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Hydrogeochemical assessment of groundwater quality in the Baya watershed (Eastern of Côte d'Ivoire)

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The large demand for drinking water in the Baya watershed (6324 km^2), located in East of Côte d'Ivoire is supplied from groundwater sources. This study investigated the specifics hydrogeochemical assessment of groundwater quality in the Baya's watershed by using statistical methods with graphical and self-organizing maps (SOM) neural network methods. It was carried out to identify the hydrogeochemical processes related to groundwater quality, conduct a hydrochemical evaluation of the aquifer systems and delineate the various factors controlling the water chemistry and general suitability for drinking purposes. To reach these goals, groundwater was sampled from 150 locations. Results indicated that the groundwater sampled is generally acid due to the acid character of the enclosing rocks (SiO_2 > 60), with an average pH of 6.54 ± 0.33 and an average electrical conductivity of 420.15 ± 248.15 µS/cm. they are moderately mineralized to the gaze of World Heath Organization (WHO) guidelines, with calc-magnesium hydrogen carbonate facies (84%) and calc-magnesium sulphate chlorinated facies. Major ions at the origin of mineralization of groundwater are produced by rock weathering, hydrolysis of silicate minerals. The NO_3^-, Cl^- and SO_4^{2-} ions are derived from a human pollution due to human activities. Water boreholes located along the major rivers and the watershed outlet are highly mineralized but also proned to anthropogenic pollution. As for the locations of the north and southeast of the Baya's watershed, there are high levels of iron and manganese, which explains the reddish appearance of these waters.

Key words: Hydrogeochemistry, mineralization, fractured Aquifer, self-organizing map (SOM), watershed of Baya.

INTRODUCTION

Any civilized society should consider the provision of safe drinking water a priority. This is so because safe drinking water is a basic need to human development, health and well-being. Contaminated drinking water has been linked with a great majority of health problems. Besides the health aspect of contaminated drinking water, aesthetically

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unacceptable drinking water will undermine the confidence of consumers. It will also lead to complaints and more importantly possibly lead to the use of water from sources that are less safe (Goné et al., 2014).

Several authors have showed that exploitation of water resources to meet the demand of agricultural products with the exponential population growth and equally supported by industrialization and urbanization put groundwater resources under great threat both in terms of quality and quantity (Soltani et al., 2013; Jothiprakash and Mohan, 2004). The groundwater quality in any area is a function of its physical and chemical parameters, which in turn are highly influenced by geological formations, climatic conditions, and anthropogenic activities (Ramkumar et al., 2012; Subramani et al., 2005). Groundwater chemically evolves by interaction with aquifer minerals or internal mixing of different groundwaters along subsurface flow-paths (Srivastava and Ramanathan, 2008; Toth, 1984). It is also reported that uncontrolled use of fertilizers used to increase agriculture production has direct and negative impact on water quality (Carpenter et al., 1998; Matson et al., 1997; Kolpin, 1997; Griffith, 2001). The change in land use/land cover pattern in an area is also being considered to have a strong impact on the groundwater quality (Basnyat et al., 1999; Rothetal, 1996; Osborne and Wiley, 1988). Therefore, assessment of groundwater quality is needed to ensure safer use of it (Vijith and Satheesh, 2007). Monitoring of groundwater sources is important because it gives information on characteristics of water and regular change in water quality, evaluate emerging water quality problems, understand possibility of different pollutants, determine nature and extent of pollution control needed and treatment option for polluted water (Seth et al., 2014; Kaown et al., 2012). Hence, groundwater quality evaluation and creating a database are useful for society as well as for planning water resources development. That is important because groundwater has a potential to ensure future demand for water, and it is important that human activities on the surface do not negatively affect the hydraulically connected groundwater system and reduce the availability of these alternative sources of potable water (Kumar and Ahmed, 2003; Adekunle et al., 2007). Once the groundwater is contaminated, it is not possible to restore the groundwater quality by preventing the pollutants from their original source (Jain et al., 2010; Kumar and Divya, 2012).

To date, many index methods have been developed for water quality assessment (Horton, 1965; Joung et al., 1979; Landwehr, 1979; Nishidia et al., 1982; Tiwary and Mishra, 1985; Prasad and Jaiprakas, 1999). Nevertheless, because of the variety of variables observed as groundwater quality data, and uncertainty involved in transport and reaction mechanism into groundwater systems, it is necessary to implement a sophisticated knowledge extraction and diagnosis tool that can provide the analysis and visualisation of multidimensional groundwater quality data. Generally, multivariate analysis methods such as factor analysis and principal component analysis (Srivastava and Ramanathan, 2008; Suk and Lee, 1999) have been used for this purpose in hydrological and groundwater systems. Due to the rapid innovation of computer technology, the artificial neural network technique, particularly self-organising maps (SOM), which is a powerful tool for multivariate, nonlinear analysis and modeling, has recently attracted considerable attention in analysis and diagnosis of dynamic systems. One reaction for this may be the increasing demand for efficient multivariate and nonlinear techniques to be applied in intelligent systems for optimal monitoring and diagnosis of dynamic systems.

In the region of the Baya watershed, natural processes and human activities such as indiscriminate refuse and waste disposal, the use of septic tanks, soak-away pit may cause changes in the land use pattern, ecological balance, and flow of water. This may in turn result in change in groundwater quality and recharge capacity. Although considerable informations have been accumulated about the weathered and fractured aquifers in the Baya watershed from previous studies (Mangoua et al., 2010; Youan et al., 2011; Mangoua et al., 2014), no systematic studies have been done to evaluate the influence of natural processes and human activities on groundwater quality. This work provides a better understanding of the hydrogeochemical quality of waters from the weathered and fractured aquifers in the Baya watershed.

Study area description

The Baya watershed is located in the Easthern part of Côte d'Ivoire, between 2° and 3° 50’50 longitudes West and 6°90’ and 8°20 latitude North and covers an area of 6,324.041 km^2 (Figure 1). The geomorphic landscape is monotonous peneplain occupied by cash crops and export (coffee, cocoa, cashew, rubber) and food crops. It is found in this place hills and mountains rising to 700 m on average (Siméon et al., 1995). The climate is tropical and humid. The catchment is drained mainly by the Baya River. The geology of this area consists of Birimian and tarkwaiennes formations (Touré, 2007). These formations are a volcano sedimentary package in which appear volcanics intrusion and eburnean granitoids (Touré, 2007). Several phases of deformation affected the area and led to the establishment of a developed fracturing. In hydrogeological terms, are found in the basin aquifers weathering and cracking. The supply of drinking water to people is through drilling capturing most often fractured aquifers. Alteration zones when they are thick, can contain significant water circulation which are sometimes exploited by wells.

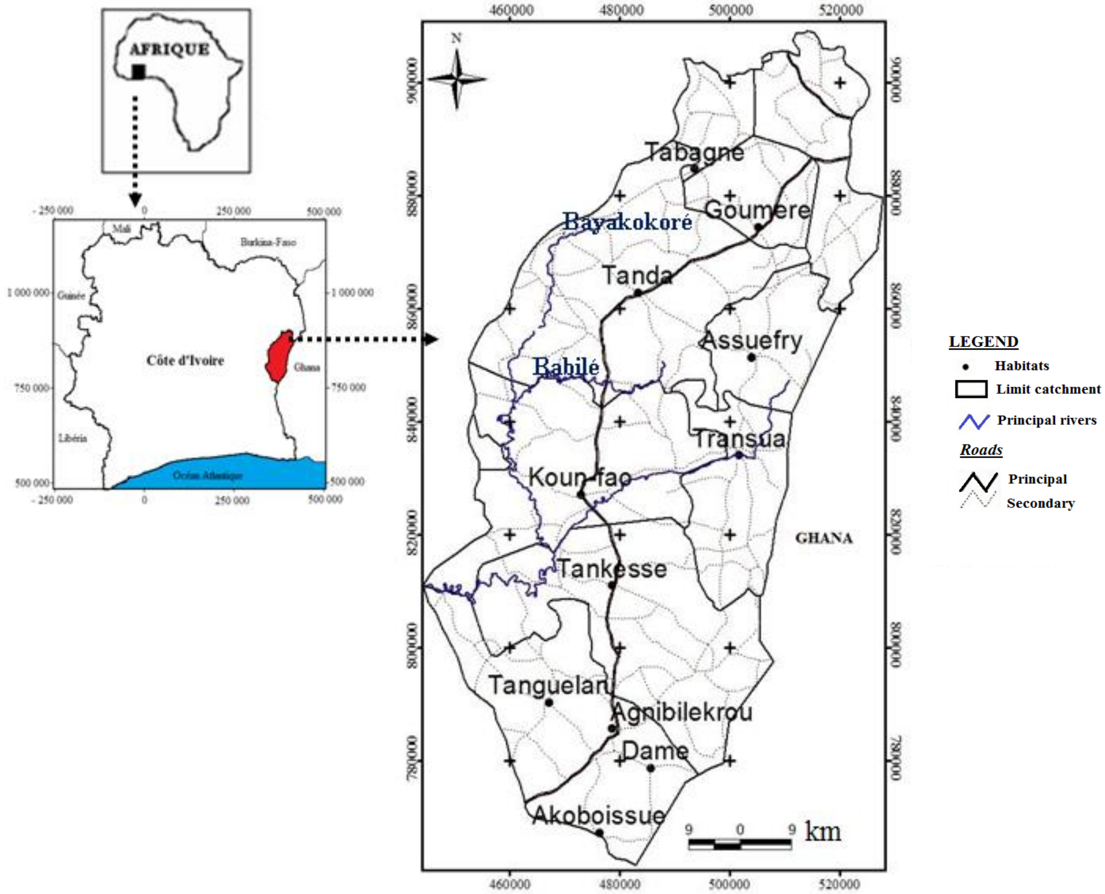

Figure 1. Study area map.

Table 1. Classification of boreholes parameters according CIEH (1985).

Class	Very low	Low	Mean	High	Very high
EA (m)	0 - 10	10 - 15	15 - 25	25 - 40	40- 70
Pt (m)	0 - 20	20 - 30	30 - 40	40 - 70	> 70

MATERIALS AND METHODS

Data collection and factors establishment

Weathered layer (WL) and Depth of the boreholes (Pt)

The boreholes depths and the weathered layer are raised on the data sheets for boreholes. These weathered layers were obtained from the difference between the total depth of the drilling depth of the roof and the plinth. Classification by CIEH (1985) was adopted to classify weathered layers (WL) and the depths of the boreholes (Pt) (Table 1).

Physico-chemical characterization of groundwater in the watershed of the Baya

To assess the actual pollution occurrence in the study area, groundwater samples were collected in 2006 to 2007 on a sampling network including 150 sampling points. The sampling points were selected based on the geographic location of wells and boreholes and the use of the wells and boreholes as sources of water for drinking purpose. Figure 2 shows the location of the selected boreholes. Water samples collection from boreholes was carried out according to the procedures described by Douagui et al. (2012). Samples were taken after pumping for 5 min. The tap and the bucket were cleaned before sampling and caution was taken to avoid splashing. Samples were collected in 500 ml polyethylene bottle. Once collected, all samples were stored on ice and immediately transported to the laboratory.

The parameters (NO_3^-, HCO_3^-,SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, PO_4^{3-}, Mn^{2+} and Fe^{2+}) were determined in laboratory according to the methods presented in Table 2. Water temperature (T°), electrical conductivity (EC), pH, dissolved oxygen (DO), color and turbidity (Turb) were measured *in situ* using the HACH Model 44600 Conductivity Meter (for T° and EC), the Multi 340i handheld (for pH and DO) and the HACH Model 2100P Turbidimeter (for Turb). Classification and interpretation of the groundwater hydrochemistry were carried out using the Piper Diagram.

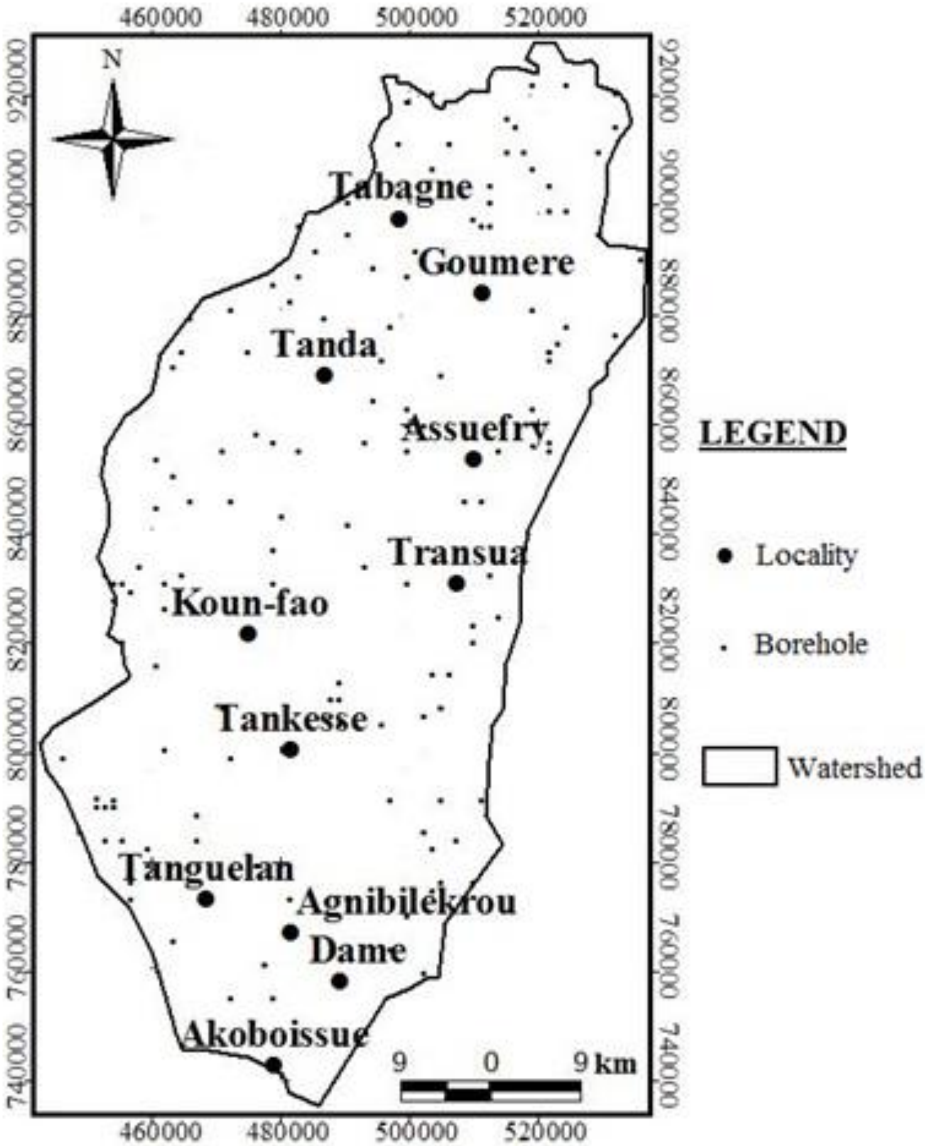

Figure 2. Distribution of selected boreholes in the study area.

Pattern analysis of the groundwater qualities due to the mineralization

Self-organizing maps

The SOM-algorithm as described by Peeters et al. (2007) and Choi et al. (2014), is used to diagnose the effect of the hydrogeochemical processes and on groundwater quality. The SOM-algorithm is based on unsupervised learning, which means that the desired output is not known a priori. The goal of the learning process is to classify data according to their similarity. In the neural network architecture proposed by Kohonen in the early 1980s, the classification is done by plotting the data in *n* dimensions onto a, usually, two-dimensional grid of units in a topology-preserving manner (Kohonen, 1995). The former means that similar observations are plotted in each others neighborhood on the 2-D-grid. This neural network consists of an input layer and a layer of neurons and the units are arranged on a rectangular or hexagonal grid and are fully interconnected. Each of the input vectors is also connected to each of the units. The learning algorithm applied to the network can be divided into six steps:

(1) An m×n matrix is created from the data set with m rows of samples and n columns of variables. The matrix thus consists of m input vectors of length n. The classification of the input vectors is based on a similarity measurement, for instance Euclidean distance. In order to avoid bias in classification due to differences in measuring unit or range of the variables, a normalization is carried out. This can be done by setting mean equal to zero and variance equal to 1 or by rescaling the range of each variable in the [0, 1] interval.
(2) Each unit is randomly assigned an initial weight or reference vector with a length equal to the length of the input vectors (n).
(3) An input vector is shown to the network; the Euclidean distances between the considered input vector $\vec{x}$ and all of the reference vectors $\vec{y}$ are calculated according to:

Table 2. Methods of analysis of groundwater in the watershed of the Baya.

Parameter	Methods	Standards
Nitrate /Phosphate	Molecular absorption spectrometry	NFT 90 012
Ammonium/ Silica	Molecular absorption spectrometry	NFT 90 015
Sulphate	Molecular absorption spectrometry	NFT 90 040
Chlorides	Titrimetry (Mohr method)	NFT 90 014
Sodium/ Potassium	Atomic absorption spectrometry	NFT 90 020
Calcium/ Magnesium	Atomic absorption spectrometry	NFT 90 112
Iron	Molecular absorption spectrometry	NFT 90 017
Hydrogenocarbonate	Titrimetry	NFT 90 036

Table 3. Distribution of boreholes by class depths.

Depth class (m)	Number of boreholes	Percentage
40 - 70	74	49
< 70	76	51
Total	150	100

$$\vec{x} = [x_1 \; x_2 \; x_3 \; \dots \; x_n]^T$$
$$\vec{y} = [y_1 \; y_2 \; y_3 \; \dots \; y_n]^T$$
$$\|\vec{y}_i - \vec{x}_i\| = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2}$$

(4) The best matching unit Mc, the unit with the greatest similarity with the considered input vector, is chosen according to:

$$\|\vec{x}_i - M_c\| = \min \{\|\vec{x}_i - \vec{y}_i\|\}$$

(5) The weights of the best matching unit and the unit within its neighborhood N(t) are adapted so that the new reference vectors lie henceforth closer to the input vector. The factor α(t) controls the rate of change of the reference vectors and is called the learning rate

$$\vec{y}(t+1) = \begin{cases} y_i(t) + \alpha(t)[x(t) - y(t)] & \forall i \in N(t) \\ y_i & \forall i \notin N(t) \end{cases}$$

(6) Steps 3 until 5 are repeated until a predefined maximum number of iterations is reached. During these iterations both α and N(t) decrease, forcing the network to converge.

The data set collected was used to analyze the effect of the hydrogeochemical processes on groundwater quality. The data set collected had 22 variables or components. These 22 components were used to create the self-organizing map (SOM). The 7 × 9 size of the map was used and the total number of nodes (63) in the hexagonal grid was displayed. After a map was created, the component planes were placed serially to analyze the dependencies between components. In each component plane, each hexagon represented one map node and its color told the value of the component in that node. Hexagons in each place on different components planes corresponded to the same map node and showed the values of the components in the weight vector of that node. Each component plane window represented the local average component value at each node in a certain color.

For more details concerning the SOM algorithm and its applications, we referred the readers to Kohonen (2001), Giraudel and Lek (2001), Park et al. (2003) and Reyjol et al. (2005). The analysis was carried out using the SOM Toolbox (Alhoniemi et al., 2005) for Matlab in a PC platform.

RESULTS AND DISCUSSION

Total depth (Pt)

The depths of the boreholes studied were between 42 and 110 m with an average of 71.33 ± 14 m. The portion of the boreholes between 40 and 70 m was 49% while 51% of drilling commonly encountered on shale formations exceeded 70m total depth (Table 3).

Weathered layers (WL)

The weathered layers varied from 2 to 92.31 m with an average of 38.77 ± 19.6 m. The weathered layers class between 40 and 70 m was the most commonly encountered (50% of total boreholes) in the watershed (Table 4). Large thicknesses alterites were usually found in the south of the shale formations, while the low thicknesses of alterites were located in the North of watershed in granitoid.

Groundwater quality

Physicochemical data of the collected water samples are summarized in Table 5. These data were also compared

Table 4. Distribution of boreholes per class thicknesses of alteration.

Classes	Very low	Low	Mean	High	Very high
EA (m)	0 - 10	10 - 15	15- 25	25 - 40	40 - 70
Numbers	11	8	17	39	75
Percentage (%)	07.33	05.33	11.34	26	50

Table 5. Statistics of the physic-chemical parameters of groundwater samples from boreholes in watershed of Baya.

Parameter	Minimum	Maximum	Mean ± σ
T (°C)	24.5	28.5	26.35 ± 0.79
pH	5.63	7.47	6.54 ± 0.33
Turb (NTU)	0.3	1.06	0.41 ± 0.12
Color (UVC)	4	25	7.92 ± 3.92
EC (µS/cm)	130.3	1236	420.15 ± 248.15
HCO_3^- (mg/L)	42.7	402.6	192.93 ± 86.78
Ca^{2+} (mg/L)	6.41	208.4	42.73 ± 34.32
Mg^{2+} (mg/L)	1.46	99.45	9.31 ± 12.48
Na^+ (mg/L)	0.34	14.52	2.84 ± 2.34
K^+ (mg/L)	0.11	6.00	1.24 ± 1.05
Cl^- (mg/L)	3.55	538.1	32.58 ± 62.73
Fe^{2+} (mg/L)	0	0.58	0.11 ± 7.53
Mn^{2+} (mg/L)	0	1.46	0.03 ± 0.13
DO (mg/L)	6.3	7.1	6.77 ± 0.14
NO_3^- (mg/L)	0	35	3.59 ± 7.53
NH_4^+ (mg/L)	0	1.34	0.02 ± 0.15
PO_4^{3-} (mg/L)	0	0.64	0.14 ± 0.10
SiO_2 (mg/L)	5.6	62.8	21.38 ± 8.14
SO_4^{2-} (mg/L)	0	248	6.29 ± 22.52

with World Health Organization (WHO) standards (2011). The pH of the groundwater sampled remained acid (95%) in fractured aquifers of the Baya watershed (Table 5). No health-based guideline value was proposed for pH. However these lower-pH values of ground waters were more likely to be corrosive. Failure to minimize corrosion could result in the contamination of drinking-water and in adverse effects on its taste and appearance.

The Ca^{2+} and Mg^{2+} ions were the dominant cations while the HCO_3^- and Cl^- were the dominant anions. The Fe^{2+} and Mn^{2+} were respectively present in proportions of 76 and 30% of water sampled. Sometimes concentrations exceeded the guide values on organoleptic characteristics of WHO (2011) (Table 6).

Waters chemical signature

The Piper's diagram indicated 84% of waters sampled belonged to the Ca-HCO_3 groundwater type. Two mains hydrogeochemical poles could be distinguished (Figure 3). The waters Ca-Mg-HCO_3 (A) and SO_4-Cl-HCO_3 waters (B).

Self-organizing maps (SOM)

The hierarchical classification obtained was used to group the 63 cells of the SOM into five sets (I to V) without regard to geological formations. The nodes that represented the high values (mean logarithmical values) were in black and those representing the low values were colored white (Figure 4). The description of each cluster is showed in Table 7. Groups I and III were characterized by the very high gradient of weathered layers and depth of boreholes with a marked presence of Fe^{2+},,Mn^{2+} , color and turbidity for group I. Waters issued from boreholes group III were low in dissolved salts and had a low gradient of conductivity and TDS. Group II, included the boreholes with high gradients of total depth, weathered layers, electrical conductivity (EC) and TDS (rate salt dissolved). The group exhibited a marked

Table 6. Localities with concentrations of iron and/or manganese above the WHO guideline (2011).

Localities	Kanasse	Kiendi-Ba	Kietan	Dah Salam	Guiméré	Petit Addis Abeba	Tchilamisse
Fe^{2+} (mg/L)	0.40	0.56	0.36	0.58	0.50	0.3	0.56
Mn^{2+} (mg/L)	0.15	0.10	0.15	0.15	0.10	1.46	0.15

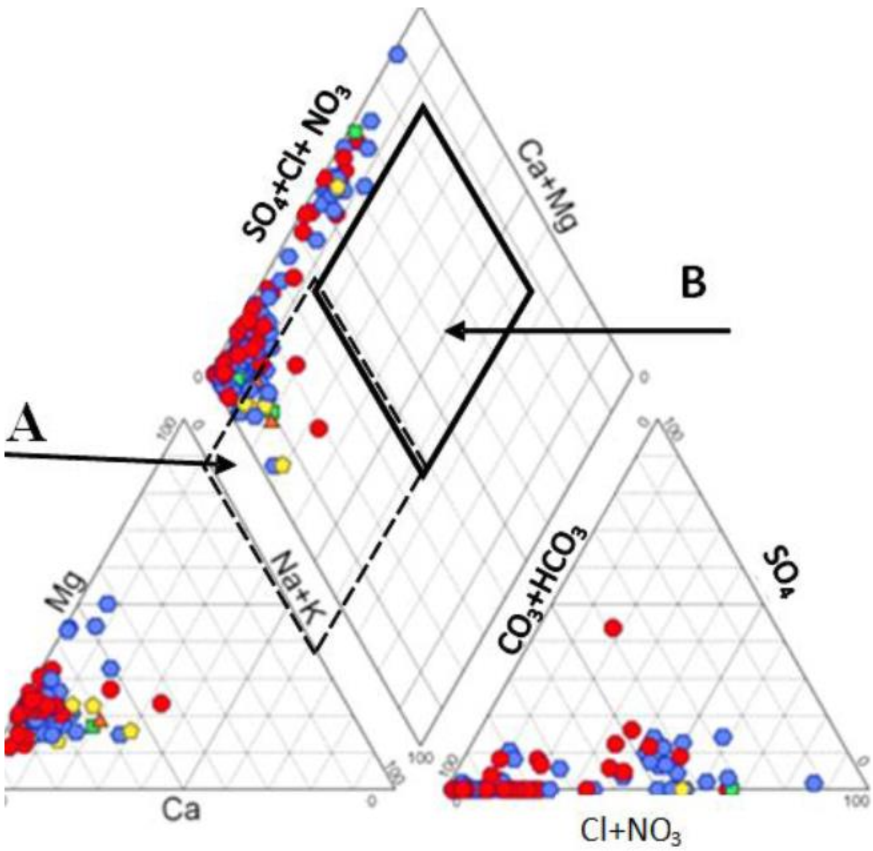

Figure 3. Piper diagram showing the groundwater chemical types of the study area.

contribution to the mineralization in HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+. The groups IV and V were characterized by low gradients of weathered layers and depth; while the gradients of EC and TDS were high with a contribution to the mineralization in Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, PO_4^{3-}, SO_4^{2-}.

Chemical signatures of water in stiff diagram

Chemical characterization performed using Stiff diagram (Piper diagram) to reflect the chemical differentiation between the groups is illustrated in Figure 5. It was found that the water reservoirs in the watershed presented a variable chemical signature. However, a similarity in chemical character was observed between the water samples of Group I, II, III. These samples were mostly marked by facies of Ca-HCO_3 in varying contents. The most mineralized waters were those of the Group V then came those of Group IV and II. Waters belonging to the groups I and III were the most weakly mineralized.

Spatial distribution of water groups in the watershed of Baya

The waters of the Groups I and II appeared as surrogate for the study area; but the group I had high concentrations of iron and manganese in the North and the South East of the watershed, specifically in the department of Transua. The waters of Group III were common in central and northern of the watershed. They were weakly mineralized waters. The presence of nitrate and phosphate in Groups IV and V might be subject to anthropogenic pollution although concentrations respected

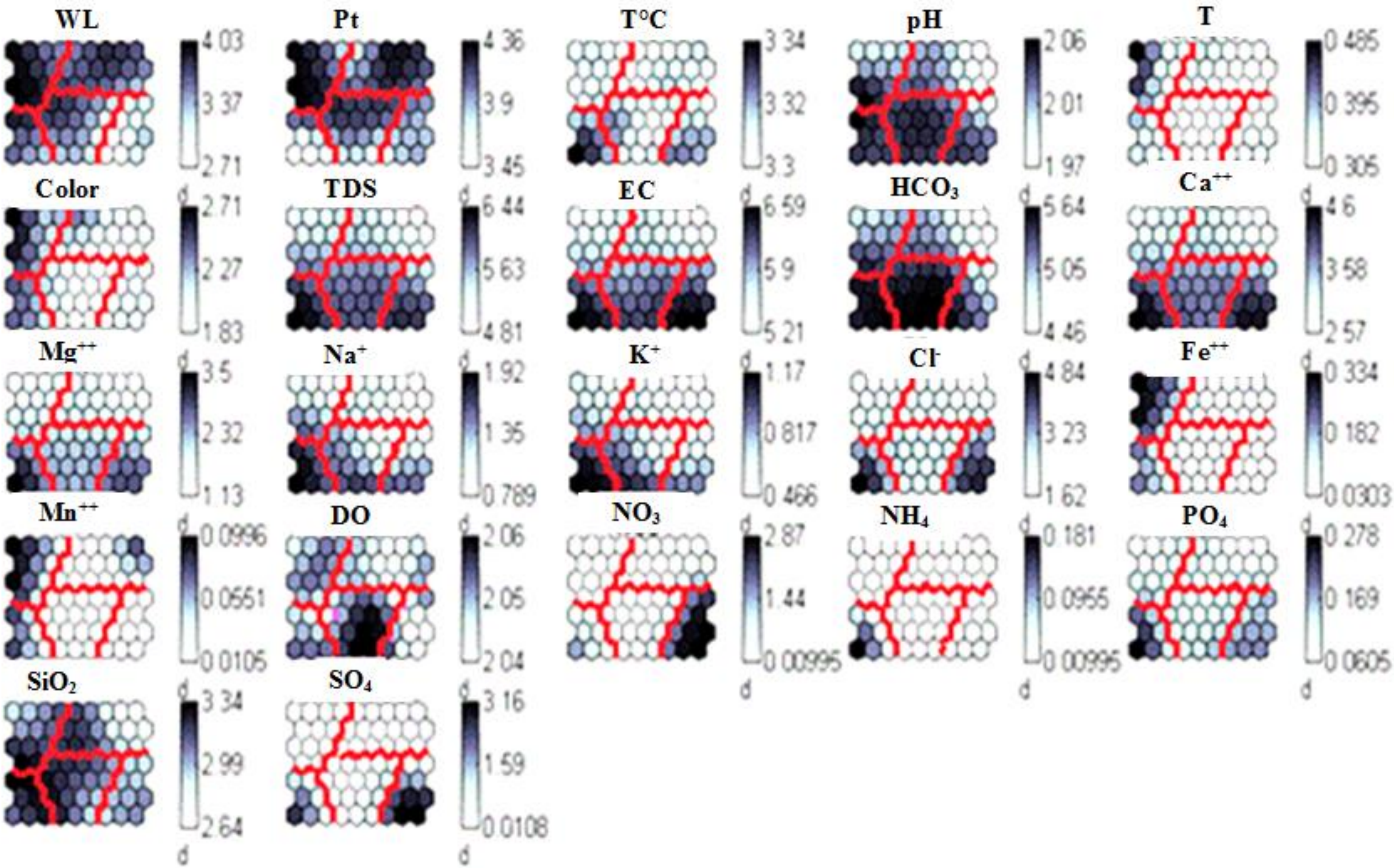

Figure 4. Component planes and SOM visualizations for the study area.

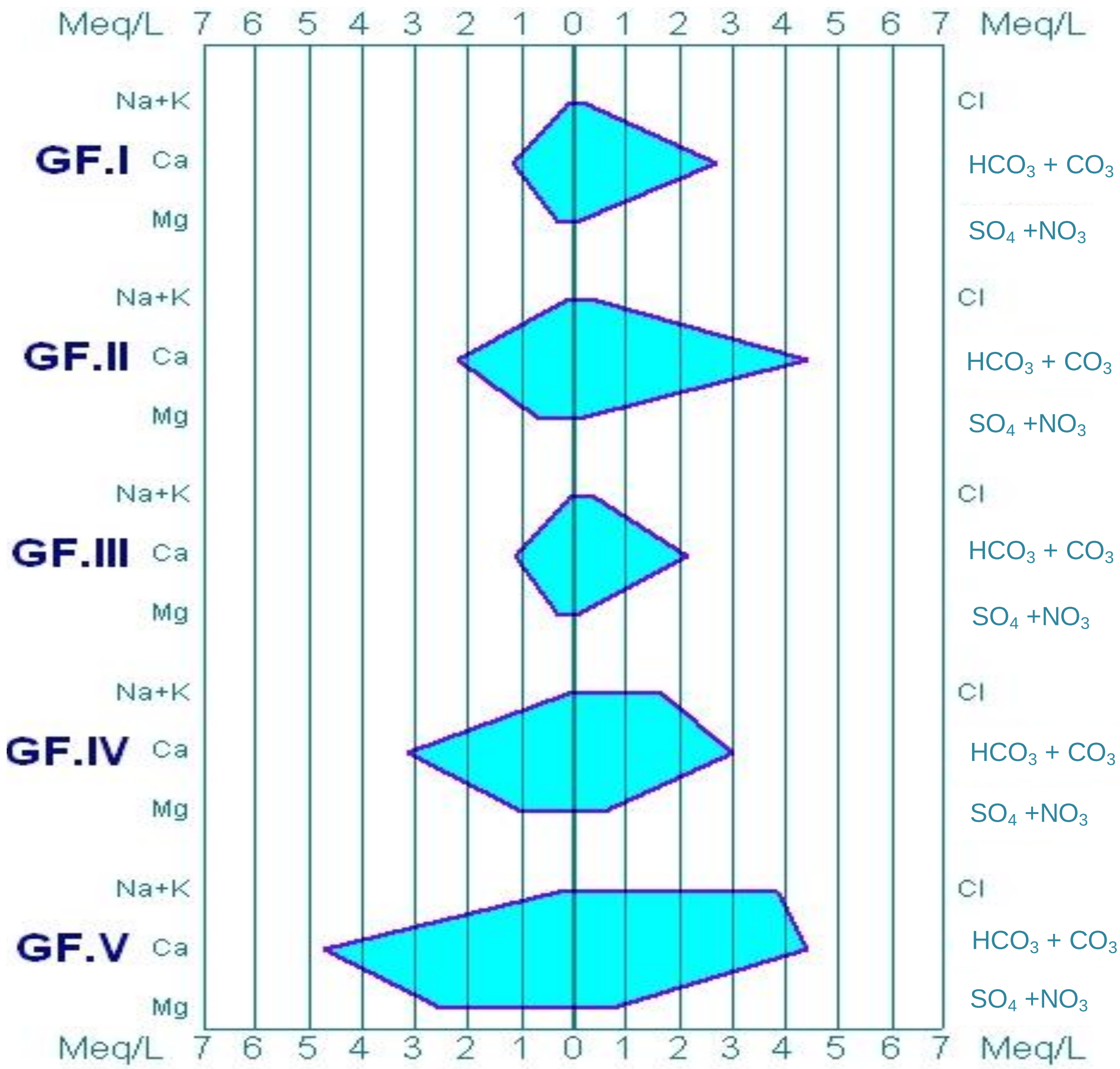

Figure 5. Graphing in the diagram Stiff average chemical composition of groundwater in the Baya watershed.

the WHO guidelines potability (<50 mg / L) (Figure 6). Most of these boreholes were grouped at the outfall and along the river's watershed.

DISCUSSION

General physico-chemicals characteristics of waters

Groundwaters from the watershed of Baya were acid with an average pH of 6.54 ± 0.33. This acidity was due to the abundance of quartz, which conferred the rocks resistance of hydrolysis phenomena responsible for mineralization of groundwaters (Boukary, 1982). In these conditions, the carbonic acid produced of the hydration of CO_2 persisted in the middle (Schoeller, 1980). The turbidity values of groundwater in the Baya oscillated around 0.41 ± 0.12 NTU. These waters contained so few particles in suspension. Concerning mineralization, the waters of the Baya Watershed were moderately mineralized with an average value of conductivity 420.15 ± 248.15 µS / cm. The mineralization of these waters could be related to the acid character of the enclosing rocks (SiO_2> 60%). The acidity and the mean mineralization of groundwater in the Baya watershed were consistent with the works of Lasm et al. (2008) and Kouassi et al. (2010) working on the fractured aquifers in the regions of Ferké and N'zi Comoé (Côte d'Ivoire).

Relatively to the hydrofacies, 84% of waters from fractured aquifers belonged to the facies hydrogen-carbonates calcic. The hydrochemical facies obtained in this study were consistent with those of Goné et al. (2005).

Table 7. Density gradient of physicochemical parameters of total depth (Pt) and Weathered layers (WL).

Group	Number	Density parameters				
		WL	Pt	TDS	EC	Discriminative physico-chemical parameters
I	30	++++	++++	+	+	Turb, color, Fe^{2+} Mn^{2+}
II	36	+++	+++	+++	+++	pH, SiO_2 , DO Na^+,Ca^{2+},Mg^{2+}
III	43	+++	++++	+	+	pH, SiO_2, HCO_3^-
IV	27	+	++	+++	+++	HCO_3^-, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, PO_4^{3-} Cl^-,
V	14	++	+	+++	+++	pH ,T°C, DO , SiO_2, HCO_3^-, Mg^{2+}, K^+, Na^+, Cl^-, PO_4^{3-}, NH_4

(+) = low, (++) = medium, (+++) = high, (++++) = very high.

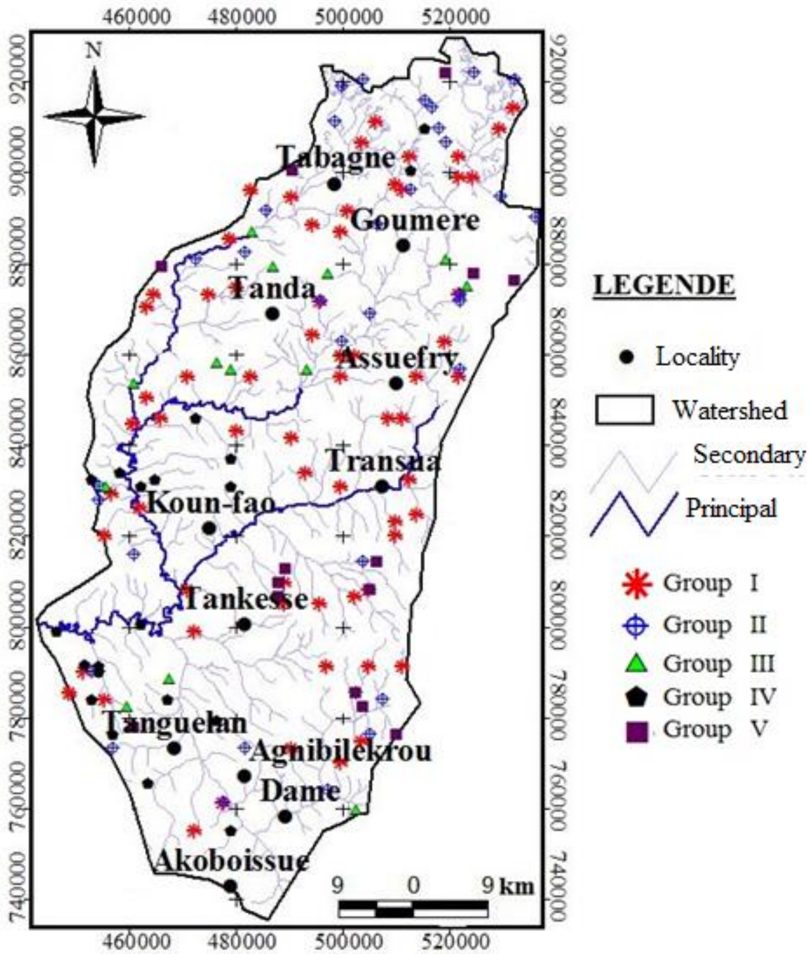

Figure 6. Spatial distribution of water groups in the Watershed of Baya.

These authors investigated the groundwaters quality of crystalline and crystallophyllian aquifers in Man areas (western of Côte d'Ivoire). According to these authors, the Ca-HCO_3 groundwater type was a major feature of groundwater from crystalline and crystallophyllian rocks. The HCO_3^- ion was mainly due to acid hydrolysis of rocks (Ligban et al., 2009). This hydrolysis was accompanied by the dissolution of cations in particular Ca^{2+} and Mg^{2+} which were the most mobile during the weathering of rocks (Goné et al., 2004,2005).

Mineralization processes of groundwater in the Baya watershed

Analysis of the chemical composition of groundwater in contact with the geological formations performed using self-organizing maps showed a High chemical variability of water encountered in the Baya watershed.

In view of the boreholes of Groups IV and V in the maps of Kohonen, regrouping of variables composed by the majority of physico-chemical parameters such as pH, Mg^{2+}, Na^{+}, Ca^{2+}, K^{+}, HCO_3^-, DO , SiO_2, Cl^-, PO_4^{3-}, SO_4^{2-}, NH_4^+, NO_3^- could indicate several phenomena leading to water mineralization. Mg^{2+}, Na^{+}, Ca^{2+}, K^{+} could result in the dissolution phenomena of rock by acid hydrolysis mechanisms of the silicate minerals. Works of Goné et al. (2005), Lasm et al. (2011) and Brou (2014), working respectively in the square degree of Man, in the regions of M'bahiakro and San Pedro also led to similar results. The Na^{+} and K^{+} were irregular (Group I and III) and sometimes marked by fairly strong variations (Group V) in water sampled. Works of Kengni et al. (2013) in Cameroon leading to the same result, specified that the irregularity of Na^{+} and K^{+} found was explained by the great instability of the feldspars and potassics micas but was also by an absorption of K^{+} in minerals neoformed during the weathering (Biemi, 1992).

Cl^-, NO_3^- and SO_4^{2-} could indicate also the contribution of human activities in the process of mineralization of the waters. The villages situated to the watershed outlet and crossed by the main river recorded high concentrations of NO_3^-, Cl^- and PO_4^{3-}. Indeed, according to Bertrand et al. (2010), natural concentrations of NO_3^- and Cl^- in groundwater were less than 10 mg / L. However in this study, observation of 102.28 mg/L of Cl^- to Ouatte (s/p Koun fao), 35 mg/L NO_3^- to Akrassikro (Koun-Fao) 248 mg/L SO_4^{2-} to Tano koffikro (s/p Tanda) could be justified by the intense use of fertilizers in agricultural activities (Namira et al., 2007). Kohonen maps confirmed this hypothesis in part because boreholes of low weathered layers (group IV and V) were loaded into nitrates and chlorides were probably due to the high anthropization in the watershed. The same observations were also made in groundwater in India by John et al. (2007) and in Ghana by Yidana (2010). Indeed, according to these authors the nitrate, sodium and chlorides contained in groundwater came from the superficial horizons leached by infiltration water. Group I included the waters whose the mineralization was low. They were above all characterized by high contents of iron and manganese in respective proportions of 76 and 30% of waters sampled. The marking of this group by Mn^{2+}, Fe^{2+} and turbidity showed that the mineralization of these waters was not only linked to the hydrolysis phenomenon of minerals from the rocks but also to the phenomenon of redox (Zobrist, 2001). These high contents of iron and manganese in water could also be attributed to the geological formations of the region as pointed Mangoua et al. (2010) in the study area Ahoussi et al. (2013) in the west of Cote d'Ivoire and in Martinique by Brenot et al. (2008). The high contents of iron and manganese in groundwater were related to the deficit of dissolved O_2 in these aquifers. Indeed, these two elements gave the water an unpleasant taste, one aspect, and a color brownish red and dark-brown. This situation forced the rural population to turn to others sources of supply whose qualities bacteriological and parasitological were dubious. This could have serious consequences on the health of populations.

Conclusion

The present study showed a significant impact of hydrogeochemical processes on the quality of groundwaters. It resulted from our investigations that the groundwater of the watershed of the Baya are acid and moderately mineralized, sometimes turbid and colored. They are mainly Ca-Mg-HCO_3 and SO_4-Cl-HCO_3. Major ions which governed the mineralization of groundwater were derived from weathering of rocks, hydrolysis of the silicate minerals and redox reactions. NO_3^-, Cl^- and SO_4^{2-} were derived from a human pollution due to human activities. This study also indicated that the water supply met many of the criteria for good quality water. We suggested that a systematic, hydrogeochemical and environmental isotopic study is essential to understand the groundwater system and prepare an appropriate measure for water quality protection.

Conflict of Interest

The authors have not declared any conflict of interest.

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