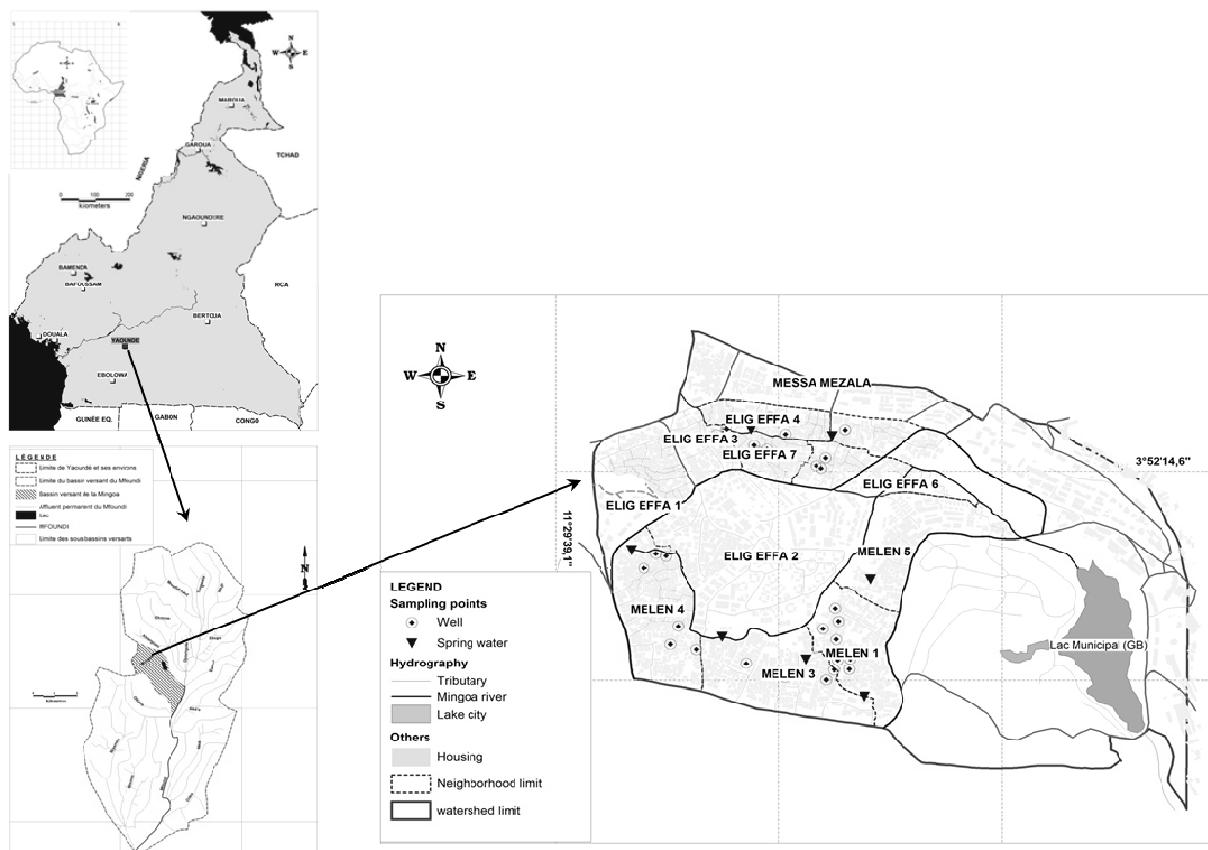


Figure 1. Location of the Mingoa drainage basin (Yaounde-Cameroon).

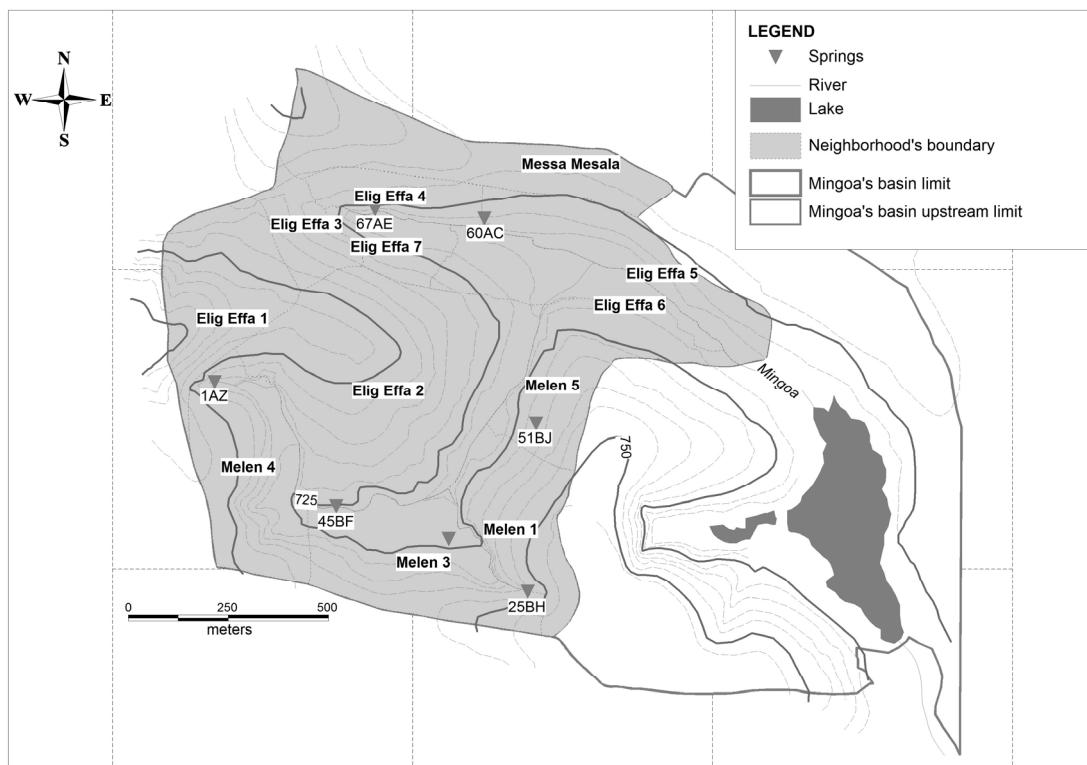


Figure 2. Groundwater sample location map of the Mingoa drainage basin (Yaounde-Cameroon).

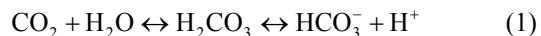
Table 1. Physical and chemical parameters of springs in the Mingoa drainage basin (Yaounde-Cameroon).

CODE	pH	K ⁺ (mg/L)	Na ⁺ (mg/L)	Mg ²⁺ (mg/L)	Ca ²⁺ (mg/L)	Cl ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	NH ₄ ⁺ (mg/L)	SDT (mg/L)	EC (μS/cm)
25BH	5.71	6.00	9.00	0.80	0.15	111.47	5.76	1.00	64.50	14.00	52.00	119.5
1AZ	5.77	3.00	7.00	0.80	0.06	58.93	19.94	1.00	34.72	53.25	222.00	401
51BJ	5.66	5.00	10.00	0.61	0.09	34.08	16.39	0.00	46.23	8.00	34.00	162.7
28BG	5.72	1.15	8.30	0.45	0.04	13.70	25.69	2.00	60.52	50.25	196.00	380
45BF	5.28	1.13	8.19	0.75	0.18	22.40	16.39	1.00	29.72	1.50	69.00	111.4
67AE	5.29	1.19	8.63	0.46	0.07	2.80	45.19	0.00	51.81	20.00	179.00	324
60AC	5.74	3.00	4.00	0.70	0.99	9.29	51.39	9.00	50.20	31.75	120.00	130.4
AVERAGE	5.60	2.92	7.87	0.65	0.23	36.10	25.82	2.00	48.24	25.54	124.57	232.71
SD	0.21	1.96	1.93	0.15	0.34	38.13	16.55	3.16	12.66	20.27	75.43	129.90
Min	5.28	1.13	4.00	0.45	0.04	2.80	5.76	0.00	29.72	1.50	34.00	111.40
Max	5.77	6.00	10.00	0.80	0.99	111.47	51.39	9.00	64.50	53.25	222.00	401.00

Sodium concentration varied from 4.00 to 10.00 mg/l, with an average value of 7.87 mg/l. The source of Na⁺ into the groundwater is due to the weathering of feldspar [25] and meteoric input. The data points of the area on the Gibbs' diagram in **Figure 3** suggest chemical weathering of rock-forming minerals and precipitation as origin of the ions. Potassium ion concentration varied from 1.13 to 6.00 mg/l, with an average value of 2.92 mg/l. Potassium is found to be higher due to weathering of K-feldspars and clay minerals from aquifer matrix [26]. Mg²⁺ ion concentration varied from 0.45 to 0.80 mg/l, with an average value of 0.65 mg/l. Ca²⁺ ion concentration varied from 0.04 to 0.99 mg/l, with an average of 0.23 mg/l. It is observed that all groundwater samples from the study area are within permissible limit according to WHO standard except ammonium ion. Ca²⁺ and Mg²⁺ are higher, due to the weathering of ferromagnesian minerals [22].

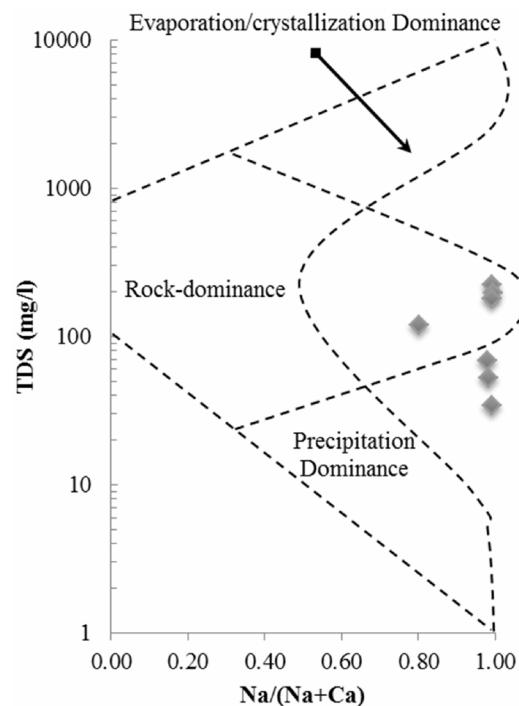
Chloride ion concentration varied from 2.80 to 111.47 mg/l, whereas bicarbonate ranged between 27.72 and 64.50 mg/l with an average value of 48.24 mg/l.

Bicarbonate is higher due to the presence of CO₂ in water from soil which facilitates the hydrolysis as following reaction:



This reaction is also favored by the production of CO₂ by plants which allows the formation of HCO₃⁻ by cons, the presence of chloride in our study area is explained by barriers to the flow of water in the weathered clay [27] and also due to domestic wastages and/or leaching from upper soil layers in dry climates [28]. It was found that amount of sulfate ranged from 0.00 to 9.00 mg/l and all samples were below the permissible limit according to WHO standard.

Higher SO₄²⁻ is noted in 60AC spring due to anthropogenic activities around this spring's area such as car

**Figure 3. Mechanism governing groundwater chemistry.**

wash, where wastewater rich in sulphur flow and enter into the groundwater. It also prove that the biological actions may also be involved mechanically (plant roots) especially by generating chemicals (humic compounds, ammonias, CO₂, HCO₃⁻, PO₄³⁻ and SO₄²⁻). This would also explain especially the presence of sulfate in groundwater [29].

Nitrate values varied from 5.76 to 51.39 mg/L. Nearly 28% of the groundwater exceeds the standard desirable limit of 50 mg/l, according to WHO standards. All of these sampling points are very close to domestic area which is characterized by the abundant presence of pit

toilets. These pit toilets are in direct contact with superficial aquifer [30]. It is observed that in the swampy lowlands where vegetable crops are located, nitrate concentrations in the groundwater sample increase and exceed the standard desirable limit. NO_3^- ion concentration in excess in drinking water creates several problems [31] like cyanosis, tumors goiter, oral cancer, cancer of colon, rectum or other gastrointestinal cancer, lymphoma, and dyspnea, and high nitrate ion concentrate in groundwater poses a small but well-recognized risk to bottle fed babies known as methemoglobinemia.

4.2. Statistical Analysis

The correlation matrix allows us to distinguish several relevant hydrochemical relationships. The contents of NO_3^- , Ca^{2+} and SO_4^{2-} are positively correlated to runoff with correlation coefficients of 0.890, 0.868, and 0.814, respectively. These values indicate that these three ions are more mobilized when the flow increases as show in **Table 2**.

Indeed, a strong positive correlation was found between K^+ and Cl^- , Ca^{2+} and SO_4^{2-} and it can also be deduced that for most of the groundwater samples these parameters originate from a common source. Sodium and calcium are negatively interrelated among themselves ($r = -0.861$). This interrelationship indicates the permanent cation's exchange process between water and soil minerals (clays).

Figure 4 shows the behavior of the variables (chemical parameters). The main contributions to F1 probably include both natural and anthropogenic elements. The F1 which explains $\approx 45.0\%$ of the total variance had high positive scores on Ca^{2+} , SO_4^{2-} , NO_3^- , and Flow. Except Ca^{2+} which originates from lithological processes taking

place here which include weathering of rocks minerals such as anorthite, we can notice that run-off from agriculture activities may be responsible for the high concentrations of nitrates in water in the area [32] because of lack of correlation between nitrate and nitrite or ammonia (**Table 2**). This is also evidence of interaction of the wetland with the groundwater. By cons, the F2 which explains $\approx 30.2\%$ of the total variance had high positive scores on K^+ , Mg^{2+} , and Cl^- which represent the group of natural influences. These ions have significant lithological origin and thus could likely be sourced from the weathering of some minerals. It is observed the opposition of Ca^{2+} and Na^+ which confirm the constant interaction between clays minerals and groundwater.

4.3. Hydrochemical Facies

Major cations and anions such as Ca^{2+} , Mg^{2+} , Na^+ , K^+ , CO_3^- , HCO_3^- , SO_4^{2-} , and Cl^- in mg/L were plotted in Piper diagram [33] to evaluate the hydrochemistry of groundwater of Mingo watershed and it is adjoining area with the help of Diagramme-software (**Figure 5**). The plot shows that groundwater samples fall in the field of $\text{Na}^+ - \text{K}^+ - \text{Cl}^- - \text{SO}_4^{2-}$ and $\text{Na}^+ - \text{K}^+ - \text{HCO}_3^- - \text{CO}_3^-$ type water.

4.4. Water for Irrigation Purpose

The quality of water used for irrigation is vital for crop yield, maintenance of soil productivity and protection of the environment [34]. At the same time, the quality of irrigation water is very much influenced by the land constituents of the water source.

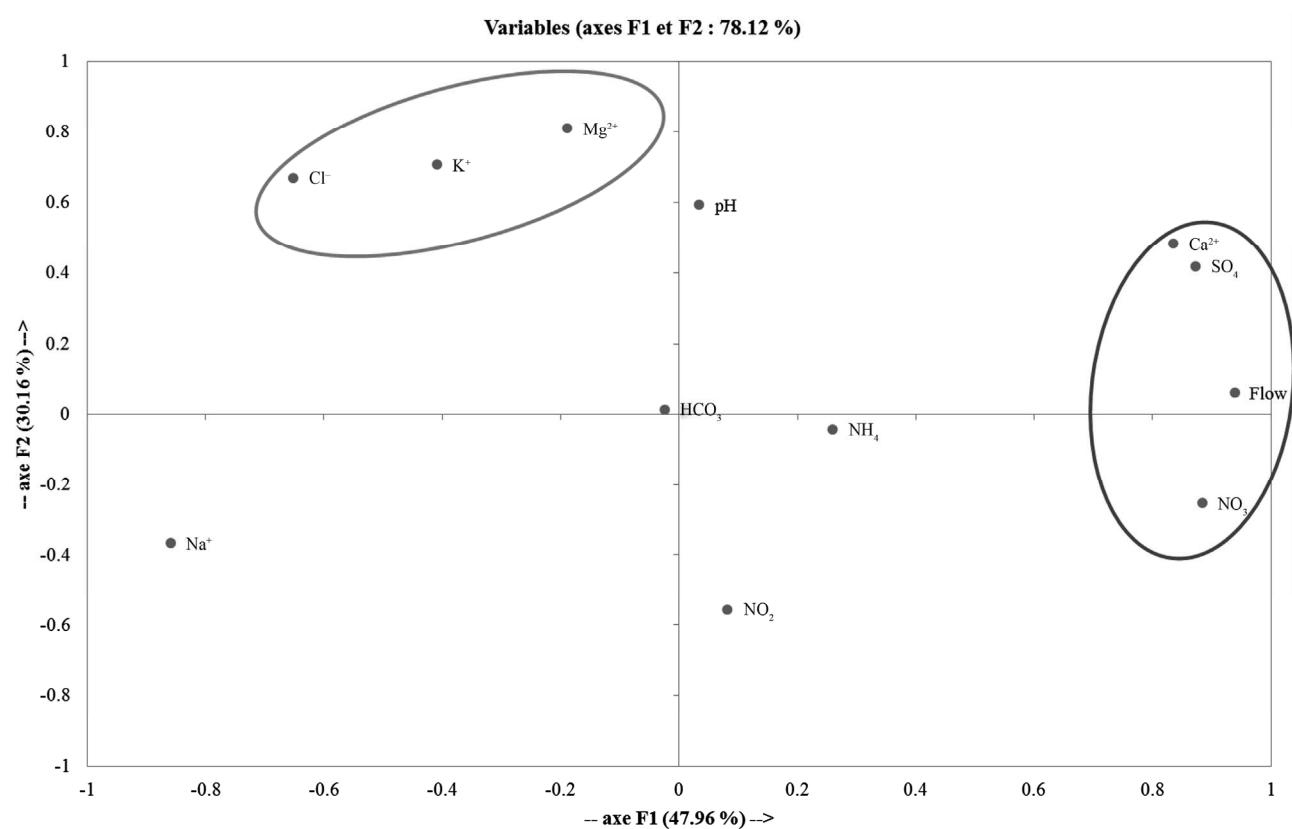
For the purpose of this work, Na% and SAR, were used to determine the suitability of the groundwater for irrigation purposes (**Table 3**).

Table 2. Pearson correlation of major ions, pH, NO_2^- , NH_4^+ and flow.

	Flow	pH	K^+	Na^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	NO_2^-	NH_4^+
Flow	1											
pH	-0.146	1										
K^+	-0.305	0.547	1									
Na^+	-0.780	-0.291	0.214	1								
Mg^{2+}	-0.126	0.256	0.508	-0.252	1							
Ca^{2+}	0.868	0.234	0.053	-0.861	0.227	1						
Cl^-	-0.583	0.413	0.777	0.284	0.667	-0.253	1					
NO_3^-	0.890	-0.150	-0.493	-0.651	-0.459	0.613	-0.746	1				
SO_4^{2-}	0.814	0.373	-0.041	-0.912	0.144	0.962	-0.279	0.619	1			
HCO_3^-	-0.012	0.364	0.337	0.139	-0.386	0.031	0.251	0.051	0.110	1		
NO_2^-	-0.159	0.213	-0.431	0.082	-0.659	-0.225	-0.297	0.078	0.011	0.478	1	
NH_4^+	-0.010	0.598	-0.253	-0.425	-0.156	0.019	-0.088	0.253	0.253	0.139	0.543	1

Table 3. Classification of groundwater quality based on EC, Na%, SAR, for suitability of irrigation the Mingoa drainage basin (Yaounde-Cameroon).

Parameters	Range	Class	N° of sample	Percentage of the samples
EC (Electrical conductivity)	<250	Excellent	25BH ; 51BJ; 45BF; 60AC	57.1%
	250 - 750	Good	1AZ; 28BG; 67AE	42.9%
	750 - 2000	Permissible	-	-
	2000 - 3000	Doubtful	-	-
	>3000	Unsuitable	-	-
Na%	<200	Maximum allowable limit	25BH; 51BJ; 45BF; 60AC; 1AZ; 28BG; 67AE	100.0%
	>200	Above allowable limit	-	-
SAR (Sodium Adsorption Ratio)	<20	Excellent	25BH; 51BJ; 45BF; 60AC; 1AZ; 28BG; 67AE	100.0%
	20 - 40	Good	-	-
	40 - 60	Permissible	-	-
	60 - 80	Doubtful	-	-
	>80	Unsuitable	-	-

**Figure 4. Representation of the F scores on the first two factors for the Mingoa springs waters: Loading plot of variables.**

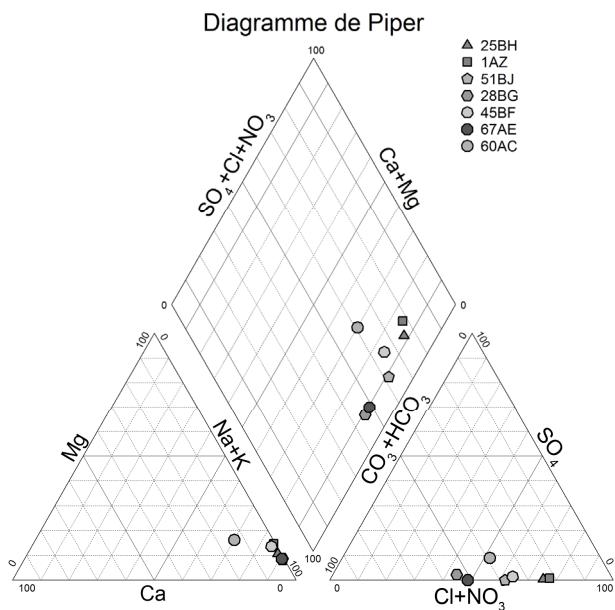


Figure 5. Piper diagram of groundwater in Mingoa watershed (Yaounde-Cameroon).

4.4.1. Sodium Percentage

Sodium is an important ion used for the classification of irrigation water due to its reaction with soil, reduces its permeability. Sodium is usually expressed in terms of percent sodium or soluble-sodium percentage (Na%). Percentage of Na^+ is widely used for assessing the suitability of water for irrigation purposes [35]. The Na% is computed with respect to relative proportion of cations present in water as

$$\text{Na}\% = \left(\frac{\text{Na}^+ + \text{K}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \right) \times 100\% \quad (2)$$

Here all the concentrations are expressed in meq/l.

The values of sodium percent are varying from 70.1% to 91.1% and are less than 200 (maximum allowable limit). The classification of samples is shown in **Table 3**.

Higher Na% is observed indicating the dominance of ion exchange and weathering from litho-units of the study area. When the concentration of sodium ion is high in irrigation water, Na^+ tends to be absorbed by clay particles, displacing magnesium and calcium ions. This exchange process of sodium in water for Ca^{2+} and Mg^{2+} in soil reduces the permeability and eventually results in soil with poor internal drainage.

4.4.2. Sodium Adsorption Ratio

Total salt concentration and probable sodium hazard of the irrigation water are the two major constituents for determining SAR. Salinity hazard is based on EC measurements.

If water used for irrigation is high in Na^+ and low in Ca^{2+} the ion-exchange complex may become saturated

with Na^+ which destroys the soil structure, due to the dispersion of clay particles [36] and reduces the plant growth.

Excess salinity reduces the osmotic activity of plants [10].

The SAR is computed, using the formula [37]

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \quad (3)$$

Concentrations of ions are expressed in meq/l. There is a close relationship between SAR values in irrigation water and the extent to which Na^+ is absorbed [38].

The computed SAR values ranges from 0.8 to 2.6 meq/l (**Table 3**). All samples are suitable (excellent) for irrigation. The analytical data plot on the US salinity diagram [39] illustrates that 42.9% of the groundwater samples fall in the field of C1S1, indicating low salinity and low sodium water, which can be used for irrigation on almost all type of soil with little danger of exchangeable sodium (**Figure 6**). 57.1% of the sample falls in C2S1 zone indicating medium salinity and low sodium, which can be used for irrigation in almost all types of soil with little danger of exchangeable sodium [40].

5. Conclusions

Groundwater is immensely important for water supply in both the urban and rural areas of developing nations. The groundwater in the study area is acid in nature.

The groundwater quality in Mingoa basin has been evaluated for their chemical composition and suitability for domestic and agricultural uses. The order of abun-

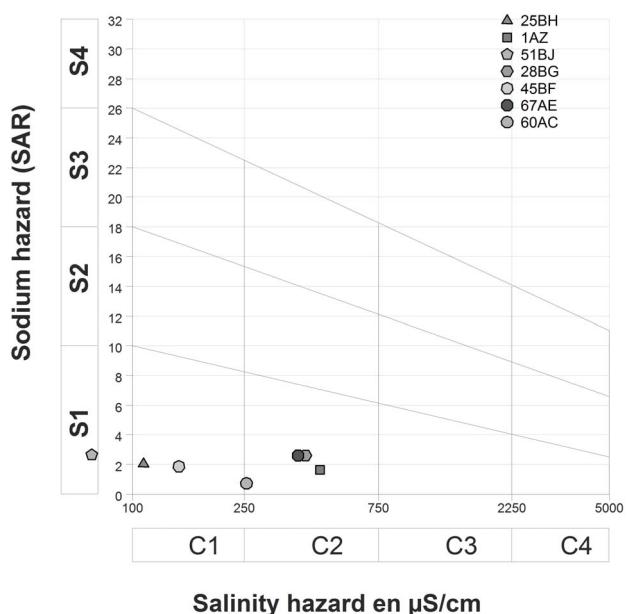


Figure 6. Suitability of groundwater for irrigation USSL (1954) diagram.

dance of chemical concentration is $\text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} = \text{Cl}^- > \text{HCO}_3^- > \text{NO}_3^- > \text{SO}_4^{2-}$ and $\text{Na}^+ > \text{Mg}^{2+} > \text{K}^+ > \text{Ca}^{2+} = \text{HCO}_3^- > \text{Cl}^- > \text{NO}_3^- > \text{SO}_4^{2-}$ for the groundwater sample. The Piper diagram indicates the action of CO_2 which chemically reacts upon the minerals present in soil and granitic rock releases HCO_3^- and reverse ion exchange process controls the water chemistry in the study area. Higher EC values are confined along up stream, indicating the influence of local lithology and anthropogenic activities. Higher NO_3^- was observed in areas where field vegetables crops are dominant. Higher Na% is observed, indicating the dominance of ion exchange and weathering from minerals of the study area. SAR is found to be lower indicating leaching and dissolution of salts during precipitation infiltrates into the aquifer matrix are done in crystalline zone context. The USSL plot shows that 42.9% of samples fall in C1S1 zone, indicating low salinity and low sodium water, which can be used for irrigation in almost all types of soil with little danger of exchangeable sodium. Overall hydrogeochemical analytical study reveals all of the samples have suitable for irrigation purposes because, the concentrations of each parameter are very low and within the permissible limit. The most conspicuous change in chemistry of groundwater is relative enrichment of nitrate beyond permissible limits ($>50 \text{ mg/l}$) of drinking water standards for the samples which are located in swampy area.

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