

Evaluation of the Degree of Pollution of the Ground Water Resources in Sedimentary Formations: Case of the Localities of Bingerville (Côte D'Ivoire)

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Abstract: *The access to drinking water in the rural zones constitutes a major concern for the authorities because of the quality of the water consumed by the village communities. The objective of this study is to assess the quality of the water intended for human consumption in the localities of Bingerville. Adopted methodology consisted in evaluating the level of pollution by the follow-up of the space variation of the contents of the various pollutants. Statistical tests were carried out to determine the probable origin of the pollutants met. A bacteriological analysis was carried out to evaluate the level of contamination of these resources. The results show that the contents of certain parameters, sources of pollution, remain high and often largely above standards WHO. The parameters more threatening remain the phosphate (PO_4^{2-}) and ammonium (NH_4^+). The results of the statistical tests reveal two major phenomena which are the pollution of surface origin represented by factor 2 (F_2) and mineralization on the level of factors 2 and 3 (F_2 and F_3). The indicators of pollution (PO_4^{2-} , NH_4^+ and NO_3^-) observed on the level of factor 1 show that the pollutants which threaten quality of these resources could come from the septic tanks as well as sites of breeding. These results are confirmed by the bacteriological tests through the proportioning of nutritive salts which made it possible to identify and count fecal and total Coliforms, fecal Streptococcus as well as Clostridium perfringens. The presence of these parameters makes these water resources unfit for consumption.*

Keywords: Groundwater, dissolved salts, fecal pollution, Bingerville, Côte d'Ivoire

1. Introduction

Water is an invaluable and essential natural resource for multiple uses. Its use at food ends or of hygiene requires an excellent physicochemical and microbiological quality. Studies undertaken in Côte d'Ivoire in urban environment by [11, 14, 18, 27] allowed to characterize precarious districts of Abidjan's well waters of domestic use and to highlight the sources of pollution of these wells. The results of this work reveal an ammonium, phosphates and nitrate well polluted water with contents higher than the guide's values of WHO. The large African cities exploit the deep nap to feed out of water. In rural region, the localities exploit the ground water through the wells and the sources. However this ground water is exposed to pollution due to the anthropic activities. The access to the services of cleansing being non-existent in rural region, the drainage of worn waters and excreta of these villages is carried out in great majority by traditional latrines non-returnable making the ground water vulnerable to pollution. It is thus significant to have a better knowledge of the exploited nap, especially information concerning, the

quality of water and the protection measures of its resources [7]. In the area of Bingerville, selected studied zones, and precisely the villages of Anan and Agban, wells, sources, and drillings are the principal sources of supply drinking water of the local populations. It is thus advisable to give a detailed attention to the problem of pollution of this water of domestic use.

2. Material and Methods

2.1. Presentation of the zone of study

Bingerville (figure 1) is located at the south-east of Côte d'Ivoire between longitudes $3^{\circ}53'$ and $3^{\circ}54'$ and latitudes $5^{\circ}21'$ and $5^{\circ}22'$, with an average altitude of 35 m. the city built itself on a hill culminating at the altitude of approximately 96 m and going down towards the Ebrié lagoon, in the south, with steep slopes. It counts 91319 inhabitants, according to the General recensement of the human population result of 2014.

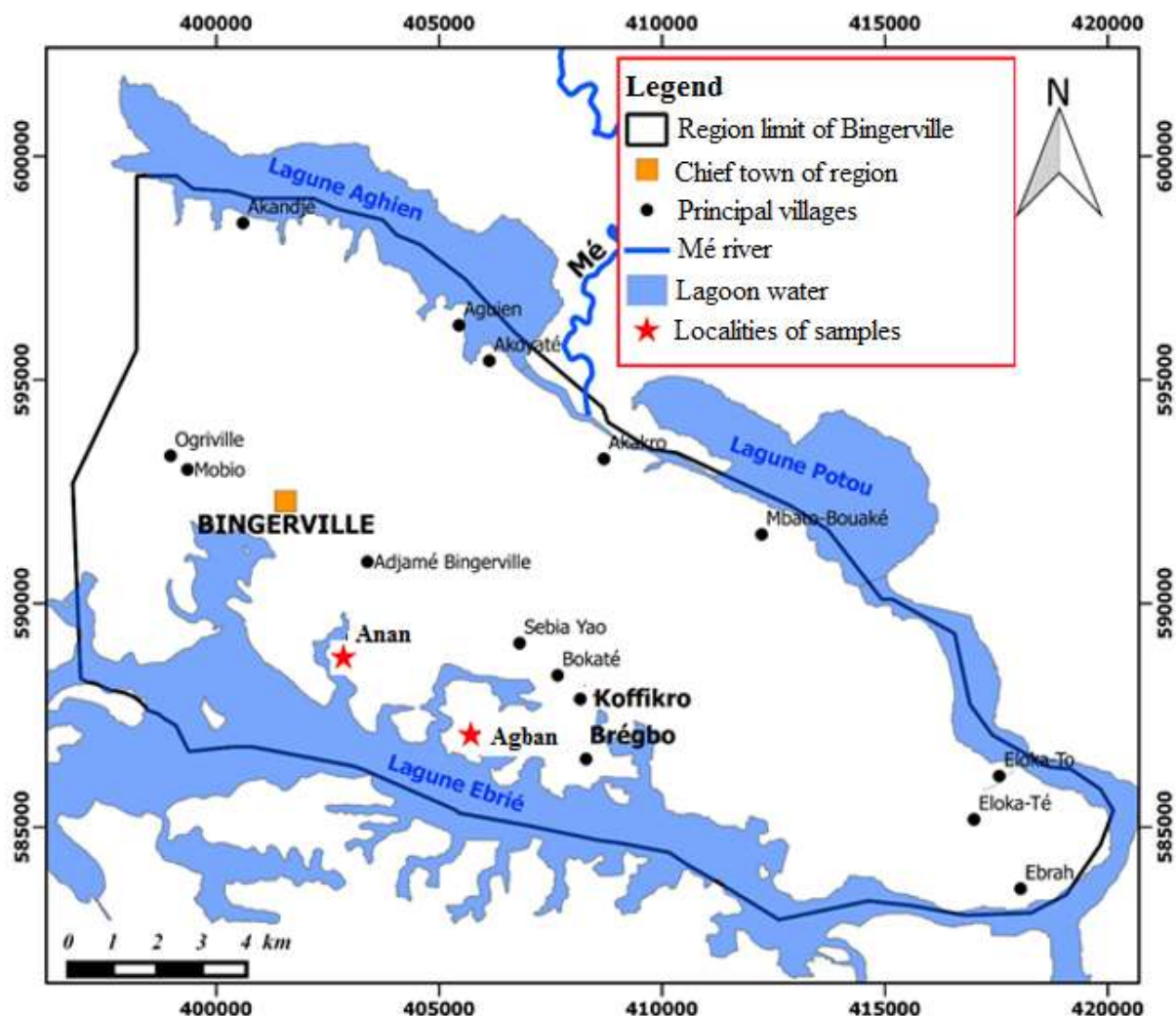


Figure 1: Geographical situation of Bingerville

The localities prospected, Agban and Anan belong to the region of Bingerville located at the South of Côte d'Ivoire (Figure 1). Bingerville covers a surface of 2 119 km² and its population is estimated at 91319 inhabitants [17]. During prospections and wells sampling campaigns in the villages of Bingerville (Anan, Agban, Adjame-bingerville, Danhokro, Elokato, Elokato, Santè, Brégbo and Koffikro), the report reveals the presence of functional water towers in almost all the villages. However the surveys carried out near the populations reveal the use of well water by themselves for the detergent, the crockery and even for consumption in the case of breakdown of the water towers allotted by the district of Abidjan. These two villages were selected to analyze the dangers to which the populations are exposed while feeding with water vulnerable to pollution. Anan and Agban were located at 4 km and 7 km from Bingerville respectively (Figure 2). These two localities cover a surface of approximately 80 km² and their

population is estimated at 3500 inhabitants [17]. The zone of study profits from a climate characterized by two rainy seasons alternated by two dry seasons with an annual rainfall of average 1800 mm. The annual rainfalls (2005-2015) of the station of Bingerville were obtained from the Airport Company of Weather Development (SODEXAM). Bingerville belongs to the sedimentary basin of the Continental Terminal (southern of the country), and primarily consists of clayey sands and sandstone dating from the tertiary sector, precisely of the pliocene [23]. On the morphological level, this area belongs to the zone known as of the "high plateaus" which occupies the Northern part of the lagoon system, of which substratum, made of clayey sands, generated a relief with soft and undulating forms, where the significant accidents are rare and altitudes, lower than 100 m [5]. Bingerville is drained by two lagoons, the Aghien lagoon and the Ebrié lagoon.

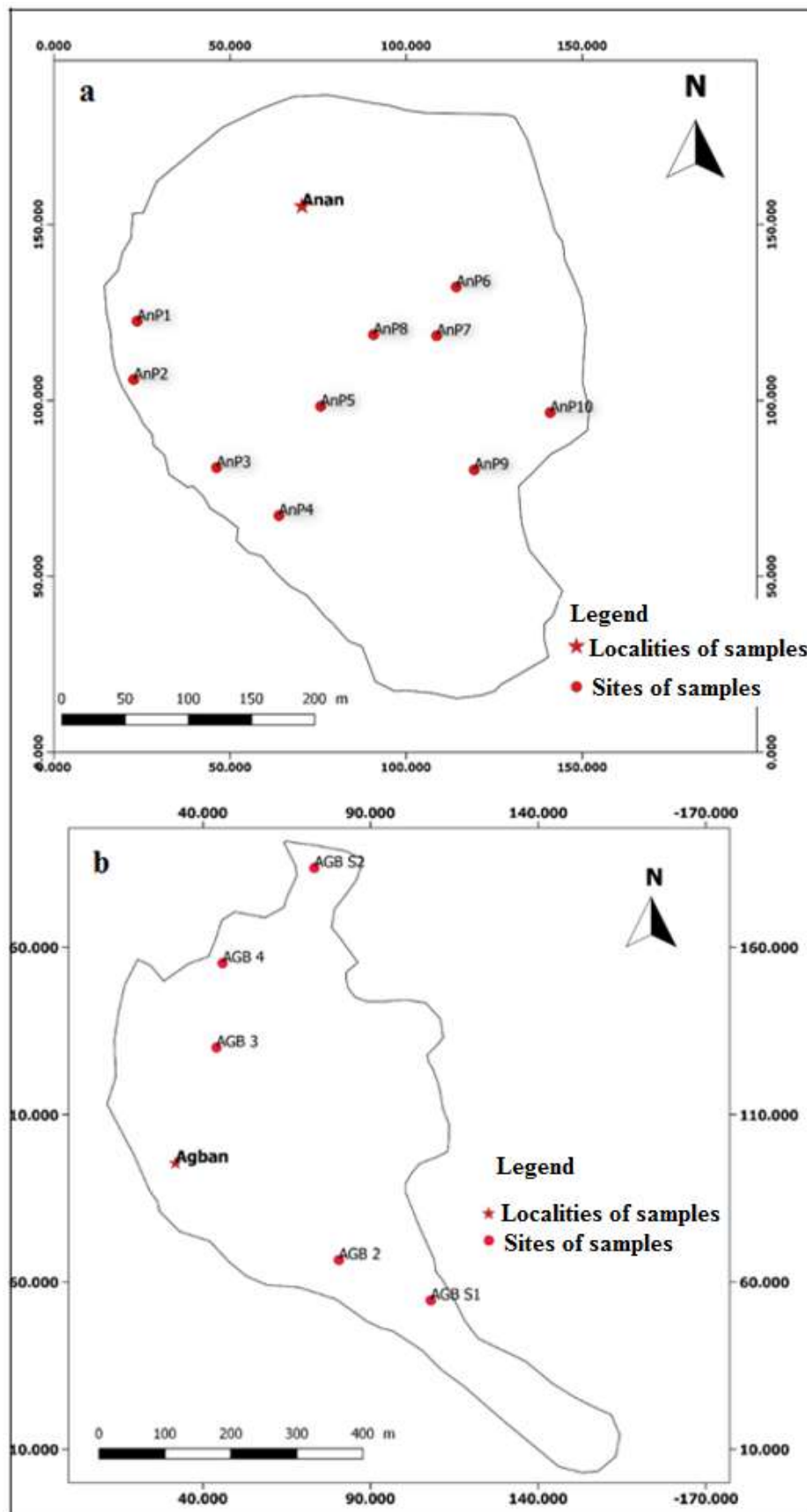


Figure 2: Presentation of the sampled localities: Anan (a) and Agban (b)

2.2. Material of Study

Field works proceeded in the region of Bingerville, precisely in the villages of Anan and Agban. On the field, a “garminetrex 30” GPS was used to determine the

geographical co-ordinates of the intake points of water; an electric sound probe piezometer was used to take the various water levels in the wells; one decameter was used to measure the distances between the wells and the zones likely to be at the origin of one supposed pollution. The taking

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away of water in the wells were carried out using a ladle connected to a cord; polyethylene bottles of capacity 1 liter and a refrigerator containing dry ices were used for the transportation and the conservation of the samples. A "YSI" multi parameter was used to measure in situ, the electric conductivity, the pH, the total dissolved salts, and the temperature of ground waters. The statistical data processing was carried out using the Statistica software.

2.3. Chemical and Bacteriological analysis

In the laboratory, the major ions (Cl^- , SO_4^{2-}), total hardness (TH) and nutritive salts were proportioned. The chlorides and alkalinity were proportioned by titration [22, 1]. Ions SO_4^{2-} were proportioned by nephelometry. The derivatives nitrogenized on the other hand, were measured by colorimetry using a "Hach DR2010" spectrophotometer, nitrates (NO_3^-) by reduction with cadmium, nitrites (NO_2^-) by diazotization and ammonium (NH_4^+) by the indophenol method. The microbiological analyses were used to identify and count fecal *Streptococcus*, total Coliforms, fecal Coliforms and *Clostridium perfringens*. These micro-organisms were identified and counted by filtering the homogeneous aliquot of 100 ml on a membrane whose pores diameter is of 0,45 μm . The membranes were then placed on selective substratum's during 24 hours at 37°C in the thermostated drying oven. The following mediums were used: KF gelose for fecal Streptococcus, ID coli for the total coliforms, TSN gelose (Tryptone Sulphites Neomycin) for *Clostridium sulfito-reducer* of which most outstanding is *Clostridium perfringens*.

2.4. Statistical analyses

The statistical analysis used is based on the principal component analysis (ACP). The ACP STATE is a statistical method (initially of descriptive statistics) the purpose of which is to include and to visualize how the effects of isolated phenomena are priori combine. It is a methodology largely used to interpret the hydrochemical data [13, 27]. The statistical analysis was carried out with 18 samples and 13 variables (temperature, pH, conductivity, NH_4^+ , PO_4^{3-} , SO_4^{2-} , Cl^- , Ca^{2+} , Mg^{2+} , K^+ , Na^+ , NO_3^- and NO_2^-). The statistical tests were carried out to know the sources of underground waters pollutions. Initially a simplified analysis of the parameters studied in comparison with standards WHO was made. Then the study of the typology of the well water pollution was made using a Normalized Principal Component Analysis (ACPN). The eigenvalues, the factorial charts and the circles of correlations were obtained with the

software Statistica 7. 1. That allow as to treat all numerical characters playing the same role [8].

3. Results and Discussion

3.1. Results

The studied wells have depths varying between 0,98 m and 8,38 m. In the village of Anan the depths of the wells vary between 0,98 m and 7,97 m with piezometric levels oscillated between 0,5 m and 7,2 m. The depths of the wells of Agban vary between 1,31 m and 7,03 m with water levels varying between 1,33 and 6,85 m. This proximity of ground water compared to topographic surface reinforces the vulnerable character of the majority of the wells of the various localities of Bingerville. The access to the modern service of cleansing being non-existent in rural zone, the majority of these water points is neighboring of the autonomous drainage systems given up or of use. The average distance between the latrines and the various water points is 19, 45 m. the drainage systems are sometimes upstream of wellwaters.

The physical and chemical parameters include the temperature, the pH, the conductivity, the TDS, the dissolved oxygen, the ammonium, the phosphate, the nitrates, the sodium, the calcium and the magnesium. In the zone of study, the temperature does not present great variations of one well at the other (Figure 3A) and remains close to the annual average temperature of the area that is 27°C, with a minimum of 25,7°C in Anan and a maximum of 28,93°C in Agban. In these two localities, the pH varies between 3,83 and 6,05 (Figure 3B). Water of this area has an acid tendency. Acidity is all the more significant in the wells of Anan.

Electric conductivity as for it lies between 64 $\mu\text{S}/\text{cm}$ and 1068 $\mu\text{S}/\text{cm}$ (Figure 3C). Water of wells A₁, A₂, A₃, A₄, A₅, A₇, A₈, A₉, AG₃ and AG₄ has an electric conductivity higher than the guide value of WHO which is of 300 $\mu\text{S}/\text{cm}$, that is to say 66,67% of the analyzed water points. Certain water points are very slightly mineral-bearing with a conductivity lower than 90 $\mu\text{S}/\text{cm}$; it is the case of the water sources S₁ and S₂ of the village of Agban (64 $\mu\text{S}/\text{cm}$ and 71 $\mu\text{S}/\text{cm}$) and of the well A₆ of Anan (85 $\mu\text{S}/\text{cm}$). The strong values of conductivity were noted with the wells A₁, A₂, A₃, A₄, A₅, A₇, A₈, A₉ and AG₃ whose values lie between 457 $\mu\text{S}/\text{cm}$ and 1068 $\mu\text{S}/\text{cm}$.

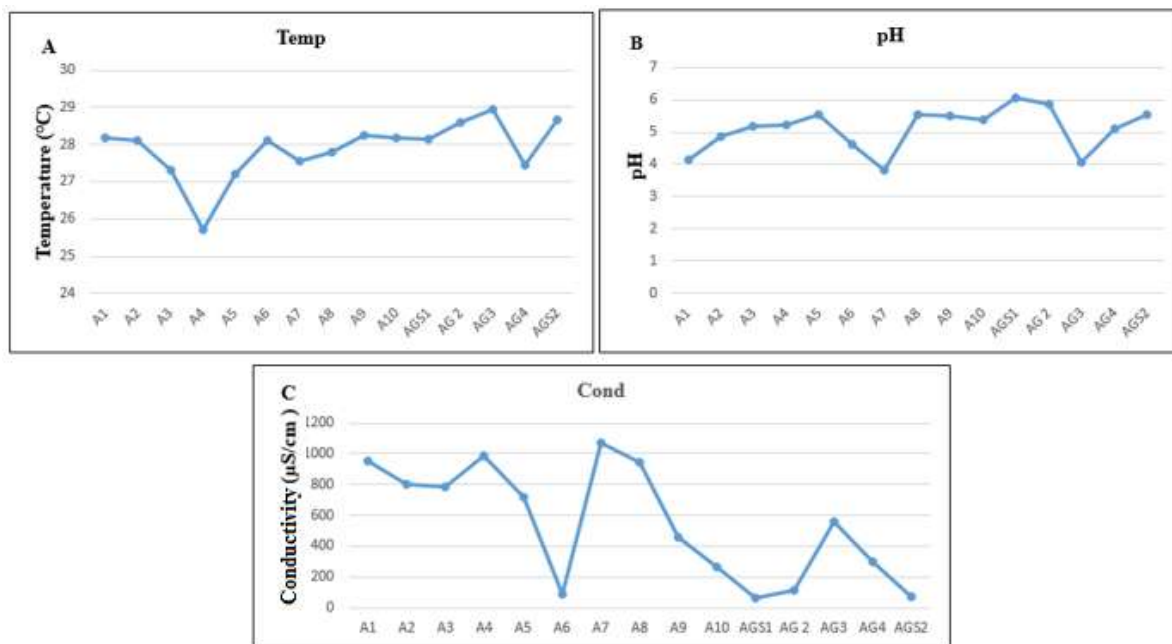


Figure 3: Spatial evolution of the physical parameters: temperature (A);pH (B);conductivity (C) in Anan and Agban

SO ₄ ²⁻	1,18	23,56	129,58	250
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Concentrations in ions NH₄⁺, PO₄³⁻, SO₄²⁻ and NO₃⁻ and the thresholds values in the wells of Anan and Agban are indicated in table 1. These parameters are pollution indicators and suggested the worse quality of water of domestic use. The concentrations of the well water of Agbanin ammonium are lower than 0,5 mg/l. That is not the case with Anan where one observes ammonium peaks going up to 2,2 mg/l. The phosphate concentrations are high in all the wells of Anan and four wells out of five in Agban that also have their phosphate concentration high. The values of this parameter in studied water are very variable and oscillate between 0,004 mg/l and 1,01 mg/l. The analysis of the nitrates contents of the wells shows a slight variation which oscillates between 0,4 mg/l and 28 mg/l and which remains lower than the threshold value of WHO (50 mg/l). So studied water is not subjugated at the risk of pollution by nitrates.

Table I: Statistical synopsis of the concentrations of the indicator ions of pollution of the wells of Anan and Agban

Ions	Min (mg/l)	Average (mg/l)	Max (mg/l)	limit Value (mg/l)
NH ₄ ⁺	<0,01	0,298	2,2	0,5
PO ₄ ³⁻	<0,004	0,2736	1,01	0,005
NO ₃ ⁻	0,4	6,67	28	50

The results of the statistical analysis (ACP) give many tables of which some are summarized in this study. The table of the eigenvalues (Table II) shows that the first three factors account for 84,90 PC of the expressed variance. They can thus make it possible to interpret the results obtained.

Table II: Eigen values and percentages of the variances expressed by the principal axes

	Eigen value	Total PC Variance	Cumul Engenvalue	Cumul (%)
F1	7. 656212	58. 89393	5,23662	58. 8939
F2	2. 055069	15. 80823	9. 71128	74. 7022
F3	1. 326681	10. 20524	11. 03796	84. 9074

The matrix of correlation (Table III) shows the various correlations between the studied physicochemical parameters. This matrix highlights significant correlations between conductivity, ammonium, nitrates, sulphate, potassium, sodium, calcium, magnesium and the ions chlorides. The matrix also reveals a correlation between magnesium and calcium (R = 0,89); between potassium and sodium (R = 0,94) and between the ions chlorides and the sulphate (R = 0,95).

Table III: Correlations between the physicochemical parameters of water

	NO ₂ ⁻	NH ₄ ⁺	PO ₄ ³⁻	NO ₃ ⁻	pH	T°C	SO ₄ ²⁻	Cl ⁻	Ca ²⁺	K ⁺	Mg ²⁺	Na ⁺	Cond
NO ₂ ⁻	1												
NH ₄ ⁺	0. 17	1											
PO ₄ ³⁻	0. 70	0. 24	1										
NO ₃ ⁻	-0. 11	0. 23	-0. 19	1									
pH	-0. 08	-0. 34	0. 16	-0. 73	1								
T°C	-0. 06	-0. 74	-0. 43	-0. 02	-0. 05	1							
SO ₄ ²⁻	0. 10	0. 59	0. 26	0. 33	-0. 23	-0. 59	1						
Cl ⁻	0. 13	0. 61	0. 23	0. 31	-0. 28	-0. 59	0. 95	1					
Ca ²⁺	0. 21	0. 79	0. 30	0. 50	-0. 32	-0. 72	0. 80	0. 82	1				
K ⁺	0. 08	0. 62	0. 20	0. 45	-0. 39	-0. 60	0. 93	0. 94	0. 86	1			
Mg ²⁺	0. 08	0. 41	0. 05	0. 42	-0. 26	-0. 36	0. 80	0. 89	0. 78	0. 86	1		
Na ⁺	0. 13	0. 61	0. 23	0. 31	-0. 29	-0. 59	0. 95	1	0. 82	0. 94	0. 89	1	
Cond	0. 27	0. 66	0. 25	0. 59	-0. 48	-0. 52	0. 89	0. 91	0. 92	0. 92	0. 86	0. 91	1

The analysis of the factorial axis (Figure 4) also reveals a correlation between the physicochemical parameters of studied water. Thus, the factor F_1 in the factorial axes F_1 - F_2 and F_1 - F_3 is determined by conductivity, potassium, sodium, sulphate, magnesium, calcium, ammonium and the ions chlorides. This axis can be compared to the mineral character of water on which depend the parameters indicated below. The axis F_3 in the factorial axis F_1 - F_3 is defined by, the phosphate, the nitrates and the nitrites. This factor expresses the water pollution by the anthropic activities and the intrusion of brackish water in the ground water. The factor F_2 in the axis F_1 - F_2 is defined by the pH, phosphate and nitrites.

The factorial chart of the wells (Figure 4) makes it possible to gather this water in three classes. Class 1 is characterized by strongly mineralized well water. The rock salt high concentrations (SO_4^{2-} , Cl^- , K^+ and Na^+) are strongly affected by the anthropic activity. The conductivity of the wells of this class lies between 716 $\mu\text{S}/\text{cm}$ and 1060 $\mu\text{S}/\text{cm}$. The pH of this water lies between 3.8 and 5.56. One finds these wells primarily in Anan (A_1 , A_2 , A_3 , A_4 , A_5 , A_7 and A_8). 28PC of the wells of class 1 have ammonium concentrations higher than 0.5 mg/l and all the wells present

the higher phosphate rates than the threshold value of WHO (0.005 mg/l). The average distance between the latrines and the various water points is 16 m.

Class 2 is characterized by fairly mineralized water with a conductivity ranging between 263 $\mu\text{S}/\text{cm}$ and 555 $\mu\text{S}/\text{cm}$. The ammonium concentrations in these wells are lower than 0.5 mg/l with phosphate rates higher than 0.005 mg/l. The wells concerned are: A_9 and A_{10} (Anan); AG_3 and AG_4 (Agban).

Class 3 is characterized by water slightly mineralized of the sedimentary basin. The concentrations of rock salt are weak with a conductivity ranging between 64 $\mu\text{S}/\text{cm}$ and 117 $\mu\text{S}/\text{cm}$. The ammonium concentrations in these wells are lower than 0.5 mg/l. 75 PC of the wells of this class show phosphate rates higher than 0.005 mg/l (the threshold value of WHO). These wells are much affected by the anthropic activities with an average distance of 18.52 m separating them from the septic tanks. At that is added the infiltration of brackish water coming from the Ebrié lagoon which is at 8 m of wells (AGS_1 , AGS_2 , AG_2 and A_6)

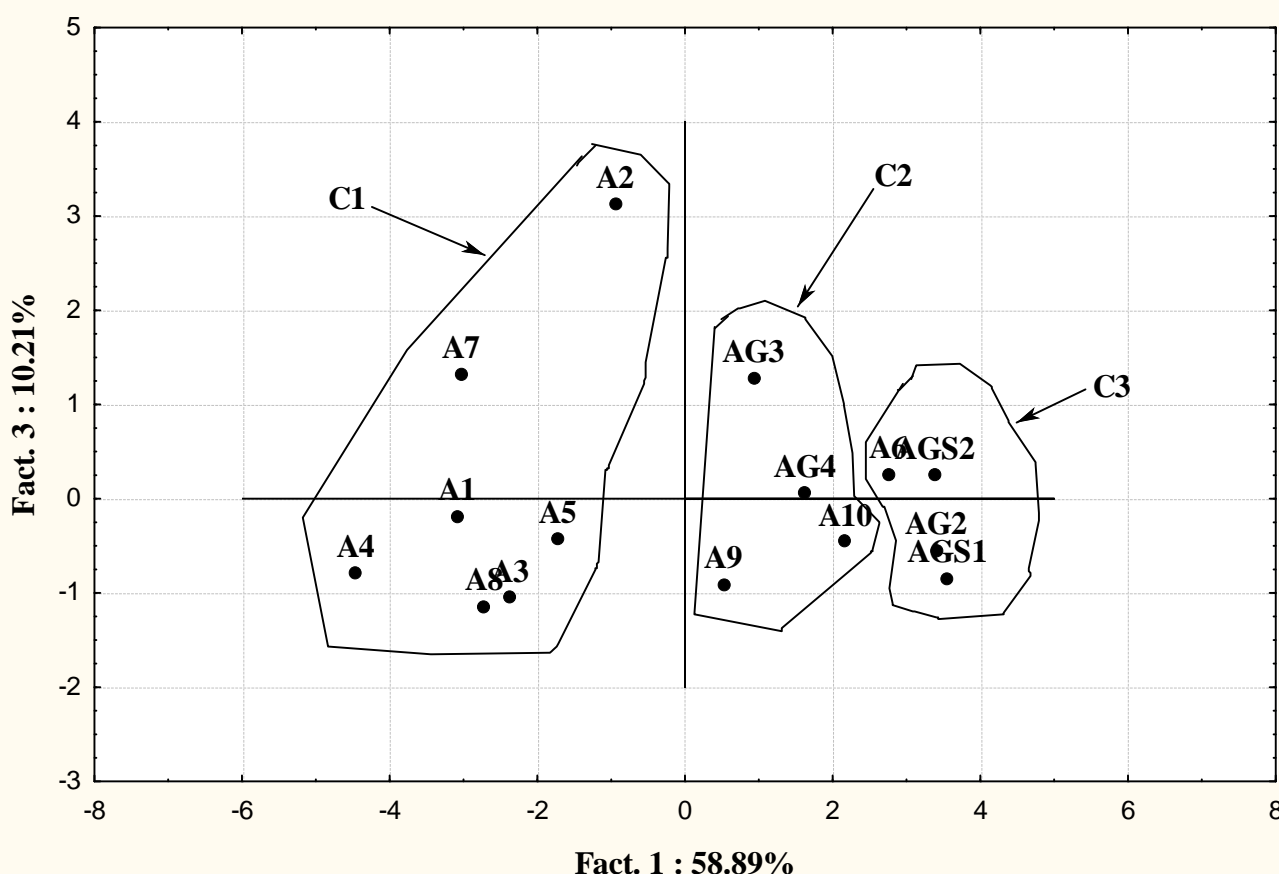


Figure 4: Graphic representation of the factorial chart of the wells of Anan and Agban

The microbiological analyses show the presence of the bacteria of the total coliforms types, fecal coliforms, fecal streptococcus and *Clostridium perfringens* in sampled ground waters (Figures 5 and 6). The total coliforms are present in all the wells of the visited localities. The total concentrations of coliforms vary from 930 UFC/100 ml to 245000 UFC/100 ml with an average of 28093 UFC/100 ml

in Anan and 180 UFC/100 ml to 15200 UFC/100 ml with an average of 4356 UFC/100 ml in Agban. The fecal concentrations of coliforms vary from 70 to 37000 UFC/100 ml with an average of 4427 UFC/100 ml in Anan and 10 to 4100 UFC/100 ml in Anan with an average of 1118 UFC/100 ml. These bacteria are good indicators of recent fecal contaminations. All the visited wells are contaminated

by the fecal coliforms. The fecal streptococcus ones are also present in all analyzed waters. Their concentrations vary from 20 UFC/100 ml to 1050 UFC/100 ml with an average of 231 UFC/100 ml in Anan and from 30 to 2680 UFC/100 ml with an average of 1228 UFC/100 ml in Agban. These bacteria are also good indicators of fecal contamination. *Clostridium perfringens* are present in 6 water samples on

15 well that is to say 40 PC of sampled waters. The concentrations vary from 2 to 34 UFC/20 ml than 10 to 170 UFC/100 ml with an average of 24 UFC/100 ml in Anan, and from 0 to 20 UFC/100 ml for an average of 2 UFC/100 ml in Agban.

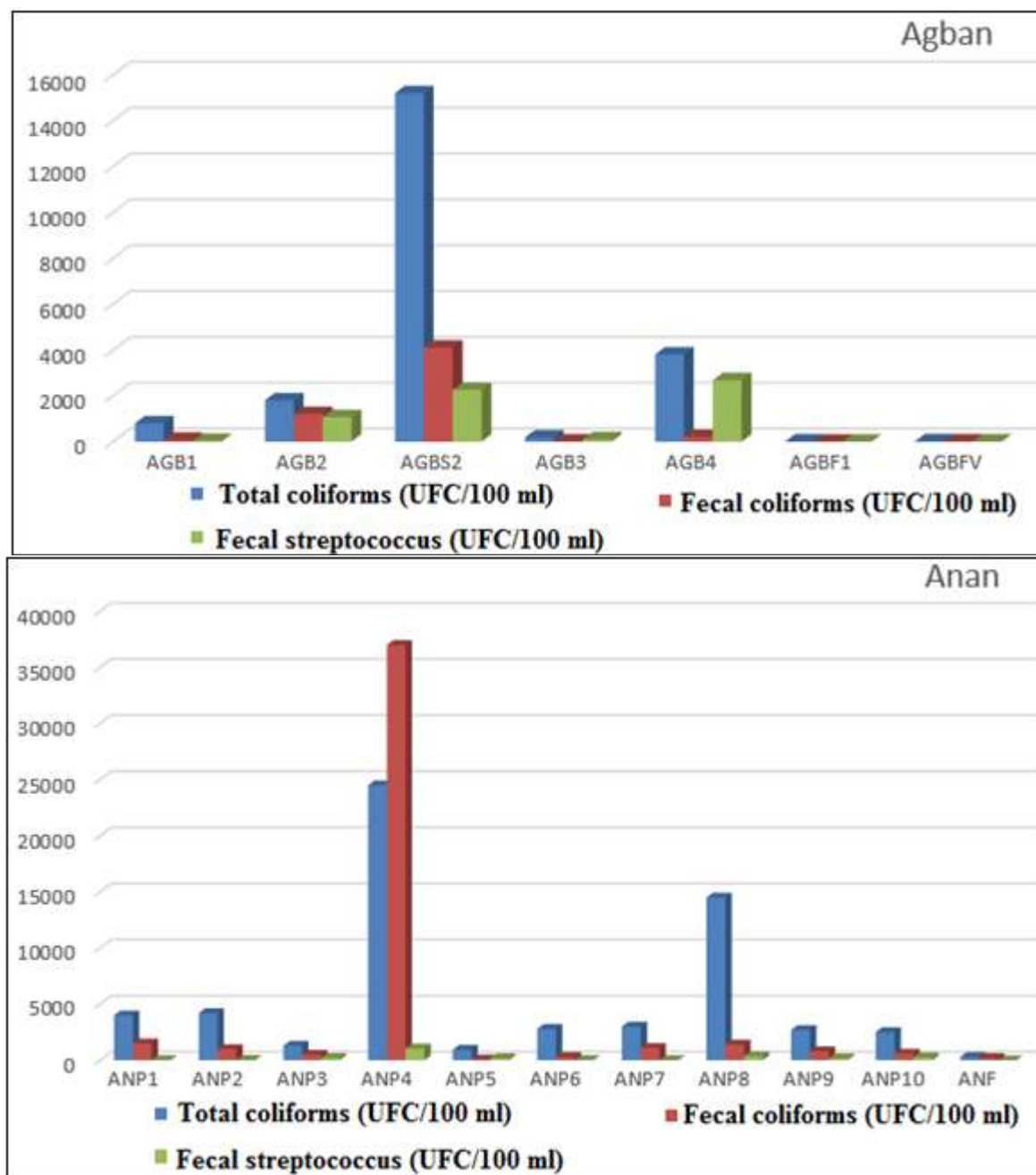


Figure 5: Histogram of three germs sought in the wells of Agban and Anan.

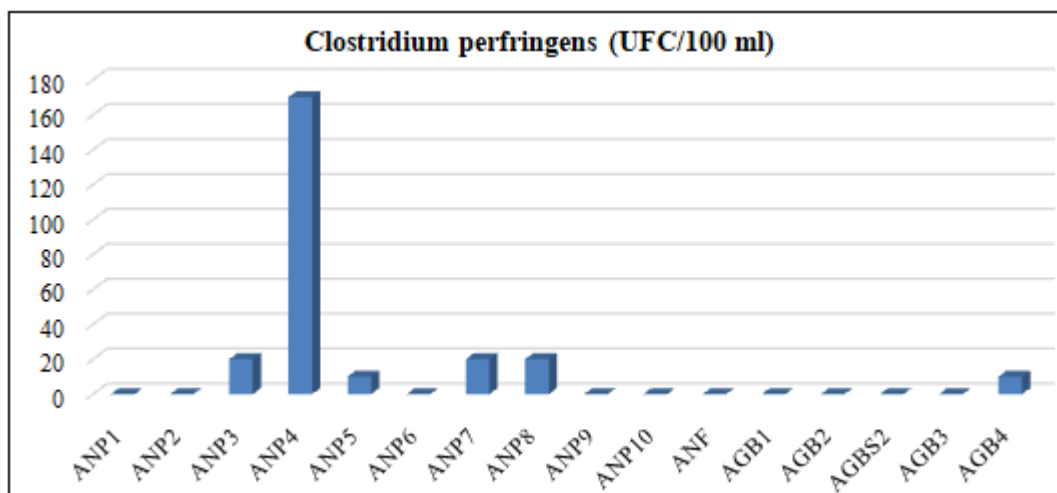


Figure 6: Variation of the rates of *Clostridium perfringens* in the various wells

3.2. Discussion

Studied water has average temperatures of 27,63°C and 28,36°C. These temperatures which correspond to the seasonal variations of the ambient temperatures register in the interval of the values defined by [21] and [4] in ground waters of the area of Abidjan and its neighboring's (25,5 to 30,4°C). [12] justified these temperatures found by the fact that in wet tropical zone, the average temperature of water is of approximately 30°C. These values of temperature indicate the opening of the aquiferous system thus, therefore its vulnerability opposite with pollution [24]. Water is acid, with an average pH of 4,99 for Anan versus 5,32 for Agban. Indeed, in wet tropical zone, this acidity comes mainly from the decomposition of the organic vegetable matter, with the production of CO₂ in the first layers of ground [19, 4]. Strong values of conductivity were noted primarily in the wells of Anan (A₁, A₂, A₃, A₄, A₅, A₇ and A₈). These values lie between 716 µS/cm and 1060 µS/cm. The value of conductivity is influenced by various natural and anthropic factors amongst other things, the geology of the catchment area (the composition of the rocks), contributions of ground waters and contributions of contaminated water coming from the human activities [16] because the contaminated rejections increase also the conductivity of water [25].

The quality of a ground water is characterized by the concentrations in ions NH₄⁺, PO₄³⁻, SO₄²⁻ and NO₃⁻. The standards of WHO (the World Health Organization) and the European union (UE) define the limiting values of NH₄⁺, PO₄³⁻, SO₄²⁻ and NO₃⁻ which are respectively 0,5 mg/l, 0,005 mg/l, 50 mg/l and 250 mg/l in a drink water.

One observes raised out concentrations of ammonium in the village of Anan with peaks of 2,2 mg/l. That is definitely higher than the threshold value recommended by WHO (0,5 mg/l) for a drink water. Ammonium is a nitrogenized component whose presence in a ground water results from a surface contamination primarily related to the domestic and industrial effluents rejections or of a natural reduction phenomenon of nitrates [3]. One notes the presence of phosphate in all the sampled wells. The phosphate concentrations vary between 0,004 mg/l and 1.01 mg/l. 93 PC of the wells present a higher phosphate concentrations than the threshold value of WHO (0,005 mg/l). This could

come from the rejections of worn water and the discharges of house refuse [20]. Nitrate average concentrations of the wells in Anan and Agban are respectively of 7,47mg/l and 5,08 mg/l, values largely lower than the threshold value of WHO (50 mg/l). Thus, the low contents met in water of Anan and Agban could be explained by the fact that these localities do not shelter any agro-industrial exploitation using significant quantities of manure.

The multivariate statistical analysis of the hydrochemical data (ACP), reveals on the basis of correlation existing between the various elements, the principal mechanisms being responsible for the evolution of the mineralization of water of the localities to be visited. The correlation of conductivity with the major ions accounts for the mineralization or the minerals hydrolysis phenomenon [4]. It should be noted that conductivity described inorganic salts present in water solution. The correlation between magnesium and calcium (R = 0,811) reflects the dissolution of the rocks related to the residence time of water in the aquifer [4]. However, the zone of study belongs to the sedimentary basin of the Continental Terminal (southern of the country) and primarily consists of clayey sands and sandstone dating from the tertiary sector, precisely of the pliocene [23]. With that the fact is added that sampled water is primarily ground water most exposed to the seasonal rainfall fluctuations, the residence time of water in contact with these rocks is very limited [11]. That explains the weak magnesium and calcium rates. Water thus does not have enough time to exchange with certain parameters of the hosts rocks. The mineralization phenomenon related to the rock is very weak. The correlation between potassium and sodium (R = 0,814) and between the ions chlorides and the sulphate (R = 0,522) highlight the salinization due to the proximity of the latrines and the intrusion of brackish water in the ground water [11]. The results of the various microbiological analyses show that this water is unsuitable for human consumption because water of well presents a strong contamination by germs of fecal origin and the standards of WHO require the total absence of fecal contamination germs in the water intended for the drink [26].

The localities of Agban and Anan use for its food drinking water the deep nap through the water towers offered by the

district of Abidjan. However in the event of breakdown these localities turn to wells water and sources which present high bacterial loads. The studied wells have depths alternatives between 0,98 m and 8,38 m with piezometric levels which oscillate between 0,5 m and 7,2 m. This proximity of ground water compared to topographic surface reinforce the vulnerable character of the majority of the wells of the various localities of Bingerville. The studies undertaken by [20] on well water of Dang in Cameroun, confirm this assertion according to which the depth of the wells and the distance between those and the latrines influence the proliferation of the germs in water. The microbiological analyses show the presence of the bacteria of total coliformstypes, fecal coliforms, fecal streptococcus and *Clostridium Perfringens* in well water of Anan and Agban. All the visited wells are contaminated by the fecal germs. That translates the defect of cleansing of the aria which exposes the water resources to strong contaminations of bacteria of fecal origin [28]. According to [15], the presence of the spores of the anaerobes sulfite-reducers in natural water makes think of a fecal contamination and in the absence of Coliforms bacteria, with an old contamination. They are very persistent and their presence is a good indicator of the vulnerability of the aquifers and wells [6]. The presence of *Clostridium* sulfite-reducers is very significant of an old or intermittent fecal pollution. The microbial load present in analyzed well water could be justified by a certain number of factors inherent to the agro-pastorals activities around the wells, a defect of installation of these wells, the proximity of the pollution sources such as the house refuse, the latrines, the septic tanks and the non-observance of the rules of elementary hygiene by users [20].

4. Conclusion

The data collected during this study reveals physicochemical and bacteriological quality ground waters of Bingerville. The spring waters, of well and drillings are still significant sources of supply water for these villages. They are intended for various uses (drink, detergents, crockery and especially in the food and the drenching of the animals). The analyzed water points are generally acid ($\text{pH} < 7$) and have a temperature which varies between 25,7°C and 28,9°C. Electric conductivities included 64 $\mu\text{S}/\text{cm}$ and 1068 $\mu\text{S}/\text{cm}$. This study also revealed the presence of ions which are indicators of pollution. The parameters more threatening remain the phosphate (PO_4^{2-}) and the ammonium (NH_4^+) whose averages remain strongly high. On the bacteriological level, all analyzed water (except water of drillings) is infected by the germs of fecal contamination and do not have to be consumed without treatment. This pollution most probably finds its origins in the insufficiency of the infrastructures of cleansing, the collection of the house refuse and the brackish water infiltrations in the ground water.

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