ISSN 2229-5518

Microbiological and physico-chemical quality of groundwater from artisanal sites of mining exploitation in the South-West of Côte d'Ivoire: case of the area of Hiré

LOKO Solange[1], AHOUSSI Kouassi Ernest[2], KOFFI Yao Blaise[2], KAKOU Nogbou François[2], KOUASSI Amani Michel[3], BIEMI Jean[2]

Abstract— Artisanal mining exploitation has direct or indirect effects on the chemical composition of groundwater of the area of Hiré. Then, the quality of groundwater is rapidly due to natural processes, and anthropogenic activities. The objective of this study was to analyze the groundwater quality of boreholes of Hiré on the basis of physico-chemical and microbiological parameters. 12 samples of boreholes were sampled for this study. The samples were analyzed in-situ for pH, Temperature (T), Dissolved Oxygen (DO), Total dissolved solids (TDS), Electrical Conductivity (EC), salinity (Sal.), Oxydo-reduction (Eh) and Turbidity were done with calibrated portable field meters (multi-meter HACH). Major ions such as Na^+, Ca^{2+}, K^+, SO_4^{2-}, NO_3^-, Cl^- etc were analyzed using ion-chromatography, and Atomic Absorption spectrometer. Samples of these boreholes were collected and measured for the total chromium, cobalt, copper, cadmium tin, and lead by Atomic Absorption spectrometer. The results showed that the groundwater in the study area are fresh and low in TDS (127-434 mg/L) and generally mildly acidic to alkaline (pH 6.25-8.10). The groundwater quality of the study area is suitable for domestic purposes, since most of the parameters measured were within the WHO recommended values for drinking water. However microbiological parameters (*Escherichia coli* and total coliforms) showed an elevated concentration in most of the samples. That pollution came from anthropogenic activities like artisanal mining exploitation. The Piper diagram shows one major water type namely Ca-Cl and is moderately mineralized.

Index Terms— Anthropogenic activity, aquifer, artisanal mining, groundwater, quality, Côte d'Ivoire; physico-chimical, Microbiology

1 Introduction

Safe drinking-water has a significant impact in the prevention of water-related diseases in communities [23]. In Africa, at least 320 million people still have no access to safe water supplies, and at least 80 % of these people live in rural areas, where shallow wells, springs and rivers, usually of doubtful quality, are the main sources of drinking-water [24].

In Côte d'Ivoire the mean axe of development of the government is the developing mining area. So many authorization of mining exploitation are give companies. Even more, the populations are interested by traditional mining exploitation. Hire is one of the city where there mining. Then many people there to exploit this gold to get money. Such activities create much pollution on the environment in general but on water suitable water. In fact, water of adequate quantity and quality is essential for sustainable development [13].
Water quality performs important role in health of human, animals and plants [17], [26]. Water quality is the critical factor that influences human health as well as the quantity and quality of grain production in semi-humid and semi-arid area [26]. Water pollution is harmful not only to fish breeding and agricultural products but also to public health in surrounding areas. Human activities are a major factor determining the quality of surface and ground water through atmospheric pollution, effluent discharges, use of agricultural chemicals, eroded soils and land use [15]. The quality of groundwater in Côte d'Ivoire is generally governed by both natural processes (such as precipitation rate, weathering processes and hydrological and anthropogenic effects (such as urban, industrial and agricultural activities and the human exploitation of water resources). Seasonal variation in precipitation, surface run-off, groundwater flow, interception and abstraction strongly affect river discharge and consequently the concentrations of pollutants in river water [17]. The impact of mining activities on water quality is gaining increasing attention. Determination of physical, chemical and bacteriological quality of water is essential for assessing its suitability for various purposes like drinking, domestic, agricultural and industrial uses [20].

Studies have indicated in the world that groundwater is heavily polluted by mining activities. The aim of this study was to determine the impact of artisanal mining exploitation on groundwater quality of Hiré city. Chemical and microbiological analyses were used to evaluate water quality of the area.

2 MATERIAL AND METHODE

2.1 Study area

This study was conducted in the region of Hiré in the south-western. The area of the study is near Yammoussoukro, the political capital of Côte d'Ivoire. Hiré is localized around of national road N1, between Abidjan and Yamoussoukro. But Hiré is near Oumé. The climate of the region is from tropical of transion to subequatorial. The average rain valor is higher than 1200 mm per year. The highest temperatures appear from February to April, with an average per month 33°C. The evaporation value of the area per year is high and is around 750 mm. In the region the vegetation is forest. This forest is destructive by anthropogenic activities such as agriculture of coffee, coco and rubber.

2.2 Geology and hydrogeology of the region

The study area covers the southern part of the green rocks belt of Oumé-Fetekro. It includes the Birimien supergroup of the lower Proterozoic. According to observations, the sector has undergone a unique phase of progressive deformation, characterized by rugged cracks, creases, tight to the North-East trend and metamorphism of greenschist facies. The geology of the area is dominated by volcanic rocks, mostly basalt with limestone. Among the other types of rocks, there are some intrusions of rocks. Those intrusions are composed of composed of black shales and fine sandstones. In the area, we also find post-birimins granitoids (**Fig. 1**).

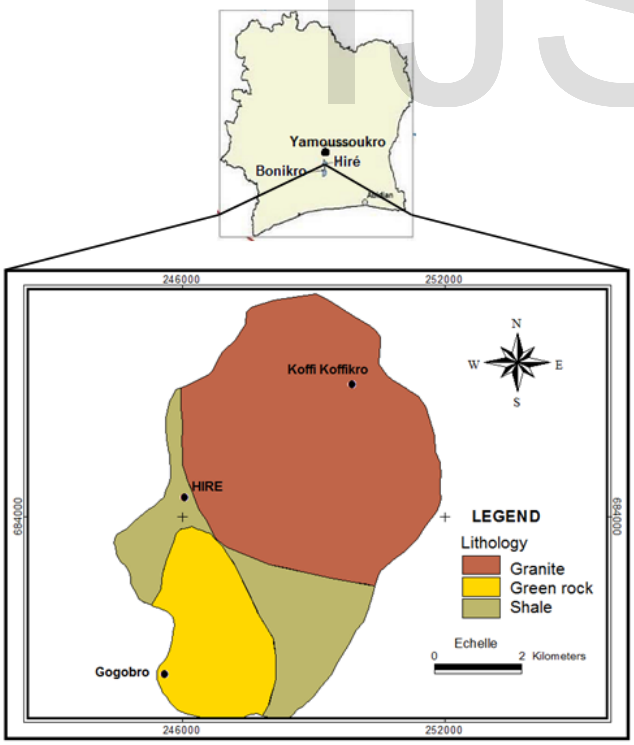

Fig. 1. Geological map of the study area

The locality Hiré belongs to crystalline or crystallophyllian base. In this area aquifers consist of three stacked aquifers. At the top is the alterites which consist of cuirass lateritic, clay and arena for-type granitoid formations. In shale formations, these alterites are clays. The middle area is formed of rock elements and alteration products, with the presence or absence of numerous cracks.

The third part is the fractured basement aquifer. It is crossed by simple fractures, or in some cases, crushed areas due to relatively high local stresses. The aquifer base is the area of deep groundwater flow. The whole system is a two-layer aquifer system consists of a semi-permeable aquifer capacitive (the alterites) above a reservoir formed cracked rocks, mainly the capacitive conductive function. Thus, in the Hiré area, two types of aquifer contain the groundwater. These aquifers are using for water supply by the population. Groundwater are taken from these aquifer by hand dug wells or boreholes. In the area, groundwater from the alterites aquifer is not usually clean because of the pollution. The groundwater from these aquifers is shallow and water quality is controlled by anthropogenic activities. In this area a lot of hand dug wells are using to take water from these aquifers. The groundwater is supply by the direct infiltration of rain water during the raining season [6].

The groundwater from cracks and fractures occurred in bedrock aquifers. They are too deep with a greater protection against anthropogenic pollution. Such of groundwater is accessed by boreholes. In the area many boreholes are using to take water from this aquifer.

2.3 Matériels et méthodes de l'étude piézométrique

This study was used material of site consisted of is 02 GPS Garmin Map 60 CSX. These materiels were used to take the coordinate of the boreholes and the hand dug wells. Piezometric measurements were performed using a light and sound OTT piezometric probe equipped with a switch background. The probe was used to measure the groundwater level and depth of drilling. Two digital cameras Canon have also been used for the images taken. A geological map at 1/200 000 of the area of Hiré yielded essential information about the geological formations of the study area. In calculating the coast of the water, the following formula was used:

$$\mathbf{C_{water} = Z - H_0 \text{ ; ou } H_0 = H+M} \qquad \mathbf{(2.1)}$$

Avec : **Z** : elevation of the piezometer (m) ; H_0 : piezométric value measured in the site ;
H : real value of the piezometric level (m) ;
M : value of the edge ;
$\mathbf{C_{eau}}$: coast of water (m).

2.4 Methode of hydrochemistry study

For this study, groundwater sample was collected in June 2012. This period is the dry season in the area. Grounwater samples were collected from boreholes and wells. Sampling equipment were properly cleaned and calibrated before field work. The sample containers were washed and rinsed thoroughly with distilled water and subsequently soaked in a diluted nitric acid. The samples for chemical analysis were collected in 1 liter and 250 ml capacity bottles that were washed prior to sampling by soaking in nitric acid solution and then washed with distilled water. On the site, before sampling bottles were washed at free times with sampling water. To avoid the contacts with atmosphere air, bottles were closed very well.

During the sampling, nitric acid was added to water collected for sample where metal analysis will take place. Sulfuric acid was also added to sample where there are nutritive elements. The samples were carried out in containers at 4°C to laboratory for analyzes. *In situ* parameters such as pH, Temperature (T), Dissolved Oxygen (DO), Total dissolved solids (TDS), Electrical Conductivity (EC), salinity (Sal.), Oxydo-reduction (Eh) and Turbidity were done with calibrated portable field meters (multi-meter HACH). The physical parameters of the water were measured directly on the site with a multimeter HACH. Calcium (Ca^{2+}), sulfur (S), magnesium (Mg^{2+}), Sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}) Carbonate ($CaCO_3$), Nitrogen Total (N), ammonium (NH_4^{+}), nitrite (NO_2^{-}), nitrate (NO_3^{-}) sulfate (SO_4^{2-}), bicarbonate (HCO_3^{-}), phosphates (PO_4^{3-}) mg/L, Total Organic Carbon Chemical Oxygen Demand (COD), Biochemical Oxygen Demand for 5 days (BOD5) were analyzed in groundwater. Major ions were analyzed by the spectrophotometric method using a spectrophotometer Varian AAS kind. The nutrients were measured by the spectrophotometric method using a spectrophotometer Shimadzu UV-type. Bicarbonates and carbonates were determined from assay using a digital titrator. Chlorides were measured by the method of Mohr titration. Sulphates, COD were determined by spectrophotometry using a HACH DR 2010 spectrophotometer. BOD5 was assayed by incubation from an incubator HACH kind. The turbidity was measured using a turbidimeter 2020.

For heavy metals, the following: Lead (Pb), iron (Fe), manganese (Mn), chromium (Cr), Silver (Ag), Molvbdène (Mo), Mercury (Hg), arsenic (As), Aluminum (Al), cadmium (Cd), selenium (Se) were measured in the water. The free cyanide and total cyanide were also the subject of analysis. Heavy metals were determined from the spectrometric method using an atomic absorption spectrophotometer VARIAN. For this study, 13 samples from boreholes were used.

2.5 Methode of microbiological study

Samples for microbiological analysis were collected in 500 ml bottles previously sterilized and kept free from contamination in a cooler at 4 ° C. In these samples, bacteriological Analyses deal with *Escherichia coli* and total coliforms. For this analysis, 13 samples from groundwater were also collected. Microbiological analysis required the use of methods depending on the desired microorganisms. Thus, for the enumeration of total coliforms, the study recommended the use of the method NF V08-50 and the method AFNOR BRD 07/1-07/93 for the enumeration of *Escherichia coli.*

3 RESULTS AND DISCUSSION

3.1. Variation of the level of groundwater

The principal results obtained from the piezometric study are shown in the table 1.

Tableau 1. Data from piézometric study

Points of mesures	Elevation (m)	Water level (m)	Water Coastal (m)
S1	220.255	-	-
S2	197.928	1.38	196.5480
S3	197.291	4.27	193.0210
S4	192.804	0.51	192.2940
S5	193.026	0.00	193.0260
S6	199.914	5.02	194,8940
S7	192,646	4,60	188,0460
S8	193,252	4,72	188,5320
S9	215,719	11,77	203,9490
S10	206.479	11.87	194.6090
S11	204.503	17.35	187.1530
S12	197.950	0.00	197.9500
S13	213.443	-	-

The piezometric level of groundwater varies from 0 m to 18.43 m, with avreage 8.27 m. This level shows that groundwater in shallow. In same area, groundwater appears on the floor surface groun.

The piezometric level of the water varies from 0 m to 18.43 m, with an average of 8.27 m. The groundwater studied in the area is shallow. In some areas, the water flush (S5 and S12) and the water is at the surface, with no deep. The quantity of groundwater is very important in this area, with a water blade observed in boreholes which ranges from 0.54 m to 93.15 m, with an average 35.62 m.

The lowest value was observed in the borehole S7 which is located in the mining traditional exploitation area. In this site, groundwater physico-chemical and bacteriological quality is mostly influenced by anthropogenic activities.

3.2 Microbiological Quality of groundwater

The results of the analysis of groundwater from Hiré are shown in Table 3.2.

These results indicate the presence of total coliform and fecal coliform (*Escherichia coli*) in the most of the water studied. In this area, only 02 samples contain clean water which respects the guideline of [23]. Water from these boreholes is considered as a drinking water at the microbiological point of view.

Tableau 2. Results of microbiological analysis of groundwater from Hiré

Samples	Units	Criterions	Total coliforms		*Escherichia Coli*	
			Methods	Values	Methods	Values
S1	ufc/100 ml	>1 /100ml	NF V08-50	0	AFNOR BRD 07/1-07/93	0
S2	ufc/100 ml	>1 /100ml	NF V08-50	280 000	AFNOR BRD 07/1-07/93	30
S3	ufc/100 ml	>1 /100ml	NF V08-50	250 00	AFNOR BRD 07/1-07/93	0
S4	ufc/100 ml	>1 /100ml	NF V08-50	300 000	AFNOR BRD 07/1-07/93	300
S5	ufc/100 ml	>1 /100ml	NF V08-50	200 000	AFNOR BRD 07/1-07/93	0
S6	ufc/100 ml	>1 /100ml	NF V08-50	0	AFNOR BRD 07/1-07/93	0
S7	ufc/100 ml	>1 /100ml	NF V08-50	300 00	AFNOR BRD 07/1-07/93	100
S8	ufc/100 ml	>1 /100ml	NF V08-50	300 000	AFNOR BRD 07/1-07/93	0
S9	ufc/100 ml	>1 /100ml	NF V08-50	350 000	AFNOR BRD 07/1-07/93	450
S10	ufc/100 ml	>1 /100ml	NF V08-50	7000	AFNOR BRD 07/1-07/93	0
S11	ufc/100 ml	>1 /100ml	NF V08-50	250 000	AFNOR BRD 07/1-07/93	0
S12	ufc/100 ml	>1 /100ml	NF V08-50	500 000	AFNOR BRD 07/1-07/93	1400
S13	ufc/100 ml	>1 /100ml	NF V08-50	178 000	AFNOR BRD 07/1-07/93	0

The microbiological pollution has human origin [5]. In the town of Hiré, there are no latrines; people usually make their personal needs in nature. The rain is very abundant in this forest area. Thus, seepage that supply groundwater flow in depth all the waste. It explains the origin of groundwater pollution. In fact the presence of fecal coliforms in water confirms the influence of human activities in the region. [7] explains the presence of fecal coliform bacteria in well water by faecal contamination and therefore the possibility that dangerous pathogens are present in the water.

In Côte d'Ivoire, the faecal pollution of water resources has been shown by authors such as [4] in surface water and groundwater in areas of Abidjan, Kossihouen and N'zianouan. In southern Kenya, [16] showed a strong microbiological pollution of anthropogenic origin in the waters of the river Ruguti Meru. The influence of human activities on water quality is also observed in the region Baikunthpur, the District of Rewa, Madhya Pradesh, India by [21].

The most common and wide spread health risk associated with drinking-water is microbial contamination [23], which is perhaps the crucial issue in the humid tropics in terms of direct effect on human health [19]. Diarrhoeal disease remains a leading cause of mortality and morbidity of children in Sub-Saharan Africa [9] where more than one child dies every minute from diarrhoea (WHO Regional Office for Africa, 2012 *in* [24]. This calls for a need for microbial examination of drinking water sources in the region. Water related diseases represent about two-thirds of all the diseases in Cameroon [24] and are responsible for approximately 50 % of the cases of death recorded [12].

In the study area, the origin of heavy metals in water is mainly due to the nature of the geological formations. The mountainous western Côte d'Ivoire is a mineral-rich area with the presence of deposits of iron, nickel and cobalt. These elements are found in source waters and groundwater after alteration of the rock.

3.3 Groundwater quality

3.3.1. Current Water Quality

The results of the physico-chemical parameters and the descriptive statistic of the samples collected at different samples are presented in table 2.

- [1]Université Technologique et Tertiaire Loko (UTTLOKO), Laboratoire de chimie et de Microbiologie, 05 BP 671 Abidjan 05 Côte d'Ivoire; Tél : 00 225 21 21 19 20. Courriel : solyfleur@hotmail.com
- [2]Université Félix Houphouët-Boigny de Cocody-Abidjan, Unité de Formation et de Recherche (UFR) des Sciences de la terre et des Ressources Minières (STRM) ; Laboratoire des Sciences et Techniques de l'Eau et de l'Environnement (LSTEE), 22 BP 582 Abidjan 22 ; Tel : (+225) 22 48 38 03 (Côte d'Ivoire) ;
- [3]Institut National Polytechnique Félix Houphouët-Boigny (INP-HB), Département des Sciences de la Terre et des Ressources Minières (STeRMi), Laboratoire du Génie Civil, des Géosciences et des Sciences Géographiques, BP 1 093 YAMOUSSOUKROU, CÔTE D'IVOIRE. Courriels : michel.a_kouassi@yahoo.fr et michel_kouassi@inphb.edu.ci

Table 2. Descriptive statistics for the measured ions in the groundwater of Hiré

	Guideline value WHO [23]	Mean	Min	Max	Ecart-type	Standard Deviation
T°	-	28,19	26,00	29,80	1,16	0,32
pH	6,5 ≤pH≤ 8,5	7,31	6,25	8,10	0,56	0,16
Turb	5	21,52	1,57	102,00	31,48	8,73
CE	1000	678,69	276,00	998,00	195,01	54,09
TDS	-	287,46	127,00	434,00	78,42	21,75
O2 (DO)	-	4,42	0,31	7,27	2,41	0,67
MES	-	30,49	3,00	83,80	27,97	7,76
S libre	-	0,01	0,00	0,02	0,01	0,00
Mg^{2+}	50	14,50	11,20	18,40	2,06	0,57
Ca^{2+}	200	79,63	71,50	85,00	4,42	1,23
Na^{+}	250	11,55	10,20	14,30	1,29	0,36
K^{+}	150	9,61	8,20	11,50	0,96	0,27
Cl^{-}	250	154,81	145,20	165,00	5,83	1,62
HCO_3^{-}		44,60	12,44	68,32	18,69	5,18
SO_4^{2-}	150	31,30	29,70	33,06	1,29	0,36
COT	-	0,88	0,00	11,30	3,13	0,87
Si	-	0,43	0,19	0,78	0,14	0,04
Eh	-	-14,18	-58,60	49,60	33,42	9,27
N	-	0,08	0,02	0,68	0,18	0,05
NO_3^{-}	50	0,36	0,10	2,96	0,78	0,22
NO_2^{-}	3	0,02	0,01	0,09	0,02	0,01
NH_4^{+}	0,5	0,35	0,05	0,91	0,31	0,09
PO_4^{3-}	1,5	0,13	0,06	0,32	0,09	0,02
DCO	-	81,15	35,00	158,00	40,80	11,32
DBO_5	-	36,46	17,00	72,00	18,07	5,01
Cn Lib	-	54,92	0,00	102,00	52,92	14,68

All the elements are in mg/L except pH (unitless), EC (µS/cm), and which is measured in mg/L.

The pH values ranged from 6.25 - 8.1 with a mean value of 7.31± 0.16 which indicates that the groundwater is neuter. However, there are some boreholes with alkalinity water (pH =8.10). The temperature ranged from 26°C – 29.80°C with a mean value of 28.19°C ±0.32°C. In the area, the highest temperature value is 29.80°C. The range and the mean concentration of TDS of groundwater in the area are 127-434 mg/L and 287.46 ± 21.75 mg/L, respectively. In general, groundwater from Hiré has a slight concentration of TDS. The electric conductivity of groundwater from Hiré ranged between 276 - 998 µS/cm with a mean conductivity 678.69 µS/cm. That shows water is mineralized and contain more dissolves ions. Those electric conductivities was the same as a previous studies [3].

The range and mean concentration of DO are 0.31–7.27 mg/L and 4.42 ± 0.67 mg/L, respectively. This means groundwater contains important values of oxygen. The low DO values could also be as a result of the degradation ogoranic waste in the water. The range and mean concentration of chemical oxygen demand are 35 - 158 mg/L and 81.15 ± 11.32 mg/L, respectively. The presence of high biodegradable matters could account for this trend. The range and mean concentration of biological oxygen demand are 17 to 72 mg/L, and average 36.46 ± 5.01 mg/L. The suspended solids are less important in the waters. They range from 3 to 83.8 mg/L, with an average of 30.49 mg/L. The turbidity of groundwater ranges in the way as the suspended solids. It is range from 1.57 to 102 NTU, an average of 21.52 ± 8.73 NTU. The concentration of chloride ranged between 145.20 - 165 mg/L with a mean concentration of 154.81 ± 1.62 mg/L. Chloride in drinking-water originates from natural sources, sewage, industrial effluents and urban runoff [2]. Excessive chloride concentration increases the rate of corrosion of metals in the water distribution system and depending on the alkalinity of the water; this can lead to increased concentrations of metals in the supply [11].

Chloride concentrations in excess of about 250 mg/L can give rise to detectable taste in water [2].

The range of sulphate concentration in the water was 29.70 - 33.06 mg/L with a mean concentration of 31.30 ± 0.36 mg/L. This could be attributed to the fact that sulphate occur naturally in numerous minerals.

The concentration of nitrate ranged from 0.10 - 2.96 mg/L with a mean concentration of 0.36 ± 0.22 mg/L. This was also slighter than those obtained from previous studies in the area of Abidjan, N'zianonouan [5].

The primary health concern regarding high levels of nitrate and nitrite in potable water is the formation of methaemoglobinaemia, so-called "blue-baby syndrome". Nitrate is reduced to nitrite in the stomach of infants. This reduction of nitrate to nitrite by gastric bacteria is also higher in infants because of low gastric acidity.

The concentration of phosphate ranged from 0.06 - 0.32 mg/L with a mean concentration of 0.13 ± 0.02 mg/L. Nitrate and phosphate are nutrients very essential for plant growth. However, high concentrations tends to pose more harm on the water as they can lead to algal growth commonly refer to as algal bloom. It has been reported that excess concentration of phosphorus of 0.015 mg/L and nitrogen concentration of about 0.3 mg/L are sufficient to cause algal bloom [14].

The chloride is the major dominant anion and calcium the most important major cation. Water had high concentration of the major cations (Ca, Mg, and Na), which could be associated with the weathering of carbonate or silicate minerals. The high concentrations of these elements depict the local geology of the area.

3.3.2 Results of heavy metals analysis in groundwater

The results of heavy metals analysis of groundwater are shown in Table 3. Heavy metals such as Cd, As and Pb are absent in groundwater of the region. However, we note the presence in groundwater of some heavy metals such as chromium (Cr), mercury (Hg), molybdenum (Mo), silver

(Ag), zinc (Zn), manganese (Mn) and copper (Cu), to below the WHO guideline value for drinking water levels. Iron is the most important metal in the goundwater of the region; however it presents no toxicity to human health.

Table 3. Results of the analysis of heavy metals in groundwater

Heavy metals	Guidelines value (mg/L) WHO [26]	Mean	Min	Max	Ecart-type	Standard Deviation
Fe (mg/L)	0.3	0.68	0.08	2.57	0.70	0.19
Cu (mg/L)	2	0.07	0.00	0.28	0.11	0.03
Mn (mg/L)	0.4	0.17	0.03	0.44	0.13	0.04
Zn (mg/L)	-	0.11	0.02	0.36	0.11	0.03
Al (µg/L)		0.67	0.33	1.05	0.25	0.07
Cr (µg/L)	0.05	71.27	2.08	102.00	47.98	13.31
Ag (µg/L)		**0**.01	0.00	0.02	0.01	0.00
Hg (µg/L)	0.006	0.90	0.68	1.10	0.13	0.04

The concentration of Fe in groundwater ranged from 0.08 - 2.57 mg/L with a mean concentration of 0.68 ± 0.19 mg/L. Corrosive materials contribute significantly to the amount of iron in water. Iron is one of the most abundant metals in the earth's crust [1]. Iron concentration in water is associated with the local geology [8]. It is found in natural fresh waters at levels ranging from 0.5 to 50 mg/L [1]. Iron is an essential element in human nutrition; however, estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50 mg/day [22].

Iron stains laundry and plumbing fixtures at levels above 0.3 mg/L.

The concentration of Mn ranged from 0.03 - 0.44 mg/L with a mean concentration of 0.17 ± 0.04 mg/L. Zn concentration ranged from 0.02 - 0.36 mg/L with a mean concentration of 0.11 ± 0.03 mg/L. Zinc value is low and less than the WHO [24] guideline value for drinking water. The zinc in groundwater is associated with geological formation.

4.3.3 Groundwater type in the area

The values obtained from the groundwater samples analyzing, and their plot on the Piper's diagram [18] reveal that the dominant cation is Ca^{2+} and the anion is Cl^-. In the study area, the groundwater type is Ca-Cl. (**Fig.2**). [9] has proposed new diagram for geochemical data presentations.

Results of analyses were plotted on Sholler berkaloff's diagram. The plot shows that all of the groundwater samples is Ca-Cl. Through this diagram, the hydrochemistry formula of groundwater is :

$$rCl^- > rHCO_3^- > rSO_4^{2-} \text{ and } rCa^{2+} > rMg^{2+} > r(Na^+ + K^+)$$

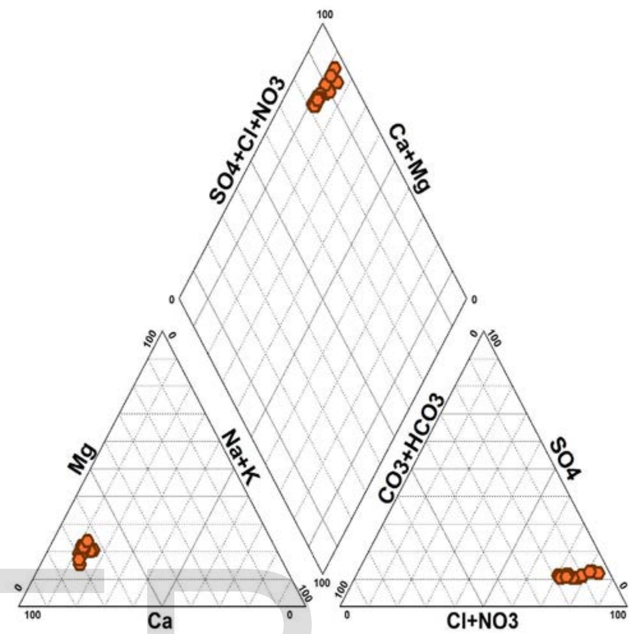

Fig. 2. Importance des Ions majeurs dans les eaux souterraines : Eaux Chlorurées calciques

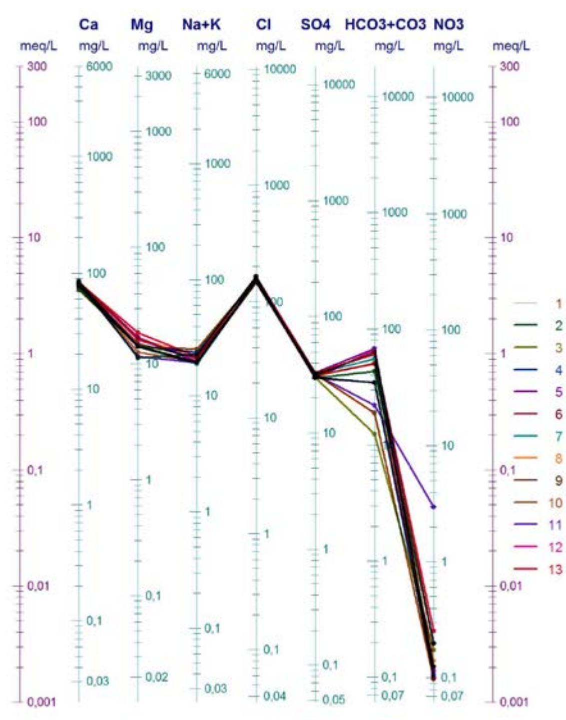

Fig. 3. Classification of groundwater with Sholler Berkalof diagram.

4 CONCLUSION

This research work studies the microbiological and physico-chemical quality of groundwater from Hiré. The study shows that the static level of the water table varies from 0.48 m to 4.52 m, with an average of 1.24 m. Microbiological analyses show the presence of fecal coliforms (*Escherichia coli*) and total coliforms in water. The presence of those microorganisms in groundwater indicates that water is confronted with anthropogenic fecal pollution. Physico-chemical Analyses show that groundwater is chlorinated and calcic. Groundwater in the study area contain heavy metals such as molybdenum (Mo), chromium (Cr), mercury (Hg), silver (Ag), zinc (Zn), manganese (Mn) and copper (Cu) to below the WHO guideline value for drinking waters levels. Iron is the most important metal in the waters of the region, but has no toxicity for human health. The origin of iron in water is related to the geological formations of the study area. In the study area artisanal exploitation of gold by the population of Hiré has a great influence on the quality of groundwater. This pollution seriously deteriorates the physico-chemical and microbiological quality of water. Thus these activities which constitute a health risk for people in that locality are largely dependent on groundwater.

REFERENCES

[1] Adebola A. Oketola, Seun M. Adekolurejo, Oladele Osibanjo, 2013. Water Quality Assessment of River Ogun Using Multivariate Statistical Techniques. *Journal of Environmental Protection*, 4: 466-479 doi:10.4236/jep.2013.45055

[2] Aghazadeh, N. and Mogaddam, A. A. (2010). Assessment of groundwater quality and its suitability for drinking and agricultural uses in the Oshnavieh Area, Northwest of Iran. J. Environ. Prot., Vol. 1, Issue.1, pp.30-40. doi:10.4236/jep.2010.11005

[3] Ahoussi K. E., Soro N., Koffi Y. B., Soro G., Biémi J. 2010. Origine de la minéralisation des eaux des aquifères discontinus sous couvert forestier de la zone Sud de la Côte d'Ivoire: cas de la région d'Abidjan-Agboville. *International Journal of Biological and Chemical Sciences,* **4**(3): 782-797.

[4] Ahoussi K. E., Oga Y. M. S., Koffi Y. B., Kouassi A. M., Soro N., Biémi J. 2011. Caractérisation hydrogéochimique et microbiologique des ressources en eau du site d'un Centre d'Enfouissement Technique (CET) de Côte d'Ivoire : cas du CET de Kossihouen dans le District d'Abidjan (Côte d'Ivoire). *International Journal of Biological and Chemical Sciences,* **5**(5): 2114-2132.

[5] Ahoussi K. E., Koffi Y. B., Kouassi A. M., Soro G., Soro N., Biémi J. 2012. Étude des caractéristiques chimiques et microbiologiques des ressources en eau du bassin versant du N'zi : cas de la commune de N'zianouan (Sud de la Côte d'Ivoire). *International Journal of Biological and Chemical Sciences,* **6**(4): 1854-1873

[6] Biémi J. 1992. Contribution à l'étude géologique, hydrogéologique et par télédétection des bassins versants Subsahéliens du socle précambrien d'Afrique de l'Ouest : Hydrostructurale, hydrodynamique, hydrochimie et isotopie des aquifères discontinus des sillons et aires granitiques de la Haute Marahoué (Côte d'Ivoire). Thèse de Doctorat d'Etat, Université Nationale de Côte d'Ivoire, p. 480.

[7] Boutin C. 1993. L'eau des nappes phréatiques superficielles, une richesse naturelle mais vulnérable. L'exemple des zones rurales du Maroc. *Sciences de l'eau*, 6(3) : 357-365.

[8] Gbolo P. and Lopez D. L. 2013. Chemical geological control on surface water within the Shade river watershed in southeastern Ohio. *Journal of Environmental Protection*, 4 : 1-11. doi :10.423/jep.2013.41001.

[9] Chadha D. K., 1999. A proposed new diagram for geochemical classification of natural water and interpretation of chemical data," Hydrogeology Journal, Vol. 7: 431–439.

[10] Hamer DH, Simon J, Thea D, Keusch GT 1998. Childhood diarrhea in Sub-Saharan Africa. Child Health Research Project Report 2.

[11] Karanth K. R., 1987. Groundwater assessment, development nd management," Tata McGraw Hill, New Delhi, pp. 720,

[12] Katte VY, Fonteh MF, Guemuh GN 2003. Domestic water quality in urban centres in Cameroon: A case study of Dschang in the West Province. Afr. Water J. Pilot Edition: 43-54.

[13] Khalil B. and Ouarda T. M. B., 2009. Statistical Approaches Used to Assess and Redesign Surface Water Quality Monitoring Networks," *Journal of Environmental Moni- toring*, Vol. 11, No. 11: 1915-1929. doi:10.1039/b909521g

[14] Klein L., 1962. River Pollution. II. Causes and Effects. But- terworth & Co. (Publishers) Ltd., London.

[15] Niemi G. J., Devore P., Detenbeck N., Taylor D., Lima A., 1990. Overview of Case Studies on Recovery of Aquatic Systems from Disturbance," *Environmental Management*, Vol. 14, No. 5, pp. 571-587. doi:10.1007/BF02394710

[16] Ombaka O. and Gichumbi, 2012. Water quality assessment of Ruguti River in Meru South, Kenya. *International Journal of Water and Environmental Engineering*, Vol.4 (12): 404-414.

[17] Pejman H., Nabi Bidhendi G. R., Karbassi A. R., Mehrdadi N., Esmaeili Bidhendi M., 2009. Evaluation of Spatial and Seasonal Variations in Surface Water Quality using Multivariate Statistical Techniques. *International Journal of Environmental Science and Technology*, Vol. 6, No. 3: 467-476.

[18] Piper A. M., 1944. A graphic procedure in the geochemical interpretation of water-analyses. Transactions, American Geophysical Union, Vol. 25: 914–923.

[19] Roche MA 1993. Water quality Issues in the humid tropics. In Bonell et al. (eds) Hydrology and water management in the humid tropics: Hydrological research issues and strategies for water management. UNESCO. Cambridge University Press, Cambridge : 344-366.

[20] Thilagavathi R.,Chidambaram S., Prasanna M. V. Thivya C., Singaraja C. 2012. A study on groundwater geochemistry and water quality in layered aquifers system of Pondicherry region, southeast India. *Applied. Water Science,* 2: 253-269. doi 10.1007/s13201-012-0045-2

[21] Tiwari R. N., Umesh Mishra 2012. Groundwater quality and pollution potential studies around Baikunthpur area, Rewa District, Madhya Pradesh, India. International Journal of *Water and Environmental Engineering*, Vol.4 (12): 377-385.

[22] WHO, 2003. Nitrate and Nitrite in Drinking Water. Background Document for Preparation of WHO Guidelines for Drink- ing Water Quali-

ty," World Health Organization, Geneva.

[23] WHO, 2008. Guidelines for Drinking-water Quality. Third edition, incorporating the first and second Addenda, Recommendations, Geneva, Volume 1, 515p.

[24] WHO (2011). Guidelines for drinking-water quality, 4th Edn. World Health Organization, Geneva. 442p.

[25] Wirmvem M.J., Fantong W. Y., Wotany E. R., Ohba T., Ayonghe S. N., 2013. Sources of bacteriological contamination of shallow groundwater and health effects in Ndop plain, Northwest Cameroon. *Journal of Environmental Science and Water Resources* 2(4) : 127 - 132

[26] Zhang B., Song X., Zhang Y., Han D., Tang C., Yu Y., Ma Y., 2012. Hydrochemical Characteristics and Water Quality Assessment of Surface Water and Groundwater in Songnen Plain, Northeast China," *Water Research*, Vol. 46, No. 8: 2737-2748. doi:10.1016/j.watres.2012.02.033

[27] Zhao Y., Xia X. H., Yang Z. F., Wang F., 2012. Assessment of Water Quality in Baiyangdian Lake Using Multivariate Statistical Techniques," *Procedia Environmental Sciences*, Vol. 13: 1213-1226. doi:10.1016/j.proenv.2012.01.115