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Sanitary mapping of well waters in the commune of Bimbo in the Central African Republic (CAR)

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Introduction

1 In the Central African Republic, water is a commodity for which there is increasing demand, but supplies are vulnerable and largely unsatisfactory—a situation that highlights the impact of water quality on public health. It is therefore important that sources of groundwater, such as the wells in the town of Bimbo, located in the province of Ombella M'poko, are adequately protected against pollutants and are tested to verify their quality. To date, there has been no systematic analysis of the well waters, nor regular control of their quality. Serious health monitoring, in which data for each well is made available, is lacking.

2 Nevertheless, results from various studies carried out in the past provide an insight into the physicochemical composition of the water. They also highlight specific problems in quality that are linked to the source of the water or its geographical location. Hence, while there is a sufficient quantity of groundwater in the country, it may be of extremely poor quality, depending on its origin. On top of this, only a fraction of the population has access to it—so all things considered, water supplies are insufficient for the growing needs of the population. The need for drinking water is partially met by exploiting surface water sources, but these are of mediocre quality and can contain significant quantities of pollutants—hence the need for this sanitary mapping of the wells of Bimbo.

3 After an analysis of the principal physicochemical and bateriological characteristics of the well waters, this study discusses a possible correlation between the various compounds present. Finally, we will establish a map of water quality in the studied zone.

Presentation of the study zone

4 The commune of Bimbo, in the province of Ombella-M'Poko, is located in the southern part of CAR's capital city, Bangui. It covers an area of 3095 km^2, and a 2012 projection puts its population at 244,441. Its climate is similar to Forested Guinea, having nine months of rainy season and three months of dry season [2]. A report on work carried out by the Japanese International Cooperation Agency (JICA,1999) shows the existence of two aquifers : one shallow, consisting of laterite covered by layers of clay, sand and conglomerate ; the other quite deep, composed of sandstone, quartzite, schist and limestone, separated by layers of clay.

Geology of the study area

5 The commune of Bimbo is largely covered in limestone. Prior geological studies of neighbouring Bangui (Cornachia & Giorgi, 1986) revealed the presence of mico-schist, sericito-schist, schist, quartzite, granite intrusions, magmatite, limestone, sandstone, conglomerate covered in laterite layers of various thickness.

Health context

6 Data collected from hospital centres in the Commune of Bimbo indicate that there are more than 700 cases per month of waterborne diseases among those aged 0 to 75 (Centre Regional de l'Ombella M'Poko).

7 According to our study, this can be explained by limited access to good quality water, a lack of information on the rules of hygiene, and above all on basic sanitation.

Materials and Methods

Materials

Sampling

8 After a preliminary phase of familiarisation with the terrain, sampling of water wells for this study was carried out over several field trips. The water was sampled and acidified for iron analysis, then conserved in an icebox and brought back to the laboratory for physicochemical and bateriological analyses.

9 At each sampling location, the following *in situ* analyses were carried out :

- pH (pH-meter WTW 340i) ;
- electrical conductivity and temperature (conductimeter WTW 340i) ; and
- alkalinity (HACH alkalinity test kit).

10 Subsequently, samples were taken in polystyrene vials for physicochemical analyses and in glass for bacteriological analyses.

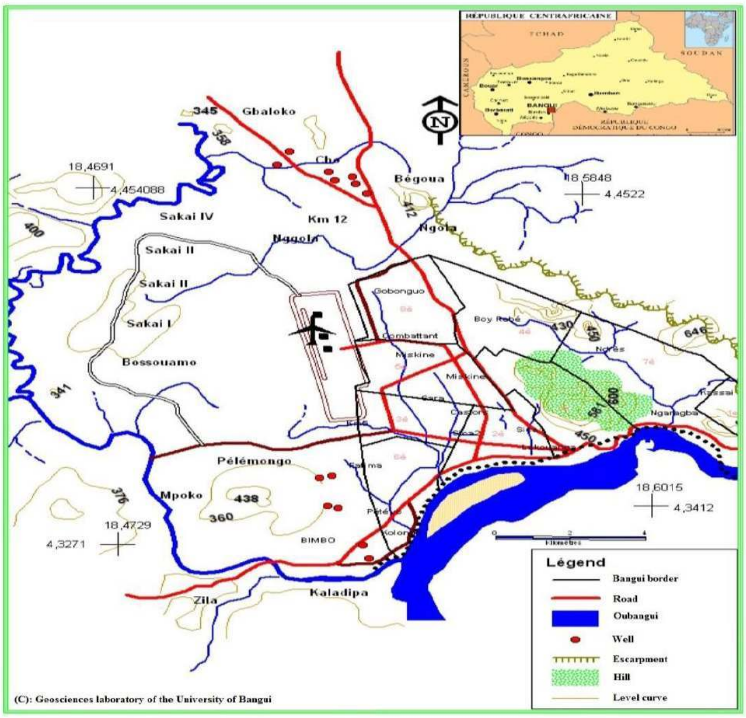
Field materials

11 To create the mapping of the study area, we used a GPS to take geographical coordinates of the different wells studied. Table 1 summarises the various fieldwork carried out.

Table 1. Geographical coordinates of test sites

Name of test site	Geographical coordinates		
	Longitude	Latitude	Altitude
Cattin (Bimbo centre)	N04°21'06.0''	EO18°31'27.4''	384 m
Samborla (Bimbo centre)	N04°19'37.2''	EO18°31'05.5''	317 m
Guitangola (Bimbo centre)	N04°21'10.7''	EO18°31'50.6''	356 m
Mbembe 1(Bimbo centre)	N04°20'24''.8''	EO18°31'31.3''	388 m
Mbembe 2(Bimbo centre)	N04°20'27.4''	EO18°31'24.5'4	390 m
Padrepio (Bimbo centre)	N04°21'03.6''	EO18°31'16.8''	391 m
HUSACA (Bimbo centre)	N04°19'20.6''	EO18°31'59.7''	350 m
Zacko 1 (Begoua)	N04°27'23.1''	EO18°31'29.3''	398 m
Toungoufara (Begoua)	N04°27'40.0''	EO18°30'47.0''	366 m
So (Begoua)	N04°28'00.5''	EO18°30'49.3''	374 m
Pk13 (Begoua)	N04°27'30.5''	EO18°31'25.9''	401 m
Yembi 1 (Begoua)	N04°27'20.3''	EO18°31'48.1''	407 m
Yembi 2 (Begoua)	N04°27'21.6'	EO18°31'46.4''	403 m
Begoua Hospital	N04°27'09.9''	EO18°31'59.3''	406 m

Figure 1. Location of wells



Methods

12 Our methodology consisted of two stages :

- Questionnaire and data collection ;
- Analytical methods used in the laboratory.

Questionnaire and data collection

13 A questionnaire was prepared for the local population. Among other issues, questions addressed their hygiene practices, equipment for drawing water, and waterborne diseases common in their households. Based on data from the questionnaire responses, we identified the various wells that would serve as our sampling points for analysis. Finally, we carried out sampling at these points over four field trips.

Analytical methods used in the laboratory

14 For this study, ten physicochemical parameters and two bacteriological parameters were measured. The physicochemical parameters chosen were those that allowed us to test (approximately) the chemical composition of the water, those for which there are thresholds beyond which the water is no longer considered fit for drinking. The bacteriological parameters chosen for analysis were those that indicate fecal contamination, because an absence of such contaminants is a strict requirement for potability.

15 The parameters tested and the methods used are summarised in Table 2 below.

Table 2. Summary of parameters tested and methods used

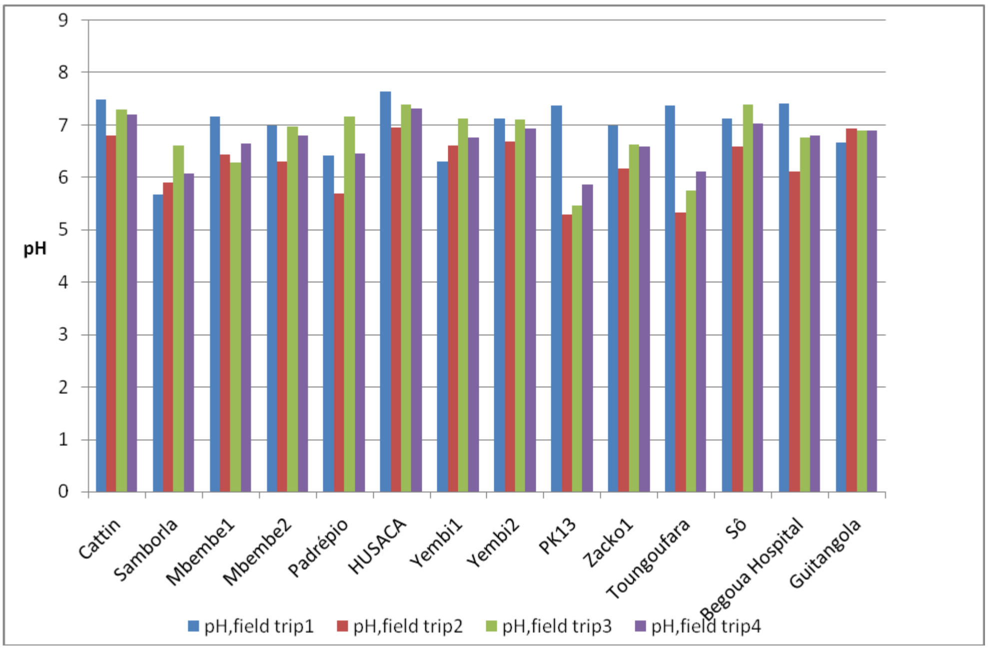
Parameters	Methods	Units
Conductivity	Potentiometric	µs/cm
Temperature		°C
pH		pH unit
$[Fe^{2+}]$	UV-visible spectroscopy	mg / l
$[No_3^-]$		mg / l
$[Cl^-]$	Volumetric	mg / l
TAC		°F
THT		°F
$[Ca^{2+}]$		mg / l
$[Mg^{2+}]$		mg / l
Fecal coliforms	Membrane filtration	CFU
Fecal streptococci		

Results and Discussion

Physicochemical parameters

pH variation in water analysed

Figure 2. Variation in pH



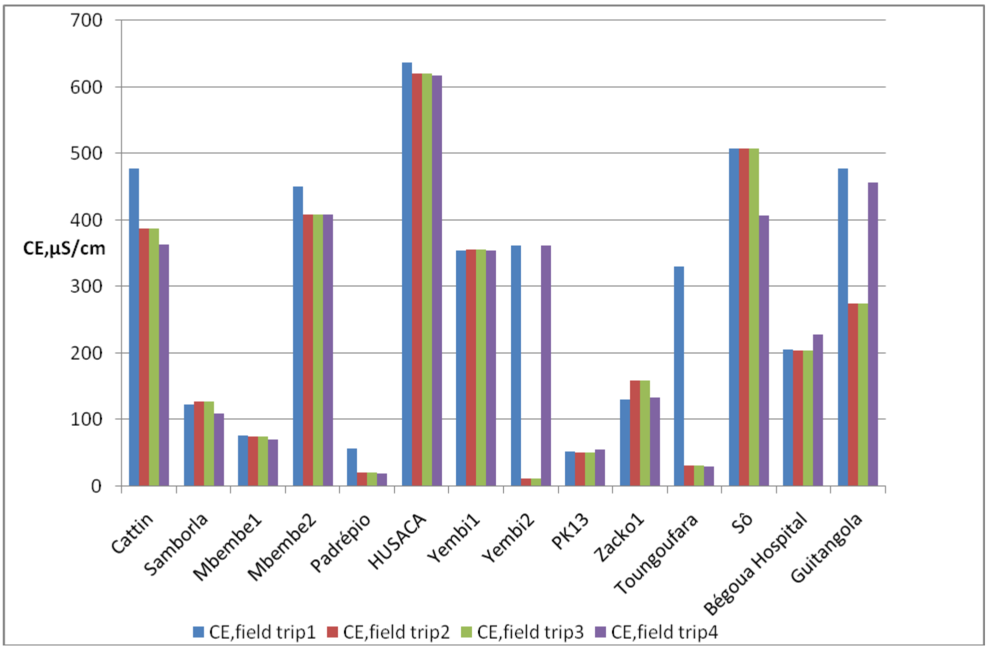
16 pH, measured in pH units, which measures the acidity or alkalinity of a sample, is a very important parameter in water analysis. The pH of our samples varied between 5.3 and 7.8.

17 In general, groundwater has an acid pH. The slight neutrality we observed could be due to infiltrations of surface water from above, or could result from the geological composition of the substrate traversed by the water.

18 Nevertheless, the pH values obtained are within the acceptable range of 6.5 to 9, according to current WHO regulations.

Evolution of the conductivity of the waters

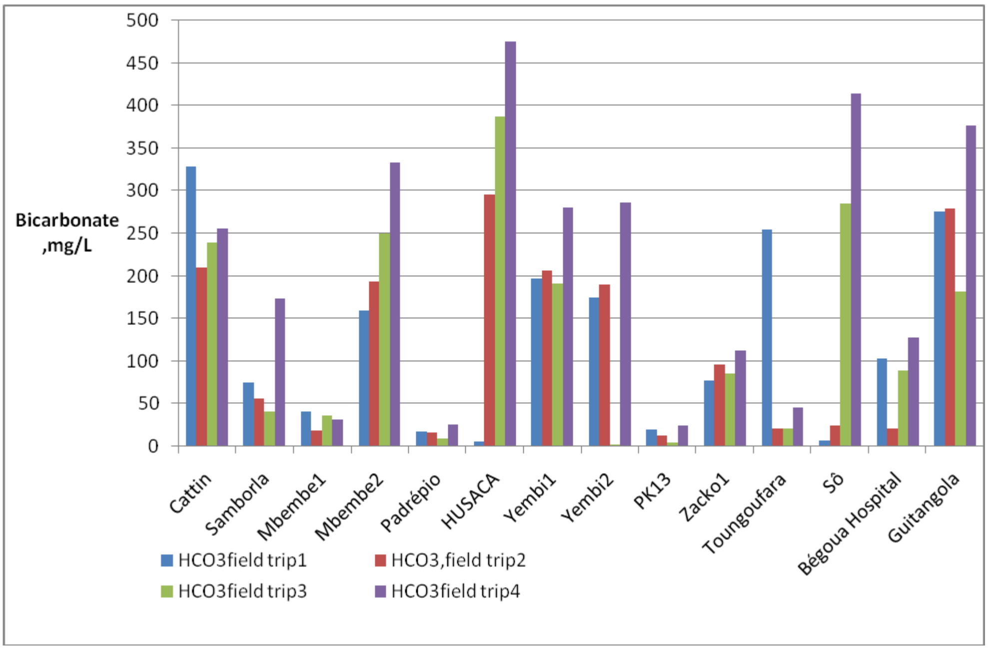
Figure 3. Conductivity measured on each field trip



19 The extent to which water is mineralised (strong, average or weak) can be deduced from measures of electrical conductivity. Results from our analysis show average mineralisation for the well waters studied ; although it should be noted that the well HUSACA demonstrates consistently stronger mineralisation, possibly due to the local soap-making industry. Figure 3 indicates that the electrical conductivity for most wells decreased slightly from the first to the fourth field trip. This decrease could be due to an external circumstance that altered the chemical composition of these well waters, for example a period of strong rain. However, the change observed was only slight.

Bicarbonate content of the water

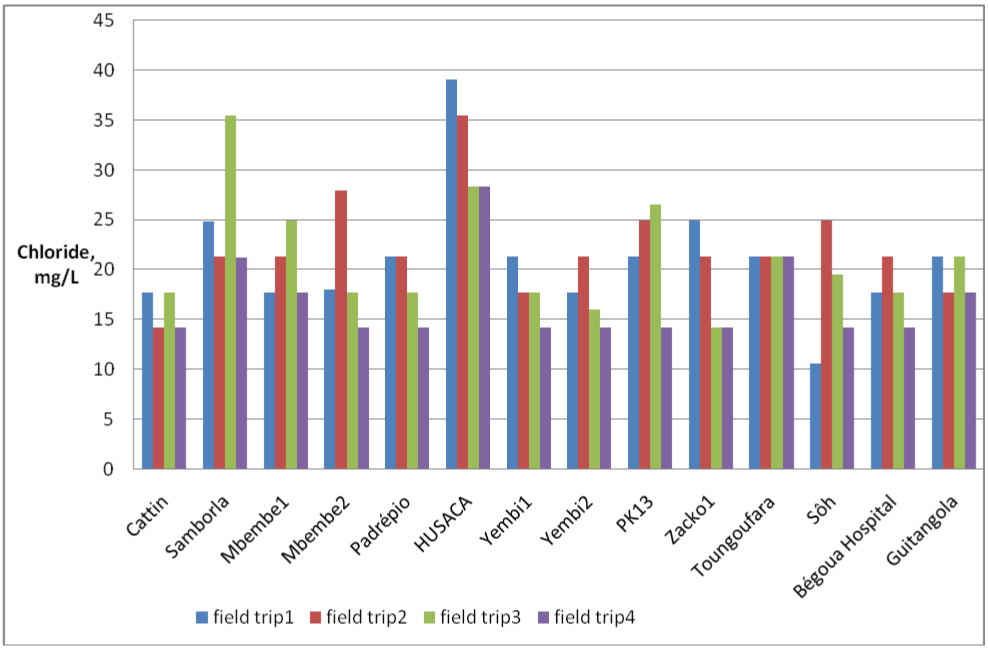
Figure 4. Bicarbonate ion content



20 The presence of bicarbonate ions (HCO_3^-) in groundwater depends on the nature of the terrain crossed : generally speaking, waters flowing through karstic terrains are rich in HCO_3^- and have increased conductivity. In the current study, we observed that the HCO_3^- content varied from one well to another. This variation can be partly explained by the geological nature of the terrain through which the water flows, and partly by the depth of the well. Like neighbouring Bangui, the study zone has a high composition of limestone, which is found at great depth. In any case, there is no regulatory limit for HCO_3^- in terms of human consumption.

Evolution of chloride ions in the waters

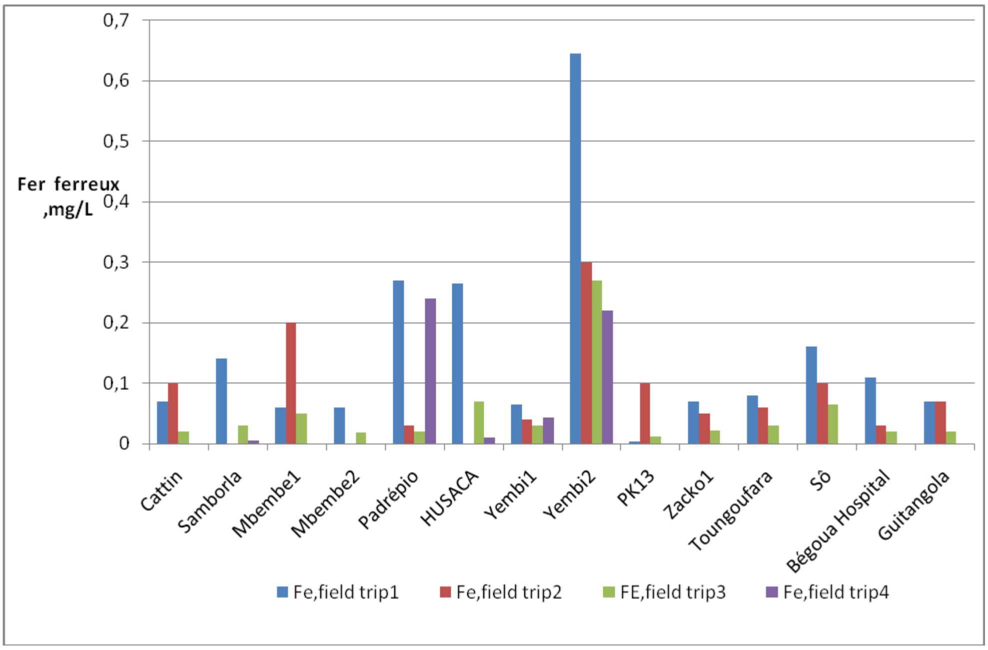
Figure 5. Chloride ion content



21 Groundwater contained in sedimentary rocks is often rich in chloride (Cl^-). Our geological survey of the study area did not indicate any sedimentary rock associated with Cl^- liberation, leading us to conclude that the chloride ions present in these waters must result from human activity—for example, the soap factory at HUSACA. Nevertheless, the content observed is within the acceptable range for potability (<200 mg/l), and there is little variation.

Concentration of Ferrous ions in the waters

Figure 6. Variation in iron content

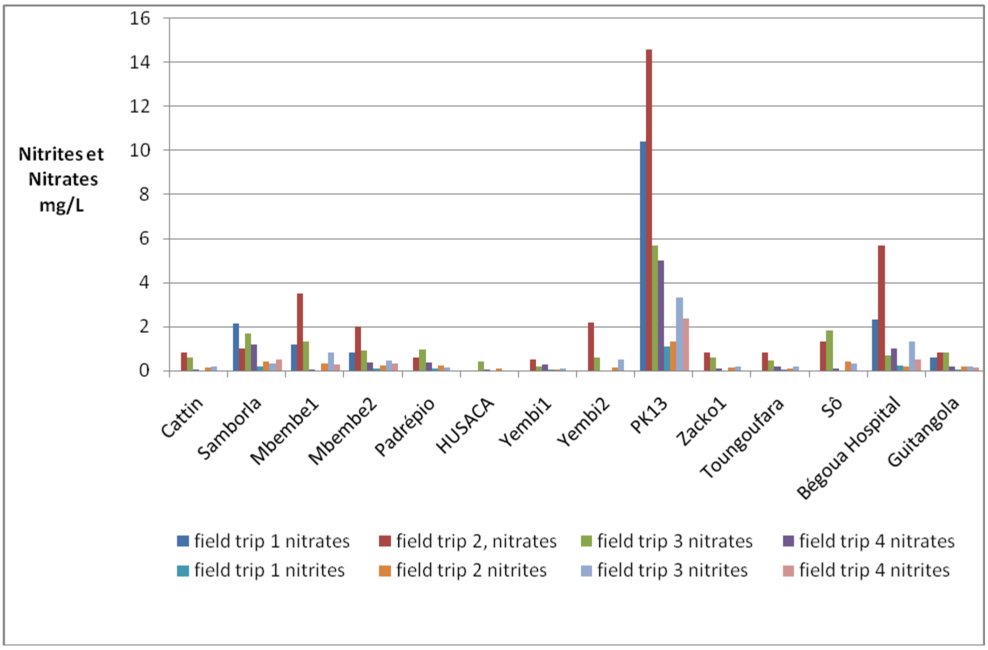


22 Iron is a chemical element that has no direct impact on human health, but influences the smell and taste of water once its concentration surpasses 0.2 mg/l [4]. Thus, in our samples, the wells at Padrépio and HUSACA exhibit elevated iron content. The well Yembi2 initially exhibited extremely high iron content, which decreased on each subsequent field trip. The elevated iron content observed at these wells could be caused by water seepage—our geological survey of the study site revealed that the layers of rock are separated by layers of laterites of varying thickness.

23 Iron content of water from all wells other than Padrépio, HUSACA and Yembi2 was below the acceptable threshold.

Evolution of nitrite and nitrate content

Figure 7. Nitrite and nitrate content



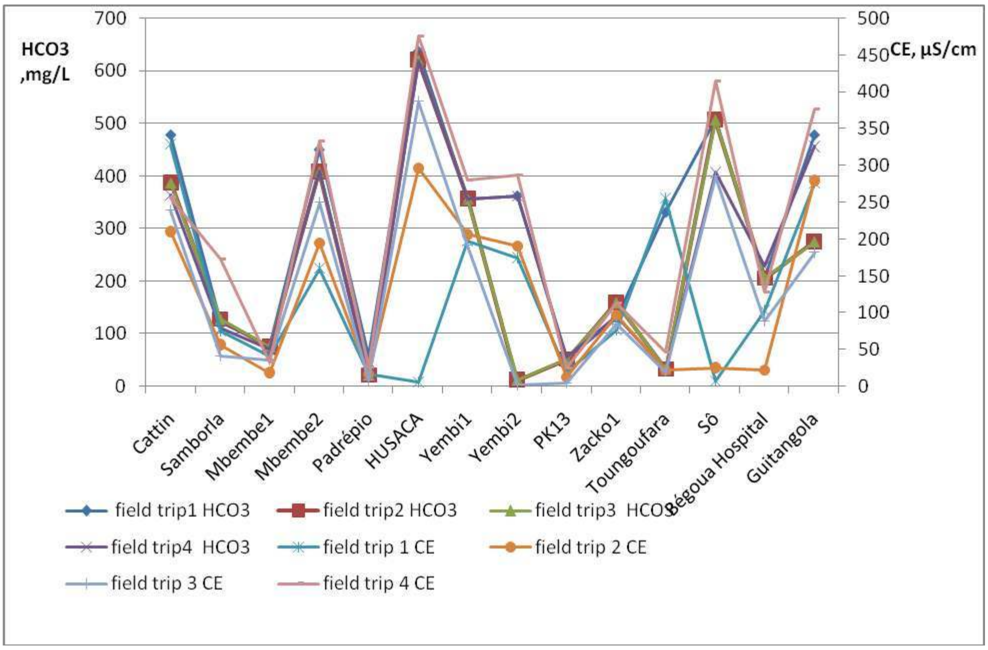
24 Nitrites (NO_2^-) and nitrates (NO_{3-}) are formed as part of the nitrogen cycle. In aerobic conditions, nitrites are produced from oxydation of ammonium (NH_4^+), while nitrates are produced from oxydation of nitrites. In anaerobic conditions, the cycle operates in reverse. It should be noted that the nitrogen cycle relies on the presence of particular microbes.

25 Nitrates are not particularly toxic to humans—the acceptable threshold is 50 mg/l. However, nitrites are highly toxic, particularly to babies and pregnant women—the acceptable threshold is 0.1 mg/l [4].

26 The nitrite content for the majority of well waters studied was below the threshold ; however the wells at Samborla, Mbembé1, Mbembé2, PK13 and Begoua Hospital had nitrite content above the threshold. In general, nitrate content was within the acceptable range for potability, and it was always greater than the nitrite content. This would be linked to the action of the nitrogen cycle in the substrate.

Correlation between bicarbonate ions and conductivity

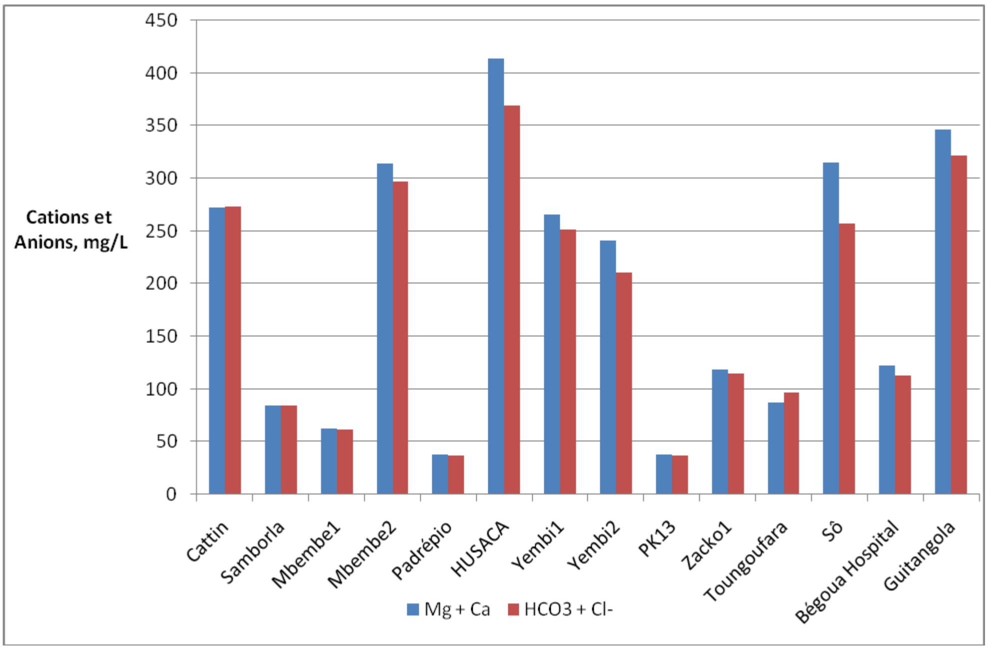
Figure 8. Correlation between bicarbonate ions and conductivity



27 In groundwater, conductivity increases as a function of the minerals present in the substrate. As shown in Figures 3 and 4 and the shape of the curves in Figure 8, we observed an overall correlation between bicarbonate ions and electrical conductivity in the samples analysed. This suggests that bicarbonate ions could be responsible for the increases in conductivity observed in our samples.

Evolution of cations (Mg^{2+} and Ca^{2+}) and anions (HCO_3^- and Cl^-) in the waters

Figure 9. Correlation between anions and cations



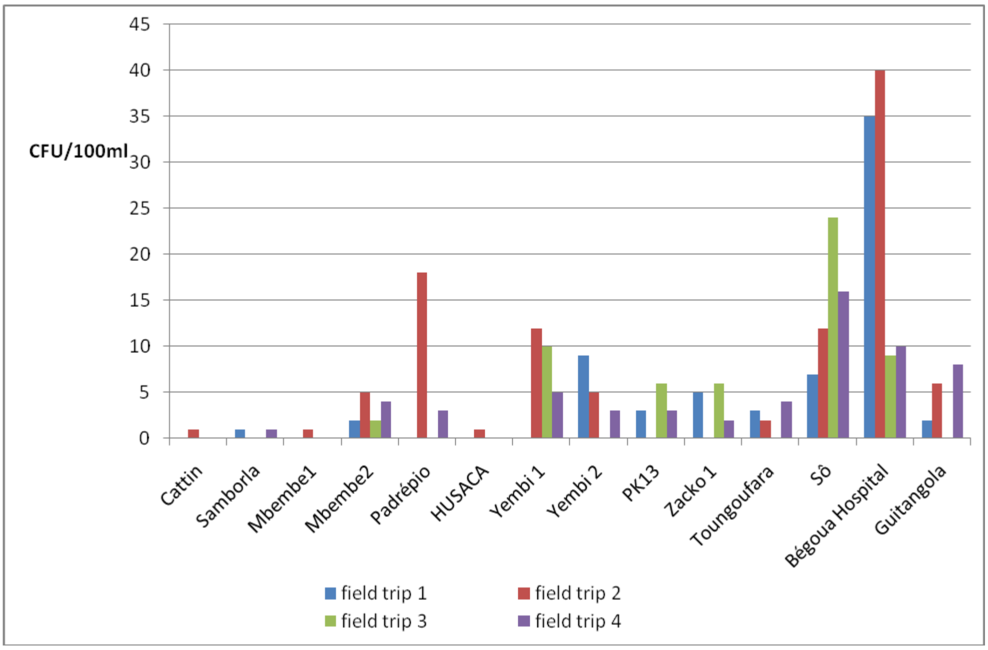
28 Groundwater generally contains mineral salts in varying concentrations, which arise from seepage that carries various minerals with it along the way.

29 In this work, we looked for a correlation between the two types of ion : anions and cations. We observed that the mineral content varied at each well, and that on average, the ionic balance between cations and anions was roughly the same. This would be linked to the varied nature of the terrain at each of our sample sites.

Bacteriological parameters

Evolution of fecal streptococci in well waters

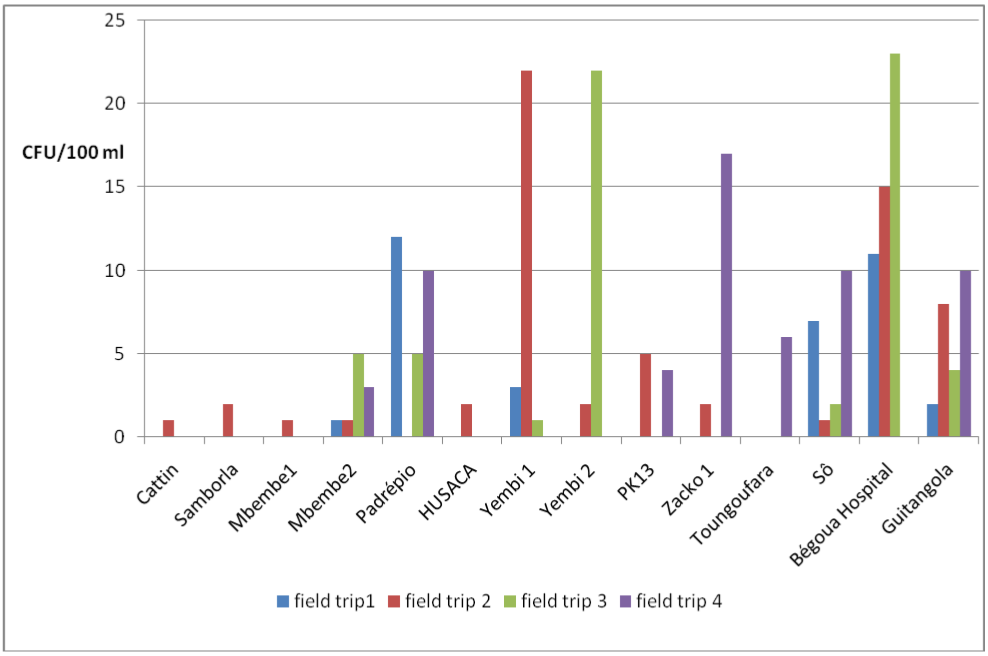
Figure 10. Evolution of fecal streptococci



Fecal streptococci are bacterial indicators of fecal contamination [4]. The permitted threshold for drinkable water is 0 CFU/100 ml. We observed the presence of fecal streptococci in all field trips, most notably during the second field trip at the Padrépio well, Yembi1, Yembi2, Sô and Begoua Hospital, even in cases where wells were chlorinated. From this analysis, it seems that the source could be contamination by users or seepage, because many of the wells are not protected.

Evolution of coliforms (*E. coli*) in the well waters

Figure 11. Evolution of coliforms (E. coli)

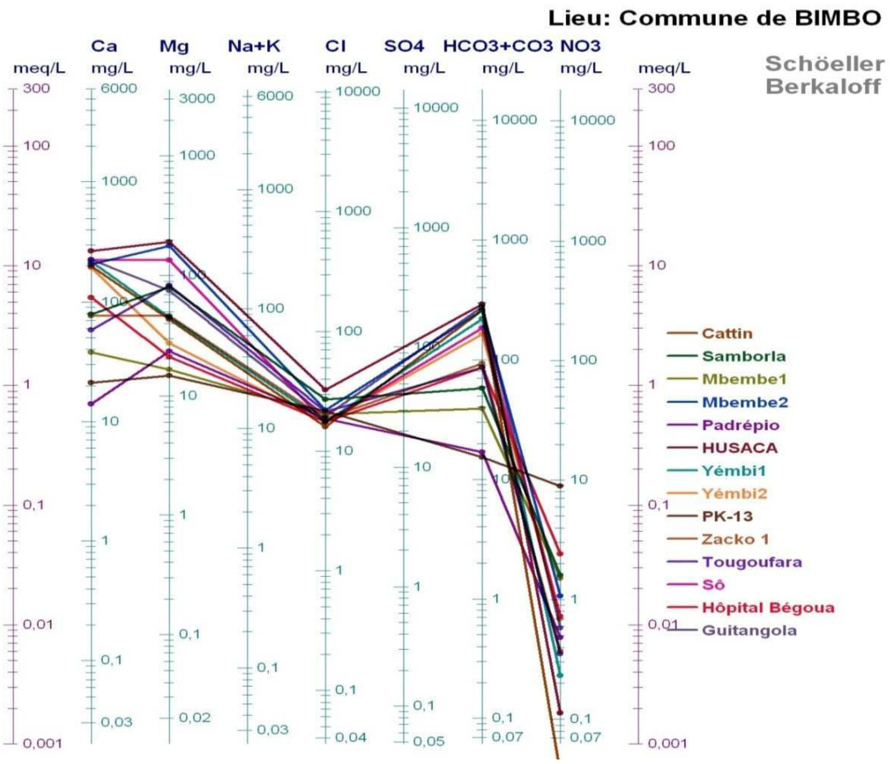


31 Coliforms are indicators of recent fecal pollution. Their presence in water increases the risk of pollution from other bacteria and/or viruses [7]. The acceptable threshold is 0 CFU/100 ml. Our observations were similar to those for fecal streptococci. The variability in contamination between the wells can be explained by human error, but also by the characteristics of each well, for example the proximity of human activity and latrines, seepage, and depth of the well.

Modelling

Schoeller Berkallof Diagram

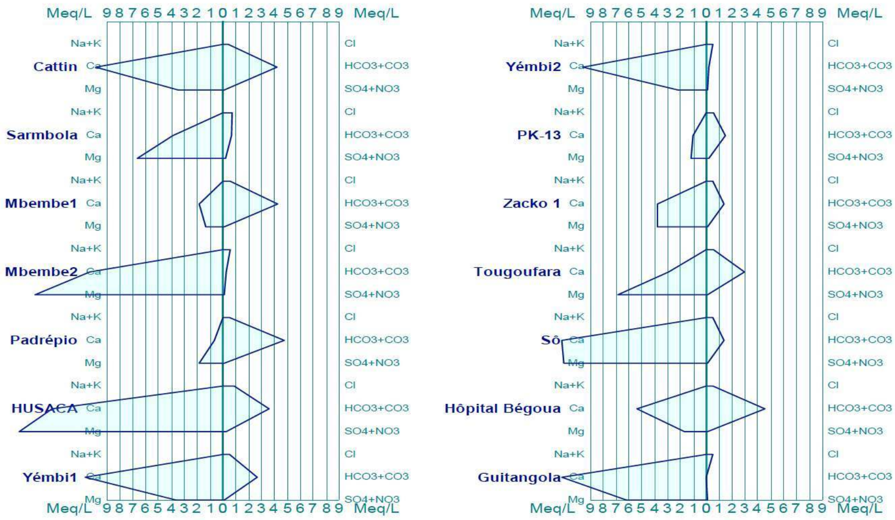
Figure 12. Schoeller Berkallof Diagram



32 The Schoeller diagram allows us to identify the most predominant minerals in each sample. In this study we observe that three quarters of the well waters are characterised predominantly by magnesium, calcium and bicarbonates, and the other quarter contain a moderate chloride content. All wells have low nitrate content. Variation between wells could arise from the nature of the terrain or from seepage.

Stiff Diagram

Figure 13. Stiff Diagram



33 Figure 13 (above) reveals a class of water characterised by a high composition of calcium (Ca^{2+}), bicarbonate (HCO_3^-) and carbonate ions (CO_3^{2-}). This water corresponds to the wells Mbembé1, Mbembé2, Padrépio, PK13, Toungounfara, So, HUSACA, Yembi1 and Begoua Hospital.

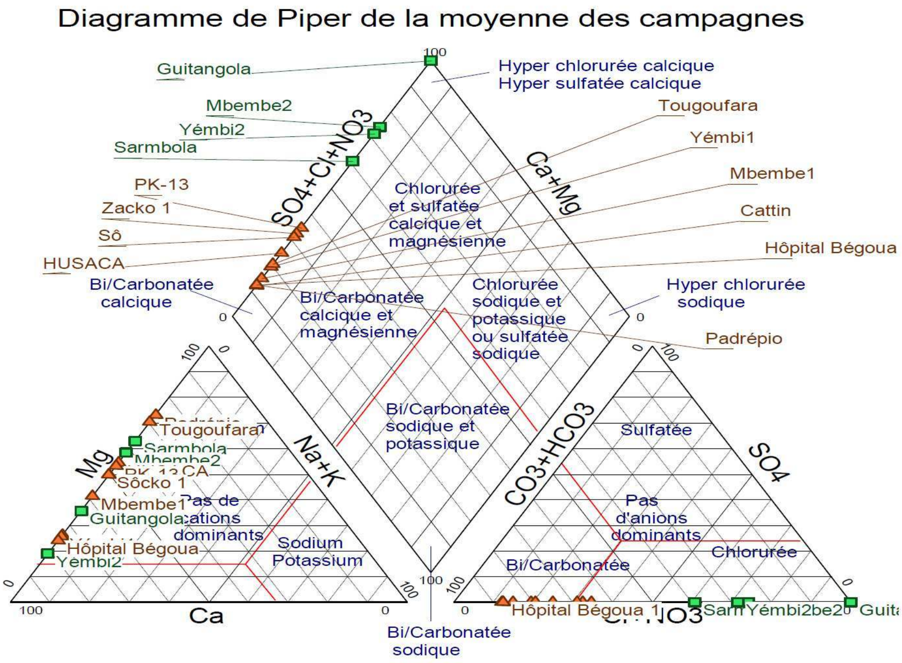
34 The wells Guitangola and Yembi2 have water whose primary composition is calcium and chloride (Cl^-) ions, while the water at Samborla and Zacko is predominantly composed of magnesium (Mg^{2+}) and chloride ions.

35 The variation in composition would be a result of either the depth of the wells or the terrains crossed by the water.

Piper Diagram

36 A Piper Diagram representation identifies the hydrochemical facies of the water samples, and allows a large number of analyses to be shown on a single diagram, which can be informative regarding the nature of the pollution.

Figure 14. Piper Diagram



37 The well water samples analysed in this study demonstrate the following characteristics. The hydrochemical facies of water from the Guitangola well was high in hyperchlorite, sulfate and calcium, while that of the Mbembe2, Yembi2 and Sambola wells was high in chloride, sulfate, calcium and magnesium. These facies result from surface water seepage. Another facies, high in calcium and magnesium bicarbonate, was observed in the waters from the Zacko, PK13, So, HUSACA, Padrepio, Cattin, Mbembe1, Toungounfara, Yembi1 and Begoua Hospital wells. This facies is caused by the geology of the terrain.

Figure 15. Sanitary map of well waters

Conclusion and Suggestions

38 The sanitary mapping of wells carried out in the commune of Bimbo (figure 15) allowed us to study both the physicochemical and bacteriological quality of these waters. Our results showed the source of contamination of some wells, which in some cases were caused by human activity, and for others had natural causes relating to the nature of the terrain (e.g. the waters high in calcium and carbonate).

39 Our analyses revealed that for the most part, the physicochemical contents of the waters were within acceptable limits, whereas the bacteriological quality of some wells demands further examination over a longer period. The presence of coliforms, including *E. coli*, and streptococci lead us to believe that runoff has contaminated some of the wells, suggesting a need to establish a protection zone around these wells.

40 The results for waters collected from the vicinity of hospital centres in the commune of Bimbo demonstrate that elementary hygience practices are lacking. The contamination of these waters could arise from construction of shallow wells that are vulnerable to seepage, or from poor construction, or from water passing between layers. We suggest regular monitoring and examination of these wells, educating users about good hygiene practices, and establishing a protection zone around the wells.

41 PK13 well (lacking hygiene)

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APPENDIXES

Photos of some of the sampled wells

HUSACA well

Mbembe2 well

Yembi1 well (unprotected).

ABSTRACTS

This study concerns the strategies for controlling and monitoring the quality of well waters consumed by the population of Bimbo, in the Central African Republic. The majority of the population has no access to clean, safe drinking water, and the distribution network of drinking water only reaches around 20 % of the urban population in the town centre. A population explosion in the Central African Republic has led to a very strong rural exodus, which has resulted in increasing consumption of poor quality drinking water. Futhermore, the virtual absence of a system for collecting wastewater only serves to increase the vulnerability of these shallow reservoirs. Such constraints are common in large African cities, where around 80 % of the population live in areas that have become urbanised in an ad hoc fashion. In such contexts, it is extremely difficult to reconcile groundwater extraction with public health.

INDEX

Keywords: mapping, urban pollution, hydrochemicals, Central African Republic, hygiene

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