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Assessment of Physico-chemical Suitability of Groundwater for Drinking and Agriculture Purposes in Bonoua and Samo (South-East Côte d'Ivoire)

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AKE and KYB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KAM and AGE managed the analyses of the study. Author BJ managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The goal of this study is to know the quality of groundwater from Bonoua and Samo, for drinking and irrigation purposes.
Methodology: Three (3) samples from boreholes and hand dug wells were taking for this study. Then groundwater quality and its suitability for irrigation and domestic purposes in Bonoua and Samo, South-East Côte d'Ivoire was examined using various physico-chemical parameters such as

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pH, electrical conductivity, total dissolved solids, total hardness, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride and heavy metals.
These parameters were used to assess the suitability of groundwater for domestic purposes by comparing with the WHO standards. Sodium adsorption ratio (SAR) and percentage of sodium (%Na) were used for irrigation suitability assessment.
Results: The groundwater is acidic with a pH that varies from 4.8 to 5.4. The electrical conductivity values is low with an average of 66.54±29.07 µS/cm. The sample analysis reveals that except to the pH, the groundwater is entirely fit for drinking with respect to WHO guidelines. The groundwater from Bonoua and Samo is a fresh water and classified into three principal hydrochemical facies depending on the dominant ions present: HCO_3-Ca-Mg; Cl-SO_4-Ca-Mg and Cl-HCO_3-Mg-Ca. The PCA results showed that two phenomenon controlled the process of groundwater mineralization in the area. In fact weathering and dissolution of minerals were found to be the major geochemical processes governing the groundwater evolution. Groundwater is also influenced by anthropogenic activities such as agricultural practices (Fertilizers spreader).
Conclusion: Groundwater from the study area is influenced by anthropogenic activities such as agricultural practices. Based on SAR and %Na almost samples are suitable for irrigation purposes.

Keywords: Agriculture; Bonoua; Côte d'Ivoire; groundwater quality; Samo; SAR; sodium percentage.

1. INTRODUCTION

Groundwater is an essential and vital component of any life support system. It is not only the basic need for human existence but also a vital input for all development activities [1]. Quality of drinking water is a necessity for mankind [2]. Water resources are harnessed for various purposes like drinking, agricultural, industrial, household, recreational, and environmental activities, etc. Water is increasingly becoming the world's most precious commodity for the more than 6.8 billion people on the planet [3]. Water quality is the critical factor that influences human health as well as the quantity and quality of grain in semi-humid and semi-arid area [4]. Water pollution is harmful not only to fish breeding and agricultural products but also to public health in surrounding areas [5]. In Côte d'Ivoire, groundwater from Bonoua is one of the major sources of drinking water for all the southern part of the country.

In the sedimentary aquifer, the nature reserve of groundwater was estimated at 13.9 billion m^3 [6]. This groundwater is located principally in two aquifers which are the Quaternary aquifer and the Terminal Continental aquifer. Water from the Quaternary aquifer is shallow and is taken by hand dug well. That shallow aquifer is often polluted by anthropogenic activities [1]. Water from Terminal Continental aquifer is used to supply the population of Bonoua and the neighboring town such is Bassam. Since groundwater is a renewable natural resource and a valuable component of the ecosystem, it is vulnerable to natural and human impacts [1]. In fact previous studies in the southern part of Côte d'Ivoire [7,8] have shown the presence of pollution in the sedimentary aquifer the area of Abidjan. Today, government has decided to supply the population of Abidjan, principal city of Côte d'Ivoire by groundwater from Bonoua. Hence, this water resource is significant freshwater source for the country and with its greatest volume must be protected against anthropogenic activities. However Bonoua and Samo are important areas of agriculture of the country. In this region people grow pineapple and rubber. That agriculture uses pesticides and fertilizer. Excessive of such of substances can lead water pollution. Human activities are a major factor determining the quality of surface water and groundwater through atmospheric pollution, effluent discharges, use of agricultural chemicals, eroded soils and land use [9].

The aim of this study was to determine physico-chemical parameters and heavy metals in groundwater from Bonoua and Samo. The data obtained was used to assess the suitability of groundwater for domestic purposes by comparing with the WHO guidelines. Sodium adsorption ratio (SAR) and sodium percentage were used for irrigation suitability assessment.

2. STUDY AREA

2.1 Location

The study area is the city of Bonoua and the village of Samo. It is located in the South-East part of Côte d'Ivoire (Fig. 1). The study area is between latitudes 5°14'47” to 5°19'17” North and longitudes 3°29'55” to 3°36'45” West.

The climate of the area is equatorial transition. Annual rainfall amounts greater than or equal to 2000 mm, with two rainy seasons: from April to July, and from September to November.

Thank to its geographical location, this area is always marked by the absence of dry months, because it rains all year round. This climate favors food and industrial crops, hence, cassava and plantain are prominently grown in large quantity. Industrial crops such as pineapple, rubber, oil palm and coconut occupy about 40% of the used sub-prefecture land.

2.1.1 Gelogical of the study area

In the localities of Bonoua and Samo there is one geological domain. It is the sedimentary basin with rocks of Tertiary and Quaternary. The sedimentary basin has a simple geology with Quaternary sands and muds south of the fault lagoons and clayey sands with some levels of clays Continental Terminal North. In this part of Côte d’Ivoire, the Continental Terminal limit-base has been clarified by the previous studies of [10] and [11].

2.2 Hydrogeology of Bonoua and Samo

In the study area geological structures contain, one type of hydrogeological units of groundwater which is the sedmentary aquifer. This aquifer is principally composed of the Continental Terminal. The aquifer which is captured to ensure the supply of drinking water to the population of the study area is that of the Continental Terminal and to a lesser extent that of the base.

The shallow aquifer is used largely for peri-urban agriculture and for some populations of Samo. In the area a part of the population takes water from this aquifer by hand dug wells.

The aquifer of the Continental Terminal is the main source of drinking water for the population of Bonoua and Samo. This nature reserve was estimated by [6] at 13, 9 billion m^3 of water. The Society of Water Supplying in Côte d’Ivoire (SODECI) uses this fresh water for supplying the population of the Bonoua and Grand-Bassam. Since 2015, the city of Abidjan was provided in fresh water by groundwater from Bonoua. The transmissivites values calculated in the area are of around 10^{-2} m/s [6]. Hydraulic conductivities vary from 0.5 10^{-4} to 13 10^{-4} m/s [12]. The storage coefficient, calculated according to the hydrodynamic model (Hydro expert, 2000 *in* [6]) is estimated at 0.09. The porosity was calculated by Pitaud *in* [6] in the sedimentary basin of Adiaké gives an average value of 13.3%. Flows encountered sometimes reach 45 m^3/h. The operating structures of groundwater in the region are boreholes, hand dug wells and natural water sources (Figs. 2, 3 and 4).

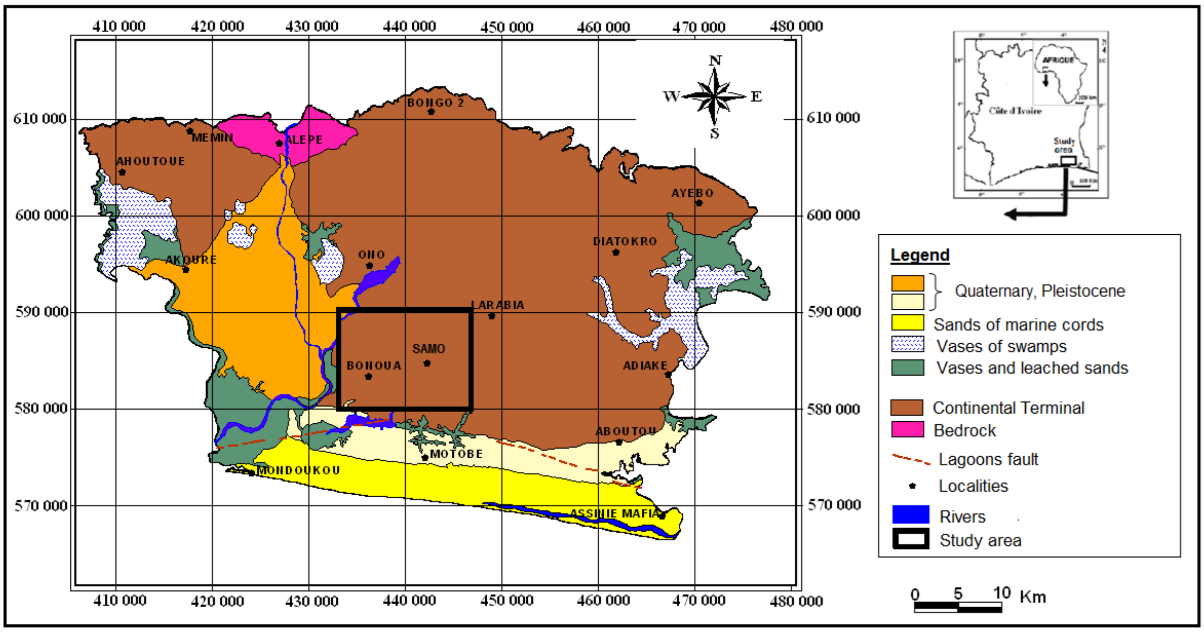

Fig. 1. Location of study area in Côte d’Ivoire

Fig. 2. Hand dug well, using for water supply in Samo

Fig. 3. Borehole in the village of Samo

Fig. 4. Borehole using by the company SODECI for supplying the population of Bonoua

3. MATERIALS AND METHODS

3.1 Methodology of Groundwater Study

This study aims to observe the quality of the water of the sedimentary basin aquifers. In fact, samples were collected from the Continental Terminal aquifer. The samples were taken in December 2012 from Boreholes and wells. For this study, the samples of groundwater were collected in 500 ml sterilized polythene bottle. For all samples collected, parameters such as electrical conductivity (EC), temperature (T) and pH values were measured in the field. On site testing was necessary for these parameters since they are likely to change during transport. These variables were measured using the pH-meter WTW 3110 and conductmeter WTW 3110.

The bottles were stored at 4°C until analysed to minimize physico-chemical changes. The samples were transported in the laboratory for analysis. A total of 3 samples from hand dug wells and boreholes were collected. Sample from well comes from the shallow groundwater, the second from the median groundwater (middle Terminal Continental) and the last from the deeper groundwater (Terminal Continental). In groundwater the parameters analyzed include calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), nitrate (NO_3^{-}) and phosphate (PO_4^{3-}) in milligram per liter (mg/L). Water samples were analysed at the National laboratory of Essais of quality and Metrology Analysis.

The major ionic composition of the samples was measured by ion chromatography following standard laboratory procedures. The bicarbonate (HCO_3^{-}) concentration of the samples was measured by titration with 0.01N hydrochloric acid, HCL using a Hach digital titrator within 24 hours of collection.

Heavy metals were also analysed and composed of Lead (Pb), iron (Fe), manganese (Mn), arsenic (As), cadmium (Cd) and copper (Cu) were measured in the water. Heavy metals were determined by the spectrometric method using an atomic absorption spectrophotometer (AAS) VARIAN. Data from chemical analysis were plotted in Piper diagram to determine the different hydrochemistry facies of the water [13].

3.2 Statistical Analysis: Principal Component Analysis (PCA)

The statistical software STATISTICA 6.0 was used for the descriptive analysis, correlation coefficient and multivariate statistical analysis of the data. In order to evaluate the most significant parameters in water quality assessment, the analysis was performed using PCA methodology. PCA provides information on the most meaningful parameters which describe the whole data set interpretation, data reduction and summarize the statistical correlation among constituents in the water with minimal loss of original information [14]. In this study, PCA of the normalized variables were executed to extract significant principal components (PCs) and to further reduce the contribution of variables with minor significance; these PCs were subjected to varimax rotation generating factors [15]. PCA was executed in this study for 22 variables from three (3) different sampling points in the area of monitoring the water quality. An eigenvalue gives a measure of the significance of the factor and factors with the highest eigenvalues are the most significant. Eigenvalues of 1.0 or greater are considered significant [15]. Classification of principal components is thus “strong”, “moderate” and “weak”, corresponding to absolute loading values of >0.75, 0.75 - 0.50 and 0.50 - 0.30, respectively. PCs were defined according to the criterion that only factors that account for variance greater than 1 (eigenvalue-one criterion) should be included. The rationale for this is that any component should account for more variance than any single variable in the standardized test score space [16]. PCA was applied using varimax rotation with Kaiser Normalization. By extracting the eigenvalues from the correlation matrix, the number of significant factors and the percent of variance explained by each of them were calculated. In this study the using of PCA method were motived by the best results obtained with this method in the area of water science by the authors such as [17-22].

3.3 Study of Irrigation Water Quality

The Sodium adsorption and the sodium percent (%Na) were used to study irrigation water quality from Bonoua and Samo. In fact, Sodium adsorption ratio (SAR) is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkali/sodium hazard to crops Nabavi *in* [23]. SAR is defined by this equation:

$$SAR = Na/[(Ca+Mg)/2]1/2 \qquad (1)$$

where all ionic concentrations are expressed in meq/L.

The sodium in irrigation water is usually denoted as percent of sodium [1,24]. Percent Na is widely used for evaluating the suitability of water quality for irrigation [25]. High Na irrigation water causes exchange of Na in water for Ca and Mg in soil, reduces permeability, and eventually results in soil with poor internal drainage [26]. In this study, the sodium percent (%Na) is obtained by this equation.

$$\%Na = [Na + K]\times 100/[Ca+Mg+Na+K] \qquad (2)$$

where all ionic concentrations are expressed in meq/L.

4. RESULTS AND DISCUSSION

4.1 Groundwater Physico-chimical Parameters

The results of the physico-chemical parameters of groundwater samples collected at different points in Bonoua and Samo are presented in Table 1. The results are compared with the standard limits recommended by the World Health Organization [27]. Considerable deviations are observed in the water quality parameters from the standard limits.

4.1.1 pH and electrical conductivity (EC)

The pH values of the samples ranges from 4.8 to 5.4 with average of 5.03±0.32. Groundwater from Bonoua and Samo is moderately acid in nature. In fact, pH is a measure of the balance between the concentration of hydrogen ions and hydroxyl ions in water. The limit of pH value for drinking water is specified as 6.5–8.5 [27]. This may be attributed to natural phenomenon like the weathering process of underlain geology of the study area.

Electrical conductivity (EC) is a measure of water capacity to convey electric current [1]. The EC of the samples ranges from 43.80 µS/cm to 99.3 µS/cm with an average of 66.54±29.07 µS/cm. The groundwater is slightly mineralized. The most desirable limit of EC in drinking water is prescribed as 1000 µs/cm [27]. The value of electrical conductivity may be an approximate index of the total content of dissolved substance in water. It depends upon temperature, concentration and types of ions present (Hem *in* [1]).

Table 1. Results of physico-chemical analyses of groundwater from Bonoua and Samo in mg/L

Parameters physico-chemical	WHO guidelines	E1	E2	E3
Color (mg Pt-co/L)	15	8.5	8.5	13.5
Turbidity (UNT)	5	0.05	4.8	18.25
Temperature (°C)		27.5	27	27.5
pH	6.5 ≤pH≤ 8.5	5.4	4.9	4.8
EC (µs/cm)	1000	56.52	43.8	99.3
TDS (mg/L)	-	49	114	100
(CO_2) (mg/L)	-	11.28	9.55	32.8
DO (mg/L)	-	5.8	4.8	4.2
SiO_2 (mg/L)	-	5.2	3.22	9.5
Bicarbonate (mg/L)	-	14.58	17.22	48.8
CaCo (mg/L)	-	0	60	0
Total Hardness	200	1.4	3.8	2
Sodium (mg/L)	250	6.1	4.9	5.6
Sulfate (mg/L)	150	0.44	0	0.53
Potassium (mg/L)	150	1.22	3.8	5
Calcium (mg/L)	200	3.4	4.12	16.03
Magnesium (mg/L)	150	4.65	9.22	0
Chlorure (mg/L)	250	7.5	71	7.5
NO_3^- (mg/L)	50	5.45	0	6.8
NO_2^- (mg/L)	3	0.01	0	0.02
Ammonium (mg/L)	0.5	0.06	0	0.32
PO_4^{3-} (mg/L)	1.5	0.02	0	0
P Total (mg/L)	5	0.25	5.44	5.44
N Total (mg/L)	50	0.8	0	1.82

4.1.2 Total dissolved solids (TDS)

According to WHO, the maximum acceptable concentration of TDS in groundwater for domestic purposes is 500 mg/L and excessive permissible limit is 1500 mg/L. TDS values of the samples ranges from 49 mg/L to 114 mg/L with a mean value of 87.67±34.2 mg/L.

According to classification of drinking water on the basis of TDS values, water of 100% samples from Bonoua was found to be non-saline. TDS values of all samples of Bonoua were not greater than acceptable WHO standards (500 mg/L).

4.1.3 Total hardness (TH), calcium and magnesium

Total hardness is an important parameter of water for its use in domestic sector. Calcium and magnesium are important parameter for total hardness. The acceptable limits of Ca^{2+} and Mg^{2+} in water for domestic use are 75 and 200 mg/L respectively. In case of non-availability of alternate source of water, Ca^{2+} and Mg^{2+} limit can be extended up to 200 and 400 mg/L. In the water samples of Bonoua, the total hardness ranges from 8.05 mg/L to 16.03 mg/L, with a mean value of 12.47±1.25 mg/L. Calcium and magnesium are the most abundant elements in the natural surface and groundwater and exist mainly as bicarbonates and to a lesser degree in the form of sulfate and chloride. Ca^{2+} concentration varies from 3.4 to 16.03 mg/L. Relatively, the higher concentration of Ca^{2+} observed is 16.03 mg/L from wells. The desirable limit of calcium concentration for drinking water is specified as 200 mg/L (WHO, 2011) which shows values are slightly under the maximum permissible limit for calcium. Magnesium content is varying from 0 to 9.22 mg/L. The maximum permissible limit of Mg^{2+} concentration of drinking water is specified as 150 mg/L [27].

4.1.4 Total alkalinity, carbonate and bicarbonate

Carbonate and bicarbonate are important parameter for total Alkalinity. Total Alkalinity, acceptable limit of total alkalinity in drinking water is 200 mg/L. Beyond this limit, taste of water become unpleasant, whereas in absence of alternate water source, alkalinity up to 600 mg/L is acceptable. The values of carbonate in the water samples vary from 0 mg/L to 60 mg/L. The concentration of bicarbonate ranges between 14.58 mg/L to 48.8 mg/L, with an average of 26.87±19.04 mg/L.

4.1.5 Sodium and potassium

Sodium (Na^+) concentration more than 50 mg/L makes the water unsuitable for domestic use and causes severe health problems. The Na^+ concentration from samples water ranges between 4.9 mg/L to 6.1 mg/L with a mean value of 5.5±0.6 mg/L. The potassium (K^+) concentration of the water samples is between 1.22 mg/L to 5 mg/L with a mean value of 3.34±1.93 mg/L. Groundwater contains low level of sodium and potassium.

Potassium is a naturally occurring element; however, its concentration remains quite lower compared with Ca^{2+}, Mg^{2+} and Na^+. The concentration of K^+ is between 1.22 and 5 mg/L from the groundwater. The maximum permissible limit of potassium in the drinking water is 12 mg/L and it was found that all the samples are below the permissible limit of WHO. In comparison with Na^+, the low concentration of K^+ is due to the high resistance of potash feldspars to chemical weathering in the study area.

4.1.6 Chloride and sulphate

For the WHO guideline, the maximum permissible limit of chloride in drinking water is 250 mg/L. The Cl^- concentration in the water samples from Bonoua and Samo is between 7.5 mg/L to 75 mg/L, with a mean value of 26.67±36.66 mg/L. The origin of chloride in groundwater may be from diverse sources such as weathering, leaching of sedimentary rocks and soils, intrusion of saltwater, windblown salt in precipitation, domestic and industrial waste discharges, municipal effluents, etc. (Karanth *in* [1]). The higher concentration of Cl^- (mg/L) is observed from the groundwater sample 2. The excess of chloride in the water is usually taken as an index of pollution and considered as tracer for groundwater contamination [28]. Chloride determinations may serve to indicate the intrusion of waters of different composition or to trace and measure rates and volumes of water mass movements [1].

Sulphate content more than 200 mg/L is objectionable for domestic purposes. Beyond this limit, causes gas- tro-intestinal irritation particularly when Mg^{2+} and Na^+ are also present in groundwater. This permissible limit of 200 mg/L may be extended upto 400 mg/L of SO_4^{2-} provided Mg^{2+} does not exceed 30 mg/L. Waters containing beyond 1000 mg/L have purgative effects. Sulphate may undergo transformation to sulphur and sulphur oxides depending upon redox potential of water. In the groundwater of Bonoua, sulphate concentration ranges from 0 to 0.53 mg/L, with a mean of 0.32±0.28 mg/L. The SO_4^{2-} contains in all samples are lower than maximum permissible prescribed limit.

4.2 Heavy Metal in Groundwater of Bonoua and Samo Area

The concentrations of heavy metals (Mn, Cu, Fe, Zn, Pb, As and Cd) in the drinking water samples collected from the concerned area of study are presented in Table 2. The results are compared with the standard limits recommended by the World Health Organization [27]. Groundwater contains slight level of heavy metal, which is lower than WHO value.

Table 2. Heavy metals analysis of groundwater in mg/L

Parameters	WHO guidelines	E 1	E2	E3
Manganese	0.4	0.01	0.02	0.02
Copper	0.2	0.1	0.06	0.1
Iron	0.3	0.01	0.01	0.01
Zinc	3	0.05	0.02	0.02
Lead	0.05	<0.019	<0.019	<0.019
Arsenic	0.05	<0.010	<0.010	<0.010
Cadmium	0.01	<0.003	<0.003	<0.003

4.3 Statistical Analysis

The Table 3 summarizes the PCA including the loadings, eigenvalues of each PCs, total variance explained as well as the cumulative variance and strong loading values highlighted. The PCA results show two PCs which explained 100% of the total variance.

The results of the factor analysis are presented in Table 4. Two principal components resulted from the application of the Kasier criterion (Kasier *in* [17]), which requires that

Table 3. Analysis statistic of groundwater from Bonoua and Samo

Factor	Eigenvalue	% of total variance	Cumul. eigenvalue	Cumul. variance
1	14,74	56,68	14,74	56,68
2	11,26	43,32	26,00	100,00

principal components to be retained in the factor analysis should have a minimum eigenvalue sum of 1.0. The cumulative variance of the two principal components resulted from the PCA is 100%.

Table 4. Analysis of groundwater from Bonoua and Samo

Parameters	Component	
	1	2
T	**0,852**	-0,524
pH	-0,183	**-0,983**
CE	**0,962**	0,271
O_2	-0,397	**-0,918**
CO_2	**0,910**	0,416
Ca^{2+}	**0,855**	0,519
Mg^{2+}	-0,997	0,023
K^+	0,337	**0,941**
Na^+	0,557	**-0,830**
SiO_2	**0,983**	0,181
HCO_3^-	**0,845**	0,535
CaCO	-0,852	0,524
SO_4^{2-}	**0,924**	-0,382
Cu	**0,852**	-0,524
Cl^-	-0,852	0,524
NO_3^-	**0,935**	-0,355
NO_2^-	**0,998**	-0,028
NH_4^+	**0,950**	0,313
Fe	-0,028	**-0.996**
Mn	0,028	**0.998**
Zn	-0,028	**-0.997**
PO_4^{3-}	-0,028	**-0.998**

The first PC explained 56.68% of the total variance and was well represented positively by T, CE, CO_2, Ca^{2+}, SiO_2, HCO_3^-, SO_4^{2-}, Cu, NO_3^-, NO_2^-, NH_4^+ and negatively by Mg^{2+}, CaCO, and Cl^-. This component probably represents dissolution of soluble salts and anthropogenic pollution. The component 1 illustrates salinity dissolution and anthropogenic activities. The correlation matrix for the groundwater parameters are given in Table 5. Electrical conductivity is significantly and positively correlated with CO_2 (0.99); Ca^{2+} (0.96), K^+ (0.58); HCO_3^- (0.96), SiO_2 (0.99), SO_4^{2-} (0.79), NO_2^- (0.95), NO_3^- (0.80), NH_4^+ (0.99) and Cu (0.68). The positive correlation implies that this component represents the major processes controlling the salinity of groundwater among all the hydrogeology aquifers sampled in Bonoua and Samo.

PC2 was dominated positively by K^+ and Mn and negatively by pH, O_2, Na^+, Fe, Zn and PO_4^{3-}, accounted for 43.32% of the total variance. In this group, there is a great correlation between pH and Fe (0.99), pH and Zn (0.99), pH and (0.99), pH and O_2 (0.98), pH and Na^+ (0.71). Most of those parameters come from anthropogenic activities like agriculture. In this area, there are plenty farms of rubber and pineapple, where were used pesticides. PC2 shows the implication of agricultural practices (Fertilizers spreader) in groundwater quality.

4.4 Groundwater Types

The analytical values obtained from the groundwater samples are plotted on Piper trilinear diagram to understand the hydrochemical regime of the study area. The Piper trilinear diagram for the groundwater samples is presented in the Fig. 5, which clearly explains the variations of cation and anion concentration in the study area. Three principal hydrochemical water types have been delineated.

These are HCO_3-Cl-Ca-Mg, water type I for the shallow groundwater from Samo (E3). This type is dominated by HCO_3 for anions and Ca for cations. The second water type Cl-SO_4-Ca-Mg designated water type where Cl and Ca are dominated. This type contains the sample E1.

The third water type is Cl-HCO_3-Mg-Ca. This water type contains sample E2 from Continental Terminal aquifer. In fact, the water type comes from the relationship rock-water, interaction involving the dissolution of carbonates by the recharging groundwater within the relatively permeable weathered zone above the underlying rocks.

4.5 Irrigation Water Quality

The analytical results have been evaluated to ascertain the suitability of groundwater of the study area for agricultural uses. Salinity indices such as sodium percentage (Na%) and sodium absorption ratio (SAR) are important parameters for determining the suitability of groundwater for agricultural uses [24]. Electrical conductivity is a good measure of salinity hazard to crops as it reflects the TDS in groundwater.

The US Salinity Laboratory *in* [29] classified ground waters on the basis of electrical conductivity. Based on this classification, 16% of samples are belonging to the doubtful category and 84% to good category.

Table 5. Correlation matrix of groundwater of Bonoua and Samo

	T	**pH**	**CE**	**O2**	**CO2**	**Ca^{2+}**	**Mg^{2+}**	**K+**	**Na+**	**SiO_2**	**HCO_3**	**CaCO**	**SO_4**	**Cu**	**Cl-**	**NO_3**	**NO_2**	**NH_4**	**Fe**	**Mn**	**Zn**	**PO4**
T	1.00																					
pH	0.36	1.00																				
CE	0.68	-0.44	1.00																			
O_2	0.14	**0.98**	-0.63	1.00																		
CO_2	0.56	-0.58	**0.99**	**-0.74**	1.00																	
Ca^{2+}	0.46	-0.67	**0.96**	-0.82	**0.99**	1.00																
Mg^{2+}	-0.86	0.16	**-0.96**	0.38	**-0.90**	**-0.84**	1.00															
K+	-0.21	-0.99	0.58	**-0.99**	**0.70**	**0.78**	-0.32	1.00														
Na+	**0.91**	**0.71**	0.31	0.54	0.16	0.05	-0.58	-0.59	1.00													
SiO_2	**0.74**	-0.36	**0.99**	-0.56	**0.97**	**0.93**	**-0.98**	0.50	0.40	1.00												
HCO3-	0.44	-0.68	**0.96**	**-0.83**	**0.99**	**0.99**	**-0.83**	**0.79**	0.03	**0.93**	1.00											
CaCO	-1.00	-0.36	-0.68	-0.14	-0.56	-0.46	**0.86**	0.21	**-0.91**	**-0.74**	-0.44	1.00										
SO_4^{2-}	0.99	0.21	**0.79**	-0.02	0.68	0.59	**-0.93**	-0.05	**0.83**	**0.84**	0.58	-0.99	1.00									
Cu	**0.99**	0.36	0.68	0.14	0.56	0.46	**-0.86**	-0.21	**0.91**	**0.74**	0.44	**-0.99**	**0.99**	1.00								
Cl^-	**-0.99**	-0.36	-0.68	-0.14	-0.56	-0.46	**0.86**	0.21	**-0.91**	**-0.74**	-0.44	**0.99**	**-0.99**	**-0.99**	1.00							
NO_3^-	**0.98**	0.18	**0.80**	-0.05	**0.70**	0.61	**-0.94**	-0.02	**0.82**	**0.86**	0.60	**-0.98**	**0.99**	**0.98**	**-0.98**	1.00						
NO_2^-	**0.87**	-0.16	**0.95**	-0.37	**0.90**	**0.84**	**-0.99**	0.31	0.58	**0.98**	**0.83**	**-0.87**	**0.93**	**0.87**	**-0.87**	**0.94**	1.00					
NH_4^+	0.64	-0.48	**0.99**	-0.66	**0.99**	**0.97**	**-0.94**	0.61	0.27	**0.99**	**0.97**	-0.64	**0.76**	0.64	-0.64	**0.78**	**0.94**	1.00				
Fe	0.50	**0.99**	-0.30	**0.93**	-0.44	-0.54	0.01	**-0.95**	**0.81**	**-0.21**	-0.56	-0.50	0.36	0.50	-0.50	0.33	0.00	-0.34	1.00			
Mn	-0.50	-0.99	0.30	**-0.93**	0.44	0.54	-0.01	**0.95**	**-0.81**	0.21	0.56	0.50	-0.36	-0.50	0.50	-0.33	0.00	0.34	**-0.99**	1.00		
Zn	0.50	**0.99**	-0.30	**0.93**	-0.44	-0.54	0.01	**-0.95**	**0.81**	-0.21	-0.56	-0.50	0.36	0.50	-0.50	0.33	0.00	-0.34	**0.99**	**-0.99**	1.00	
PO_4^{3-}	0.50	**0.99**	-0.30	**0.93**	-0.44	-0.54	0.01	**-0.95**	**0.81**	-0.21	-0.56	-0.50	0.36	0.50	-0.50	0.33	0.00	-0.34	**0.99**	**-0.99**	**0.99**	1.00

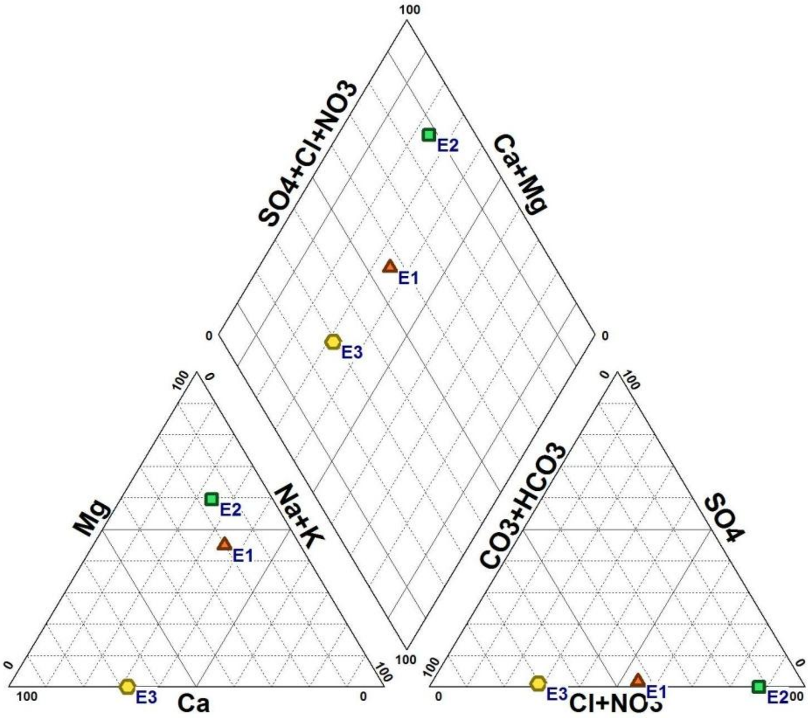

Fig. 5. Piper diagram shows hydrogeochemical facies for groundwater of the study area

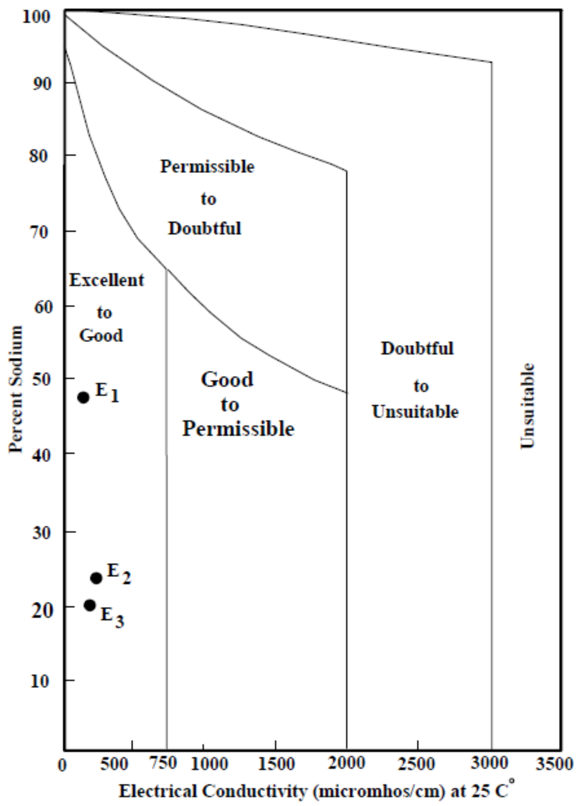

Fig. 6. Classification of irrigation water quality, with respect to total salt concentration and sodium percent

4.5.1 Sodium percent (Na%)

The sodium in irrigation waters is usually denoted as percent of sodium. According to [25], in all natural waters Na% is a common parameter to assess its suitability for irrigational purposes. The Wilcox diagram relating sodium percent and total concentration shows that 100% of the groundwater samples fall in the field of excellent to good (Fig. 6).

4.5.2 Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is a measure of the suitability of water for use in agricultural irrigation, because sodium concentration can reduce the soil permeability and soil structure (Todd *in* [1]). The SAR value of water for irrigation purposes has a significant relationship with the extent to which sodium is absorbed by the soils. Irrigation using water with high SAR values may require soil amendments to prevent long-term damage to the soil, because the sodium in the water can displace the calcium and magnesium in the soil [1]. This will cause a decrease in the ability of the soil to form stable aggregates and loss of soil structure. This will also lead to a decrease in infiltration and permeability of the soil to water leading to problems with crop production.

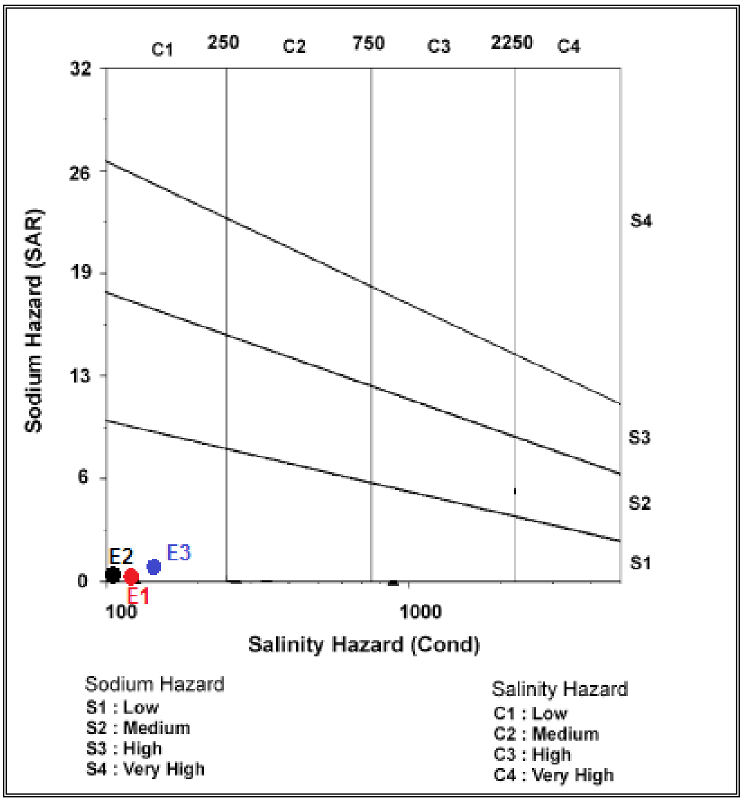

Fig. 7. Classification of irrigation water quality, with respect to salinity hazard and sodium hazard

The SAR values range from 0.22 to 0.49 with an average of 0.34. The classification based on SAR values shows that all of samples are belong to the excellent category. SAR can indicate the degree to which irrigation water tends to enter into cation-exchange reactions in soil. Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure and becomes compact and impervious (Raju *in* [1]).

The SAR values of all the samples are found with the range of excellent to good category, which is found to be unsuitable for irrigation purpose. For rating irrigation waters the US salinity diagram was used, in which the SAR is plotted against EC. The plot below indicates that 100% of the groundwater samples fall in C1S1 (low salinity–low sodium type). This reveals that the water type in the study area has low salinity with low sodium content and it can be used for irrigation on all type of soil (Fig. 7 above).

5. CONCLUSION

Analysis of the Hydrochemical data from the South-East part of Côte d'Ivoire has revealed that, the groundwater from the Continental Terminal aquifer is generally acidic. This study shows that groundwater has a low electrical conductivity and is slightly mineralized. Major cations were generally low with bicarbonate being the most dominant anion and calcium the most cation. The groundwater in the study area is natural and fresh. The physico-chemical parameters are within the WHO guidelines for drinking water. Based on the major constituents analyzed, in general, groundwater from the study area corresponded to HCO_3-Cl-Ca-Mg, Cl-SO_4-Ca-Mg and Cl-HCO_3-Mg-Ca. The PCA showed that weathering and dissolution of minerals were found to be the major geochemical processes governing the groundwater evolution in the study area. In addition to this source, groundwater are influenced by anthropogenic activities such as agriculture. Based on the TDS of almost all samples, the groundwater from Bonoua and Samo is found to be safe and suitable for drinking purposes. The Classification of irrigation water quality shows that groundwater from the study aeria respect salinity hazard and sodium hazard. The majority of groundwater belong to C1S1, indicating low sodium water, which can be used for irrigation on all types of soil without danger of exchangeable sodium.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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