

# Contribution to the Assessment of the Quality of the Drilling Waters of the Regions of Lobaye and Ombella - Mpoko in the South - West of the Central African Republic

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**Abstract** Drilling water consumed in the South-West of the Central African Republic is the main source of drinking water. However, the chemical and bacteriological quality of these resources remains unclear. This study allowed us to classify the boreholes in the region according to their chemical and bacteriological quality in order to assess the risks associated with their consumption. The results obtained showed that the boreholes have an acidic pH and are weakly mineralized. Three chemical facies have been identified from the piper diagram which are calcium and magnesium bicarbonate, chloride and calcium sulfate, finally magnesium and sodium and potassium chloride. The mineralization of these boreholes is influenced by the nature of the rocks, in particular the carbonates, granites, clays and shales present in the region and also the external inputs due to the leaching of the soil. The results of bacteriological analyzes show the presence of fecal contamination germs in certain boreholes. The study revealed three quality classes: first class for good quality drilling water, which meets WHO standards, second class for acceptable quality water and third class for poor quality water.

**Keywords:** drilling water, mapping, water quality, chemical facies

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## 1. Introduction

Drilling water is a valuable resource used by humans for various purposes. They are the main source of drinking water in several regions of the Central African Republic (CAR). Most of the Central and Southwest CAR region that hosts this study is not served by drinking water systems. For example, the government, in partnership with the agencies, has drilled many holes to facilitate access to drinking water in the region. Drilling water is often the only economically exploitable source of water due to its generally good quality and proximity to the place of consumption. Although hidden and invisible, groundwater can be vulnerable to the many sources of contamination from human activities. This study assesses the physicochemical and bacteriological quality to classify the region's drilling waters according to their facies and to map the quality of these resources.

## 1.1. Presentation of the Study Area

### Location

Ombella-M'poko and Lobaye are prefectures of the Central African Republic located in the south-west near the capital Bangui, bounded in the north by Ouham, in the south by Congo, in the east by the Democratic Republic of Congo and in the west by Mambéré Kadéï. The Ombella-M'poko covers an area of 319.14 km<sup>2</sup>, with the capital of Bimbo and the Lobaye with Mbaiki as the capital covering 185.70 km<sup>2</sup>.

## 2. Geological and Hydrogeological Context

### 2.1. Geology

The Central African Republic is located on the northern border of the Congo craton. This craton was affected by a

tectonic movement that today is responsible for many networks of faults and cracks. According to earlier work, the geological formations of the CAR are essentially Precambrian (more than 80% of the surface). The prefectures of Ombella-M'poko and Lobaye in which this study is carried out have been the site of numerous research projects which have resulted in the brief description of the rocks grouped at the basement formations. This Precambrian base underwent a metamorphism that gave rise to secondary and tertiary formations generally metamorphic and granitic. Several geological units characterize the formations of this region from the base to the cover and the structural analysis of the formations reveals at least phases of deformations characterized by folds, faults passing through the shales and folded quartzites with dip between  $10^\circ$  and  $25^\circ$  [12]. From the geological point of view, the formations of Umbella-M'poko and Lobaye are related to the Precambrian group, unevenly distributed. They are distinguished by two sets in these regions:

-The upper group attributed to Precambrian A characterized by the presence of siliceous, carbonate and clay facies [10]. There are also small basic intrusions in places in the Lobaye near Mbaiki and Ombella M'poko near Damara. The town of Bimbo in Ombella-M'poko benefits from the extension of the essentially carbonated Fatima series, characterized by rocks such as limestones, dolomites, etc. In addition, the Yangana-Pama series is marked by an alternation of fine sandstones, shales and quartzites [12].

-The base complex to precambrian D domain of crystallophyllian and crystalline facies. These crystallophyllian facies are marked by shales (sericite and

chlorite), micaschists (towards Bossembele, Damara in Ombella-M'poko, Boda and Mbaiki in the Lobaye), quartzites and conglomerates and finally gneisses (around Boda in the Lobaye). The crystalline facies are marked by the presence of granites (around Boda in the Lobaye, Lambi, Damara in the Ombella-M'poko) and basic intrusions in the Lobaye.

From a hydrogeological point of view, two main aquifers can be distinguished for the time being

-Surface aquifers generally consisting of lateritic, alluvial levels with intercalation of clay-sandy layers and shales. They are shallow, captured through drilling and shallow wells. Depending on the particle size of some formations, water productivity in surface aquifers may vary from borehole to borehole (water flows easily through gravel and sand rather than clay). These aquifers are close to the surface and sensitive to rain and also lack of a compact cover exposes them to various external pollution [8,10]. The permeability of these aquifers is generally low due to the high proportion of clays [5].

-Deep aquifers owe their existence to the networks of fractures (fault and crack) that developed within the compact formations during tectonic movements [14,15]. The faults and cracks are dense and open enough to conduct and store water between the particles. Thus, if the opening forms a fairly extensive network, these aquifers can become quite large [11].

The relief is characterized by hills around the Ombella-M'poko, Bangui-Damara road to the Lobaye near Mbaiki. These hills are covered with rocks, trees and downwards are steep valleys. The rocky formations observed from the top of the hills consist largely of quartzites and sandstones resting on folded shales with dips between  $10^\circ$  and  $25^\circ$ .

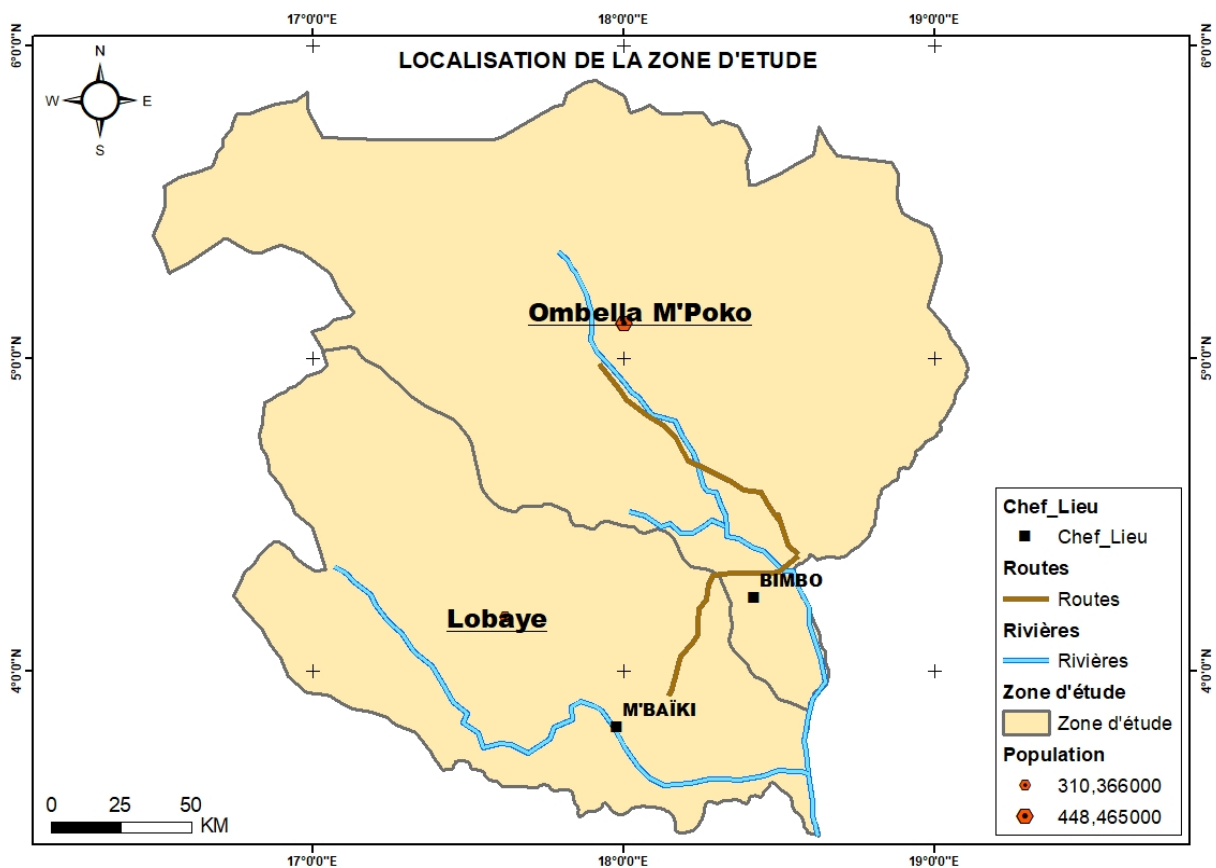


Figure 1. Location of study area

### 3. Materials and Methods

After a phase of recognition of the works to be taken in the field by the laboratory team, during the campaign, 54 points were sampled, including 26 boreholes in the Lobaye and 28 in the Ombella-Mpoko.

The following in situ analyzes were carried out at each water point to be sampled:

- pH (pH-meter WTW 340i)
- Electrical Conductivity and Temperature (WTW 340i Conductivity Meter)
- Alkalinity (HACH Alkalinity kit)

A series of samples was taken for various chemical analyzes

- 3 bottles of 30 ml filtered over 0.45° for the determination of cations (then acidification by HNO<sub>3</sub>), anions and trace elements (then acidification by ultra-pure HNO<sub>3</sub>) respectively. On each borehole, measurements and samples were taken after having sufficiently renewed the water in the column of the structure when the equipment allowed it.

The chemical analyzes were carried out at the Hydrosiences Lavoisier Laboratory of the University of Bangui in the Central African Republic.

The cations were analyzed by an atomic absorption spectrometer, **Varian AA55** mark, either by absorption or by emission.

The anions were analyzed by a **JENWAY 6850** double beam UV-visible spectrometer.

## 4. Results and Discussion

### 4.1. Hydrochemical Characterization

This operation consists of processing the data collected according to the two criteria previously chosen, namely the hydrochemical and water quality study from different data analysis tools such as Avignon Diagram software, GIS software QGIS 3.4 and Excel 2013.

#### 4.1.1. In Situ Parameters

The data measured in situ (Table 1) as a whole show homogeneous characteristics for most points. The pH values are between 3.45 and tend towards 8 this range reflects the acidic and alkaline nature of the waters in the two prefectures. Measuring the electrical conductivity of the water makes it possible to evaluate the overall mineralization of the water and the amount of dissolved salts (chlorides, sulfates, calcium, sodium, magnesium, etc.). EC values range from 14.2 to 70 on average with higher values up to 265 MS/cm for points impacted by domestic pollution. Drilling water analyzed in both localities is low and moderately mineralized (EC < 500 knots/cm). The alkalinity measured in the field also

remains at a low level between 0.8 and 42.82 mg/l with a maximum of 244 mg/l.

#### 4.1.2. Major Elements

The dissolved substance content is an important parameter in determining the physico-chemical quality of water. The major elements make it possible to refine the approach to the terrain and to identify the main processes of water-rock interaction. Calcium levels obtained ranged from 1.27 mg/l to 48.32 mg/l for all boreholes. The magnesium values obtained vary from 0.01 mg/l to 27.7 mg/l, the sodium contents are around 0.07 and 58.9 mg/l and the potassium contents are on the other hand low and vary between 0.07 and 12.35 mg/l.

Bicarbonates (HCO<sub>3</sub><sup>-</sup>) have high concentrations at all drilling sites, ranging from 0.8 to 244 mg/l. Chloride concentrations range from 7.1 to 87.5 mg/l, while sulfate concentrations range from 1 to 19 mg/l. On the other hand, the nitrate contents are low and range from 0 to 13 mg/l.

#### 4.1.3. Statistical Analysis

On the basis of the results obtained, a distribution of major chemical elements is made from the statistical method to define the evolution of the chemical elements in the drilling waters of the study region.

Statistical treatment of all the water chemistry data of the two prefectures allows to find the following results:

Based on the mean of the analytical results observed in the table above, the dominant cations in these boreholes are calcium (Ca<sup>++</sup>) and sodium (Na<sup>+</sup>) and for anions bicarbonate (HCO<sub>3</sub><sup>-</sup>) and chloride (Cl<sup>-</sup>). The least abundant elements are nitrate (NO<sub>3</sub><sup>-</sup>) and potassium (K<sup>+</sup>), with an average value < 2 mg/l.

Thus, the values obtained are ordered in the following manner:

- The cations have the following order of abundance: **Ca<sup>++</sup> > Na<sup>+</sup> > Mg<sup>2+</sup> > K<sup>+</sup>**
- For anions, we have: **HCO<sub>3</sub><sup>-</sup> > Cl<sup>-</sup> > SO<sub>4</sub><sup>2-</sup> > NO<sub>3</sub><sup>-</sup>**

### 4.2. Chemical Facies of Water

The chemical facies of the waters were determined from the major elements projected on the Avignon Diagram software.

#### 4.2.1. Piper Diagram

The projection of the analytical results of the 54 boreholes selected, including 26 Lobaye and 28 Ombella-M'poko samples, on the Piper diagram (Figure 3) reveals several chemical facies.

Three major families of water chemical facies differ from the boreholes studied: calcium and magnesium bicarbonate, then calcium and magnesium chloride and sulfate and finally sodium and potassium chloride.

Table 1. Statistical results in major elements

	pH	C, 25°C µS/cm	Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>	HCO <sub>3</sub>	NO <sub>3</sub>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>-</sup>
			(mg/L)							
<b>Min</b>	3.48	14.2	1.27	0.01	0.07	0.07	0.8	0	7.1	1
<b>Max</b>	7.52	265	48.32	27.7	12.35	58.9	244	13	87.5	19
<b>Medium</b>	5.66	70.00	9.00	3.52	1.32	5.02	42.80	1.07	26.92	6.01
<b>Standard Deviation</b>	0.97	60.03	8.41	4.42	2.32	8.95	52.03	2.77	18.85	4.32

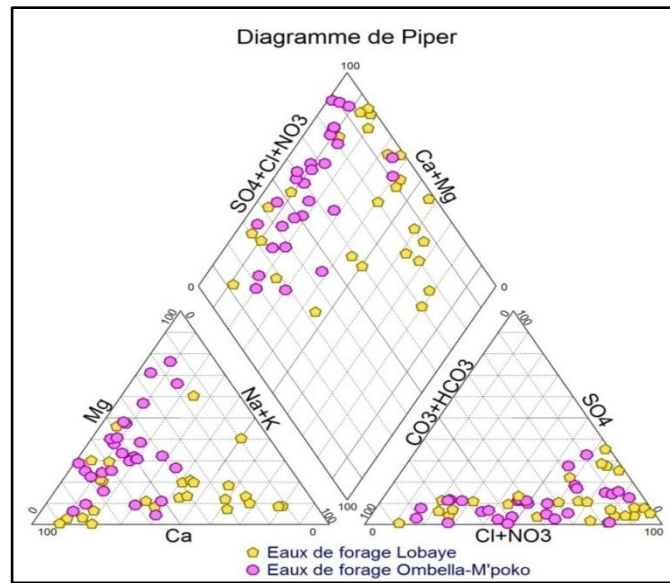


Figure 2. Chemical facies of the drilling waters of Ombella-M'poko and Lobaye

The overall Piper diagram obtained on the drilling waters studied has the following chemical facies:

- Facies bicarbonate calcium and magnesium: 7 of the Lobaye and 11 of the Ombella-M'poko boreholes;
- Chlorinated and sulphated calcium and magnesium facies: 12 boreholes in the Lobaye have this tendency and 17 in the Ombella-M'poko;
- Sodium and potassium chloride facies: 7 boreholes all

located in the Lobaye. The diagram shows a distribution of the boreholes according to a specific family in which the waters of the two localities are shown and indicates that the Lobaye region has the three facies obtained, however that of L'Ombelle M'poko has two facies bicarbonate calcium and magnesium and chlorinated and sulphated calcium and magnesium. These results show the variability of the chemical nature of the cash-outs in the different regions.

Stiff Diagram

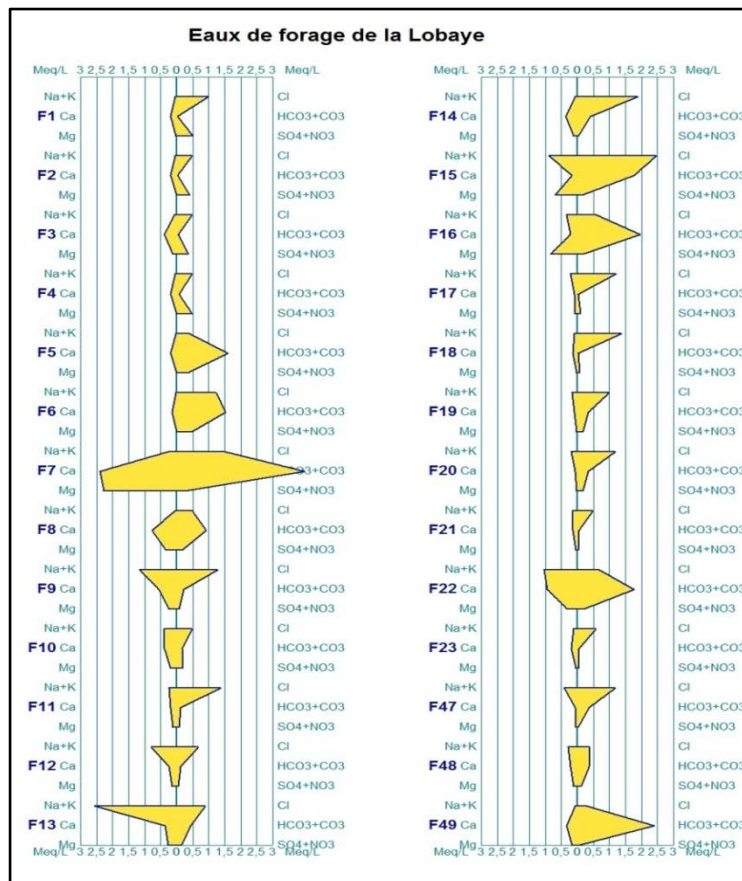


Figure 3. Stiff diagram for Lobaye drilling water

The Stiff diagram above confirms the mineralization of the waters at each point of the drilling water analyzed.

The highly mineralized boreholes are **F7, F9, F13, F15, F16, F22, F49**. The high mineralization of these drilling waters is due to the bicarbonate and/or carbonate, calcium and magnesium ions, thus indicating a carbonated casing exploited by these boreholes. The medium mineralized ones are **F5, F6, F8, F10, F11, F12, F14, F20, F47, F49**. The origin of this medium mineralization may come from leaching of the surface layers during water infiltration and finally those with low mineralization: **F1, F2, F3, F4, F17, F18, F19, F21, F23, F48** those waters come from a shale deposit.

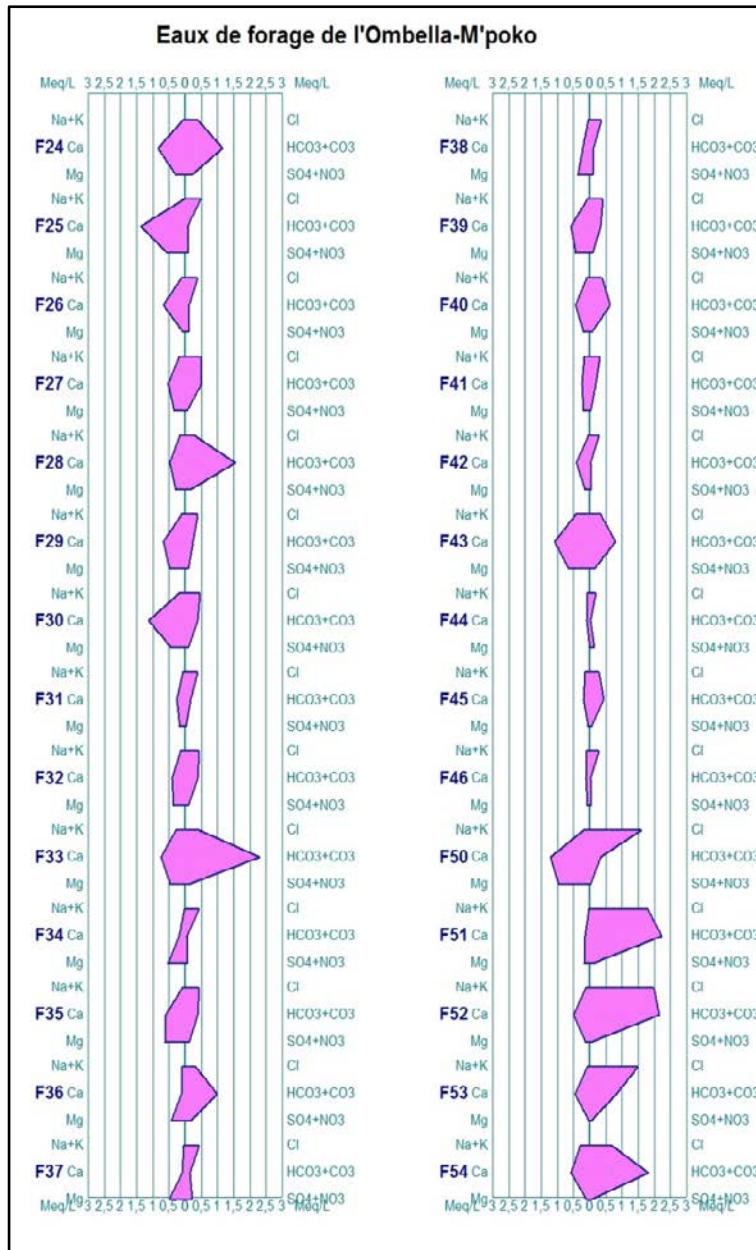


Figure 4. Stiff Diagram for Umbella-M'poko Drilling Waters

The high mineralization boreholes are F24, F25, F28, F30, F33, F43, F50, F51, F52, F53, F54, those medium mineralized are F27, F29, F32, F35, F36, F38, F39, F40 and low mineralized are F26 F31, F34, F37, F38, F41, F42, F44, F45, F46.

**4.2.5. Correlation**

Correlations were established between the elements that have the important coefficients. It is done using correlation coefficients determined by statistical calculations. Bicarbonates play an important role in the mineralization of analyzed drilling waters. Conductivity also changes at different boreholes, and the higher the

concentration of HCO<sub>3</sub><sup>-</sup>, the higher the conductivity of the water. The clustering of the points observed on one side is probably related to the geological formations and on the other side there is a slight evolution of the stationary points reflecting the heterogeneity of the facies found in the two prefectures.

A good correlation is also observed between Mg<sup>++</sup> and Ca<sup>++</sup> from the borehole waters of this region. Figure 5 above shows a dispersion of the drilling points on both sides, more than 52 boreholes are located below characterizing an excess of Ca<sup>++</sup> and a low Mg<sup>+</sup> content and one borehole is located at the top reflecting the importance of Mg<sup>++</sup>.

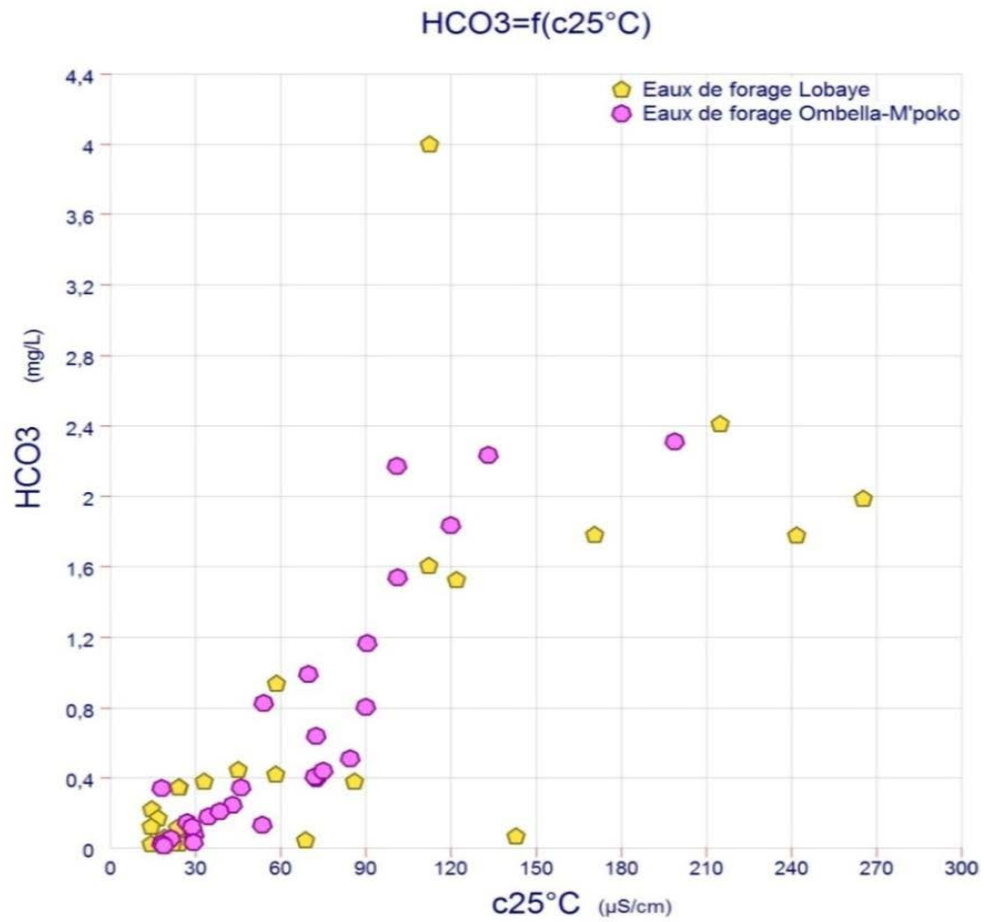


Figure 5. Correlation between bicarbonate and conductivity

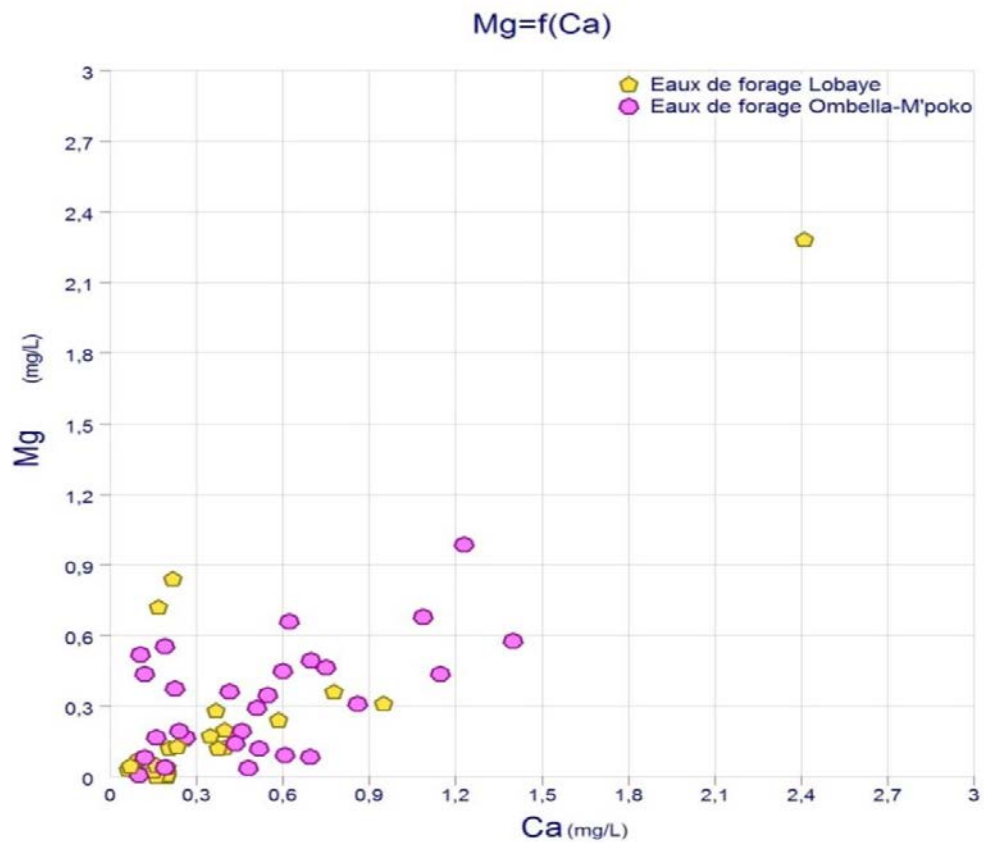


Figure 6. Correlation between calcium and magnesium

#### 4.2.6. Origin of Mineralization

##### - Facies bicarbonate calcium and magnesium

26.9% of the Lobaye boreholes are characterized by this facies and 39.28% in Ombella-M'poko. Bicarbonate, which is the dominant element of this facies, is derived from the dissolution of carbonated minerals in aquifers, as well as from the CO<sub>2</sub> (carbon dioxide) content. This dissolution confirmed the ion exchange by the presence of calcium and magnesium carbonate, which are the essential elements of calcite and dolomite in limestone. The calcium level in this facies is higher than that of magnesium because the Ca<sup>2+</sup> / Mg<sup>2+</sup> is greater than 0 [11].

So this facies comes from carbonate rocks and is fed by deep-seated sheets.

##### - Chlorinated and sulphated calcium and magnesium facies

46.15% of the Lobaye and 60.71% of the Ombella-M'poko boreholes have this tendency. It is the dominant face of the borehole water analyzed in both prefectures, with chloride as the main element. Land leaching is the primary source of chloride enrichment in these boreholes, followed by infiltration from anthropogenic activities. The sulfates, calcium and magnesium of this facies are derived from interactions with sedimentary rock-water.

Indeed, the origin of this facies is linked to clay-limestone formations because the description of the surface aquifers of this region is identical to these formations [11].

##### - Sodium and potassium chloride facies

This facies is mainly found in the Lobaye borehole waters with 26.92%, the dominant element of which is chloride. Land leaching and the solubilization of sodium and potassium salts released by clay minerals are responsible for the enrichment of these boreholes. The Na/Cl ratio is less than 1 and thus reflects the importance of chlorides in this facies, so the origin of the facies is probably related to anthropogenic activities [7,11].

## 5. Drilling Water Quality Assessment

The assessment of a water is the determination of its quality to satisfy human consumption. This quality is defined from physico-chemical and bacteriological parameters. In this quality study, we attempt to establish the relationship between these parameters in order to determine the quality of the water analyzed from a simplified grid (Table 2, Table 3) and to produce the quality map.

Thus, the pollution parameters were selected and compared with the drinking water quality standards set by WHO. Fecal contamination indicators were considered for bacteriological quality followed by physico-chemical parameters such as turbidity, chloride, nitrate, ammonium and iron.

Based on the data collected, bacteriological analysis was based on fecal contamination indicators such as Total Coliforms, Fecal Coliforms and Fecal Streptococci.

## 5.1. Quality Classes

The quality class assigns to boreholes of different colors to identify the quality points [2,15]. Thus, the boreholes in the study area are divided into three classes, each of which is identified by a color from blue which means good quality water, acceptable yellow water, and red which indicates poor quality water (Table 2).

Table 2. Bacteriological Quality Assessment Grid

Quality Class	Bacteriological parameters		
	Total coliforms	Fecal coliforms	Fecal Streptococci
Good	≤ 0 CFU	≤ 0 CFU	≤ 0 CFU
Acceptable	≤ 0 CFU	≤ 0 CFU	≤ 0 CFU
Bad	> 0 CFU	> 0 CFU	> 0 CFU

Table 3. Physico-chemical quality assessment grid

Quality Class	Physico-chemical parameters				
	Turb mg/l	Cl <sup>-</sup> mg/l	NO <sub>3</sub> <sup>-</sup> mg/l	NH <sub>4</sub> <sup>+</sup> mg/l	Fe <sup>2+</sup> mg/l
Good	≤ 3	≤ 100	≤ 10	≤ 0.5	≤ 0,1
Acceptable	3.1 - 5	100-20	10-50	0.6-0.7	0.1-0.2
Bad	> 5	> 200	> 50	> 0.7	> 0.2

The 54 boreholes were studied according to the potability criterion and classified from the simplified grids above, the results obtained are recorded in the table attached hereto. As a result of this study we have:

- 31 drilling sites have good quality water, including 15 in the Lobaye (F1, F2, F5, F6, F7, F8, F9, F10, F11, F12, F14, F15, F21, F23, F48) and 16 in the Ombella-M'poko (F27, F30, F32, F33, F34 F35, F36, F37, F38, F39, F40, F41, F42, F43, F44, F45), these waters meet the current WHO quality standards and are declared potable;
- 11 other points have acceptable qualities, 5 are located in the Lobaye (F3, F4, F13) and 6 in the Ombella-M'poko (F24, F25, F26, F28, F29, F31, F47, F49), the bacteriological quality meets the WHO standards, while from the physico-chemical point of view, these waters have high turbidity levels that far exceed the standards. For these boreholes, filtration treatment is recommended;
- 12 boreholes in this region have poor water quality, including 6 in Ombella-M'poko (F46, F50, F51, F52, F53, F54) and 6 in Lobaye (F16, F17, F18, F19, F20, F22). The water is of poor bacteriological quality with varying levels of coliforms and streptococci: this drilling water is therefore non-potable. Filtration treatment followed by disinfection is recommended for these boreholes

## 5.2. Drilling Water Quality Mapping

This study classified the boreholes according to hydrochemical and quality criteria and also represented the results obtained on the map of the study area.

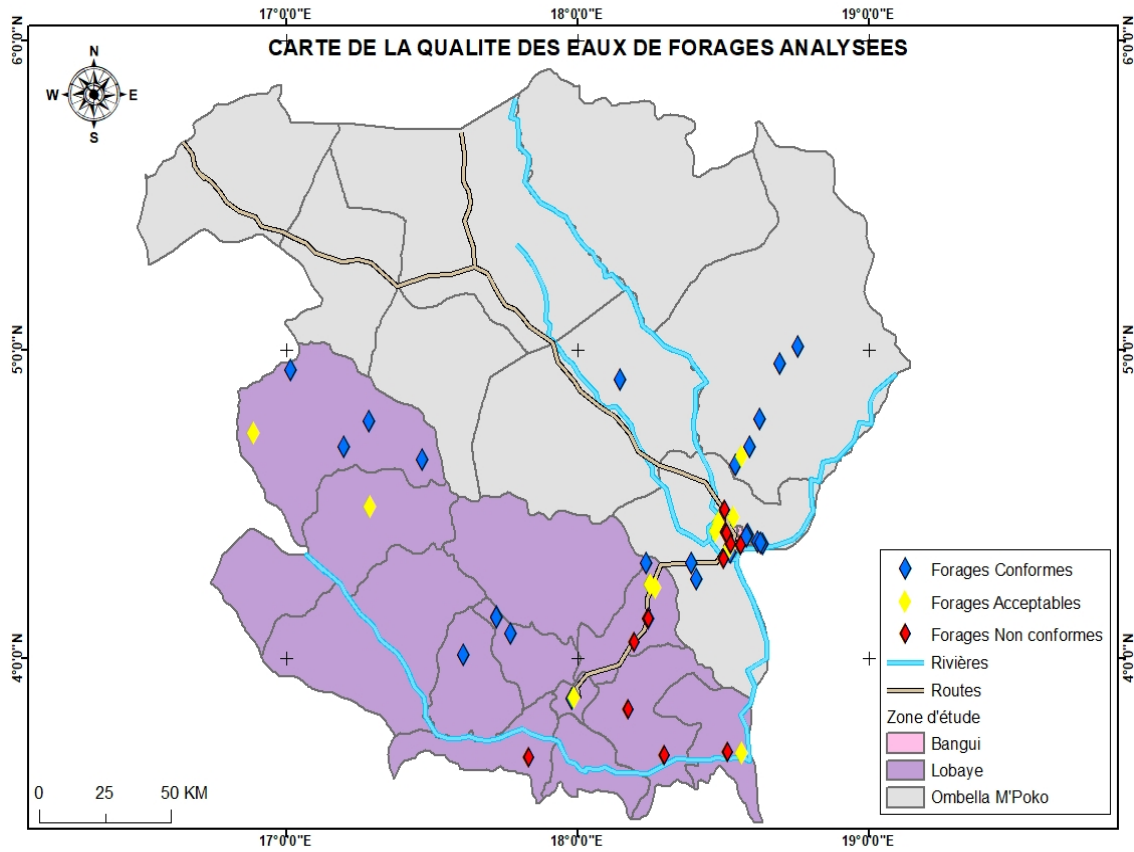


Figure 7. Drilling Water Quality Map

The map above shows a linear grouping of good quality boreholes from Ombella-M’poko to Lobaye: these boreholes are close to the roads and far from the sites of activity. In the middle, a mixture of the three quality classes obtained is observed, this quality mixture is due to certain boreholes exposed to pollution linked to human activities in the region.

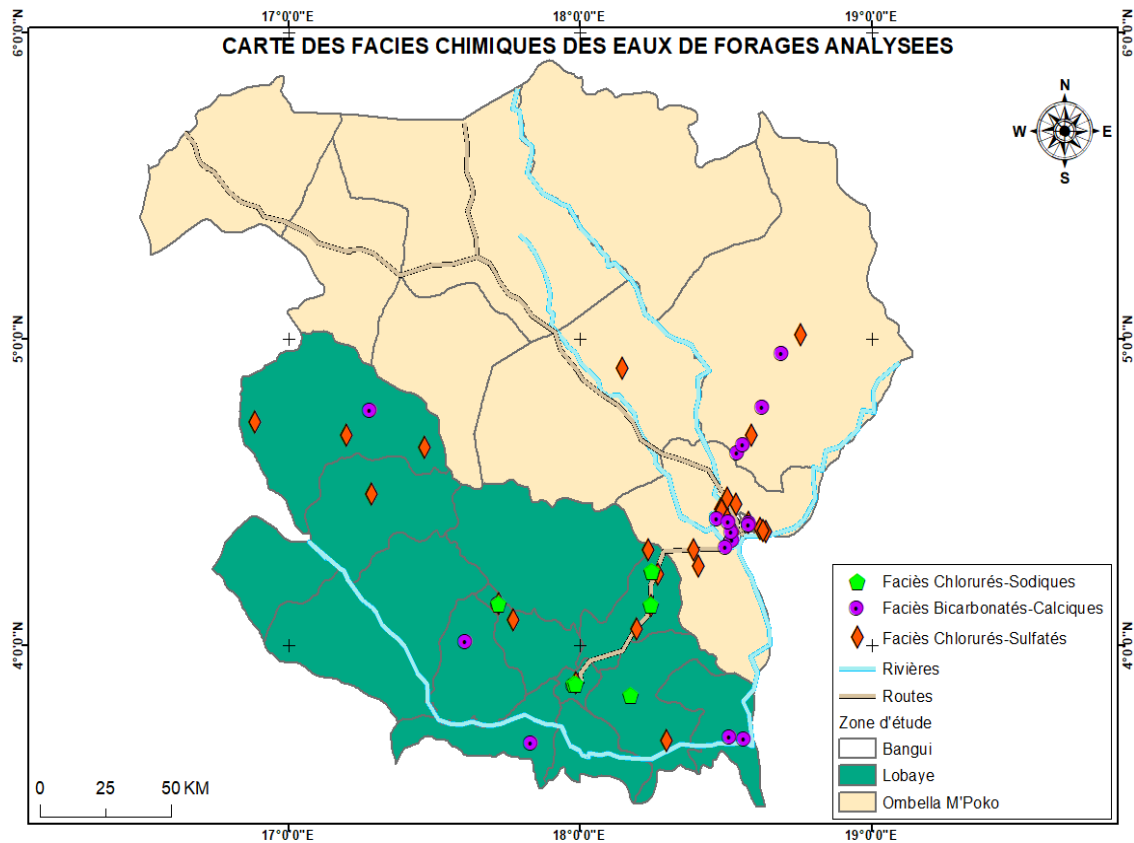


Figure 8. Map of Chemical Facies of Drilling Water Analyzed

The chemical facies of the water obtained led to the conclusion that 80% of the samples analyzed had geological formations with identical aquifers. The more than 20% sodium and potassium chloride facies obtained in the Lobaye made it possible to distinguish the geological formations of the two prefectures.

By superimposing the facies obtained on the water quality classes, we obtained the following map:

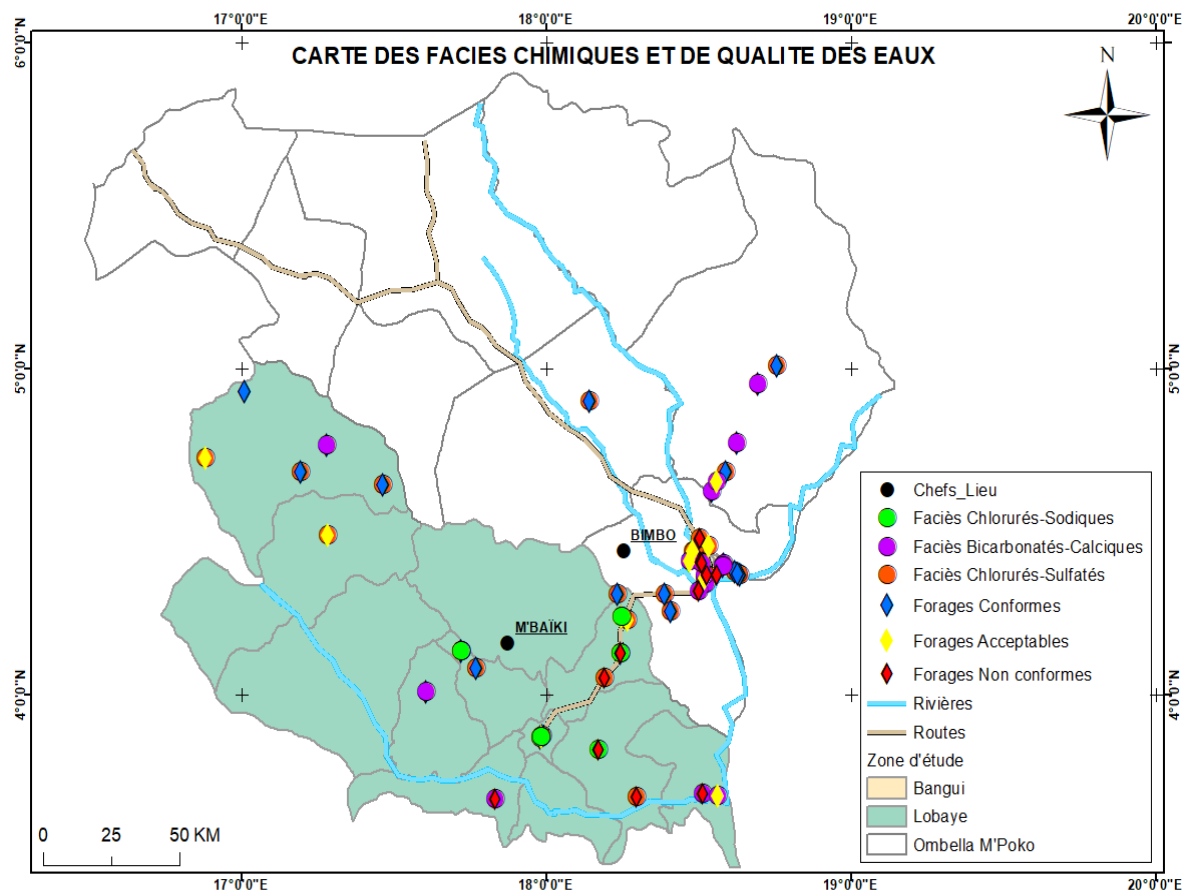


Figure 9. Map of chemical facies and water quality

In terms of resource quality, samples from both prefectures are mostly of acceptable quality.

## 6. Conclusion

This work involves the study of the quality of drilling water in the southwest region of the CAR. Deep borehole waters are a valuable resource that is highly sought after by communities. Human and household activities related to housing cause water quality at certain points to be exposed to different sources of contamination. However, according to the results of the study, several samples analyzed during these periods are of good quality (WHO standards are met). These results also reveal three main chemical factors: calcium and magnesium bicarbonate, calcium and magnesium chloride and sulfate, and sodium and potassium chloride. These main facies have made it possible to trace the origin of the mineralization of the waters and to conclude that the boreholes which have the chlorinated facies generally come from the surface aquifers, exposed to the various contaminations and the others come from the deep aquifers with adequate mineralization resulting from the dissolution of the rocks.

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