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Assessment of Physicochemical and Heavy Metal Properties of Groundwater in Edéa (Cameroon)

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Abstract In order to assess the physicochemical and heavy metal properties of groundwater consumed in Edéa (Cameroon), 8 boreholes were randomly chosen from 8 sites and their suitability was evaluated using three norms viz Cameroonian Norm (NC207:2003-02) and International standards including (CODEX: 108-1981 and European Union, EU:1998). Water samples were collected in triplicates bimonthly and analyzed using standard methods. Physicochemical analysis showed high temperatures with a mean value of (30.26 ±2.4) °C, acidic pH 5.94±0.34 and very weak mineralization leading to an electrical conductivity value of (134, 96 ± 49.59) µS/cm. The relative abundance of major ions was Ca^{2+}>Mg^{2+}>Na^{+}> NH_4^{+}>K^{+} for cations and NO^{-}_3> HCO^{-}_3> PO_4^{3-}> SO_4^{2-}>Cl^{-} for anions. All these ions fell within acceptable limits recommended by NC207:2003-0 boreholes 2, CODEX: 108-1981 and EU: 1998 with an exception for nitrates, ammonium and phosphate contents which were above acceptable limits. Among heavy metals analyzed, results showed that only lead and manganese values were above the standards'; all boreholes were contaminated by Lead while only 32.5% was contaminated by Manganese. The main water types were Mg-Ca-SO_4^{3-}-Cl^{-} and Mg-Ca-HCO_3^{-} can't result to an alteration of the aquifer matrix (dissolution of Gypsum chloride) and influence of anthropogenic activities through infiltration of agricultural, industrial and domestic waste water. These results showed that water of Edéa is not suitable for human consumption and must be appropriately treated before any usage.

Keywords: *borehole, physicochemical properties, heavy metals, hydrochemicalfacie, Norms*

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1. Introduction

Water is needed by the human body for its functioning given that it assures hydration of cells and help in transportation of nutrients around the body [1]. Unfortunately, in developing countries, inadequate water supply is still a major challenge with more than 18 million people dying each year from water-borne diseases [2]. This is evident in Cameroon like in most countries in Sub Saharan Africa where less than 50% of the population are connected to the national pipe-borne water network [3]. Water quality guidelines can be used to identify constituents of concern in water, to determine the levels to which the constituents of water must be treated for drinking purposes [4].

Although it's the second country in Africa in terms of quantity of available water resources estimated at 322 billion m^3 [5,6], Cameroon is unable to attain the second target of objective 7 of the Millenium Development Goals [7] to reduce to the half, the percentage of the population that doesn't have access to drinking water in a sustainable way on 2015. Face on these realities, the majority of households in villages and towns turn to non-conventional sources of water supply such as streams, groundwater like springs, wells and boreholes [8] whose quality is often unknown and poorly managed [9].

Groundwater constitutes 21.5% (about 57 billion m^3) of the country's water source [10] and is an important source of drinking water for most Cameroonians [11]. Unfortunately, this resource which was once of excellent quality is now pruned to diverse sources of contamination. The chemical composition of groundwater is controlled by many factors that include composition of precipitation, mineralogy of water head and aquifers[12], climate, topography as well as anthropogenic influence such as urban, industrial and agricultural activities [10] also hygiene and sanitation of water sources [13,14].

Several studies have pointed out the poor quality of groundwater in the main Cameroon metropolitan towns such as Yaoundé [15,16,17,18], Douala [19,20], Bafoussam [21], Bamenda [10], Adamawa [22], Maroua [23]. However, there is paucity of information on groundwater quality of secondary towns (peri urban zones) such as Edéa and there is no compliance with the national standard norms for water quality.

In Edéa like most peri urban zones of Cameroon, public pipe borne water supply is insufficient for the dueling population who resort to groundwater without worries of its physicochemical qualities. Keeping this in view and knowing that there is not previous studies done in the peri urban zone of Edéa, the aim of this study is therefore to evaluate the groundwater quality and its suitability for consumption and compare the results to the National (NC 207, 2003-02) [24] and International Standard norms (CODEX, 108-1981, European Union, 1998) [25,26].

2. Materials and Methods

2.1. Study Area

Edéa has a surface area of about 180km2 (Figure 1) and is located between latitude 3°48' and 3°83' N and longitude 10°7' and 10°12' E. The zone has a humid tropical climate characterized by 2 main seasons, a long rainy season (March to August) and a short dry season (December to February). Annual mean rainfall is about 2602mm and annual mean temperature oscillates between 26°C and 27°C [27]. Its vegetation which was originally made of a humid dense forest is now due to anthropogenic activities, changed a secondary forest consisting of shrubs such as ferns. The soil types are yellow and red ferritic derived from sedimentary rocks [28]. The landscape is made of numerous small hills separated by slow-flowing streams. Apart from its economic characteristic and demographic evolution, Edéa exhibits a diversified and heterogeneous settlement comprising of the indigenes and immigrants (Douala, Béti and Bamiléké) [29].

2.2. Sampling Site

Eight boreholes were randomly chosen across the town and labelled W1, W2, W3, W4, W5, W6, W7 and W8 as shown in Figure 1 and Figure 2. The sampling points were chosen in relation to their uses by the local population (Table 1).

2.3. Sampling

Sampling was done twice a month and ran from April to August 2017. Each water sample was triplicate collected in 1500ml polyethylene bottles. All samples was codified and then transported to the Soil, Plant, Water and Fertilizer Analyses Laboratory (LAPSEE by its French acronym) of the Institute of Agricultural Research for Development (IRAD by its French acronym), Yaoundé for analyses. The physicochemical parameters were measured according to the standard protocols of [30] as given in Table 2.

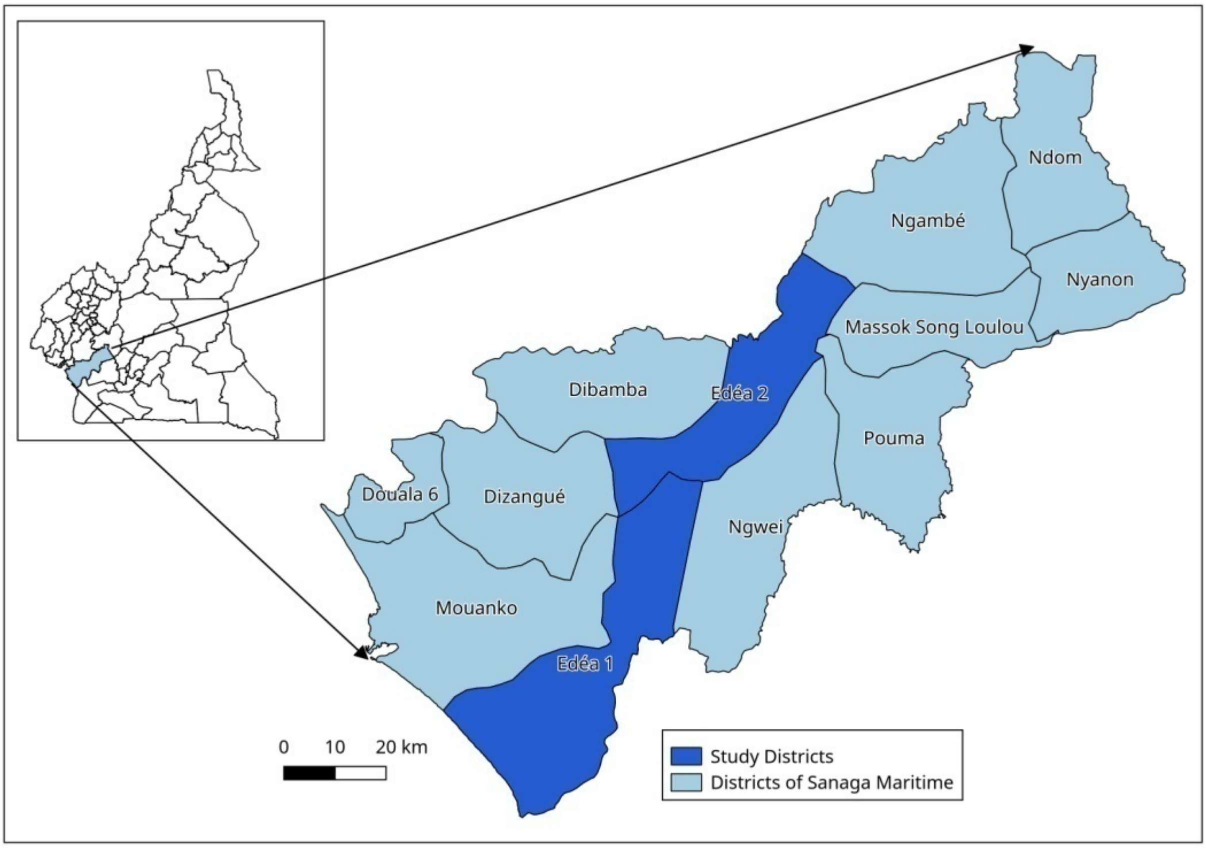

Figure 1. Location of study area (Source: INC 2013)

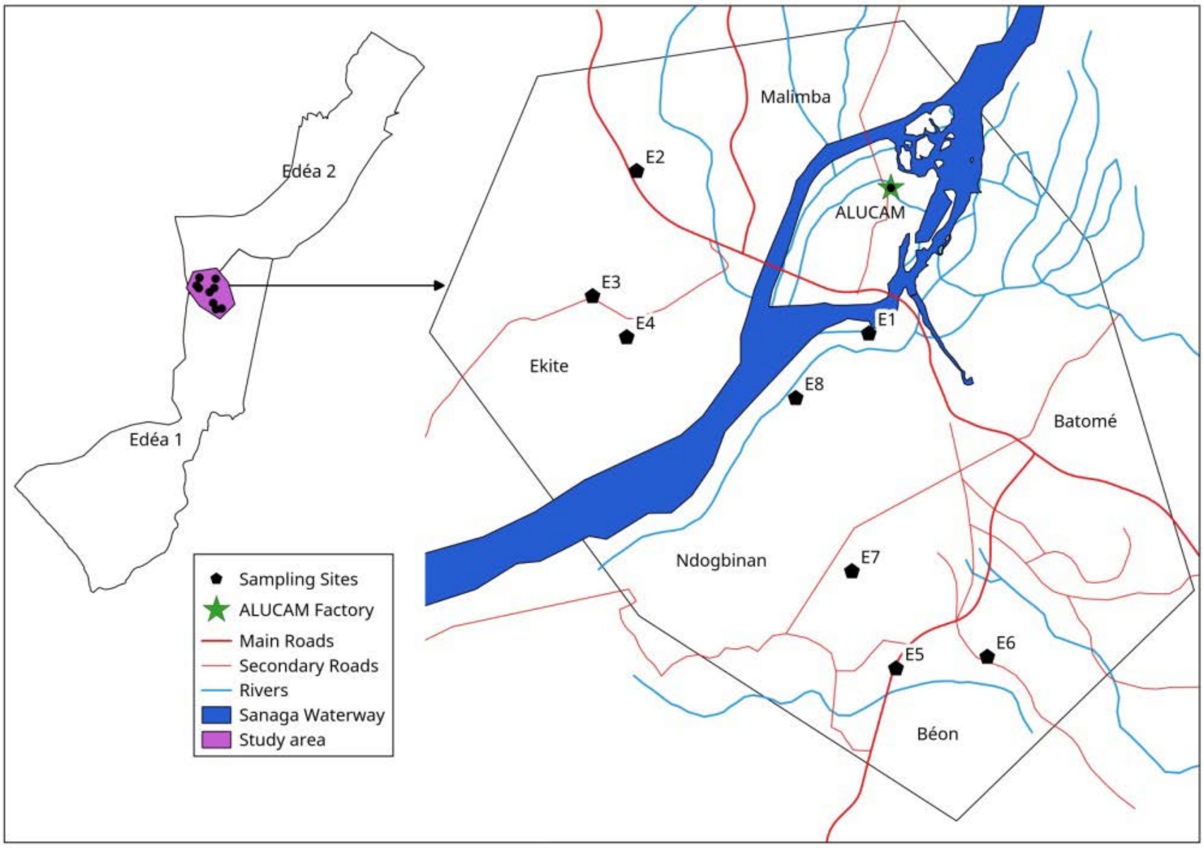

Figure 2. Location of sampling borehole

Table 1. Characteristics of sampling points

SN.	Quarter	Type of quarter	Activity	Description
W1	ECOLE ANNEXE D'EDÉA	Residential (the largestmarket)	Trade, Carwash, Steel factory and pressing	Vegetation almost absente
W2	EKITE	Residential	Small-scale Agriculture	Presence of manyfarmlands
W3	EKITE2 MISSION PROTESTANTE	Residential	Small-scale Agriculture	Presence of manyfarmlands
W4	MALIMBA FARM	Residential	Small-scale Agriculture	Presence of many fruit trees
W5	BEAN	Residential	Small-scale Agriculture	Few trees
W6	MBONDANDICK	Residential	Small-scale Agriculture	Presence of many trees
W7	NLON A MIOH	Residential	Small-scale Agriculture	Presence of many trees
W8	MBANDA	Administrative	Small-scale Agriculture	Presence of some shrub-like trees

Table 2. Water quality parameters and analytical methods

Parameter	Technique	Site of analysis	Apparatus	Method
Temperature (°C)	Direct	In situ	Thermo-scientific ORION STAR 225 Multiparameter test kit	NF ISO 10523, NF EN 27888
pH	Direct	In situ	Thermo-scientific ORION STAR 225 Multiparameter test kit	NF ISO 10523, NF EN 27888
Electrical conductivity (µS/cm)	Direct	In situ	Thermo-scientific ORION STAR 225 Multiparameter test kit	NF ISO 10523, NF EN 27888
Bicarbonate (HCO_3^-)	0.25N Hcl Titrimetry	Laboratory	Titrator	NF EN ISO9963-1
Sulfates (SO_4^{2-})	Baryum chromate Gavimetry	Laboratory	Spectrophotometer jenway 206	NF ISO 11048:1995
Phosphates (PO_4^{3-})	Molybate	Laboratory	Spectrophotometer jenway 206	NF ISO 6878: 2004
Chloride (Cl^-)	Silver nitrate Mohr's method Titrimetry	Laboratory	Spectrophotometer jenway 206	NF ISO 9297
Nitrate (NO_3^-)	Sulphosalicylic acid	Laboratory	Spectrophotometer jenway 206	NF ISO 7890-3: 1988
Ammonium ($NH4^+$)	Direct	Laboratory	Spectrophotometer jenway 206	NF T 90-015-2
Major cations (Na^+, K^+, Ca^{2+}, Mg^{2+})	Direct Spectroscopy	Laboratory	ICP OES (Optima 8000)	NF ISO 11885
Heavy metals (Cu, Pb, Fe, Mn, Zn and Cd)	Direct Spectroscopy	Laboratory	ICP OES (Optima 8000)	NF ISO 11885

2.4. Data Analysis

Mean and standard deviations of the various parameters studied were used to analyze data and to evaluate the dispersion of values for each parameter and boreholes. Correlations between samples (parameters and sampling points) were determined by performing the Principal Component Analysis and Pearson's Square using XLSTAT 2007. The Piper's diagram (1944) was used to characterize the different facies or the evolution of studied groundwater from one facie to another [31].

3. Results and Discussion

3.1. Physicochemical Parameters of Groundwater and Their Comparison with Standards

Physicochemical groundwater assessment parameters are presented in Table 3 and the permissible limit of each parameter as recommended by the Cameroonian (NC 207, 2003-02), CODEX (108-1981) and the European Union Standards (EU, 1998) for drinking water are showed in Table 4.

3.1.1. Physical Parameters

Water temperatures of the studied boreholes ranged from (27.8±2.2)°C for the sampling water W8 to (37.4±2.6)°C for sampling water W1 with a mean value of (30.26 ±2.4) °C. The highest values were recorded in W1, W3 and W5. Cool water is generally more appetizing than warm water. All the sampled well water exceeded the recommended [32] Standard of 15°C, making them not appetizing to and extend and according [33], water temperatures between 25-28°C could be good for microbial growth because according to [34], when the temperature is high than 30°C, the pollution is excessive.

The pH remained slightly acidic water throughout the period of study with the highest pH recorded in W6 and the lowest in W3 (Table 3) due to the dissolution of bicarbonates into carbonate [10] as indicated by the present results. It could also be due to the sandy nature of the soils in the studied area and short residence time of water, which provides alow degree of water-rock interaction, so that the groundwater still retains most of its rainfall signatures [20]. These values were also, in accordance with the Cameroonian Standard (NC 207) on pH for potable or drinking water.

Table 3. Physicochemical parameters of bore wells in Edéa

Points of sampling				Chemical Parameters					
				Anions					
	T°C	pH	CE (µS/cm)	HCO_3^-	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	
W1	37.4±2.6	5.71±0.5	51.09±12.2	12.81 ±6.1	0.071±0.02	83.5±20.6	10.429±6.0	7.240±3	
W2	28.6±2.4	5.58±0.2	142.08±58.6	16.165±4.9	Nd	28.5±08.3	1.698±1.1	7.289±3	
W3	30±2.6	5.23±0.3	117.33±61.2	14.335±5.3	Nd	23.5±7.4	1.698±1.0	7.273±3	
W4	29.9±2.2	5.67±0.4	67.98±16.1	28.67±8.8	Nd	235±55.6	2.192±1.2	7,305±3,0	
W5	31.5±2.6	6.74±0.4	147.47±71.6	134.505±16.9	Nd	100±22.7	6.619v4.0	7.256±2.1	
W6	28.9±2.4	6.76±0.2	293.25±74.1	193.37±29.6	Nd	40±14.7	5.032±2.0	7.338±3.1	
W7	28±2.4	5.67±0.4	64.62±22.6	22.27±11.1	Nd	240±28.1	4.397±2.0	7.273±4.1	
W8	27.8±2.2	6.12±0.3	195.86±80.3	132.065±33.1	Nd	35±24.2	15.032±4.2	7.321±2.2	
Points of sampling	Physical Parameters			Chemical Parameters					
				Cations					
	T°C	pH	CE (µS/cm)	NH_4^+	Na^+	Pb^{2+}	Mn^{2+}	Mg^{2+}	Ca^{2+}
W1	37.4±2.6	5.71±0.5	51.09±12.2	3.85±0.2	0.266±0.1	0.62±0.3	nd	0.406±0.2	0.196±0.1
W2	28.6±2.4	5.58±0.2	142.08±58.6	3.962±0.2	0.992±0.5	0.63±0.3	0.132±0.1	0.82±0.2	0.587±0.2
W3	30±2.6	5.23±0.3	117.33±61.2	3.87±0.4	0.818±0.2	0.149±0.1	0.039v0.01	0.567±0.1	0.442±0.2
W4	29.9±2.2	5.67±0.4	67.98±16.1	3.89±0.1	0.376±0.1	0.048±0.01	0.002±0.01	0.385±0.2	0.2±0.1
W5	31.5±2.6	6.74±0.4	147.47±71.6	3.90±0.3	0.649±0.2	0.062±0.2	0.123±0.01	2.109±1.0	3.299±1.1
W6	28.9±2.4	6.76±0.2	293.25±74.1	3.84±0.4	0.317±0.1	0.046±0.03	0	1.873±1	5.684±3.3
W7	28±2.4	5.67±0.4	64.62±22.6	4±0.4	0.331±0.2	0.036±0.02	0.005±0.01	0.195±0.1	0.336±0.2
W8	27.8±2.2	6.12±0.3	195.86±80.3	3.99±0.3	0.593±0.3	0.049±0.02	0.081±0.04	2.321±1.2	6.946±3.6

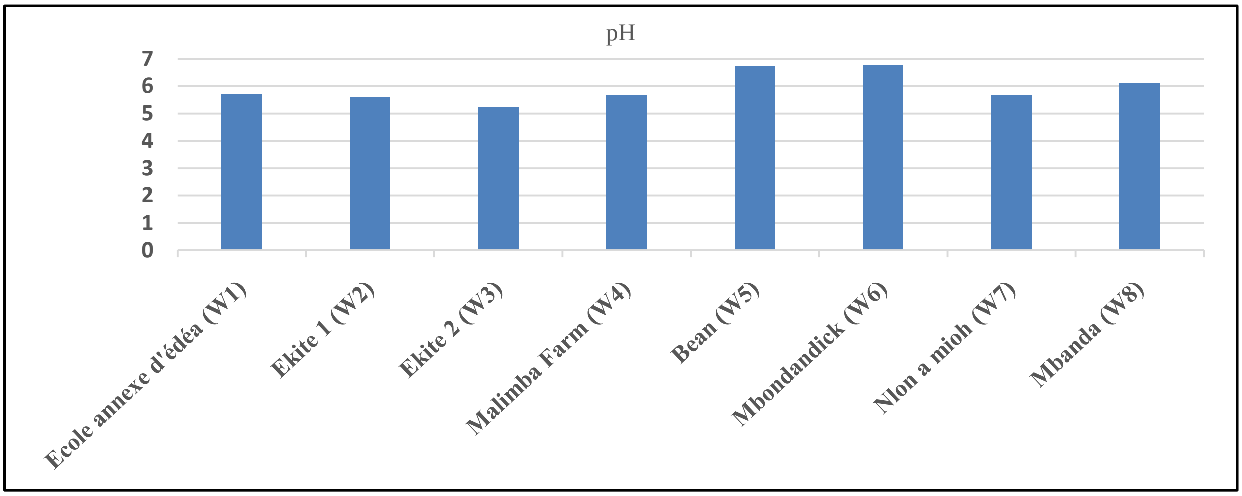

Figure 3. Concentration of pH in the various of sampling borehole

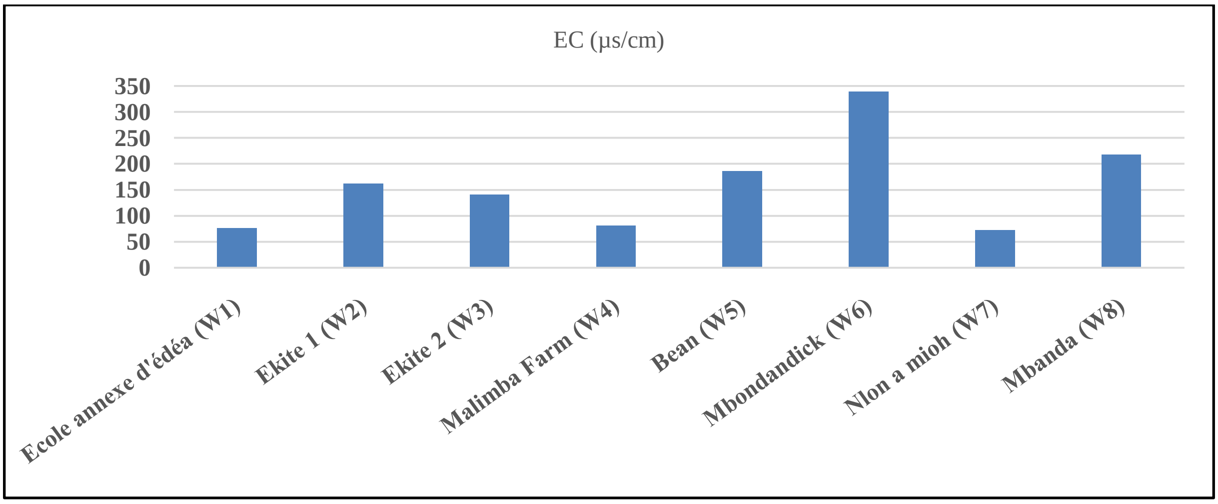

Figure 4. Concentration of Electrical conductivity in the various of sampling borehole

Table 4. Well water quality in conformity with drinking water standards of NC207, CODEX and EU

Parameter	Cameroonian norm NC 207 (mg/L)	CODEX 108-1981 Norm (mg/L)	EU (1998) Norm (mg/L)	Wells not in conformity with norms	Percentage of contaminated wells
pH	6.5-8	/	/		
Magnesium	≤ 50	/	/	None	0
Potassium	≤ 12	/	/	None	0
Sodium	≤ 150	/	≤ 200	None	0
Sulfates	≤ 250	/	≤ 250	None	0
Chlorides	≤ 200	/	≤ 250	None	0
Ammonium	≤ 0,5	/	≤ 0,5	All	100
Bicarbonates	/	/	/		
Nitrates	≤ 50	≤50	≤ 50	W1, W4, W5, E7	50
Phosphate	≤ 5			All	100
Lead	≤ 0,025	≤ 0,01	≤ 0,01	All	100
Cd	≤ 0,005	≤ 0,003	≤ 0,005	None	0
Ni	≤ 0,05	≤ 0,02	≤ 0,02	None	0
Cu	≤ 0.05	≤ 1	≤ 2	None	0
Zn	/	/	/	None	0
Mn	≤ 0,05	≤ 0,04	≤ 0,05	W2, W5, W8	32,5%

Electrical conductivity (EC) values were very low regardless of the sampled boreholes though W6 recorded the highest EC. These results showed that groundwater of Edéa is weakly mineralized and that the values (51.09 to 293.25µS/cm) fell within the permissible limits of 750µS/cm [34], so the studied groundwater was classified as the fresh water type [10].

3.1.2. Chemical parameters

Contents of Calcium ions were highest in W6 and W8 while Magnesium ion contents were highest in W5 and W8. Sodium ions were highest in W2 and Ammonium in W7. Irrespective of the sampled boreholes, Potassium ion contents remained below detectable limit. The relative tendency of major cations in the sampled well water was in the following order: Ca^{2+}>Mg^{2+}>Na^{+}> NH_4^{+}>K^{+}.

The relatively high values of Ca^{2+} and Mg^{2+} cations in certain boreholes could be explained as result of hydrolysis of mineral silicates present in the soil as explained by [35]. Regardless of all the boreholes, the major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were within acceptable ranges of NC 207, CODEX and EU Standards while NH_4^{+} values were largely above acceptable limits of the 3 Standards (Table 4). The high content of ammonium observed could be from the fertilizers used in the surrounding farms which leaches into the water and infiltrates into the aquifer matrix and could also be from natural sources such as organic (metabolic processes) and inorganic (rock weathering and hydrothermal activity [10,36]. Moreover, the presence of these high contents of ammonium could be toxic and could cause esophagus, stomach and duodenum hemorrhages [37].

With respect to anions, the relative tendency in the sampled boreholes was in the following order: NO^{-}_3> HCO_3^{-}>PO_4^{3-}>SO_4^{2-}>Cl-. Nitrate contents were significantly higher in W1, W4, W5 and W7 while bicarbonate contents were higher in W5, W6 and W8. Phosphates ions did not vary significantly irrespective of the sampled well with a mean value of (7.287±2.9) mg/L. Sulfate ions were relatively low in all sampled wells though peak values were observed in W1 and W8. Chloride ions in the sampled wells were below detectable limits except for W1 which was still relatively low.

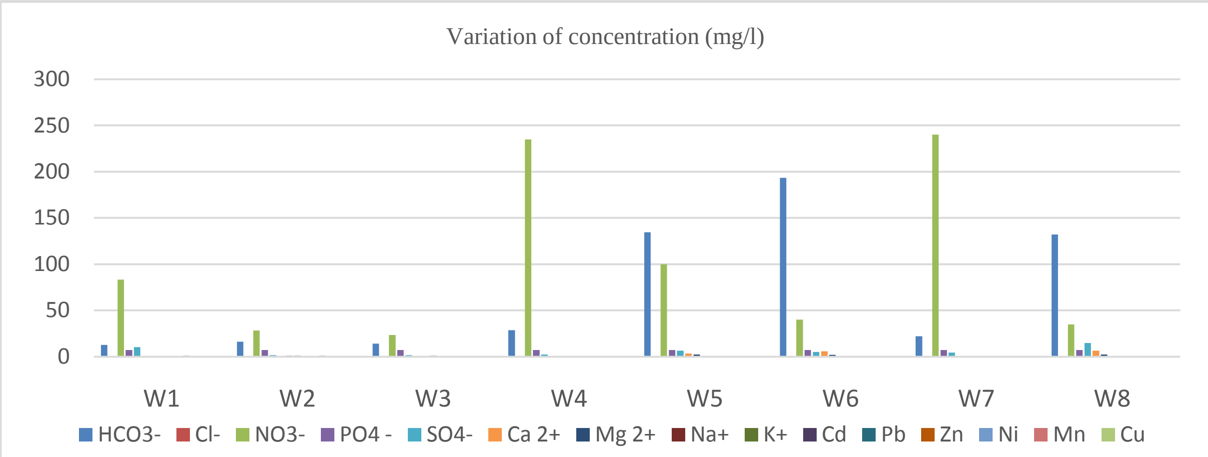

Figure 5. Concentration of chemical parameters in the various of sampling borehole

The high contents of nitrate ions observed in 50% of the studied wells were all out of NC 207, CODEX and EU Standard ranges and could be a result of domestic sewage and runoff from farmlands around these wells [12,38]. In fact, W1 is situated at the heart of the main markets of Edéa which share boundaries with the Aluminum manufacturing industry (ALLUCAM); it is thus contaminated by infiltration of waste water, waste of anthropogenic and industrial origins. According to [39,40], high nitrate levels in water have been associated with methemoglobinemia (blue-baby syndrome), gastric ulcer, cancer, sterility and urinary track diseases.

Bicarbonate contents were within the acceptable limit of 240mg/L [34] for drinking water irrespective of the sampled water. The presence of this ion could be explained as a result of weathering, precipitation and organic matter decay [10].

Knowing that the maximum permissible limit of phosphate concentration set by NC 207 Standard for drinking water was ≤5 mg/L, it was observed that all the groundwater samples showed higher concentrations (Table 4). Phosphates occur in natural water in low quantity as many aquatic plants absorb and store phosphorous more than is needed [9]. The high values of phosphates observed in this study could mean that the application of phosphate fertilizers in the nearby farmlands is very high [9] and that these phosphate ions leach into the aquifer matrix [10].

Sulfate contents were very lower than the acceptable limits of NC207, CODEX, and EU (1981) Standards for drinking water in all the collected samples. Sulfates are generally derived from natural sources such as sulfate minerals common in igneous rocks [41]. Thus, the low contents observed maybe a consequence of gradual dissolution [42].

The low to below detectable values of chloride ions observed in the sampled boreholes are in accordance with [38] who observed that in the highest topographically areas, more precipitation goes into runoff resulting in low chloride concentration and electrical conductivity in groundwater.

Heavy metal analyses of the studied boreholes showed that Cadmium, Zinc, Nickel and Copper were below detectable limits irrespective of the sampled well. However, high contents of Lead were observed in all the sampled boreholes while Manganese contents were detected only in W2, W3, W5, W7 and W8.

Cadmium, Zinc, Nickel and Copper contents were far below NC 207, CODEX and EU Standards while Lead contents were out of the range of the three drinking water standards irrespective of the sampled boreholes. Manganese contents were out of the range in 3 boreholes (Table 4).

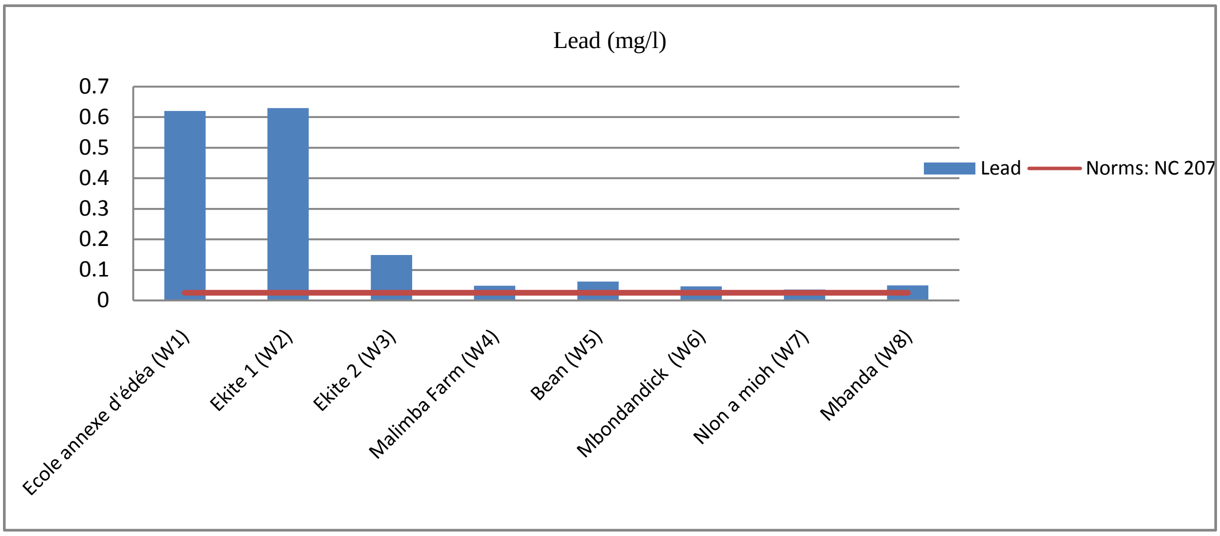

Figure 6. Concentration of Lead in the various of sampling borehole

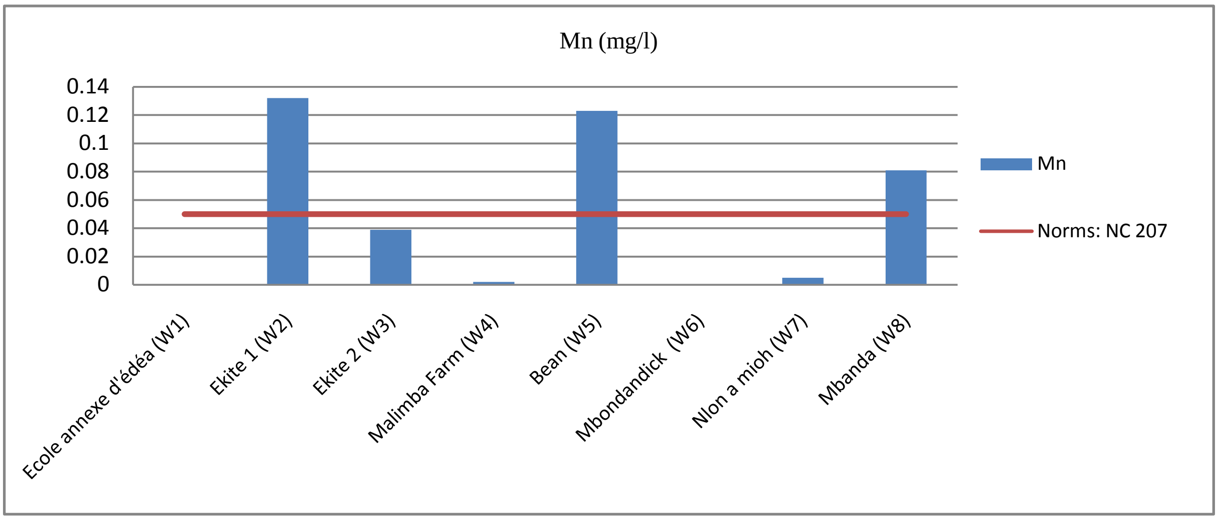

Figure 7. Concentration of Manganèse in the various of sampling borehole

The presence of Lead could be due to the degradation of the water distribution pipes, which Lead is a constituent. There has been a lot of attention paid to Lead levels because of is relative widespread due to anthropogenic activities, its historical use in many commercial products [43] and the well-knowledge of adverse health effects it could cause. Exposure to Lead can result in neurological complications especially in children [44,45]. The high content of Manganese observed in some boreholes could be attributed to the acidic nature of the studied water as acidity increases solubility of Manganese [46].

3.1.3. Hydrochemical Facies

The Piper diagram (Figure 3) provides information on the different chemical facies of the studied well water and indicated that groundwater of Edéa is grouped into twohydro chemical facies: Mg-Ca-SO_4^{3-}-Cl^- type representing 62.5% of the studied wells (W1, W2, W3, W4 and W7) and Mg-Ca-HCO_3^- type representing 37.5% (W5, W6 and W8).

The Mg-Ca-HCO_3^-water type expresses mineral dissolution during recharge of water while Mg-Ca-SO_4^{3-}-Cl^- type suggest the mixing of groundwater with surface contaminating sources such as fertilizers, domestic waste water containing $SO_4^{3-}$and Cl^- [47].

3.1.4. Origin of Groundwater Mineralization

Correlations between the 13 parameters were profiled using Principal Component Analysis as illustrated in Figure 4. Two main axes were realized with F1 regrouping Electrical conductivity, pH, Calcium, Magnesium, bicarbonate, phosphate and sulphate and F2 regrouping Sodium, Chloride, Manganese, Nitrates and Ammonium. F1 and F2 components respectively explained 42.87% and 19.92% of the total variance corresponding to a total of 62.79%. Electrical conductivity, pH, Calcium, Magnesium, bicarbonate and phosphate were positively correlated to F1while Sodium, Manganese and nitrates were correlated to F2.

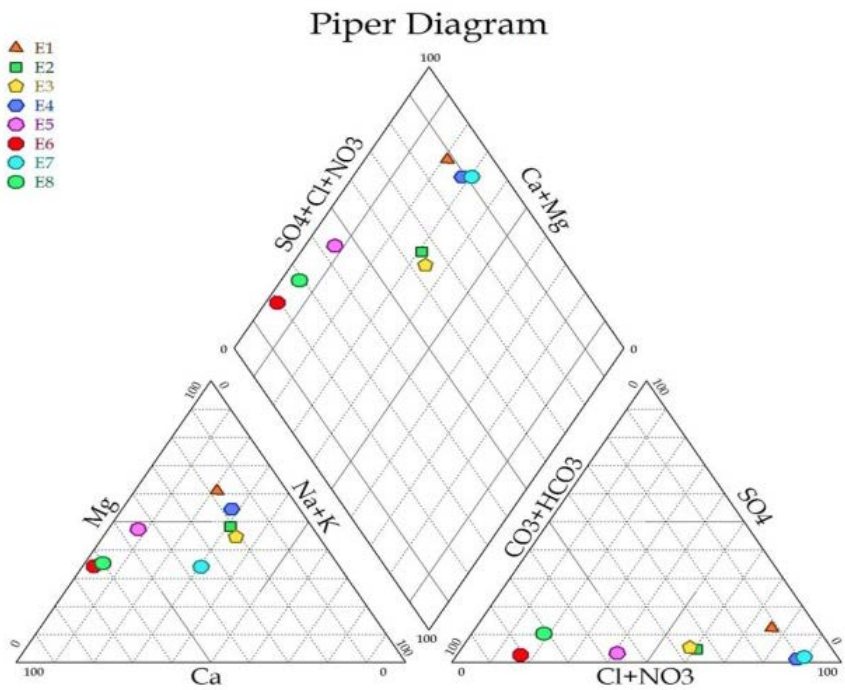

Figure 8. Piper diagram of groundwater in the study area

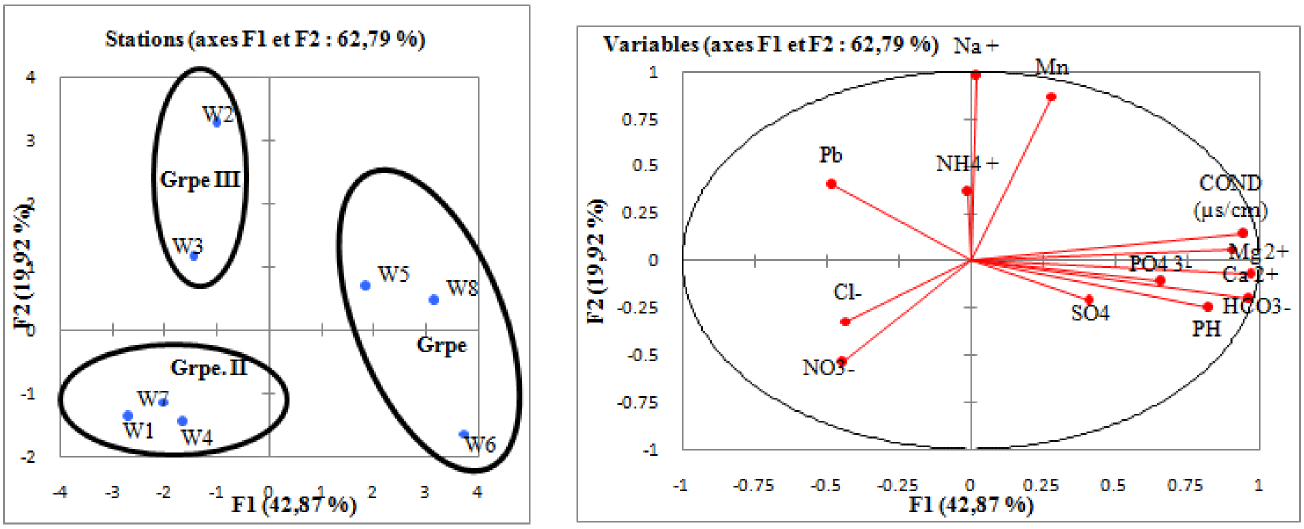

Figure 9. PCA on distribution of the physicochemical parameters in the 8 well

Table 5. Pearson coefficient matrix between physicochemical properties

Parameters	PH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	NO_3^-	NH_4^+	Cl^-	SO_4^{2-}	HCO_3^-	PO_4^{3-}	Pb	Mn
PH	**1**												
EC	**0,721***	**1**											
Ca^{2+}	**0,759***	**0,847***	**1**										
Mg^{2+}	**0,807***	**0,797***	**0,929***	**1**									
Na^{+}	-0,273	0,095	-0,078	0,139	**1**								
NO_3^-	-0,146	-0,609	-0,441	-0,506	-0,541	**1**							
NH_4^+	-0,173	-0,218	0,056	0,040	0,262	0,242	**1**						
Cl^-	-0,163	-0,371	-0,299	-0,316	-0,422	-0,066	-0,385	**1**					
SO_4^{2-}	0,343	0,162	0,595	0,535	-0,308	-0,224	0,196	0,388	**1**				
HCO_3^-	**0,923***	**0,885***	**0,926***	**0,896***	-0,183	-0,322	-0,151	-0,316	0,388	**1**			
PO_4^{3-}	0,326	**0,684***	**0,646***	0,443	-0,050	-0,149	0,079	-0,573	0,038	0,580	**1**		
Pb	-0,385	-0,281	-0,448	-0,358	0,279	-0,352	-0,092	**0,641***	-0,032	-0,510	- 0,451	**1**	
Mn	0,171	0,196	0,196	0,480	**0,817***	-0,449	0,402	-0,341	0,046	0,127	-0,101	0,217	**1**

* Correlation is significant at the 0.05 level.

Based on the PCA analysis, three groups could be identified:

- **Group 1 wells** (W5, W6 and W8) were characterized by relatively high concentrations of hydrogen carbonate ions (HCO_3^-), Ca^{2+} and Mg^{2+} and are subjected to less lead contamination.
- **Group 2 wells** (W1, W4 and W7) were characterized by low mineralization and subject to important chemical pollution in terms of nitrates, ammonium and phosphates.
- **Group 3 wells** (W2 and W3) were characterized by medium mineralization and subject to relatively less important pollution in terms of nitrates but contaminated by Lead.

The mineralization of the studied boreholes water is due to the alteration of the aquifer matrix (dissolution of Gypsum chloride) for the parameters of F1 (pH, Conductivity, Ca, Mg, HCO_3^-, Sulfate and phosphate) and anthropogenic activities through infiltration of waste waters concerning the parameters of PC (Na^+, Cl^-, Mn^{2+}, NO_3^- and NH_4^+) [48]. In the same light, the Pearson coefficient matrix (Table 5) revealed that EC, magnesium, calcium and bicarbonate showed significant positive strong correlations with pH and each other. The strong correlation observed between EC and the ions Ca^{2+}, Mg^{2+}, PO_4^{3-} and HCO_3^- indicated that Edéa well water not sufficiently loaded.

4. Conclusion

The groundwater quality of Edéa was assessed for its suitability for human consumption in conformity with the national (NC207:2003-02) and international (CODEX: 108-1981; EU:1998) standards for drinking water through elucidating some physicochemical and heavy metal parameters. Results showed that groundwater of Edéa is acidic and weakly mineralized and also revealed that nitrates, phosphates and ammonium which are major indicators of water pollution were higher than the acceptable limits of the 3 standards when compared to other parameters. Similarly, heavy metals such as Lead and Manganese also exceeded the permissible limits. The studied wells exhibited two hydro chemical facies: Mg-Ca-SO_4^{3-}-Cl^- and Mg-Ca-HCO_3^-. Overall, all the results presented show that groundwater of Edéa is unfit for human consumption and is highly recommended that it should be treated before any use.

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