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CHEMICAL CHARACTERIZATION OF GROUNDWATER SEDIMENTARY BASINS: THE CASE OF THE WATERS OF THE AQUIFER OF THE CONTINENTAL TERMINAL OF THE TOWN OF ABOMEY-CALAVI (BENIN).

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ABSTRACT

We conducted from March to June 2014 a study that focuses on the chemical characteristics of the wells water in the town of Abomey-Calavi. This work required sampling campaigns, and the statistical analyzes of the measurement results. Thus we found that the water studied is mainly acid. The most abundant ions in these waters are generally chlorides and sodium ions. These ions come from seawater intrusion, base exchange related to clay minerals that fix the calcium in the water after release of sodium and masses precipitating steam mainly original oceanic rich in Na^+ and Cl^- from the evaporation of sea water. The facies of studied waters is chlorinated potassic sodic. These water present an abundance of iron and nitrate which certainly come from surface (respectively, soil and wastewater). These high levels of iron and nitrate have disadvantages on the potability of water and justify the abandonment of certain drilling by the population.

Thus do we see in the waters studied high levels of dissolved CO_2. This demonstrates that the water circulate in open system relative to CO_2. The pHeq = f (pHreal) diagram shows that these waters are all aggressive. The diagram ISD = f (ISC) indicates that the aquifer waters of the continental terminal of the town of Abomey-Calavi are relatively recent. They have a short residence time and a high circulation velocity.

KEYWORDS: Groundwater, facies, residence time, velocity, open system.

INTRODUCTION

The poor quality of surface water has led most of the governments in the world to turn to the exploitation of groundwater but the control and the followed by the quality of the groundwater remains a challenge in poor countries.

In Ivory Coast, in the view to improving the supply condition of drinking water of populations in general and rural communities in particular, the government has invested heavily in many localities equipment (towns, villages and camps) in drinking water points (boreholes or modern wells) (Oga et al, 2009). A total of 13,312 boreholes and wells are now in operation according to the assessment report and the evaluation of the national rural water program on May 1999 (JICA, 2001; Oga et al, 2009). After the drilling of these borings and before delivery to the population, some physical and chemical analyzes are performed to ensure the potability of the water. Thereafter, analysis is no longer performed. Previous work indicates high levels of certain elements in the regions of Bongouanou, Toumodi dark in Côte d'Ivoire (Babut 1984; Oga et al, 2009). Other studies performed have shown that the prevalence of bicarbonate ions ($HCO3-$) and chloride (Cl) in groundwater is a groundwater characterization of African pedestal regions (collectively, 1984 Cefigne, 1985 Biémi 1992; Soro 2002 Oga et al, 2009; Lasm et al, 2011). Facies perspective, the waters of the plinth have a bicarbonate facies which is different to groundwater Sedimentary Basin, which mostly have a facies chlorinated sodic potassic (Oga, 1998).

In Benin, as part of the strengthening of the drinking water supply of the town population of Abomey, SEME and Cotonou the bigest city of the country, the General Directorate of Water (DG-Water) and the National Water Company of Benin (SONEB) have conducted extensive drilling in the town of Abomey-Calavi (Hounsinou et al, 2014). If populations have groundwater quantity, challenge remains as regards the quality. The abandonment of some borings by the population shows that the water quality from these wells in the study area is bad. The poor quality of drinking water is a public health problem (WHO, 1981; Edmunds, 1994; WHO, 2005; World Health Organization, 2006; Oga et al, 2009). This study aims to determine the chemical characteristics and the facies of groundwater of the continental terminal of the study area; to assess the relative age of these waters, their velocity in the aquifer and the origin of the mineralization of these waters.

MATERIALS AND METHODS

Presentation of the study area

The town of Abomey-Calavi has seventy (70) villages and urban neighborhoods on nine (09) districts which are: Abomey-Calavi (center), Godomey, Akassato, Zinvié, OUEDO, Togba, Hêvié, Kpanroun and Glo-Djigbé. The town of Abomey-Calavi, located in the southern part of the Republic of Benin is limited to the north by the municipality of Zè, south by the Atlantic Ocean, to the east by the municipalities Sô-Ava and Cotonou and west by the municipalities of Tori-Bossito and Ouidah. It is the largest municipality in the Atlantic department and occupies over 20% of the area. It covers an area of 536km² representing 0.48% of the national area of Benin. The town of Abomey-Calavi is the edge of the largest water lagoon in Benin: Lake Nokoué. Indeed, with 20km Long (East-West) and 11km wide (North-South), the Nokoué lake has a water low surface of 160km2 and is the largest lake Benin lagoon and most important of point of view of its development because of its proximity to the city of Cotonou (Dovonou, 2012). The Lake Nokoué significantly influences the groundwater pollution close to him (Hounsinou, 2012).

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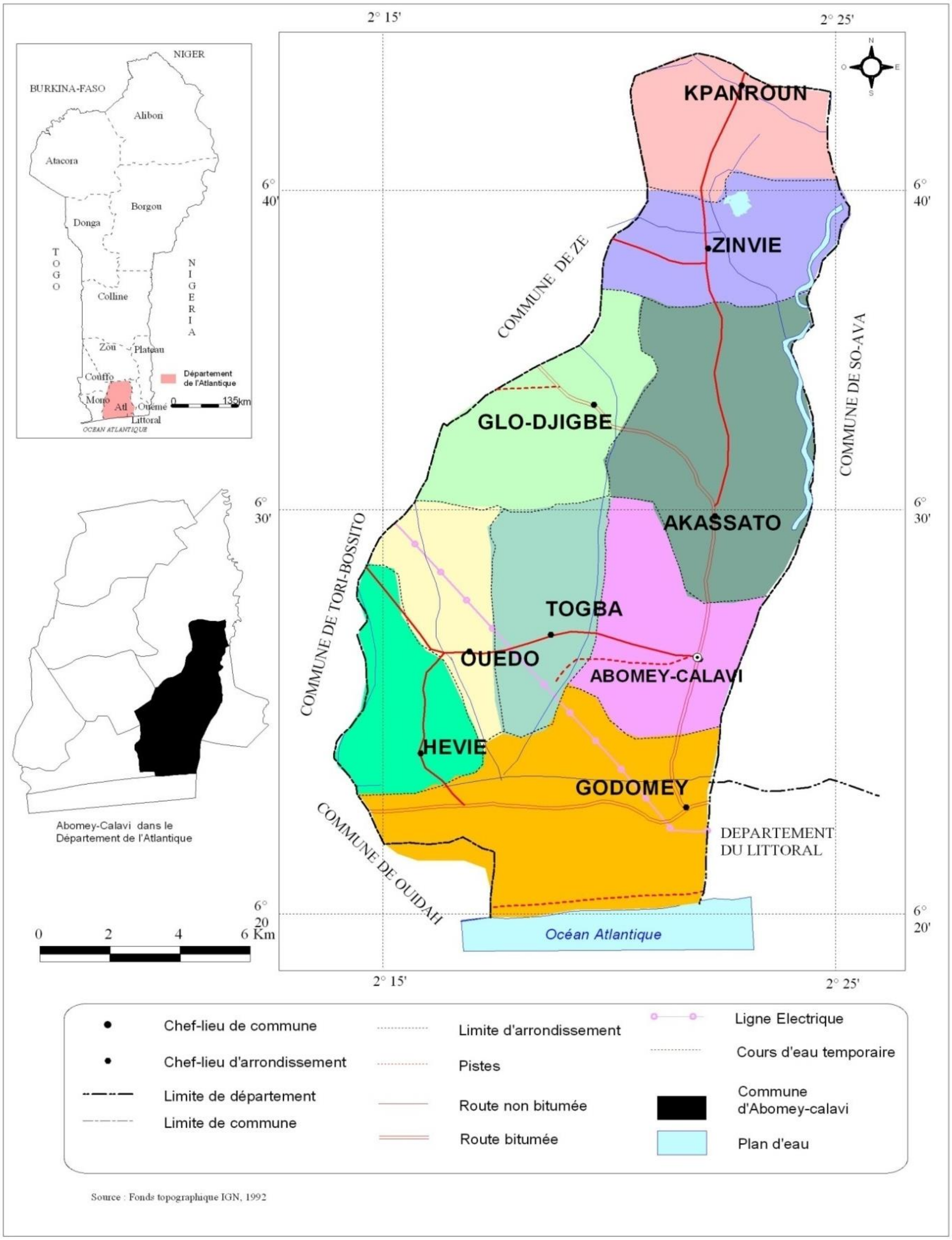

Figure 1: Location of the town of Abomey - Calavi in Benin

Material and methods

Material

It was carried out a total of 45 specimens from 45 boreholes for physical and chemical analysis .The geographical coordinates of drilling were obtained using a GPS (Garmin). We used the 1/200000 scale maps published in 1992 by the National Geographic Institute (IGN).

The physical and chemical analysis were conducted in Applied Hydrology Laboratory (LHA) at the University of Abomey and the Department of Hygiene and Basic Sanitation (DHAB).

Dosage

The physical parameters (temperature, pH, electrical conductivity and turbidity) were measured in situ. The chemical parameters were measured in the laboratory. The storage of water samples was performed in a cold room at 4 ° C, protected from light. The parameters measured in the laboratory are: TDS, color, hardness, alkalinity, calcium, magnesium, sodium, potassium, total iron, ammonium, bicarbonate, chloride, sulfate, nitrate, nitrite and phosphate. Depending on the parameters to be measured, methods for analyzing water samples are conductivity, spectrophotometry and pH-metry ... The material used is composed of the pH / Oximeter, Conductivity meter, colorimeter HACH DR 890 spectrophotometer NOVA 60 and the ion chromatograph.

Determination of facies

The typology of water exclusively through the determination of facies hydro. As part of this study, we used the PIPER diagram of the computer program "diagramme 2" (Smiler, 2007) of Hydrogeology Laboratory of Avignon (France). The elements are considered Ca^{2+}; Mg^{2+}; ($Na^+ + K^+$) for cations and ($HCO_3^- + CO_3^{2-}$); ($Cl^- + NO_3^-$) and SO_4^{2-} for anions.

The PIPER diagram (1953) has three areas:

- A parallelogram divided into 4 parts used to determine the name of the facies on the same basis as STRATLER characteristics formulas;
- Two triangles, a left, a right in which it is put respectively representative points of cations and anions.

The projection in the parallelogram of the points placed in the anions and cations triangles, class solution facies following the predominant ions.

H_2CO_3-CO_2 system

The principle of H_2CO_3-CO_2 system is based on the calculation of the following variables: CO2 partial pressure (Pco_2) and dissolved CO_2, the equilibrium pH and water saturation indices relative to carbonates (calcite, dolomite). The values of the saturation indices relative to calcite (ISC) and dolomite (ISD) and the values of the partial pressure of CO_2 (pCO_2) and dissolved CO_2 were calculated using the software "diagramme 2". The equilibrium pH was calculated from the real pH values and ISC values.

The characterization of water by this method makes use of ISD / ISC diagram and the diagram pH equilibrium - pH real. The diagram pH equilibrium - pH real defines two domains, the domain of encrusting waters and that of aggressive water. The diagram ISD / ISC provides information on water relative age (residence time), the permeability of the aquifer and the speed of water flow (Figure 2).

- If ISC> 0, the waters are supersaturated compared to the calcite. These waters can be considered "very old", because, only very prolonged contact between the water and the aquifer can justify the presence of carbonates precipitated in groundwater. Indeed, in contact with the dissolved CO_2 and carbonic acid H_2CO_3, the minerals rich in iron and magnesium favor the development of purely secondary carbonates and may increase the water saturation indices secondary carbonates (ISC and ISD) to zero and positive values. The waters characterized by ISC positive values are non-aggressive water flowing very slowly into the aquifer (Lasm et al, 2011).
- When ISC <0, the waters are undersaturated compared to carbonates (calcite). In this case, the waters are generally rich in dissolved CO_2 and very aggressive with great circulation velocity. These waters can be considered "recent" in the aquifer because they are constantly recharge by infiltration water (Lasm et al, 2011).

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The diagram ISD= f (ISC) allows to highlight:

- The alignment Representative points of the water according to their proportion in carbonates;
- The Grouping samples into families according to the water residence time;
- The Permeability of the aquifer;
- The water velocity.

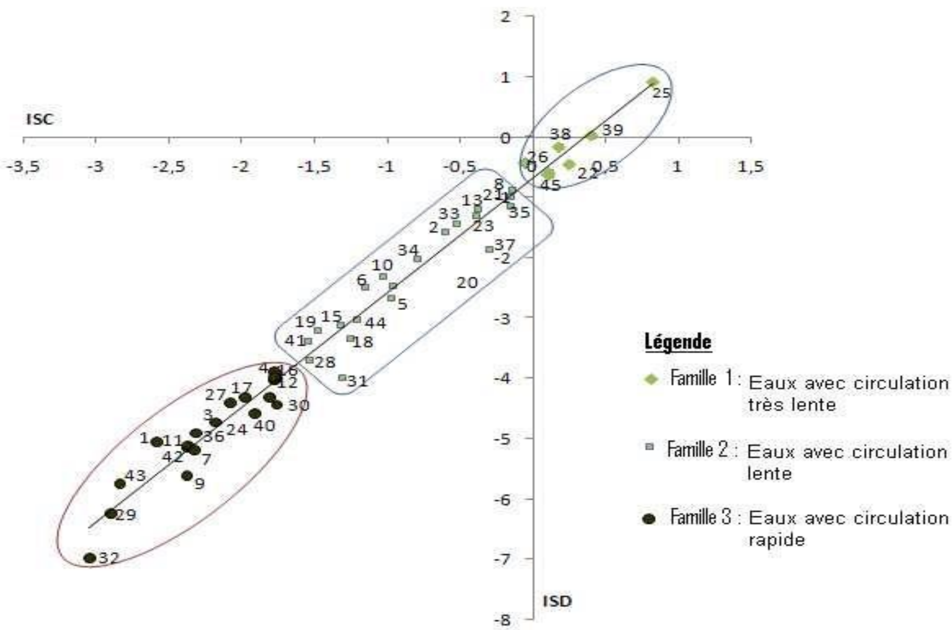

Figure 2: Diagram ISD / ISC of groundwater in the San Pedro region in Ivory Coast (Lasm et al, 2011).

Origin of mineralization

Abomey-Calavi is a coastal town. So we suspect among other a marine mineralization of groundwater in the study area.

The identification of the origin of the mineralization of groundwater requires a multidisciplinary approach. In particular, the detection of marine intrusion requires a multidisciplinary approach. Several authors (Demirel Z. 2004; A Elachheb, 2003; Gemail K. et al, 2004; S. Grassi et al, 2004; Kafri U. et al, 1979; Lebbe L. et al 1989; Paine JG 2003; Pulido- Beef P. 2004; Spechler RM 1994; Trabelsi R. et al, 2005; Wilson SR et al, 2006; Kouzana L. et al, 2007), by analytical methods, geophysical and modeling, have studied the phenomenon for locate the position of the interface between fresh water and sea water. Other studies [D.M. Allen et al, 2005; E. Farber et al, 2004; S. Grassi et al, 2004; P. Hudak F 2000; FS Martos et al 2001; Pulido-Le Boeuf P. et al, 2003; Trabelsi R. et al, 2005; Vengosh A.et al, 1994; Kouzana L et al, 2007) defined the processes and chemical reactions that characterize the mineralization and which would thus be responsible for the enrichment or depletion of groundwater chemical elements.

For this study, the search for the origin of the mineralization of underground waters will be through with the study of the diagram Na + = f (Cl) and the IEB.

When the content ratio of Na^+ / Cl^- remains relatively constant around 1 ± 0.5, this suggests a single origin for these species (Lasm et al, 2011). However, some samples may show a Na^+ / Cl^- moving away from the unity. Groundwater whose ratios are <1 correspond generally to the waters affected by the contribution of precipitation (recent recharge). When the Na^+ / Cl^- ratios> 1 this can be explained by an excess of sodium due to ion exchange between water and minerals such clay. After drawing the diagram Na + = f (Cl), when the coefficient of determination (R2 = O. 9 or 1) this means that Na+ and Cl- have a marine or brackish origin.

The index of base exchange (IEB) of each water sample was used to characterize the reactions of ionic exchange between the groundwater and the aquifer. The IEB was defined by Schoeller (1934) (Bouziane and Labadi, 2009). It is given by the following expression:

$IEB = [rCl^- - r(Na^+ + K^+)] / rCl^-$

Where IEB represent the index of base exchange and is whithout unit; rCl^- is the milliequivalent concentration of chloride ions, $r(Na^+ + K^+)$ is the milliequivalent concentration of the sum of sodium and potassium ions.

This index defines the direction of the ion exchange between the water and the surrounding ground (Bouziane and Labadi, 2009; Ahoussi, 2008). So if IEB = 0 then there is no exchange, if IEB <0 then Ca^{2+} and Mg^{2+} are exchanged by Na^+ and K^+ and if IEB> 0 then Na^+ and K^+ are exchanged by Ca^{2+} and Mg^{2+}.

RESULTS

The groundwater temperature values of the town of Abomey-Calavi are between 23.1 ° C (Adjagbo) and 30.6 ° C (Tokpa-Zongo) on a range of 7.5 ° C. The depth of drilling is between 3O.91 and 103.21m. The slightly alkaline water (pH > 7.0) represent approximately 6.66%; those more or less acidic (pH < 7.0) represent 91.11% of the studied boreholes. Of these, four water points (8.88%) indicate a neutral or near neutral pH ($6.5 \leq pH \leq 7.0$).

The studied water are generally characterized by low mineralization leading to electrical conductivities values ranging from 48 to 315 $\mu S.cm^{-1}$. The slightly mineralized water (conductivity < 100 $\mu S.cm^{-1}$) represent 84.44%; moderately mineralized water (100 $\mu S.cm^{-1}$ < conductivity < 200 $\mu S.cm^{-1}$) represent 11.11% of the studied boreholes and those with a fairly strong mineralization (200 $\mu S.cm^{-1}$ < conductivity < 333 $\mu S.cm^{-1}$) represent 4.44%.

Sodium is the most abundant cation in groundwater in this region. These levels range from 2.88 mg L^{-1} to 534.24 mg L^{-1}. Calcium is the third most abundant major cation in groundwater in this region with values ranging from 1.20 mgL^{-1} to 36.87$mg.L^{-1}$. The magnesium ion contents are generally low and vary from 0.22$mg.L^{-1}$ to 5.83$mg.L^{-1}$. $Mg^{2+} < Ca^{2+} < (K^+ + Na^+)$ for virtually all the water in the region.

The $Fe^{2+/3+}$ are present in the waters of the region with concentrations ranging from 0$mg.L^{-1}$ to 1.54$mg.L^{-1}$. Overall, it should be noted that for 17.77% of the sampled drilling, iron concentrations is higher than the WHO standard that is 0.20$mg.L^{-1}$.

The anions predominant in most of the waters of the town of Abomey-Calavi are chlorides with contents of between 0.17$mg.L^{-1}$ and 35.45$mg.L^{-1}$ and are well below the WHO standard (250mg. L^{-1}). The carbonates contents in the groundwater of the study region vary from 0.09$mg.L^{-1}$ to 1 372.10$mg.L^{-1}$. Nitrates are less abundant in the waters of the study area. Nitrate concentrations vary from 0$mg.L^{-1}$ to 97.23$mg.L^{-1}$. In 2.22% of the studied water has nitrate levels that far exceed the guideline value recommended by WHO (50$mg.L^{-1}$). Sulphate levels vary between 0 mg L^{-1} and 125.06 mg L^{-1} and are acceptable for human consumption.

We then noticed that several wells in the study area have levels of iron and nitrates well above the WHO standard.

Chemical facies water

The Chemical facies of the water in the town of Abomey-Calavi are indicated on the Piper diagram (Figure 3).
The chlorinated facies concerns 93.33% of the water in the region. There are two variants: the chlorinated sodic potassic waters overwhelmingly and chlorinated sulfated magnesia waters.
The facies bicarbonate calcium and magnesium concerns 6.66% of samples.
The bicarbonated sodic potassic facies of a drilling in GLO-DJIGBE is a singular case.

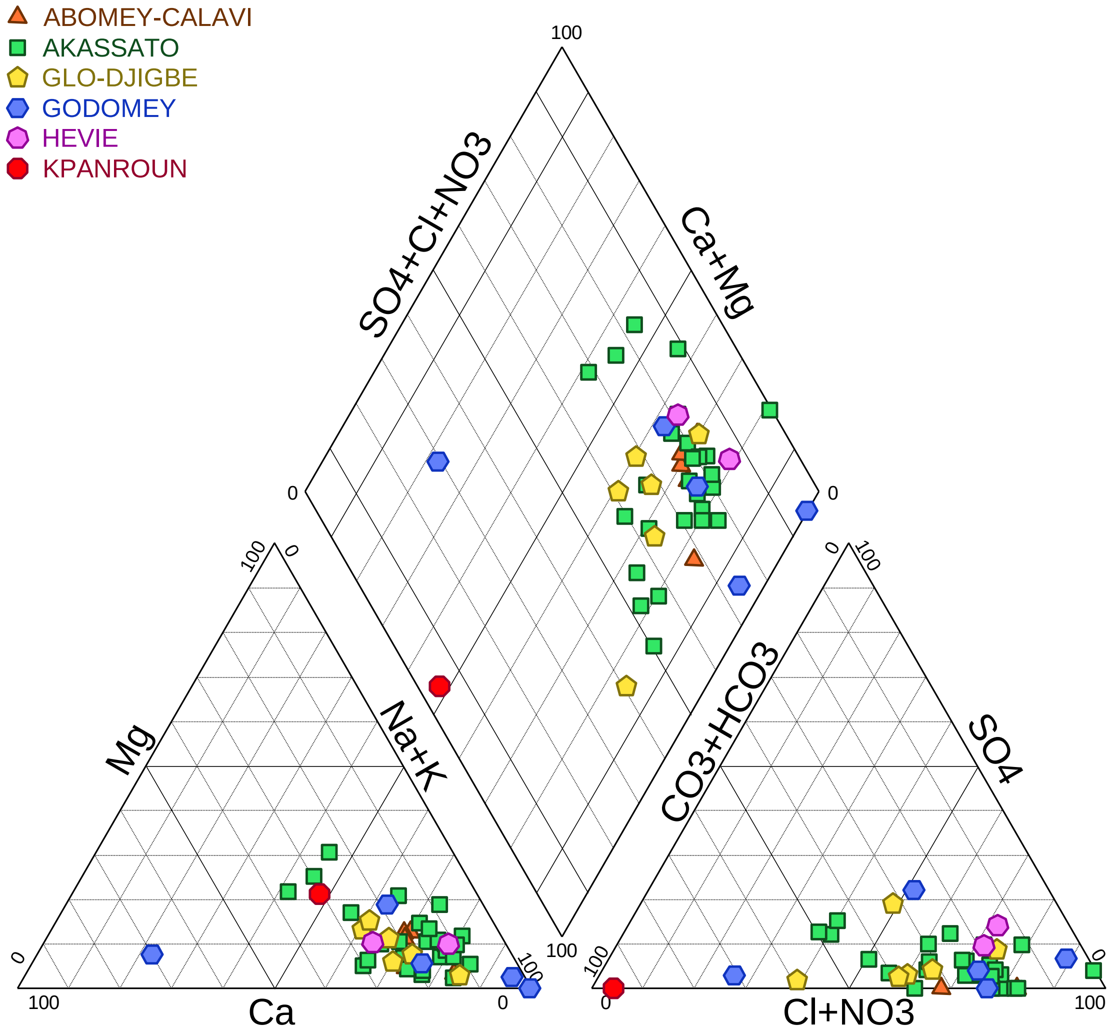

Figure 3: Piper diagram of drilling water in the town of Abomey-Calavi.

H_2CO_3-CO_2 groundwater system

The CO_2 concentrations and pCO_2 of the borings of the region respectively vary from 0.602mg.L^{-1} to 1039.51 mg.L^{-1} and from 0.00043 to 0.74251 atm. In the town of Abomey-Calavi, the majority of groundwater is rich in dissolved CO_2.

All the studied drilling water has a subsaturation both compared to the calcite (ISC <0) and dolomite (ISD <0). The waters of the town of Abomey-Calavi were divided into three groups according to the values of the ISD.

On the graph ISD = f (ISC) (Figure 4), the points representing the water samples are aligned along a line on which it is possible to adjust a regression line equation: $ISD = 0.91 \times ISC - 0.51$. The coefficient of determination ($R^2 = 0.98$) indicates that the statistical test is satisfactory.

Note that if CO_2 levels are high and the values of ISC and ISD are low, the groundwater is relatively young.

The groundwater of Abomey-Calavi is class into three different categories according to their velocity. These are the families of slow water flow, fast and very fast (Figure 4).

Family 1 (-4 <ISD <- 0.5)
This family includes two water samples representing 4.44% of the samples. These waters have a sub-saturation both compared to the calcite and dolomite, and they have an average content of dissolved CO_2 equal to 14.42 mg L^{-1}. These values reflect a low aggressivity of waters compared to the rocks. They water are old with long residence time and therefore a slow flow in aquifers that contain them. These borings groundwater are in the district of Godomey.

Family 2 (-7 <ISD <- 4)
This family includes seven water samples with important CO2 levels increasingly and therefore characterized by greater aggressiveness than the family 1.

The waters of family 2 represent 15.55% of the studied waters. The average content of dissolved CO2 is 19.98 mg L-1. These waters are more aggressive than that of the family 1 and they have lower values of saturation indices compared to secondary carbonates. These waters are young with a mean residence time and a rapid flow speed. The aquifers of these waters are characterized by a moderately permeability.

Family 3 (ISD <- 7)
The waters of the Family 3 account for 80% of groundwater. The average content of dissolved CO2 waters of this family is the highest with averaging 126.12 mg L-1. These waters are very aggressive because of their high content of dissolved CO_2 and their very low saturation indice compared to secondary carbonates. These waters are young with a short residence time and have a very rapid velocity of circulation in certainly very permeable aquifers.

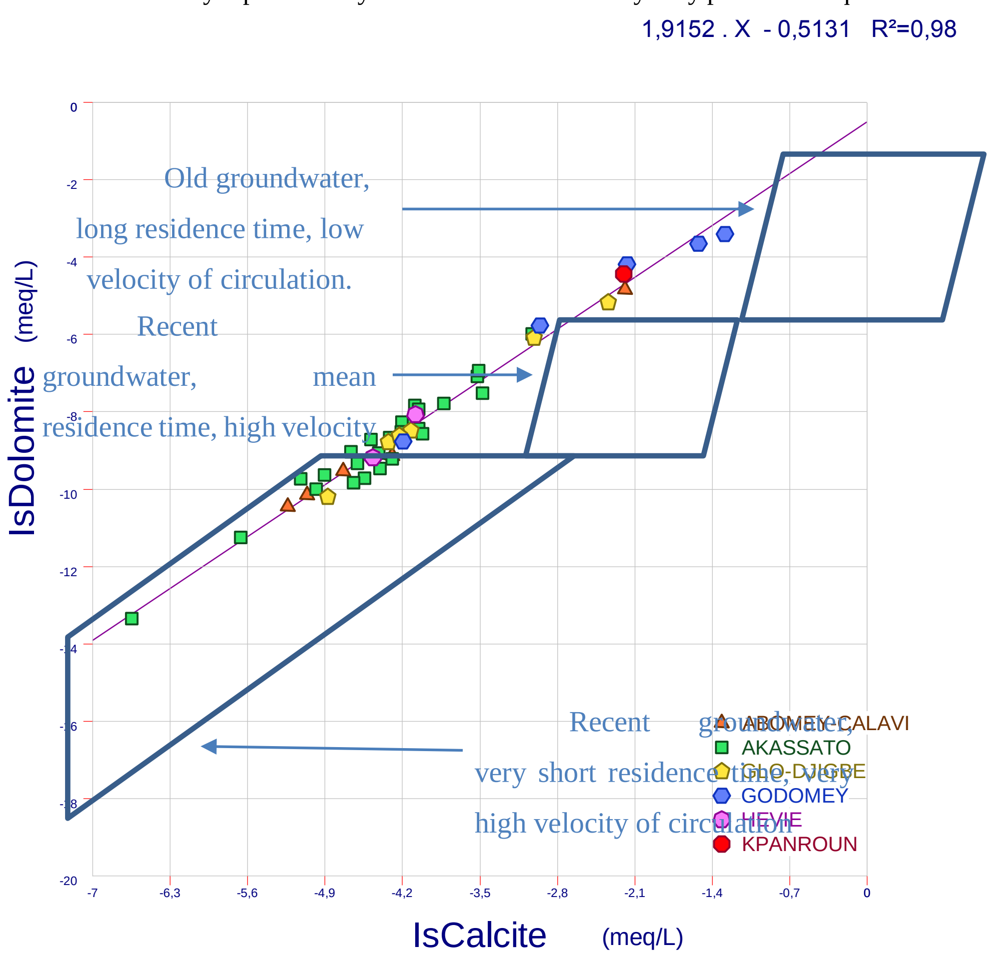

Figure 4: Diagram ISC / ISD of the drilling waters of the town of Abomey.

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Table 1: Proportion of studied groundwater by drilling families in comparison with some bibliographic data.

	Proportion of studied groundwater by drilling families			
Study area of groundwater	**(ISD <- 0.5) Old waters, very long residence time, water with slow velocity or zero.**	**(-7 <ISD <- 4) Recent waters, long residence time, fast speed circulation of water**	**(-7 <ISD <- 4) Recent waters, mean residence time, fast speed circulation of water**	**(ISD <- 7) Recent water, very low residence time, very fast speed circulation of water**
Tisalé (Ivory Coast) (plinth area) (Oga et al, 2009)	Minority	Majority	Very Minority	-
San-Pedro in Ivory Coast (plinth area) (Lasm et al, 2011)	Very Minority	Majority	Very Minority	-
District of Abomey in Benin (Sedimentary Basin) (this study)	-	Very Minority	Very Minority	Majority

This comparative study shows that groundwater sedimentary basins, are more recent, have a shorter residence time in aquifers and higher circulation velocity than the groundwater of plinth areas.

The water aggressiveness can be demonstrated using the diagram "pHeq -pH real." The projection of groundwater in this diagram (Figure 5) shows that all the points are located in the area of aggressive water.

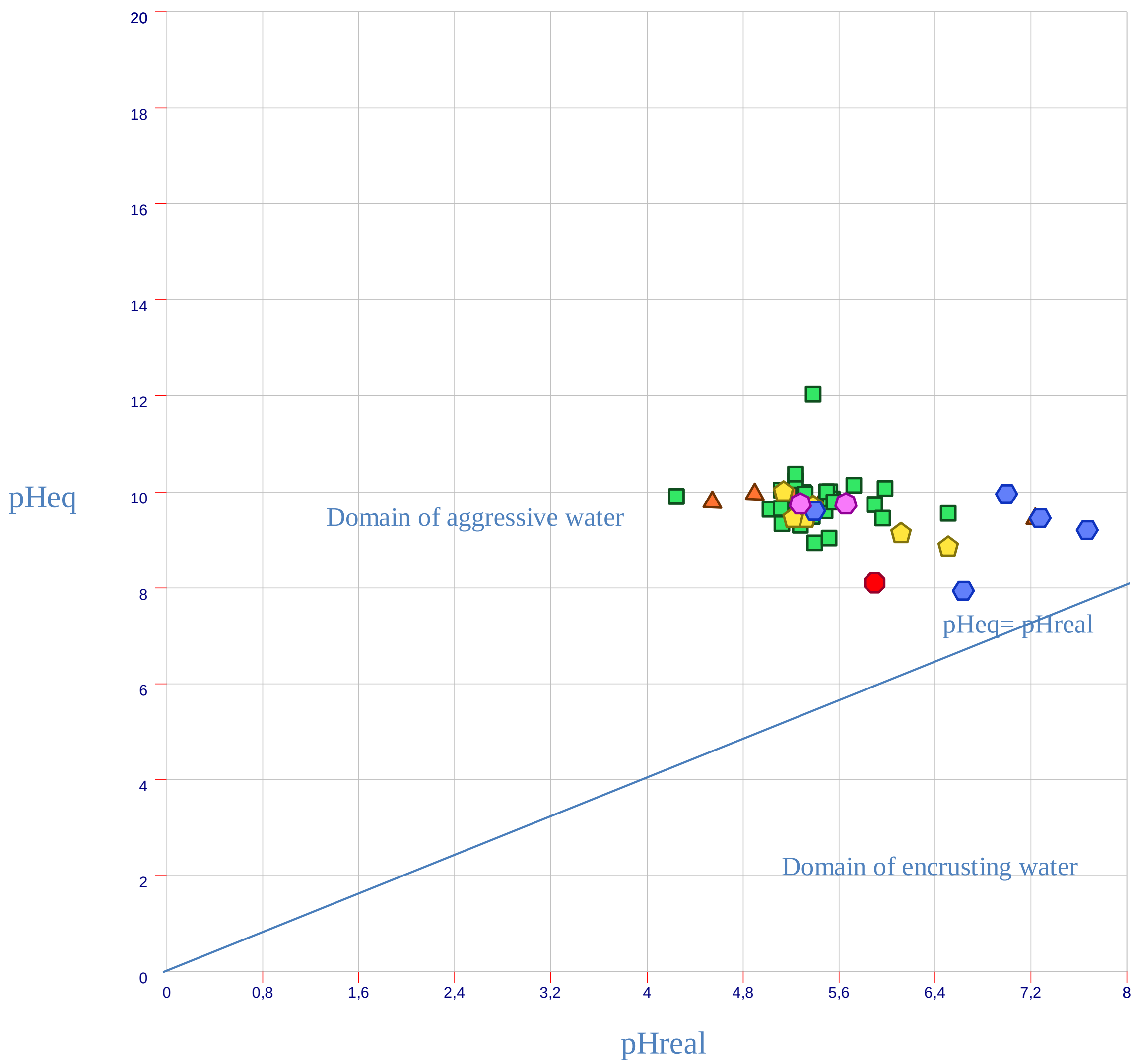

Figure 5: Diagram pH eq -pH real of water boreholes of Abomey-Calavi.

Origins and mineralization processes of groundwater

On the graph Na^+ f = (Cl^-) (Figure 6), the points representing the water samples are aligned along a line on which it is possible to adjust a regression line equation: $Na^+ = 0.6699 \times Cl^- + 0.1409$. The coefficient of determination ($R^2 = 1$) indicates that the statistical test is satisfactory. This suggests these species are marine or brackish origin.

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0,6699 . X + 0,1409 R²=1

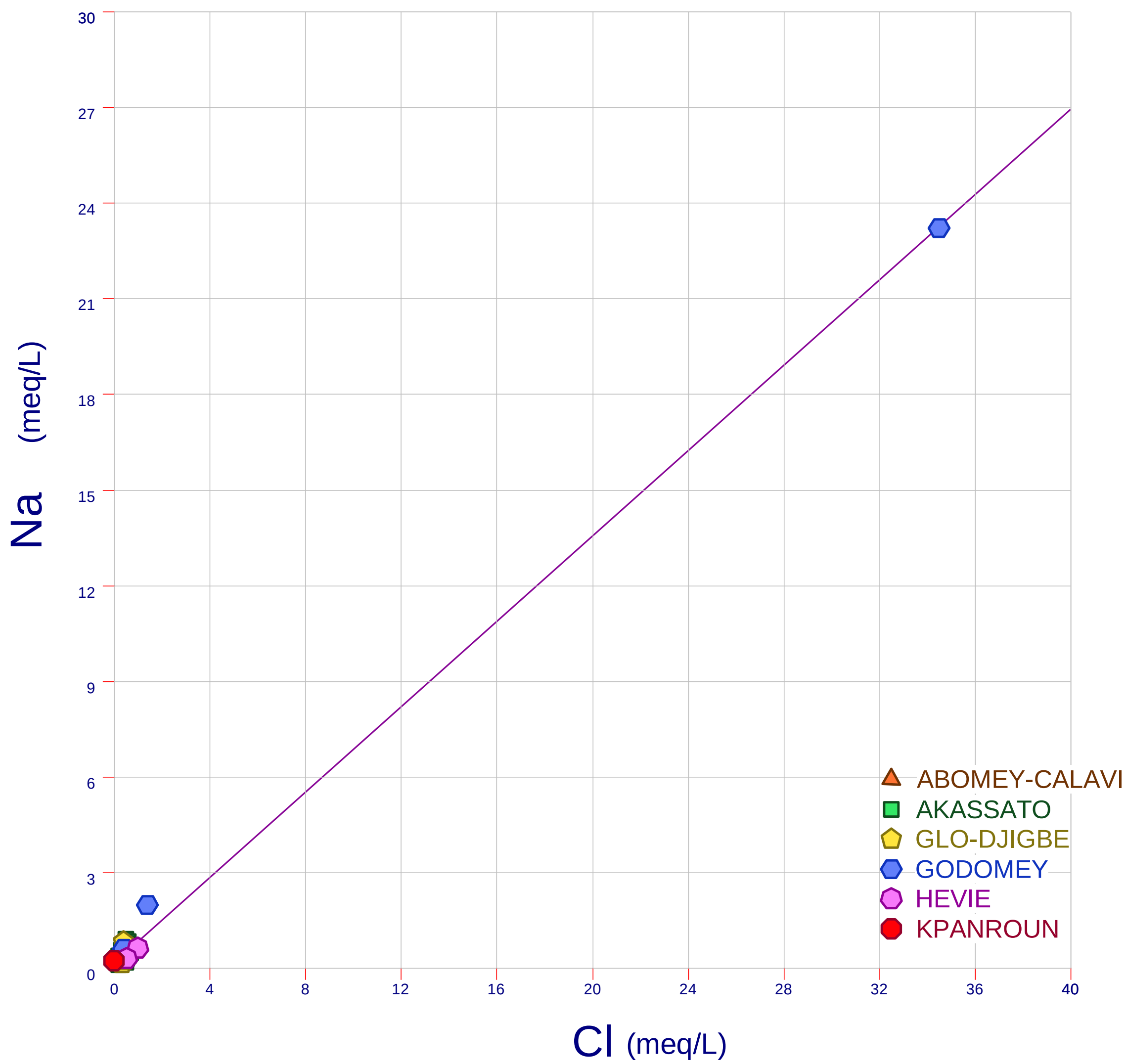

Figure 6: Diagram $Na^+ = f(Cl^-)$ of drilling waters of Abomey-Calavi.

Characterization of ion exchange between the groundwater and the aquifer

The water base exchange index ranges from -3.69 to 0.37 (Figure 7). No null index was recorded on all the studied waters. Negative values represent 86.66% of the indices determined and positive values represent only 13.34%.

The predominance of negative values of the IEB indicates a base exchange related to clay minerals that fix the calcium in the water after release of sodium.

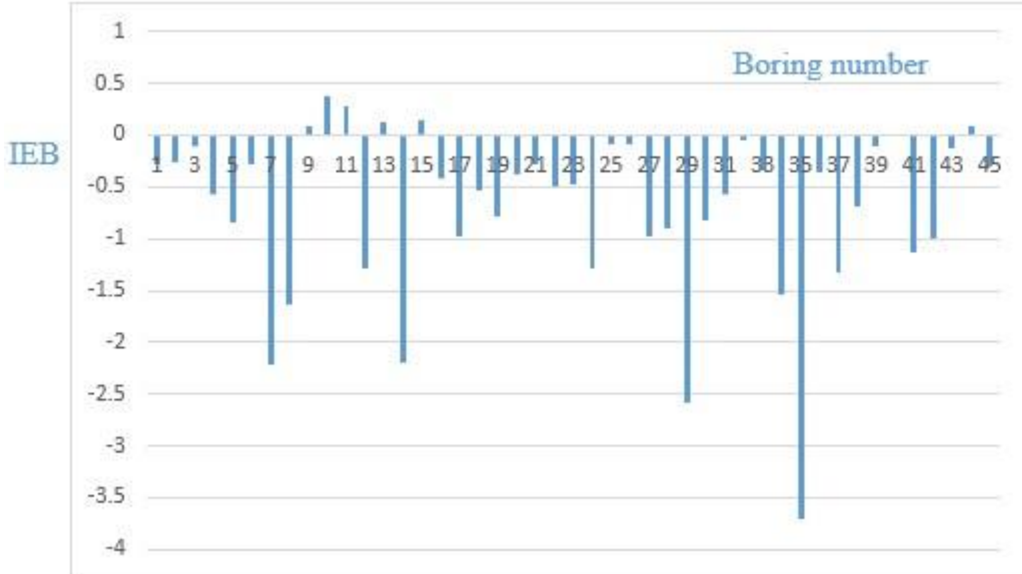

Figure 7: Change of IEB in drilling water of Abomey-Calavi.

DISCUSSIONS

91.11% of water wells studied are acid (4.25 ≤ pH ≤ 6.64). This acidity of deep drilling water is probably linked to the ground and confirms the results we obtained previously in this county at the traditional shallow wells (Hounsinou, 2015) .It shows that the pH of groundwater don't depends to the depth of drilling. The drilling water representing the remaining 8.99% have a slightly basic pH (7.28 ≤ pH ≤ 7.67). There are 3 holes located in the districts of Topka-Zoungo and Godomey. These three wells are located on or close to old landfills, not yet stabilized. It is the pollution of groundwater by leachate landfills which led these singular slightly basic pH values of these three water wells. Indeed, during the acid fermentation phase of anaerobic decomposition of waste, young leachates are rich in volatile organic compounds. During this phase, the pH values are generally lower than 4 (Tchobanoglous et al, 1993). As they age of the landfill, leachate is depleted of volatile organic compounds. This will then cause a rise pH to 7 or above (Kjeldsen et al, 2002).

Chloride ions are the most important anions in the studied drilling. The most important cations that combine with the chlorides are sodium and potassium. The chemical facies mainly found in the waters of drilling studied is the facies chlorinated sodic potassic. This confirms the results of Oga in 1998 which found in Ivory Coast that groundwater of sedimentary basin mainly present a chlorinated sodic potassic facies. As against other studies have shown that plinth area, the most encountered facies in groundwater is the facies bicarbonate (Oga, 2009; Lasm, 2011).

The abundance of sodium ions in the groundwater in the study area is brackish or marine origin. Three reasons for this abundance of sodium and chloride ions.

- The navy intrusion.
- The diagram $Na^+ = f(Cl^-)$ suggests the origin of a common source of these ions and an identical mechanism of mineralization. The natural phenomenon promoting groundwater salinity is certainly marine influence. This interpretation is consistent with the proximity of the sea and the high rainfall in the study area. Indeed, the town of Abomey-Calavi is a coastal town, there is steam masses precipitating essentially, oceanic origin, rich in Na^+ and Cl^- from the evaporation of sea water. The waters rich rain Na^+ and Cl^- reach underground aquifers by infiltration.
- A base exchange related to clay minerals that fix the calcium in the water of the web after release of sodium (Figure 7).

The drilling water of the town of Abomey-Calavi are weakly mineralize. This mineralization is independent of the depth of drilling and confirms the results obtained in this district in traditional shallow wells (Bossou, 2002; Dégbé 2004; Hounsinou, 2015).

We denote high levels of iron and nitrate exceeding WHO standards in the waters of some wells. This testifies to the pollution of groundwater by leachate.

The CO_2 plays a significant role in the dissolution of the rocks as shown in the following equation and the equilibrium constant K:

$$CO_2 + H_2O + CaCO_3 \quad \rightleftharpoons \quad (Ca^{2+} + 2\ HCO_3^-)$$

$$K = \frac{(HCO3^-)_2\ (Ca^{2+})}{(CO2)}$$

We see that for a given water, if the calcium hardness and alkalinity are fixed, there is only one value of CO_2 to maintain balance and this value is called CO_2 "balancing"

- If, in water, the CO2 available is less than the equilibrium value, the equilibrium is moved to the left, there is precipitation of $CaCO_3$ and the water is encrusting. This leads to deposits in the containers and pipes, especially at high temperatures because the solubility of gases decreases with increasing temperature. The encrusting waters are often, the hard water with alkaline and the CO_2 balancing relatively strong and difficult to achieve.
- If, in water, the free CO_2 available is greater than that equilibrium value: the balance of the equation moves to the right. The limestone is attack and the water is aggressive. This is usually the case of freshwater with low alkalinity and the value of CO_2 balancing is low.

The aggressive or encrusting of water is related to her alkalinity, to her calcic hardness and her CO_2 content and thus its pH.

All the wells waters of the town of Abomey-Calavi have a pH above pHeq and so are all aggressive. Indeed, in the waters studied, the CO_2 values are generally higher than the values observed in groundwater plinth by Biémi 1992 Savané in 1997, Oga in 2009 Goné in 2001, Soro in 2002 and in 2011 Lasm.

A high concentration of CO_2 in the water causes the dissolution of the rocks over the years; an increase of calcium saturation index (ISC) and dolomite (ISD). Thus, for groundwater, if the CO_2 values are high while the ISC and ISD values are low, the water is relatively young. A comparative study (Table 1) shows that the groundwater of the sedimentary basin of Abomey-Calavi are relatively younger, have a lower residence time in the aquifer and higher circulation velocity than the groundwater in plinth region. Indeed, we note the existence in plinth region, a very old groundwater that is not found in the groundwater of the studied sedimentary basin. Reciprocally, we note the existence in the groundwater of the sedimentary basin studied recent groundwater, with fast traffic speeds that are not found in the groundwater of the base areas.

The calculation in the aquifer studied 14C levels by the "diagramme 2" software revealed relatively high and variable values (50 to 100 cfm), characteristic of recent water recharge. This confirms the high velocity of these waters.

CONCLUSION

In the district of Abomey-Calavi, the groundwater has a slightly acid pH and some borings water are rich in Fe^{2+} and NO_3^-. Cl^- and Na^+ are abundant in these waters because of the seawater intrusion, the base exchange related to clay minerals that fix the calcium in the water after release of Na^+ and steam masses of precipitating origin primarily ocean rich in Na^+ and Cl^-. The studied groundwater has a chlorinated sodic potassic facies for the majority of the sampled waters. They are aggressive and undersaturated with respect to calcite and dolomite. The abundance of dissolved CO_2 in the waters of the town of Abomey-Calavi suggests a large infiltration of precipitation water. The diagram ISD / ISC indicates that the studied water has a low residence time in the aquifer with a high circulation velocity.

REFERENCES

[1] Ahoussi KE, Soro N, Soro G, Lasm T, Oga M, Zade SP. 2008. Groundwater pollution in Africa biggest towns: case of the town of Abidjan (Côte d'Ivoire). Eur. J. Sci. Res., 20: 302-316.

[2] ALLEN D.M & SUCHY M. 2001. Results of the Groundwater Geochemistry Study on Saturna Island, British Columbia. Rapport final préparé pour: Islands Trust Victoria, B.C. Earths Sciences Simon Fraser University. 119p.

[3] Bouziane MT, Labadi A. 2009. Les Eaux Profondes de la Région de Biskra (Algérie). Eur. J. Sci. Res., 25: 526-537.
[4] Biémi J. (1992) : Contribution à l'étude géologique, hydrogéologique et par télédétection des bassins versants subsahariens des socle précambrien d'Afrique de l'Ouest : hydro structurale, hydrodynamique, hydrochimie et isotopique des aquifères discontinus de sillons et des aires granitiques de la Haute Marahoué (Côte d'Ivoire), Thèse d'Etat, Univ. Cocody, 480p.
[5] Babut M. (1984) : Eaux d'alimentation en zone rurale ivoirienne. Approche de la qualité chimique (éléments toxiques et indésirables) et de la vulnérabilité des aquifères. Thèse de Doctorat en Pharmacie, Univ. Lille II.
[6] Bossou B. (**2002**) : Analyse et esquisse cartographique de la contamination bactériologique de la nappe phréatique alimentant les puits traditionnels de la ville de Cotonou et sa banlieue. Mémoire de DESS/MEQUE, FAST, UAC
[7] CEFIGRE et Laboratoire de Géologie Dynamique et Appliquée (Avignon) (1992) : l'hydrogéologie de l'Afrique de l'Ouest-Synthèses des connaissances socle cristallin et cristallophyllien, et sédimentaire ancien. Collection Maîtrise de l'eau ; Ministère des Relations Extérieures, Coopération et Développement 2ème édition, 147p.
[8] Collectif (1984) : Synthèse des connaissances sur l'hydrologie du socle cristallin et cristallophyllien, et sédimentaire ancien de l'Afrique de l'Ouest C.E.F.I.G.R.E. Sophia Antipolis, France, 1ère édition, 121p.
[9] DEMIREL Z. 2004. The history and evaluation of saltwater intrusion into a coastal aquifer in Mersin, Turkey. *Journal of Environmental Management*, 70: 275-282.
[10] Dégbey C **(2004):** La qualité de l'eau de puits dans la commune d'Abomey-Calavi et les facteurs exogènes de sa pollution. Mémoire de fin de formation de DEA, Environnement et Santé Publique FLASH, UAC, Bénin,
[11] Dovonou, F. E. (2012). Diagnostic qualitatif et environnemental de l'aquifère superficiel du champ de captage intensif de Godomey au Bénin (Afrique de l'Ouest): Eléments pour un plan d'actions stratégiques de protection des ressources en eau souterraine exploitées. Thèse de doctorat, spécialité hydrologie, CIPMA, FAST, UAC.
[12] Edmunds (1994): Groundwater chemistry and development. In Groundwater Quality edited by H. Nash and McCall. Published in 1994 by Chapman and Hall, pp. 5-7.
[13] ELACHHEB A., MANIA J. & MUDRY J. 2003. Mécanismes d'acquisition de la minéralisation des eaux souterraines dans le bassin Sahel-Doukkala (Maroc Occidental). Approche par des traceurs hydro-géochimiques. IGME. Madrid. ISBN. 84-7840-470-8.
[14] FARBER E., VENGOSH A., GAVRIELI I., MARIE A., BULLEN T.D., MAYER B., HOLTZMAN R., SEGAL M. & SHAVIT U. 2004. The origin and mechanisms of salinization of the Lower Jordan River. *Geochimica et Cosmochimica Acta*,. 68, 9: 1989-2006,
[15] Faillat J.P. et Blavoux B. (1989). Caractères hydrochimiques des nappes des roches endogènes en zone tropicale humide : l'exemple de la Côte d'Ivoire. Journal of Africa Earth Sciences, Vol. 9, n°1, pp31-40.
[16] Gallo G. (1979) : Utilisation complémentaire des isotopes de milieu et de l'hydrochimie pour SM-228/21, pp. 367-407.
[17] GEMAIL K., SAMIR A., OELSNER C., MOUSA S. E. & IBRAHIM S. 2004. Study of saltwater intrusion using 1D, 2D and 3D resistivity surveys in the coastal depressions at the eastern part of Matruh area, Egypt. *EAGE, Near Surface Geophysics*, 2: 103-109.
[18] GeoHive (2004) : Population de Côte d'Ivoire http/www.geohive.Com/cd/link.php?xml=ci&shn ed.
[19] Goné 2001 : Contribution de l'étude des paramètres physico-chimiques des eaux souterraines à la compréhension du fonctionnement des systèmes hydrauliques en milieu fissuré de la région semi-montagneuse de Man (Ouest de la Côte d'Ivoire). Thèse 3ème cycle Univ. Abobo-Adjamé, 179p.
[20] GRASSI S. & CORTECCI G.2004: Hydrogeology and geochemistry of the multilayered confined aquifer of the Pisa plain (Tuscany - central Italy). *Applied Geochemistry*, 20: 41-54.
[21] Hounsinou P. (2012). Pollution chimique et bactérienne des eaux de pluie, des eaux de surface et des eaux souterraines dans la commune d'Abomey-Calavi (Sud Bénin). Mémoire pour l'obtention du Diplôme d'Etudes Approfondies en Chimie et Applications option chimie minérale, Faculté des Sciences et Techniques, Université d'Abomey-Calavi (UAC).
[22] Hounsinou P.,*, Mama D., Alassane A. and Boukari M. (2014). Hydrogeology and Chemistry Synthesis of the deep Boring of the Township of Abomey-Calavi, Benin. Research Journal of Chemical Sciences, ISSN 2231-606X Vol. 4(12), 103-116, December (2014).

[23] Parfait HOUNSINOU, Daouda MAMA, Flavien DOVONOU, Abdoulkarim ALASSANE, Aristide AKPO and Moussa BOUKARI. 2015: Survey and cartography of the spatial variation of the pollution of the waters from well of some districts of the township of Abomey-Calavi, Benin. Journal of Applied Bioscences.85:7751-777. ISSN 1997-5902.
[24] HUDAK P. F 2000: Sulfate and chloride concentrations in Texas aquifers. *Journal of environment International*, 26: 55-61.
[25] JICA (2001) : Agence Japonaise de Coopération Internationale : plan directeur de gestion Intégrée des ressources en eau en République de Côte d'Ivoire ; rapport final, Janvier 2001 N°37.212 p.
[26] Junner N. R (1940). Geology of the Gold Coast and Western Togoland. Bull. Gold Coast Geol Surv., n°11, 40p.
[27] KAFRI U. & ARAD A. 1979: Current Subsurface intrusion of Mediterranean seawater. Apossible source of groundwater salinity in the rift valley system, Israel. *Journal of Hydrology*, 44: 267-287.
[28] KJELDSEN P., BARLAZ M.A., ROOKER A.P., BAUM A., LEDIN A., CHRISTENSEN T.A. (2002). present and long-term composition of MSW landfill leachate, Crit. Rev. ,*Environ. Sci. Technol*., Vol. 32, n°4, 297-336.
[29] Kortatsi K, Tay K, Anomu G, Hayford E. et Dartey A (2007) : Hydrogeochemical evaluation of groundwater in the lower Offin basin, Ghana; Environ Geol 2: Springer-verlag, 12p.
[30] Kouzana, L., Abdallah Ben Mammou, A. B., and Gaaloul, N. (2007) Seawater intrusion and salinization in a coastal water table (Korba, Cap-Bon, Tunisia). Geo-Eco-Trop, 2007, 31: 57-70
[31] Lasm T., De Lasme O., Oga M. Y., Youan Ta M., Baka D., Kouame F. Et Yao T. K. (2011) ; Caractérisation hydrochimique des aquifères fissurés de la région de San-Pedro (Sud-Ouest de la Côte d'Ivoire). Int. J. Biol. Chem. Sci. ISSN 1991-8631 5(2), pp 642-662.
[32] LEBBE L., WALRAEVENS K., VAN BURM P & DE BREUCK W. 1989. L'évolution de la distribution des eaux douces et salées dans la nappe libre de la plaine maritime aux environs de la frontière belgo-française. *Ann. Soc. Géol. Nord,* CIX : 55-65.
[33] MARTOS F.S., BOSCH P.A., SANCHEZ L.M. & VALLEJOS-IZQUIERDO A 2001: Identification of the origin of salinization in groundwater using minor ions Lower Andarax, Southeast Spain. *The Science of the Total Environment*, 297: 43-58.
[34] Millot G. (1964): Géologie des argiles Altérations sédimentologie géologie, Masson et Cie Editeur, 499p.
[35] Piper A.M. (1953): A graphic procedure in the geochemical interpretation of water analysis. US Geol Surv Groundwater Note 12 Sulin VA (1984) Water of petroleum formation in system of natural waters. Costoptekhisdat, Moscow, 96pp.
[36] Rodier J. (1996): L'analyse de l'eau naturelle, eau résiduelle eau de mer, Dunod techniques 8ème edition, 1384p.
[37] Oga Y. M-S. (1998) : ressources en eaux souterraines dans la région du Grand Abidjan (Côte d'Ivoire) : Approche hydrochimiques et Isotopiques. Thèse de Doct. Univ. Paris XI, Orsay, 241p.
[38] Oga Y. M-S., Lasm T., Yao K. T., Soro N., Saley M. B., Kouassi D. et Gnamba F : (2009). Caractérisation chimique des eaux des aquifères de fracture : Cas de la région de Tiassalé en Côte d'Ivoire. European journal of scientific research. ISSN 1450-216X Vol.31 No 1, pp.72-87.
[39] Oragnisation Mondiale de la Santé (1981) "Eau potable et assainissement ; 1981-1990. Contribution de l'OMS à la Décennie Internationale de l'Eau et de l'Assainissement 36p.
[40] Organisation Mondiale de la Santé (2005) : célébration de la décennie internationale d'action l'eau, source de vie (2005-2015). Guide de sensibilisation 34p.
[41] PAINE J.G. 2003. Determining salinization extent. Identifying salinity sources and estimating chloride mass using surface borehole and airborne electromagnetic induction methods: *Water Resources Research*, 3, 3: 31-310.
[42] PULIDO-LE BOEUF P. 2004: Seawater intrusion and associated processes in a small coastal complex aquifer (Castell de Ferro, Spain). *Appl. Geochem.* (2004) (Article in press).
[43] Savané (1997) : Contribution à l'étude géologique et hydrogéologique des aquifères discontinus du socle cristallin d'Odiénné Nord-Ouest de la Côte d'Ivoire. Apports de la télédétection et d'un système d'information hydrogéologique à Référence Spatiale. Thèse Doct. D'Etat Sci. Nat.Univ. Abidjan386p.
[44] Smiler, (2007) : Diagramme. Logiciel libre du Laboratoire d'Hydrogéologie, Université d'Avignon, France.
[45] Soro N. (2002) Hydrochimie et géochimie isotopique des eaux souterraines du degré carré de Grand-Lalou et ses environs (Sud-Ouest de la Côte d'Ivoire). Implication hydrologique et hydrogéologique. Thèse de Doctorat d'Etat ès sciences Nat. Univ. Cocody Abidjan 272p.

[46] SPECHLER R.M. 1994. Saltwater intrusion and quality of water in Floridian aquifer system, Northeastern Florida: U.S. Geological Survey Water-Resources Investigations Report 92-4174, 76 p.
[47] Tardat M. ; Henry ; Baudry J.P (1984) : Chimie des eaux. 1ère édition, revue, corrigée, 340p.
[48] Tardy Y. (1969) : Géochimie des altérations. Etudes des arènes et des eaux de quelques massifs cristallins d'Europe et d'Afrique ; Mém. Ser.Géol. Als. Lorr., 31, 199p.
[49] TCHOBANOGLOUS G., THEISEN H., VIGIL S. (1993). Integrated Solid Waste Management, McGraw-Hill International Edition, New York, 978 p.
[50] TRABELSI R., ZAÏRI M., SMIDA H. & BEN DHIA H. 2005. Salinisation des nappes côtières : cas de la nappe nord du Sahel de Sfax, Tunisie. *C. R. Acad. Sci. Paris*, 337: 515-524.
[51] VENGOSH A. & ROSENTHAL E. 1994. Saline groundwater in Israel: It's bearing on the water crisis in the country, *Journal of Hydrology* (Amsterdam) 156, 1-4: 389-430.
[52] WILSON S.R., INGHAM M. & Mc CONCHIE J.A 2006: The applicability of earth resistively methods for saline interface definition. *Journal of hydrology*, 316: 301-312.
[53] World Health Organization. (2006) Guidelines for drinking-water quality [electronic resource]: incorporing first addendum. Vol. 1, Recommendations. 3rd ed. 595p.