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ASSESSMENT OF WELLS WATER QUALITY AND THEIR SUITABILITY FOR DRINKING IN M'BAHIAKRO CITY (CÔTE D'IVOIRE)

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Abstract

The present study was carried out to assess the quality and the suitability of the well waters for drinking in M'bahiakro city (centre-east of Côte d'Ivoire). The work was performed on 71 wells in February 2012 (dry season) and June 2012 (rainy season). Groundwater levels and physico-chemical parameters (pH, temperature, electrical conductivity, redox potential (Eh), Total Dissolved Solid (TDS) and Salinity) were measured to assess the water table fluctuation and the groundwater quality. Standardized Principal Component Analysis (SPCA) was calculated to group the well waters and to evaluate their suitability for drinking according to different classes. Water table varies between 125 and 135 m during the dry season and between 127 and 136 m during the rainy season with a West-East flow direction. The recharge values ranged between 0.57 m and 5.57 m. Wells waters are generally acidic (pH<6.5), high mineralized with conductivities and Total Dissolved Solids (TDS) respectively above 600 µS/cm and 300 mg/l. Well water salinity values ranged between 0.30 and 0.5%. The Standardized Principal Component Analysis (SPCA) allowed distinguishing three important groups of water within M'bahiakro area: the first group of wells with high mineralized water, the second group of wells with high potential redox (Eh) and the third group of wells with pH closer to neutral. The first and second groups are not very suitable for drinking because they are suspected of being contaminated by anthropogenic sources such as septic tanks and wild dump. Waters of these wells need to be treated before any domestic use.

Keywords: *well water; water table; recharge; water quality; M'bahiakro.*

Introduction

Due to the ever-increasing demand for potable water and the development of diseases linked to surface water pollution, the importance of groundwater is increasing exponentially everyday [1]. So groundwater becomes an important source of drinking water because of its high-quality, small seasonal variations, storage, easy exploitation, and socioeconomic development [2]. But, due to the recent rapid technological developments and population increasing, groundwater is in danger of severe pollution in the world [3].

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In most of the developing countries, rapid population growth and urban development are increasing groundwater pollution and raising public health concerns about groundwater quality [4, 5]. In these countries, the sanitation and water supply are often inadequate [6-10]. As a result, many low-income urban communities in these countries rely on groundwater from shallow aquifer for drinking and other domestic purposes [11]. Unfortunately, most of the wells are located in close proximity to refuse and dumpsites, underground sewage tanks, and pit latrines [9]. Recent studies showed that the contamination of well water were due to their proximity to urban sources of pollution [8, 9, 12, 13]. Some of the most common concerns for well water quality in relation to human health in the urban environment include contamination with pathogenic microorganisms, nitrate and toxic organic compounds.

The urban town of M’bahiakro, centre-east of Côte d’Ivoire, relies its economy heavily on the agricultural sector. The National Rice Program is constructing a dam in M’Bahiakro over the N’Zi River in order to promote increased production of paddy rice to ensure food security and to generate revenues for the local low-income population. The population of M’bahiakro city is estimated at about 40,000 inhabitants and will increase with the rice project which will be in its active phase in 2013.

In geological setting, M’Bahiakro is on the sedimentary deposits composed of sand, shaly sandstone and shale. In these formations, groundwater occurs at shallow depths (< 10 m). M'bahiakro city is supplied with drinking water from taps by the water distribution company. However, approximately 90% of families have at least one well to overcome the potential lack of drinking water from taps or for use as main sources of water for the family. In addition, M'bahiakro does not have an adequate sanitation in all parts of the town. Therefore, the wastewater from showers and toilet waste is stored in septic tanks. Most of the time, these septic tanks are located in the vicinity and upstream of the wells. Monitoring of the quality of well water consumed by these families is normally the responsibility of the Health Ministry staff but this information is not available. Also, no research was made on the physical and chemical quality of the water to determine the risk associated to the consumption of the well water by the population.

The aim of this study is to assess the wells water quality and their suitability for drinking in M’bahiakro city.

Materials and methods

Study area

The study area is located in the centre-east of Côte d’Ivoire. It covers the area between latitude 7°26’30” N and 7°28’12” N and longitude 4°19’35” W and 4°20"53”W. It is divided into 4 districts namely Koko, Baoulekro, Dougouba and N’gattakro (Fig. 1). This area is under the influence of the attenuated equatorial transition climate with four distinct seasons [14]: a long dry season (November-Mars), a long rainy season (April-July), a short dry season (August-September) and a short rainy season (October-November). The mean annual rainfall is 1000 mm. The study area is located on volcano-sedimentary formations consisting essentially of sandstone, shale and shaly sandstone [15]. It covers approximately 5.538 km^2 and is characterized by a plain with elevations ranging from 120 to 135 m. The hydrographic network is dominated by the N'Zi River near the city and the surrounding large lowlands which allow rice production.

Field work

The study was performed on 71 wells (Fig. 1) on February 2012 (dry season) and June 2012 (rainy season). The water table and water quality are influenced by recharge or withdrawal of groundwater which can modify the physico-chemical characteristics of the water. Consequently, groundwater levels with reference to ground elevation and the physico-chemical parameters (pH, temperature, electrical conductivity, redox potential (Eh), Total Dissolved

Solid (TDS) and Salinity) were measured to assess water table fluctuation and groundwater quality. All parameters were monitored in situ for each well using a HERON instrument Dipper-T piezometer (100 m) and a Multiparameter HANNA 9828, probe with 20 m cable (Fig. 2).

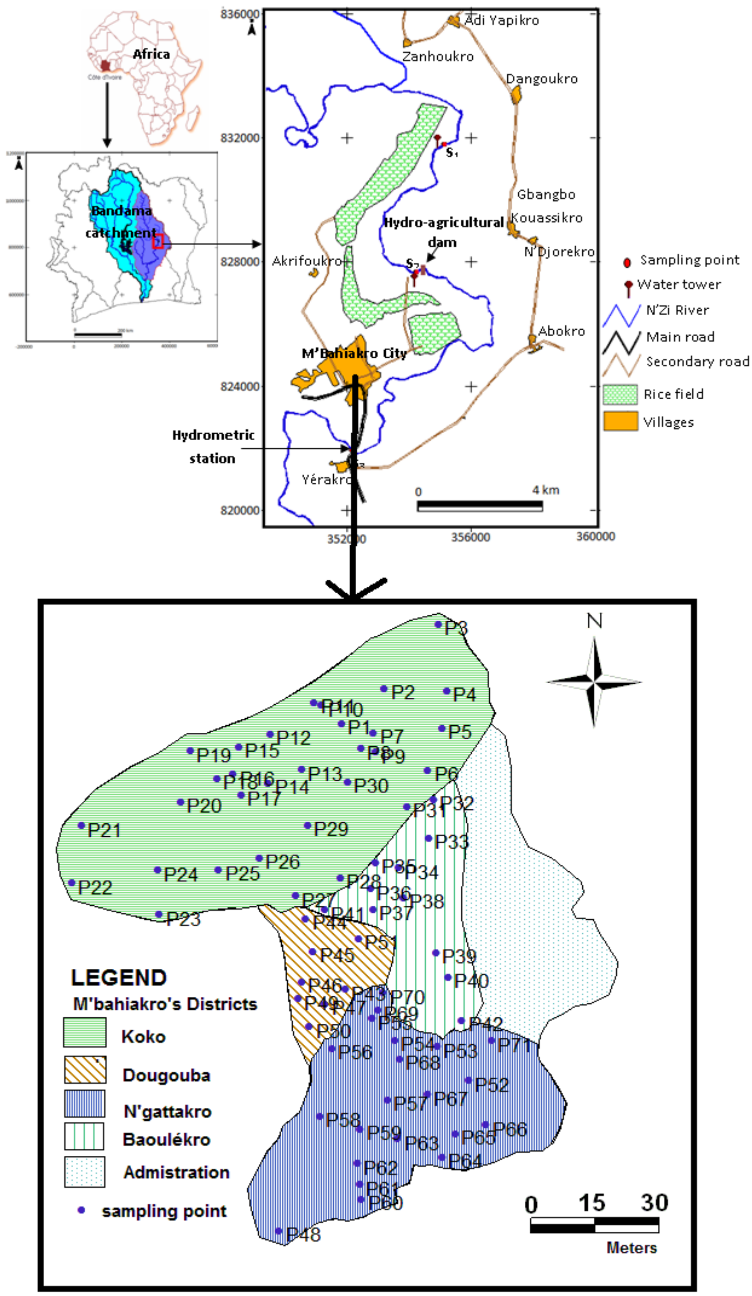

Fig. 1. M'bahiakro city and sampling points

Fig. 2. Measurement of piezometric level (a) and physico-chemical parameters (b)

Data treatment

a. Water table fluctuation assessment

In order to determine water table fluctuations in the study area, groundwater levels during the rainy and dry seasons were represented on M'bahiakro's map using ARCGIS 9.0 software. Then, the water table fluctuation enabled the calculation of groundwater recharge during the rainy season.

b. Water quality assessment

The well water characteristics were subjected to statistical analyzes. The descriptive data included the minimum, maximum, mean concentrations and the standard deviation (SD) were computed using SPSS 13.0 for windows. A Standardized Principal Component Analysis (SPCA) was made using the NCSS.6 software to classify the well waters and to evaluate their suitability for drinking according to different classes. SPCA is a statistical tool that identifies the main factors which correlation with the variables allows an explanation of the phenomena involved. To admit that the phenomenon is sufficiently expressed, the cumulative sum of the contributions of the main factors considered must be approximately 70% [16].

Results and Discussion

a. Water table fluctuation

Groundwater levels during the dry and rainy seasons are presented in Fig. 3. Water levels vary between 125 and 135 m during the dry season and between 127 and 136 m during the rainy season. Generally, the water levels are higher in the rainy season than in the dry season. This indicates that there is a groundwater recharge during the rainy season. However, water levels change increasingly from south to north, ie from N'gattakro district to Koko district. Overall the groundwater flows in the West-Est direction.

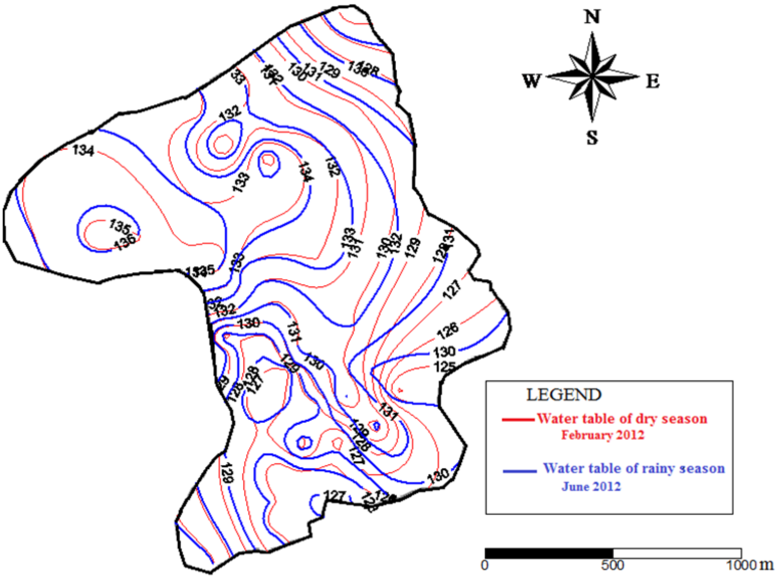

Fig. 3. Water table contour map (February 2012- June 2012)

b. Groundwater recharge distribution

Figure 4 is used to specify the distribution of recharge in the area of M'bahiakro city.

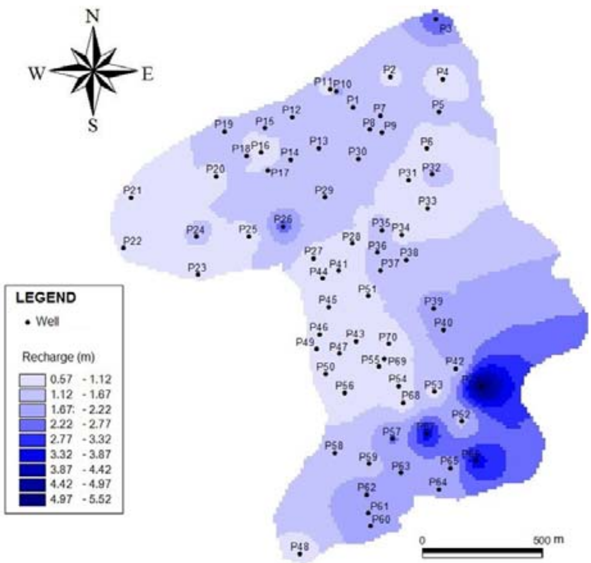

Fig.4. Groundwater recharge after rainy season

The recharge is more important in the district of N'gattakro (3 - 6 m) situated in the south of the city and moderately high in the district of Koko (1-3 m) in the north while it is lower in the districts of Dougouba and Baoulékro in the central part with values ranging from 0.57 to 1

m. The values of the recharge in the districts of Koko and N'gattakro could be explained by the nature of the superficial layer. Indeed, in these two districts, the superficial layer of the aquifer consist mainly of coarse sand [15] which favor water infiltration whereas in the areas of Baoulekro and Dougouba the presence of lateritic duricrust on the top layer of the aquifer could slow down the infiltration of rainwater. The most important recharges were recorded in the wells P3 and P26 in the district of Koko and P66, P67 and P71 in the district of N'gattakro probably due to their position in depressions.

c. Well water quality

The seasonal variations of the physico-chemical parameters in the well water such as pH, Temperature, Total Dissolved Solids, and Electrical Conductivity of M'Bahiakro city are discussed below (Table 1).

Table 1. M'Bahiakro's well water quality

Districts		pH	Eh (mV)	Temperature (°C)	Conductivity µS/cm	TDS mg/l	Salinity (%)
KOKO							
	N=31						
	Mean	5,91	67,16	28,64	675,48	336,74	0,33
Dry season	Minimum	3,99	-46,10	26,98	99,00	50,00	0,05
	Maximum	7,80	180,30	29,98	1961,00	981,00	0,99
	SD	0,99	58,05	0,68	418,50	210,23	0,21
	N=31						
	Mean	5,92	62,65	27,87	652,13	326,00	0,32
Rainy season	Minimum	4,02	-11,00	26,11	112,00	56,00	0,05
	Maximum	7,17	173,60	29,04	1981,00	990,00	1,00
	SD	0,93	53,59	0,73	417,17	208,52	0,21
DOUGOUBA							
	N=11						
	Mean	5,24	106,12	29,02	957,18	479,64	0,47
Dry season	Minimum	3,86	41,70	28,01	145,00	72,00	0,07
	Maximum	6,34	186,70	29,94	2603,00	1302,00	1,33
	SD	0,84	48,96	0,59	784,72	394,23	0,41
	N=11						
	Mean	5,26	101,44	28,11	965,55	482,91	0,48
Rainy season	Minimum	3,87	14,40	25,62	122,00	61,00	0,06
	Maximum	6,76	182,40	28,83	2594,00	1297,00	1,33
	SD	0,92	53,40	0,93	824,56	412,43	0,43
BAOULEKRO							
	N=8						
	Mean	6,28	45,49	28,76	813,75	406,75	0,40
Dry season	Minimum	5,33	26,90	28,17	487,00	243,00	0,23
	Maximum	6,60	100,30	29,37	1183,00	592,00	0,58
	SD	0,42	24,62	0,38	217,76	109,02	0,11
	N=8						
	Mean	6,21	46,54	28,13	899,88	450,00	0,44
Rainy season	Minimum	5,08	17,40	27,38	480,00	240,00	0,23
	Maximum	6,70	112,50	28,62	1387,00	694,00	0,69
	SD	0,55	32,39	0,38	277,85	139,13	0,14
NGATTAKRO							
	N=21						
	Mean	6,30	43,40	28,29	662,52	333,21	0,32
Dry season	Minimum	4,48	-19,5	26,88	233	117	0,11
	Maximum	7,35	150,9	30,99	1285	643	0,64
	SD	0,714	41,455	0,717	150,117	75,123	0,075
	N=21						
	Mean	6,41	35,10	27,84	705,10	356,38	0,35
Rainy season	Minimum	4,85	-19,5	26,88	233	117	0,11
	Maximum	7,35	125,1	29,16	1285	643	0,64
	SD	0,60	35,03	0,64	244,35	122,04	0,12

Water in the wells is generally acidic with low pH variations observed between the two seasons. The mean values of pH recorded during the dry and rainy seasons are respectively 5.91 and 5.92 in Koko district, 5.24 and 5.26 in Dougouba district, 6.28 and 6.21 in Baoulekro district and 6.30 and 6.41 in N'gattakro district. Water is more acidic in districts of Koko and

Dougouba compared to those of Baoulekro and N'gattakro districts. According to the human consumption, all samples can be considered to be generally unfit for consumption, because pH values are below the WHO standards which recommend that drinking water should have pH values ranging between 6.5 and 8.5 [17]. This low pH could contribute to the high EC and TDS of the well waters as low pH waters have been reported to increase the tendency of water to dissolve minerals and metal, thereby increasing EC and TDS [18]. Then, water is highly mineralized in all the area with conductivities and Total Dissolved Solids (TDS) respectively above 600 µS/cm and 300 mg/l. This mineralization is greater in the districts of Dougouba and Baoulekro compared to those of Koko and N'gattakro districts. In the district of Dougouba, the conductivity reaches maximum values of 2603 µS/cm in the dry season and 2594 µS/cm in the rainy season. This high mineralization may be influenced by anthropogenic sources, such as domestic sewage and septic tanks which are numerous in the M'bahiakro area. Generally, the higher TDS and conductivities decrease palatability, and causes gastrointestinal irritation in the consumers. There is also laxative effect, especially upon transits [19]. And, the prolonged intake of water with the higher TDS can cause kidney stones [20-22]. Water temperatures range between 27 and 29°C with higher values during the dry season compared to the rainy season. The city of M'bahiakro is a plain area, the water temperatures are in the same temperature range as that of the sedimentary basin of Côte d'Ivoire [23]. Well water salinity values range between 0.30 and 0.5%. In the water samples, most of the matter is in dissolved form and mainly of organic salts, small amount of organic matter, and dissolved gases, which contributes to TDS [24]. Based on the TDS values, groundwater is classified as follows: <1000-nonsaline; 1000 to 3000-slightly saline; 3000 to 10000- moderately saline; >10000-very saline [25]. So in the light of TDS values in the study area, the water of the districts of Koko, Baoulekro and N'gattakro are not saline while in the area of Dougouba a fraction of well water with TDS ranging between 1000 and 1500 mg/L is moderately saline.

d. Mechanisms governing the well water quality

The standardized principal component analysis (SPCA) applied to water samples allowed to highlight the mechanisms that govern the well water quality in M'bahiakro area taking into account the two seasons (dry and rainy season). For all of the two seasons (dry and rainy seasons), the first two factors F1 (dry season: F1 (49.66%); rainy season: F1 (53.84%)) and F2 (dry season: F2 (25.63%); rainy season: F2 (26.74%)) express more than 70% of the variance and were retained for interpretation of the mechanisms. The indices G and G' characterized the groupings of the dry and the rainy season respectively.

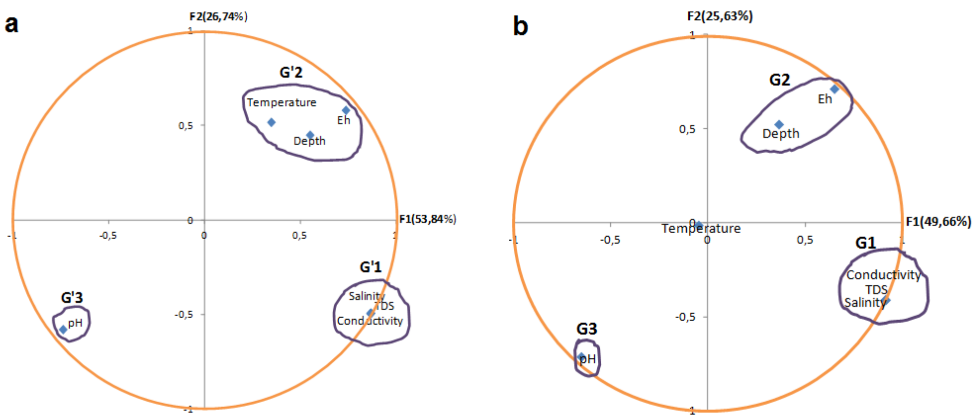

Fig. 5. Seasonal representation of different parameter groups of F1-F2 factorial plan: a - parameter groups in dry season; b - parameter groups in rainy season

The analysis of factorial plans F1-F2 (Fig.5 a and b) reveals three major groups of physico-chemical parameters. The first group (G1, G'1) for dry and rainy season consists of conductivity, TDS and salinity. The second group (G2) is formed by Eh and Depth of the well in the dry season when G'2 is composed of Eh, Depth and Temperature in the rainy season. The third group (G3 and G'3) is formed only by pH for the two seasons.

e. Analysis of the first Groups G1 and G'1 (Conductivity, TDS, Salinity)

The analysis of the correlation matrix (Table 2) allowed identifying a correlation of 0.99 between the parameters of the first group in both seasons. This high correlation indicates that these three parameters are strongly linked. Indeed, some authors [26, 27] showed that the salinity is expressed by the electrical conductivity or by the Total Dissolved solid (TDS).

Table 2. Correlation matrix

	Variables	pH	Eh	Temp,	Cond,	TDS	Salinity	Depth
Dry season	pH	1						
	Eh	**-0.99**	1.00					
	Temp.	0.06	-0.06	1.00				
	Cond.	-0.30	0.29	-0.03	1.00			
	TDS	-0.30	0.29	-0.03	**0.99**	1.00		
	Salinité	-0.30	0.29	-0.02	**0.99**	**1.00**	1.00	
	Depth	**-0.41**	**0.41**	0.09	0.14	0.14	0.13	1.00
Rainy season	pH	1.00						
	Eh	**-0.99**	1.00					
	Temp.	**-0.38**	**0.38**	1.00				
	Cond.	-0.34	0.34	0.09	1.00			
	TDS	-0.35	0.34	0.09	**0.99**	1.00		
	Salinity	-0.34	0.33	0.09	**0.99**	**0.99**	1.00	
	Depth	**-0.52**	**0.52**	0.31	0.25	0.24	0.26	1.00

Statistical units indicate that the groups G1 and G'1 characterize the well water with a very high mineralization, ie water with high conductivity and TDS (Fig. 6 &7). Wells that characterize the group G1 (fig.6) are made up of P2, P4, P14, P36, P37, P41, P51 while those of the group G'1 (fig.7) are composed of P2, P4, P14, P36, P37, P38, P41, P44, P51. The mechanism that governs the axis of factor F1 is therefore the mineralization of the well water. Indeed, during the rainy season, the groundwater recharge accelerated the mineralization of the wells P38 and P54. These two wells are therefore added to the series of mineralized water of the dry season.

f. Analysis of the second groups G2 (Eh, depth) and G'2 (Eh, Depth and Temperature).

For these groups, there was a significant correlation of 0.4 between Eh and depth during the dry season (G2) while this correlation is 0.52 between these two parameters during the rainy season (G'2). There is also a small but significant correlation between Eh and Temperature (0.38). Redox potential appears to be influenced by the depth of the well water during the dry season and by the depth and the temperature of the well water during the rainy season. The mechanism governing the groups G2 and G'2 is therefore the oxidation of the well water. This mechanism is opposed to that of the third group G3 because Eh is negatively correlated (-0.99) with pH. The statistical units corresponding to these groups G2 and G'2 indicate that wells have water that evolve in oxidizing conditions and are characterized by high values of Eh, ie by low pH values. The redox potential is a potential caused by various redox reactions in groundwater [28]. Higher recharges of well water occur in rainy season. It's also observed that most of the wells of the group G2 (fig.6) such as P32, P60, P62 and P65 characterized by a high redox potential during the dry season are absent from the group G'2 (Fig.7) equivalent to G2 during the season rains. In addition, only the well P36 was recorded in the group G'2 during the rainy season. This means that the oxidation process of water in the study area is more intensive during the dry season. This process takes place in deep well water in the dry season, while during the rainy season this reaction seems to be influenced by the temperature when the well depth increases.

g. Analysis of the third groups G3 and G'3 (pH)

In these groups (G3 and G'3) (Fig.6 and 7), the water is characterized by high pH water compared to the water of the second groups (G2 and G'2).

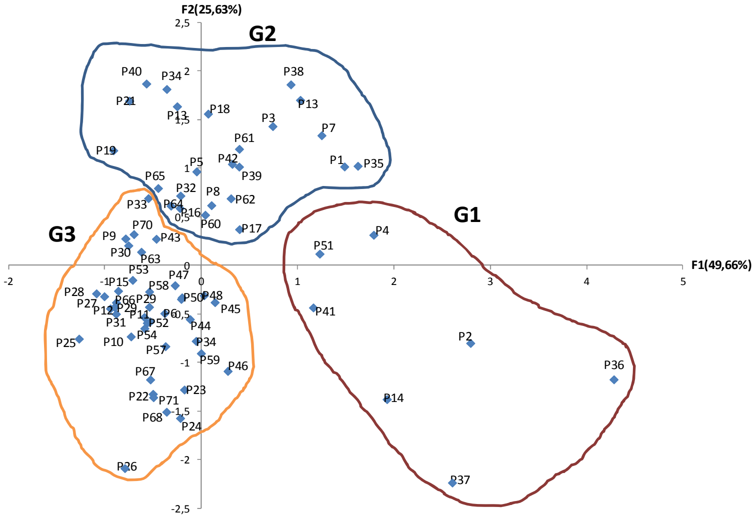

Fig. 6. Grouping of statistical units during the dry season

Well water from the groups G3 (Fig.6) and G'3 evolves therefore under reducing conditions (Fig.7) with pH close to neutrality during the rainy season. So the wells originally belonging to group G2 (P32, P60, P62, P65) and to group G1 (P38) during the dry season migrated to the group G'3 during the rainy season by a reduction process.

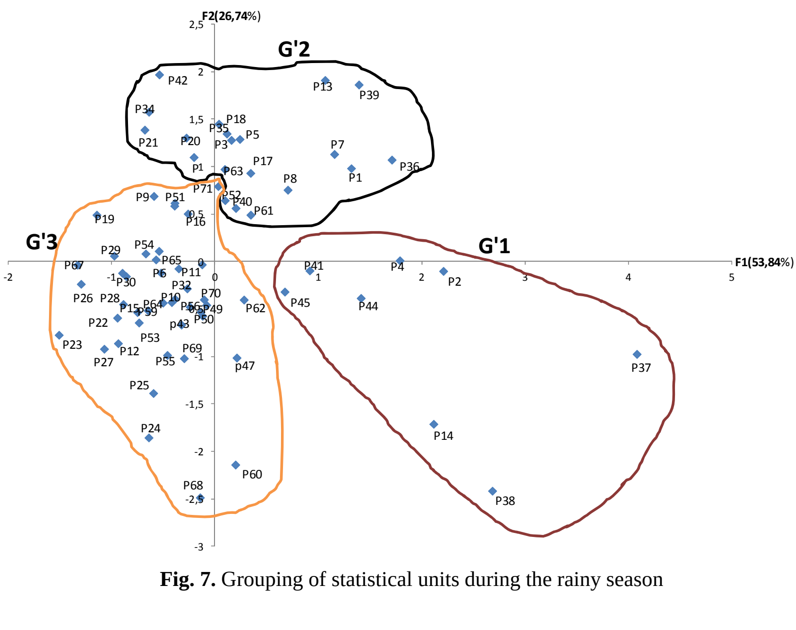

Fig. 7. Grouping of statistical units during the rainy season

Conclusions

The groundwater in M'bahiakro city flows in a West-Est direction with water table ranging between 125 and 135 m during the dry season and between 127 and 136 m during the rainy season. The recharge is more important in the district of N'gattakro (3 - 6 m) situated in the south of the city, moderately high in the district of Koko (1-3 m) in the north and lower in the districts of Dougouba and Baoulekro in the centre with values ranging from 0.57 to 1 m. Well waters in all the study area are generally acidic (mean pH < 6.5), high mineralized with conductivities and Total Dissolved Solids (TDS) respectively above 600 µS/cm and 300 mg/l and with salinity ranged between 0.30 and 0.5%. Three important groups of water within M'bahiakro area were identified by the Standardized Principal Component Analysis (SPCA). The first group of wells is characterized by a high mineralization, the second group of wells by a high potential redox (Eh) and the third group of wells by pH closer to neutral. According to the WHO drinking water standards, the first and second groups are not very suitable for drinking because they are suspected of being contaminated by anthropogenic sources such as septic tanks and dump wild. Waters of these wells need to be treated before domestic use. For the third group, water can be used for domestic purposes if there is an assurance on the chemical parameters such as nitrate and especially bacteriological parameters.

Acknowledgments

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