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Physicochemical Characterization of Water of the Plateau of Mbe in Pool-North in Republic of Congo Brazzaville

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Abstract: The physicochemical characterization of water of the Mbe Plateau was carried out starting from thirty-two (32) samples of water taken between November 2017 and May 2018 in six months (rain season with a seasonal intercalation enters mid-January and at the end of February known as small dry season). Four (04) boreholes (Massa, Dieu le veut, Ingha and Ivoumba), three (03) rivers (Maty, Mary and Gamboma) and one (01) well (Ignié) were sampled during this study. The study of this water was based on measured parameters in-situ (the temperature, TDS, pH, the EC, dissolved oxygen, dissolved complete iron and salinity) and at the laboratory in particular: hardness, Ca^{2+}, Mg^{2+}, K^+, Na^+, Al^{3+}, NH_4^+, Cu^{2+}, Fe^{2+}, Pb^{2+}, Cd^{2+}, Mn^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-, PO_4^{3-} and alkalinity. The elements measured in situ were checked at the laboratory to reassure results. The results obtained showed that the values of measurements of the physicochemical parameters of analyzed water were all in conformity with the standards prescribed by WHO for the drink water, except in the case of the abnormal temperature proven with an average of 27°C and an average pH of 5.0 what confirms the acid character of water in all this zone of study. These results were treated starting from a hydrochemical method, by using the diagrams: of Piper, of Stabler, Schoeller-Berkaloff, Stiff, Wilcox and statistical methods traditional with software XLSTAT. The analysis enabled us to highlight the prevalence of facies chemical total chlorinated and sulphated calcic and magnesian in this water of the Plateau of Mbe. The dominant ions are the chlorides for the anions and magnesium for the cations.

Keywords: Groundwater, Surface Water, Physicochemistry, Plateau of Mbe, Pool North Congo

1. Introduction

Water requirements of the world population are more and more growing and the resources increasingly rare. The access generalized to drinking water, the irrigation, the urban development, industrial development and tourism are as many factors which make increase these pressures [1-6].

In Congo-Brazzaville, in the plateau of Mbe (Figure 1), water is major factor limiting, on the one hand, for agriculture, the breeding, industrial development, etc. And on other for the food of the populations which leave the districts of Brazzaville-North because of erosions, silting and the floods to settle there. The plateau of Mbe, in spite of the semi-arid climate, the problem of water arises in terms of development. The scarcity of surface water and the non perenniality of this resource on surface due to the geological conditions supported the use of the deep water aquifer like palliative to satisfy the requirements out of water for this population. The plateau of Mbe has an important aquiferous potential. This water tank is widespread in practically all plateaux [7]. The hydraulic system of the zone of study consists of several perched aquifers not very productive, the marshes and the aquifer deep which is the subject of this study.

The question of water about the Batekes Plateaux was put for a long time being given the lack of water points surface, bad water quality that one finds there and in many cases their draining in dry season [7]. Several reports/ratios give a description of the situation: [8-13] and reports/ratios of some projects. But, there does not exist any study detailed on the characterization of the deep aquifer.

It is thus advisable to know and follow the quality of this resource. The chemical composition of a water resulting from the natural environment is very variable. It depends on the geological nature of the ground from where it comes and also of the reactive substances which it could have met during flow [14].

Groundwater quality can be faded when external substances come into contact with the aquifer. Such is the case of the even toxic and undesirable substances which make groundwater unsuitable and toxic for various uses in particular for the use most paramount that is water of drink. The intensive use of the natural resources and the increase in human activities generate serious problems on the quality of groundwaters [15-17].

The present study relates to the physicochemical characterization of surface and groundwater of the Plateau of Mbe. With this intention, the sampling campaigns were undertaken. The physicochemical parameters, measured in situ and at the laboratory, were useful for the characterization of this water, the follow-up of the space-time evolution of the physicochemical parameters, to consider their mineral origin and to integrate the hydrogeological studies.

2. Presentation of the Zone of Study

The department of Pool is located in the southernmost part of the Republic of Congo. It is limited to North by the Léfini river; in the East by the Congo river; in the South by the Congo river and the Democratic Republic of Congo (RDC) through the watersheds of the Plateaux of the cataracts. In the North-West by the river Bouenza (Lali); in the West by Ndouo (Niari).

Administratively, the department is limited to North by the Plateaux; in the East and the South by the Democratic Republic of Congo; in the North-West by the department of Lékoumou and in the west by the department of Bouenza. The zone of study, which is not other than the Plateau of Mbe (Figure 1) lies within a broader geographical scope. It belongs to a whole of the Plateau which resemble each other enormously: the natural landscape is the same one except for nuances [18]; the inhabitants are all Batekes authentic. They are the Batekes Plateaux. However the Plateau of Djambala and that of Nsah are almost as deprived of inhabitants as that of Mbe. This triple correspondence seems to lead to a simple explanation of the deficit of settlement, feature common to the three Plateaux. One immediately thinks of accusing, or the medium exploited by Batekes, or the techniques which they use. The first could not lend itself to a sufficiently productive farm for many men. One can suspect as well Batekes of exploiting their plateaux in a so ineffective way as it would result a great wasting from its surface. But there exists a fourth plateau, the Koukouya Plateau. Completely similar to the others, its reduced dimensions do not prevent it from carrying a population of more than 10,000 inhabitants is a density of 20 hab /km2 approximately, one of strongest of Congo. This aberrant fact shows that the things are more complex than it appeared at first sight [18].

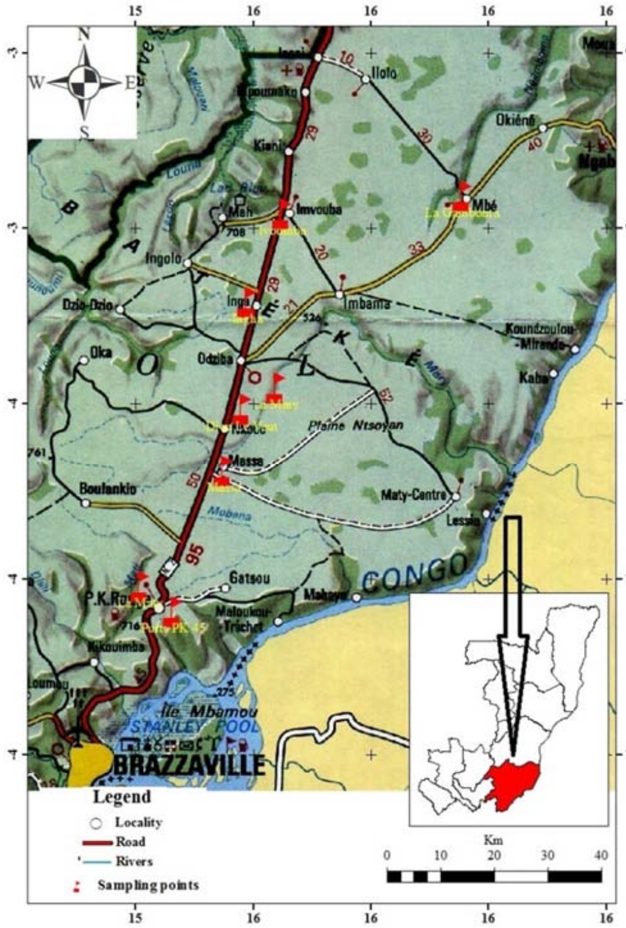


Figure 1. Presentation of the zone of study and the sampling points.

2.1. Climatic Framework

The local climate belongs to the southernmost congolese sector of the guinean subequatorial field, intermediary between the guinean-forester field and the field soudano-guinean [19]. It is characterized by:

a relatively constant and low temperature due to altitude (annual average: 23°C);

a high relative moisture (annual average: 78%) with a tension annual average of least low vapor of Congo.

One 3 months marked dry season, where the freshest temperatures of the year appear (from13° to 16°), a rather strong pluviometry annual passing from 1,500 mm (sector of Mbe) to 1,700 mm (sector of Odziba) and distributed over approximately 100 days.

2.2. Geological Framework

The geology of the zone of study (Figure 2) belonged to the geological unit of Congo called: Batekes Plateaux.

The Batekes Plateaux correspond to an immense plateau reaching 700 m of altitude, which extends as far as RD-Congo [20], subdivided in several small plateaux (Djambala, Koukouya, Mbe…) by deep rivers such as Alima, Mpama, Lefini, Nkeni… These deep rivers show a prevalent orientation parallel with taking down faults NE-SO.

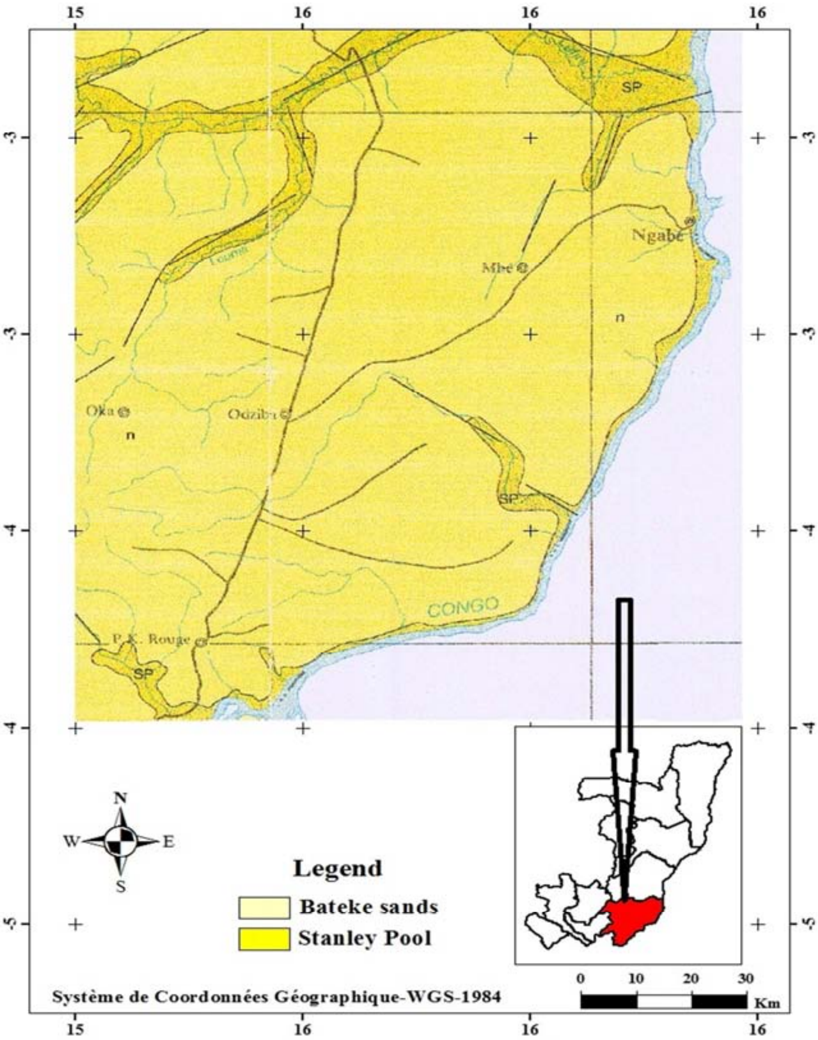


Figure 2. *Geological map of the zone of study.*

2.3. Framework Hydrogeological

Mass of the tender likings of the Batekes Plateaux form an important groundwater tank. This tank is supplied by the vertical infiltrations which constitute a significant proportion of precipitations. As there does not exist any side trap, there is a continuous flow on the circumference of each plateau and their removed topographic positions make very difficult the use of stored water. The sector of the sources of Mary and Gamboma (Figure 1) is however privileged, but a hydrogeological study supplements would not be justified that within the framework of a project of development of the zone [7].

In his study on the sandstone model, [21] shows the staged provision of the aquifers locked up inside the sandy layers by levels of less permeability. The circulation of water, from top to bottom, between these aquifer is done via the plan of dip and joints. Only the higher sheets of water are fed directly by precipitations. It results from it strong oscillations of their piezometric surface in areas at marked dry season. On the other hand, the aquifers deep have a practically permanent flow.

This assumption is confirmed by the boreholes carried out on the Koukouya Plateau. In their respective works, [7] and [13] concluded on the existence of an important aquifer deep to the base of the plateaux and small aquifers perched at a depth close to 50 m.

3. Materials and Experimental Method

Water points: well (Ignie); boreholes (Massa, Dieu le veut, Ingha and Ivoumba) and rivers (Maty, Mary and Gamboma) sampled were selected in such manner to cover the whole of the zone of study (Figure 1). These water points were located by their geographical coordinates using the GPS. On the whole eight (08) intake points were retained what made it possible to collect 32 samples for the physicochemical analyses between November 2017 and May 2018. These samples were taken in rain season, period which corresponds to the refill of the aquifers by precipitations; and also during the period of deceleration of the rains between mid-January and at the beginning of March called still small dry season. The samples are carried out and conditioned in bottles of 1.5 liter of polyethylene especially prepared for this purpose. The samples for boreholes provided with taps are carried out after having made run water in the vacuum during several minutes. The bottles of sampling before filling were rinsed several times with water to be taken and are then filled at ends of analysis. For the well (Ignie), the samples are carried out using an especially designed sampler. The device of sampling is carefully rinsed three (03) times with the water sampled before each sample. The totality of the surface water points and the aquifer deep of the Mbe Plateau is intended for the drinking water supply, for the irrigation of the arable lands, etc. To be used, water must meet certain standards which vary according to the type of use. For each test, physical parameters namely: pH, temperature, electric conductivity, salinity, TDS, dissolved oxygen and the dissolved complete iron were measured in situ using a pH-meter, a TDS-3 (TDS/TEMP) and a conductimeter of mark Consort C6030 (electrochemical analyser). The water samples were immediately stored with 4°C in a refrigerator containing ice, the analysis was quickly carried out less 24:00 after the taking away. Major elements and others, in particular, electric conductivity (EC), pH, the temperature, hardness, Ca^{2+}, Mg^{2+}, K^+, Na^+, Al^{3+}, NH_4^+, Cu^{2+}, Fe^{2+}, Pb^{2+}, Cd^{2+}, Mn^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, alkalinity, and dissolved oxygen are analysed at the laboratory of the IRSEN. These analyses were carried out using a spectrophotometer by using the traditional methods recommended by French standards AFNOR.

The potability of water is defined by physical, chemical and even biological parameters, but especially according to its use [22]. A comparison of the contents of physical and chemical elements of water of boreholes, wells and rivers to the standards of the World Health Organization ([23-24]) was carried out. The hydrochemical analysis was then carried out using the digraph of Piper in particular to characterize the geochemical facies of water of the plateau of Mbe. This diagram is very frequently used and gives very good performances [25-31]. The treatment was possible thanks to the software DIAGRAM. The statistical analysis was carried out on 32 samples and 22 variables using software XLSTAT 2016. These various analyses make it possible to characterize the physicochemical aspects of groundwater and surfaces of the plateau of Mbe. The various methods used in this study will make it possible to know on the one hand the mechanism of mineralization of water of the studied sites and on the other the relations which exist between these water resources and the anthropic activities of the zone of study.

The quality of the analyses were controlled thanks to the ionic balance for the reliability of the results.

4. Results and Discussion

The physical parameters of groundwater and surfaces measured on the ground are consigned in Table 1.

Table 1. *Results of the physical parameters measured in situ.*

N°	Type of water	Works	T (°C)	pH	TDS (ppm)	CE (µs/cm)	Fe (mg/l).10-6
1	Surface water (wells and waterway)	well 45	26	5.85	6	17.28	0.96
2		La Maty	27	4.98	7	8.63	0.96
3		La Mary	29	5.19	0.00	4.17	0.97
4		La Gamboma	25	5.00	0.00	8.15	0.97
5	Deep aquifer (drilling)	Massa	27	4.55	8	20.7	0.95
6		Dieu Le Veut	28	4.85	2	9.36	0.95
7		Ingha	27	4.90	2	7.3	0.95
8		Ivoumba	27	4.77	3	11.22	0.95
Mean			27	5.0	4	10.85	0.96

The temperature of water of the zone of study varies between 25 and 29°C (surface water with the temperature highest) with an average of 27°C. This almost constant temperature that it is for surface water and for underground. The temperature of this water slightly exceeds the standards prescribed by WHO [23-24].

The pH of surface water lies between 4.98 and 5.85. The groundwater has a pH ranging between 4.55 and 4.90 with a general average of 5.00, which shows that the water resources of the plateau of Mbe as well of surface as underground are acid.

Water presents very low values of electric conductivity as a whole. This one varies from 4.63 to 17.28µs/cm, for surface water, and from 7.3 to 20.7µs/cm for groundwater, with a total average of 10.85 µs/cm. The values of the TDS (Total of Dissolved Solids), vary as follows: for surface water from 0.00 to 7 (ppm) and for groundwater from 2 to 8 (ppm). Dissolved complete Iron present the very low values, that it is for surface water (from 0.96 to 0.97 (mg/l) .10-6) and groundwater of 0.95 (mg/l) .10-6. However, the salinity and the dissolved oxygen of surface water and underground measured in situ are equal to 0.

4.1. Physicochemical Parameters

Table 2 shows us the physicochemical results of surface water and underground of the plateau of Mbe measured at the laboratory.

Table 2. *Physicochemical results of the laboratory.*

Parameters	Wells	Boreholes				Rivers			Standard of WHO (mg/l)
	Ignié	Dieu le veut	Ivoumba	Massa	Ingha	La Mary	La Ngomboma	La Maty	
pH	4.9	5.1	5.4	5.9	3.4	5.1	4.7	5.1	6.5 – 8.5 (1)
T°C	26.7	26.5	26.9	26.1	26.7	26.8	26.7	26.6	25 (1)
CE	9.7	8.1	10.0	9.0	5.6	11.3	10.7	8.7	< 300.0 (2)
TDS	10.0	11.7	7.0	7.0	8.4	9.9	9.0	8.1	< 600 (1)
Ca^{2+}	9.7	9.0	15.3	15.7	8.3	12.3	9.3	11.3	75.0 (2)
Mg^{2+}	8.0	9.7	10.0	8.0	5.4	7.7	13.0	8.0	50 (2)
K^{+}	1.6	1.6	1.7	1.8	1.1	1.4	2.4	1.5	12 (2)
Na^{+}	0.1	0.2	0.2	0.1	0.1	0.4	0.4	0.2	< 200 (1)
Al^{3+}	0.6	0.3	0.5	0.4	0.3	0.3	0.7	0.3	0.9 (1)
NH_4^{+}	0.4	0.1	0.4	0.1	0.0	0.0	0.2	0.0	0.2 (1)
Cu^{2+}	0.3	0.6	0.5	0.5	0.4	0.6	0.5	0.6	2 (1)
Fe^{2+}	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.2 (1)
Pb^{2+}	0.2	0.2	0.3	0.4	0.2	0.4	0.3	0.8	0.01 (A. T) (1)
Cd^{2+}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.003 (1)
Mn^{2+}	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.5 (2)
HCO_3^{-}	12.9	11.1	4.9	9.5	5.8	8.6	6.2	6.7	< 200 (2)
Cl^{-}	13.1	5.8	7.2	9.3	4.5	5.2	6.0	5.9	< 250 (1)
SO_4^{2-}	4.1	4.0	4.7	6.9	4.1	5.0	4.5	3.8	< 250 (1)
NO_3^{-}	1.5	0.4	0.5	0.2	0.1	0.4	0.2	0.4	50 (1)
PO_4^{3-}	0.2	0.1	0.3	0.2	0.0	0.3	0.3	0.2	5 (2)
TH	9.6	10.6	11.3	5.0	4.9	7.0	8.3	5.4	100 – 300 (1)
Alcalinity	29.7	31.0	29.0	36.3	21.3	52.3	53.0	58.3	100 (2)

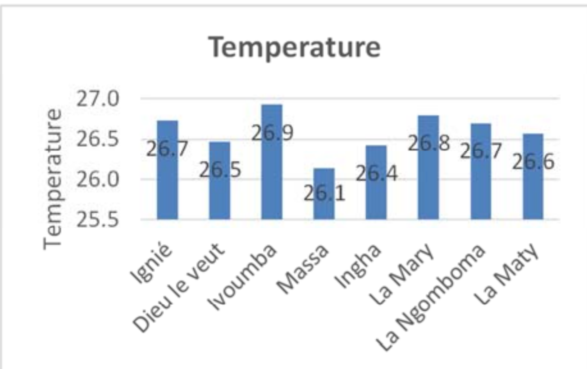
1 Directives of quality for the drinking water [24].
2 Directives of quality for the drinking water [23].

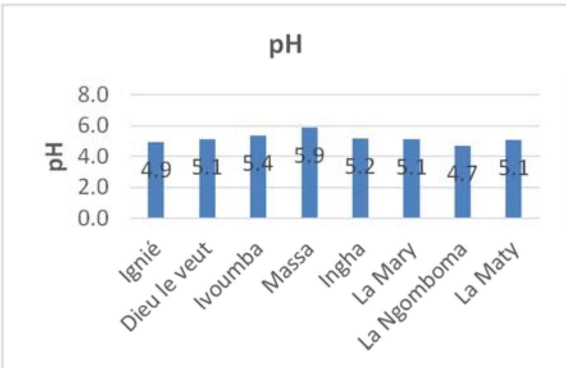
The temperature of water is a big factor in the watery environment owing to the fact that it governs almost the totality of the physical, chemical and biological reactions [32]. In this zone of study, the temperature does not present a great variation of a point to another (Figure 4) with a minimum of 26.1°C (borehole of Massa) and a maximum of 26.9°C (borehole of Ivoumba, follow-up of the river Mary with 26.8°C). These values are higher than that recommend by WHO [23-24]. The anomalies of temperatures observed are controlled by the geological structures which condition the geometry and the type of the underground circulation of water. Also, the temperature variations can correspond to a circulation of relatively fast water within privileged networks of circulation [33].

4.2. Ph

The pH of water informs about its acidity and its alkalinity. According to [34], the pH of natural water generally is included between 6.6 and 7.8 and according to [35], it varies from 7.2 to 7.6. Usually, the values of the pH range between 6 and 8.5 in natural water [32]. The nature of the grounds crossed by water is the natural cause, causing important variations of the pH. The analysis of this water revealed that the pH of the zone of study varies between 4.7 and 5.9; including surface water. All the sampled water points, the values of pH are lower than 7, which has an acidity of this water (Figure 3). This acid water is aggressive (0<pH<7) and corrodes the metal parts of the drains of distribution for example.

These results confirm that of the study undertaken by the Inter African Committee of Hydraulic Studies [36] on the Plateaux Batekes (Congo-Gabon-Zaire) with a pH of 6, therefore lower than 7. Unfortunately, this study was based only on surface water (river and pounds), in particular Gamboma in our zone of study.





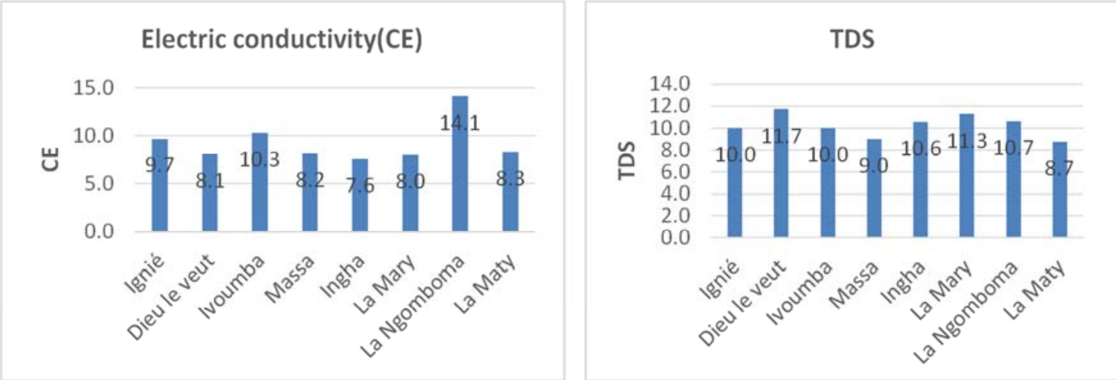


Figure 3. *Variation in the temperature, pH, electric conductivity and the TDS of water of the zone of study.*

4.3. The Electric Conductivity of Water

Electric conductivity indicates the capacity of water to lead an electric current. It is determined by the content of dissolved substances, the ionic load, the capacity of ionization, the mobility and the temperature of water. Consequently, electric conductivity informs about the degree of mineralization of a water. Waters of the controlled points are mineral-bearing (Figure 3), with values which oscillated between 7.6 and 14.1 µS/cm. It is noted that strong conductivities are that of the river of Gamboma and followed by the borehole of Ivoumba. All these points have values lower than the standard of WHO (300 µS/cm), which means that this water is slightly mineral-bearing.

4.4. Sulfates and Bicarbonates

Under the natural conditions, the sulfates, form of dissolved sulphur the most common in natural water, have primarily two origins: geochemical and atmospheric [37]. Because of high solubility of sulfates, the groundwater in normal conditions can contain some up to 1.5 g/l [38]. The oxidation of sulfides as well as the degradation of the biomass in the ground constitute other possible sources. Many human activities and natural can generate sulfate contributions in groundwater: application of sulphated manures, sulfur dioxide precipitations charged. The values of sulfates in studied water are very variable, they oscillated between 2.2 mg/l and 6.2 mg/l. And one can note that the highest values are that of boreholes of Ingha and of Massa (Table 2). The ions sulfates with concentrations higher than the value guides in the drink water can cause diarrheas at the human being. The analysis of our data shows that the contents sulfate are acceptable.

The content bicarbonates in groundwater depends especially on the presence of minerals carbonated in the ground and the aquifer, as well as the content CO2 of the air and the ground in the storing reservoir [38]. The content bicarbonates of groundwater not subjected to the anthropic influences, varies between 50 and 400 mg/l [38]. The median values of the contents bicarbonates are around 302 mg/l in the usual field of not polluted groundwater [38]. The contents bicarbonates of the studied points vary from 4.9 mg/l with 12.9 mg/l.

4.5. Calcium and Chlorides

Calcium is generally the element dominating of drinking water and its content varies primarily according to the nature of the crossed grounds (calcareous or gypseous ground) [39]. The calcium contents of controlled water varied from 9 mg/l to 15.7 mg/l. All the studied points have concentrations lower than the acceptable maximum value which is of 200 mg/l.

The chlorides are important inorganic anions contained in variable concentrations in natural water, generally in the form of salts of sodium (NaCl) and potassium (KCl). They are often used like an index of pollution [40]. The chlorides exist in all water with very variable concentrations. The origin can be natural [41].

4.6. Percolation Through Salted Grounds

Infiltration of marine water in the aquifer deep;

Effect of the human activity;

Minings and derived (soda, saltworks, mines mugs up, oil industries…).

Magnesium and Sodium.

The majority of natural water generally contain a minor amount of magnesium, its content depends on the composition of the sedimentary rocks met. It comes from the attack by carbon dioxide of the magnesian rocks and the setting in solution of magnesium in the form of carbonates and bicarbonates [42]. In certain aspects of the chemistry of water, magnesium and calcium are regarded as having similar effects while contributing to its hardness in spite of their different geochemical behaviour. Element for beneficial purposes for the body, the deficit in magnesium results in cardiac symptoms and disorders neuromuscular. In the analysed water points, the magnesium contents varied between 7.7 and 13 mg/l, and all the values do not exceed the standards of WHO.

Sodium is an element known as conservative because once in solution, no reaction makes it possible to extract it from subterranean water. Precipitations bring a tiny quantity of sodium in subterranean water, the abnormally high contents can come from the salt scrubbing, or the percolation through salted grounds or brackish water infiltration [39, 42]. In not polluted groundwater and without contact with evaporites, the sodium content ranges between 1 and 20 mg/l [38]. The data analysis showed that the average contents sodium in water of the studied points varied from 0.1 mg/l with 0.4 mg/l. The high percentages of sodium of water of the aquifer have the same origin as that of chlorides. Indeed, sodium generally accompanies pollution due to the chlorides. It is noted that the values obtained after this study, do not exceed the value prescribed by WHO.

4.7. Potassium and Nitrates

Potassium is generally the major element least abundant in water after sodium, calcium and magnesium; it takes only exceptionally the third rank of the cations. Potassium is found in the form of double chlorides in many ores such as the corrollite and sylvinite. One also finds it in ashes of the plants in the form of carbonate. Potassium is an element essential to the life and in particular to the growth of the plants. In agriculture, it is used as manure in the form of sulfate of potassium, chloride potassium, or nitrate of potassium. The potassium content is almost constant in natural water. This one does not exceed usually 10 to 15 mg/l [2]. Its concentration in the controlled water points varied between 1.4 mg/l and 2.4 mg/l. The highest potassium value is recorded at the river Gamboma of 2.4 mg/l. They all are lower than the value recommended.

The nitrates constitute the final stage of the oxidation of organic nitrogen, their presence in a polluted water attests that the process of self-purification is already started. The human activity accelerates the process of enrichment in this element on the grounds undergoing erosion, which causes the infiltration of waste water, by the rejections of mineral industries and of nitrate fertilizer [41]. The studied zone and as it is indicated the contents nitrates varied between 0.2 mg/l and 1.5 mg/l. The results obtained do not pose problem with respect to the standard.

4.8. Chemical Facies of Water Tested

We used the diagram of Piper (Figure 4) which makes it possible to represent the chemical facies of a whole of water samples. It is composed of two triangles making it possible to represent the cation facies and the anion facies and of a rhombus synthesizing the total facies.

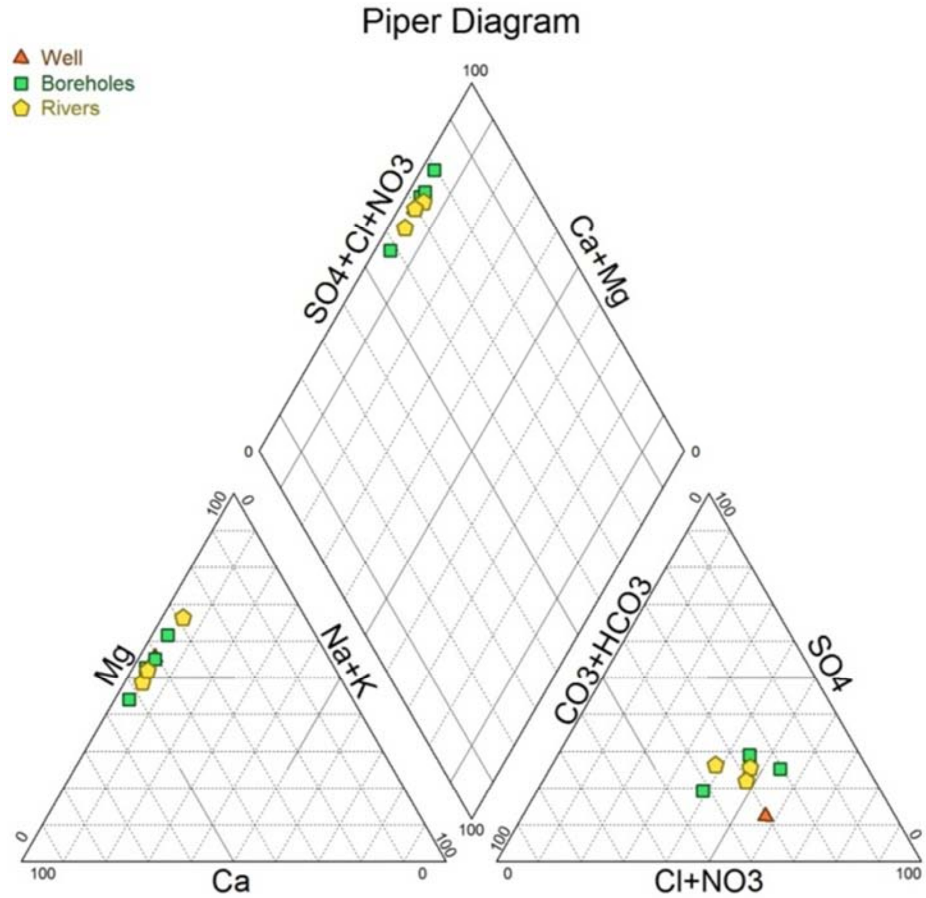


Figure 4. *Classification of water of the plateau of Mbe starting from the Diagram of Piper.*

This diagram of Piper highlights the facies of the two categories of water, in particular: surface water and groundwaters.

The carry forward of results of the analyses of water on the triangular diagram of Piper (Figure 4), highlights the incidence of the lithological facies on water quality and also makes it possible to estimate the percentages of the chemical elements and their classification.

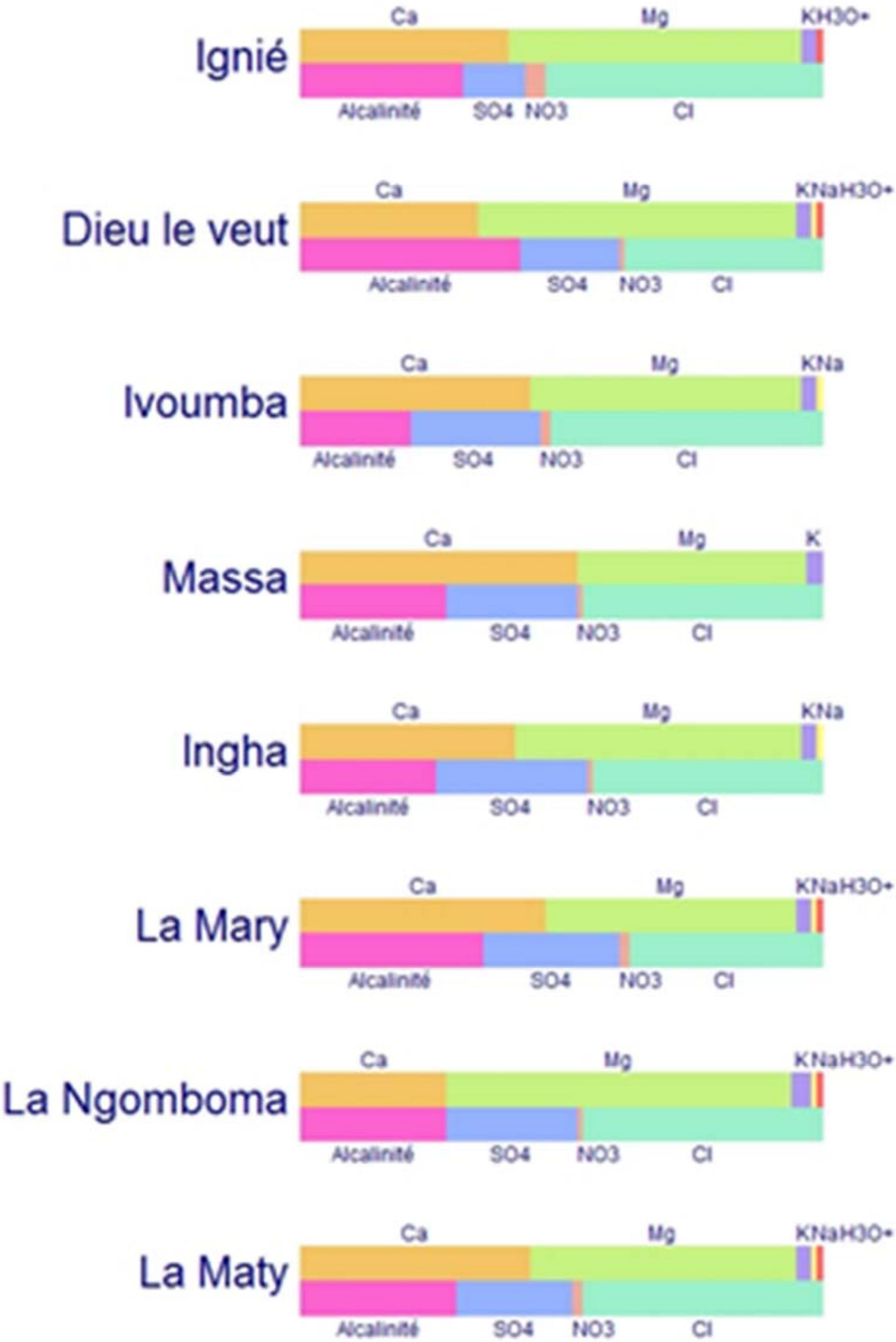


Figure 5. *Classification of the ions starting from the Diagram of Stabler.*

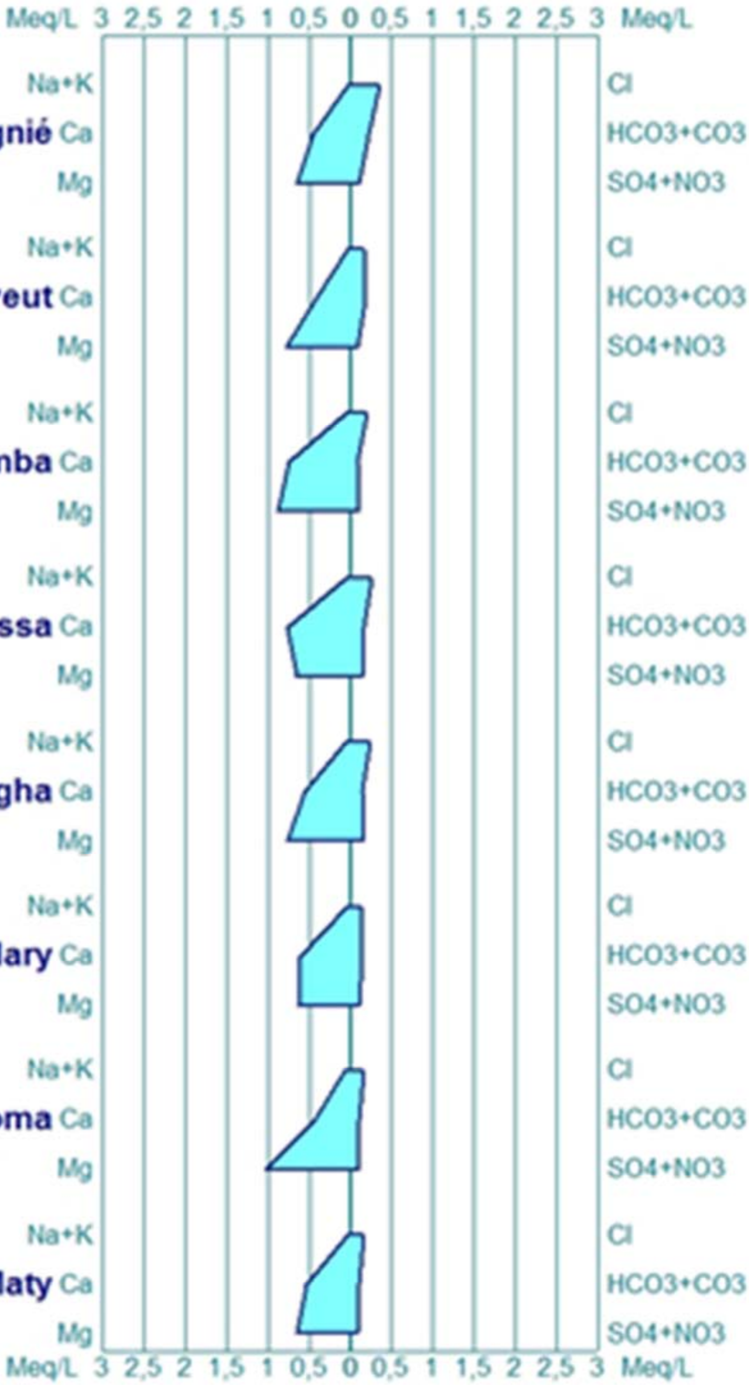


Figure 6. *Diagram of stiff.*

In the plateau of Mbe, water is thus characterized by a prevalence of the ions chlorides on the bicarbonated and sulphated ions. Magnesium (Mg++) constitutes the most important cation, then comes then calcium (Ca^{2+}), Figure 5.

The diagram of Schöeller-Berkaloff (Figure 7) makes it possible to represent the chemical facies of several water. Each sample is represented by a broken line. The concentration of each chemical element is illustrated by a vertical line in logarithmic scale. The broken line is formed by connecting all the points showing the various chemical elements. When the lines cross, a chemical change of facies is highlighted.

The prevalence of the calcic and magnesian facies chlorinated and sulphated is shown through the diagram of Stiff (Figure 6). Through these representations, the surface water and underground of the plateau of Mbe presents a calcic and magnesian facies chlorinated and sulphated. According to the diagram of Schöeller-Berkaloff (Figure 7), the dominant ions are the chlorides for the anions and magnesium for the cations. The concentrations are ordered as follows:

$$Cl^- > HCO_3^- > SO_4^{--} \text{ and } Mg^{++} > Ca^{++} > Na^+K$$

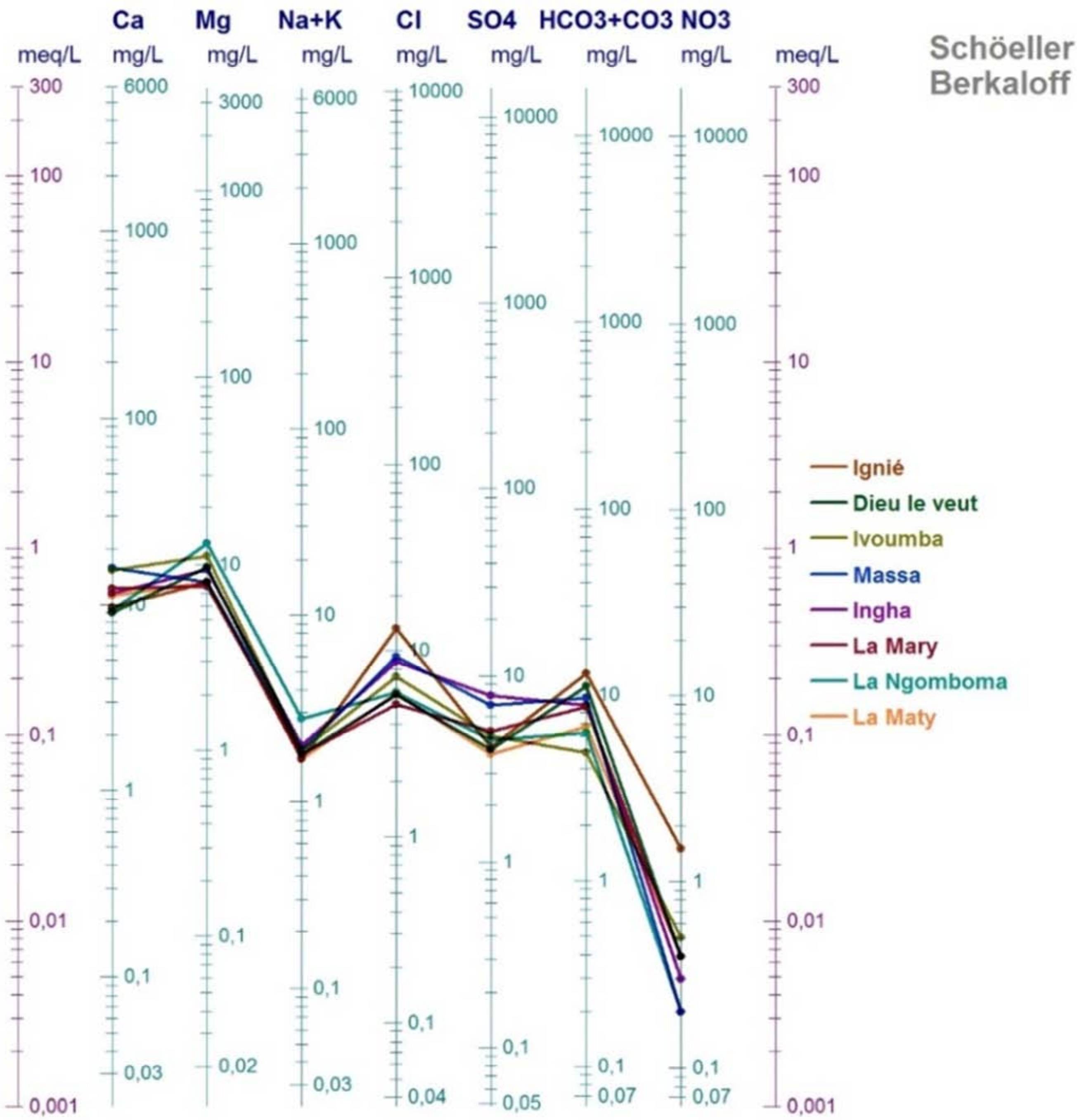


Figure 7. *Schöeller-Berkaloff Diagram.*

The diagram of Wilcox (Figure 8) watch that the surface water and underground of the plateau of Mbe is excellent.

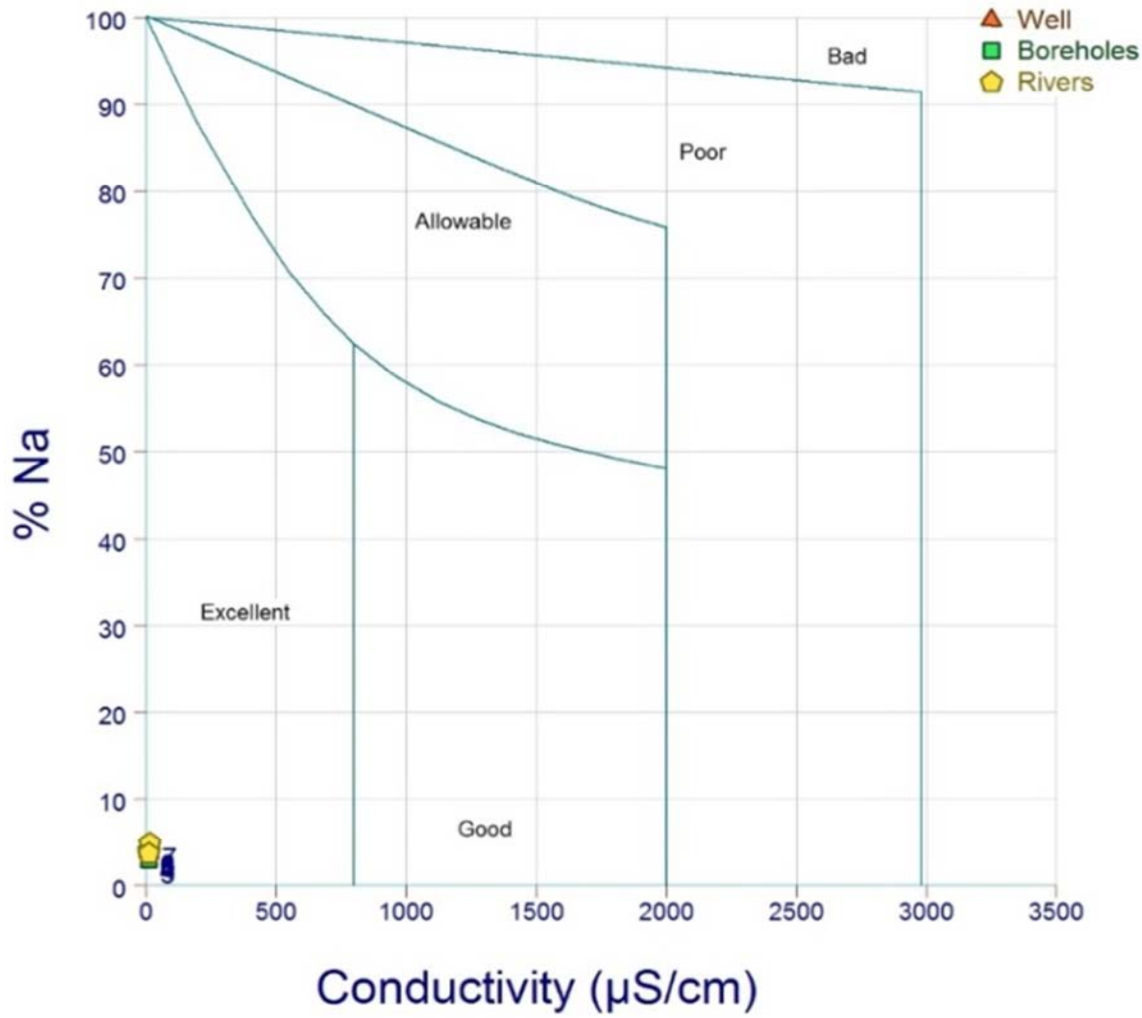


Figure 8. *Diagram of Wilcox.*

4.9. Analyses in Principal Components (ACP)

The eigenvalues of the factors are presented in Table 3. The first three factors account for 69, 92% of the expressed variance (Table 3). These factors gather the maximum of the expressed variance and are sufficient to translate exactly the required information. The matrix of correlation between the different variables is presented by Table 5.

Table 3. *Eigen value of ACP.*

	F1	F2	F3	F4	F5	F6	F7
Eigen value	7.305	4.740	3.337	2.533	2.113	1.360	0.612
Variability (%)	33.205	21.544	15.169	11.514	9.606	6.180	2.782
% cumulated	33.205	54.749	69.918	81.432	91.038	97.218	100.000

The classification of the water points according to their resemblance within the framework of an environmental follow-up of the studied water points is given by Figure 9. This dendrogram highlights two groupings of the studied water points. The first regrouping takes into account surface water and groundwater (C2 and C4) and the second contains also surface water and groundwater (C1 and C3). For the follow-up of water quality, it is important to choose a point of follow-up in each grouping. Thus, two water points are necessary (a well and a river).

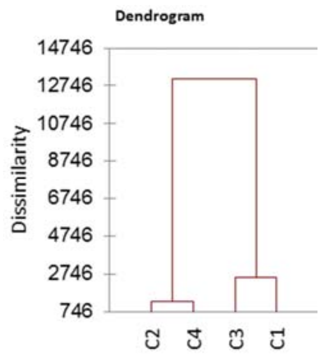


Figure 9. *Dendrogram for the classification of the water points.*

Table 4 watch the physicochemical classification of the parameters by class. It should be noted that the class C3 is the first regrouping with eleven (11) parameters. The second regrouping, it is the C1 class which contains nine (09) parameters and finally, the third regrouping (C2 and C4) with one respective element.

Table 4. *Classification of the parameters by class.*

Class	C1	C2	C3	C4
Parameters	pH; CE; TDS; Ca^{2+}; HCO_3^-; Cl^-; SO_4^{2-} et TH	T°C	K^+; Na^+; Al^{3+}; NH_4^+; Cu^{2+}; Fe^{2+}; Pb^{2+}; Cd^{2+}; Mn^{2+}; NO_3^- et PO_4^{3-}	Alc.

Table 5. *Correlation matrix between the variables.*

Variables	pH	T°C	CE	TDS	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	NH_4^+
pH	1.00									
T°C	-0.24	1.00								
CE	-0.43	0.45	1.00							
TDS	-0.20	0.14	-0.30	1.00						
Ca^{2+}	0.83	0.02	-0.17	-0.48	1.00					
Mg^{2+}	-0.17	0.05	0.51	0.25	-0.37	1.00				
K^+	0.07	-0.37	0.28	-0.01	0.00	0.70	1.00			
Na^+	-0.39	0.60	0.24	0.39	-0.20	0.21	-0.19	1.00		
Al^{3+}	-0.26	0.24	0.76	-0.32	0.05	0.41	0.62	-0.06	1.00	
NH_4^+	-0.14	0.34	0.51	0.04	-0.11	0.50	0.51	-0.23	0.77	1.00
Cu^{2+}	0.23	-0.24	-0.61	-0.02	0.06	-0.21	-0.36	0.20	-0.75	-0.73
Fe^{2+}	0.19	0.05	0.40	-0.37	0.21	0.27	0.47	-0.63	0.69	0.85
Pb^{2+}	0.43	-0.38	-0.40	-0.49	0.52	-0.32	-0.04	0.02	-0.31	-0.65
Cd^{2+}	-0.62	0.45	0.62	0.19	-0.60	0.59	0.28	0.10	0.60	0.81
Mn^{2+}	-0.38	0.90	0.64	0.20	-0.21	0.34	-0.11	0.43	0.45	0.63
HCO_3^-	-0.05	-0.45	-0.43	0.13	-0.26	-0.41	-0.18	-0.72	-0.24	0.06
Cl^-	0.17	-0.24	0.24	-0.54	0.26	0.05	0.50	-0.76	0.67	0.66
SO_4^{2-}	0.67	-0.21	-0.43	0.07	0.67	-0.10	0.44	-0.22	0.12	0.13
NO_3^-	-0.24	0.71	0.24	-0.18	-0.10	-0.20	-0.60	0.10	0.02	0.28
PO_4^{3-}	-0.10	0.54	0.61	-0.01	0.25	0.17	0.08	0.64	0.43	0.05
TH	-0.07	0.45	0.19	0.41	-0.33	0.56	0.08	0.04	0.10	0.65
Alc.	-0.33	-0.26	-0.05	-0.13	-0.10	-0.24	-0.08	0.43	-0.14	-0.69

Table 5. *Continued.*

Variables	Cu^{2+}	Fe^{2+}	Pb^{2+}	Cd^{2+}	Mn^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	TH	Alc.
pH										
T°C										
CE										
TDS										
Ca^{2+}										
Mg^{2+}										
K^+										
Na^+										
Al^{3+}										
NH_4^+										
Cu^{2+}	1.00									
Fe^{2+}	-0.65	1.00								
Pb^{2+}	0.73	-0.38	1.00							
Cd^{2+}	-0.54	0.50	-0.74	1.00						
Mn^{2+}	-0.49	0.31	-0.67	0.76	1.00					
HCO_3^-	-0.20	0.21	-0.36	0.00	-0.31	1.00				
Cl^-	-0.54	0.90	-0.12	0.29	-0.02	0.33	1.00			
SO_4^{2-}	-0.05	0.21	0.31	-0.38	-0.31	-0.05	0.31	1.00		
NO_3^-	-0.01	0.21	-0.29	0.45	0.67	0.00	0.02	-0.48		
PO_4^{3-}	-0.39	-0.12	-0.08	0.02	0.44	-0.68	-0.24	0.04		
TH	-0.17	0.40	-0.62	0.71	0.67	0.00	0.05	-0.17	1.00	
Alc.	0.35	-0.71	0.55	-0.45	-0.45	-0.29	-0.43	-0.14	-0.81	1.00

4.10. Parameters of Pollution

The biogenic salts that we classified among the parameters of pollution were followed for each water (water surfaces and underground) sampled. Their concentrations are represented in Figure 10.

In view of these results, the contents of the analyzed parameters do not exceed the standards of potability of WHO [23]. Figure 10, presents three elements in particular: HCO_3^-, Cl^- and SO_4^{2-}, although not exceeding the limits prescribed by WHO, but they are in a uniform way on all the zone of study, i.e. on groundwater and of surfaces and surface one's of the zone of study.

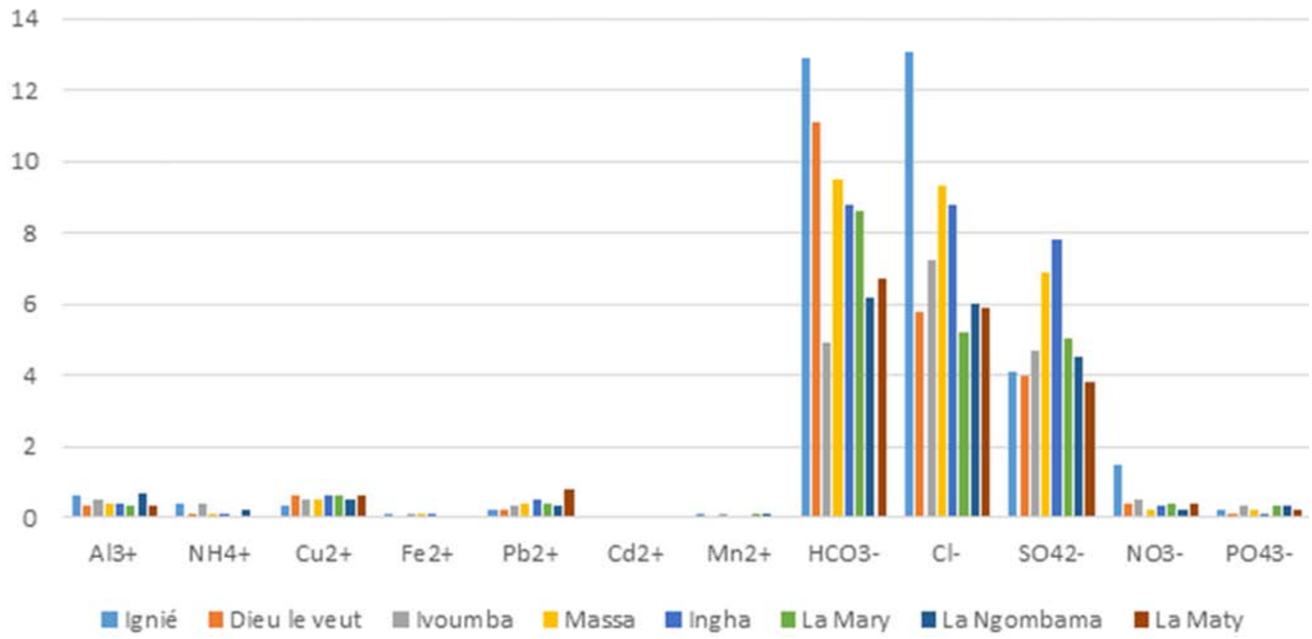


Figure 10. *Some parameters of pollution of groundwater.*

5. Conclusion

In terms of physicochemical analysis, there does not exist any concrete study, only the Interafricain Committee of Hydraulic studies (CIEH) in 1979 [36], undertook a study called "Given for the improvement of the water supply on the Batekes Plateaux (Congo-Gabon-Zaire) and this study was based only on surface water (enough and river). Five (05) parameters were analysed, of which two (02) confirm our study. In our zone of study, Gamboma was the only one concerned in 1979's studies.

The study undertaken on water of the Plateau of Mbe enabled us to characterize this water on the physicochemical level. Indeed, it arises according to the results obtained that the values of the 22 parameters tested (electric conductivity (EC), pH, the temperature, TH, Ca^{2+}, Mg^{2+}, K^+, Na^+, Al^{3+}, NH_4^+, Cu^{2+}, Fe^{2+}, Pb^{2+},Cd^{2+}, Mn^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, alkalinity, and oxygen dissolved) in situ just like at the laboratory, are all in conformity with the allowed standards by WHO, except the pH which is lower than the required value, which translates the acid character of this water. Consequently we can conclude that the groundwater and of surface of the plateau of Mbe is of a physicochemical good quality; the diagram of Wilcox (Figure 9) shows that it is an excellent water.

This study also made it possible to highlight the prevalence of facies chemical total chlorinated and sulphated calcic and magnesian in groundwater and of surface of the Plateau of Mbe. The dominant ions are the chlorides for the anions and magnesium for the cations. The use of the statistical methods in this work highlighted the processes which control the chemical composition of studied water.

Concerning the parameters of pollution, the groundwater and surfaces of the zone of study does not present any danger to the human health.

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