Original Research Article

Assessment of groundwater physicochemical quality in Gbêkê region of Côte d'Ivoire using water quality indices and multivariate analysis

ABSTRACT

The large demand for drinking water in Gbêkê region of Côte d'Ivoire is supplied from groundwater sources. This study investigated the groundwater physicochemical quality in Gbêkê region of Côte d'Ivoire based on preselected 24 boreholes. Groudwater evaluation index and focused focused principal components analysis were used to assess water physicochemical quality, which is a major factor for controlling the groundwater quality in term of drinking purposes. Most of the groundwater was acidic and presented low mineralization. Hydrochemical facies was Mg-Ca-Cl type. Groundwater quality index values ranged from 11.69 to 119.37. The analysis shows that about 96% of the samples were belonging to excellent quality water for drinking purposes. Focused principal components analysis suggests that groundwater quality was mainly related to geogenic (rock–water interaction) and anthropogenic source (agrogenic and domestic sewage) in the study area. It is expected that outcomes of the study will provide insights for decision makers taking proper measures for groundwater quality management in central Côte d'Ivoire.

Keywords : Hydrochemistry ; Groundwater quality ; chemical pollution ; Gbêkê region.

1. INTRODUCTION

Groundwater has become the major source of water supply for drinking, domestic, household, agricultural, industrial and environmental activities. This has led to an increase in the demand of water supply which is met mostly from the exploitation of groundwater resources (Douagui et al. 2019, Selvakumar et al., 2017). Studies like Atwia et al. (2013); Jellalia et al. (2013), Anomohanran (2015) ; Abu Risha and Temamy (2016); Anaba Onana et al. (2017), Haj-Amor et al. (2018); Hamad et al. (2018); Boujghad et al. (2019) and El Baghdadi et al. (2019) showed that in many African cities, groundwater is a vital water source outside of surface water resources. The wise management of groundwater resources is fundamental for sustainable development for reliable water sources supply for urban and rural areas.

Determination of groundwater quality is important for assessing various usages. Variation in groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by natural processes such as geological formations and anthropogenic activities (Selvakumar et al., 2017). The study of hydrogeochemical processes in groundwater helps to understand and distinguish between the rock-water interactions and anthropogenic influences. The geochemical processes occuring within the groundwater and the reaction with aquifer minerals have a profound effect on water quality (Srivastava, 2008 ; Goné et al., 2014). Groundwater chemically evolves by interaction with aquifer minerals or internal mixing of different groundwaters along subsurface flow-paths (Toth, 1984 ; Srivastava, 2008). Therefore spatial distribution of chemical species gives some idea about the direction of groundwater movement.

Evaluation of groundwater quality is a complex process that undertaking numerous variables capable of causing various stresses on general groundwater quality. The integrated approachs that include drinking water indices and multivariate statistics are used to characterize the groundwater quality. Various researchers have tried to develop a wide range of WQIs for evaluation of groundwater quality;

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the choice of index depends on the groundwater input parameters and the desired results (Vasanthavigar et al., 2010; Singh et al., 2013; Tiwari et al., 2014; Shahid et al., 2014). Referring to recent works (Bodrud-Doza et al., 2016, Bhuiyan et al., 2016 ; Douagui et al. 2019), water quality index (WQI) is an effective technique for assessing drinking water quality suitability in any area and to communicate the information on overall water quality. Multivariate analysis methods such as focused principal component analysis are a sophisticated knowledge extraction and diagnosis tool that can provide the analysis and visualisation of multidimensional groundwater. This is explained by the variety of variables observed as groundwater quality data, and uncertainty involved in transport and reaction mechanism into groundwater systems (Goné et al, 2014).

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Gbêkê region in Côte d'Ivoire is located in an environment of crystalline rocks and is densely populated (Douagui et al. 2018). Pressure on environment and on water resources is still tremendous. The quality of groundwater which is the main source of drinking water in rural and urban zones is threatened. However, few groundwater quality studies have been conducted in the region. Thus, there is a need to provide more insight into the groundwater quality in crystalline formations in this region to assist local authorities in developing plans and regulations and in implementing actions to reduce human health and environmental risks.
The objective of this work is to evaluate the physicochemical quality of groundwater in Gbêkê region on suitability for drinking purposes.

2. MATERIALS AND METHODS

2.1. Study area

The study area is Gbêkê region, located in the center of Côte d'Ivoire. It covers the area between longitudes 4˚24' and 5˚43'N and latitudes 7˚12' and 8˚12'W (Fig. 1). The population is estimated at 1200000 inhabitants. This area is under the influence of the wet tropical climate with two distinct seasons: a long dry season (November-March) and a long rainy season (April-October). The study area covers 9136 km^2. The geological bedrock consists of the volcano-sedimentary and the granitoides, which are essentially constituted by granites (Fig. 1). On the one hand, the volcano-sedimentary includes meta-sediments mostly constituted of sandstone and schists intruded by several generations of granitoids. On the other hand, the volcano-sedimentary is covered by metavulcanites which consist of amphibolites, meta-andesite, rhyolites, meta-basaltes, metagabbro and metadolerite.

Two aquifers exist in the study area for the groundwater extraction. The most important aquifers are the fractured aquifers of crystalline and schist rocks. Their permeability is conditioned by the presence of discontinuities such as faults and joints and, in some cases, by lithlogic contacts. Over the fractured rocks, the weathered layer may constitute a porous aquifer.

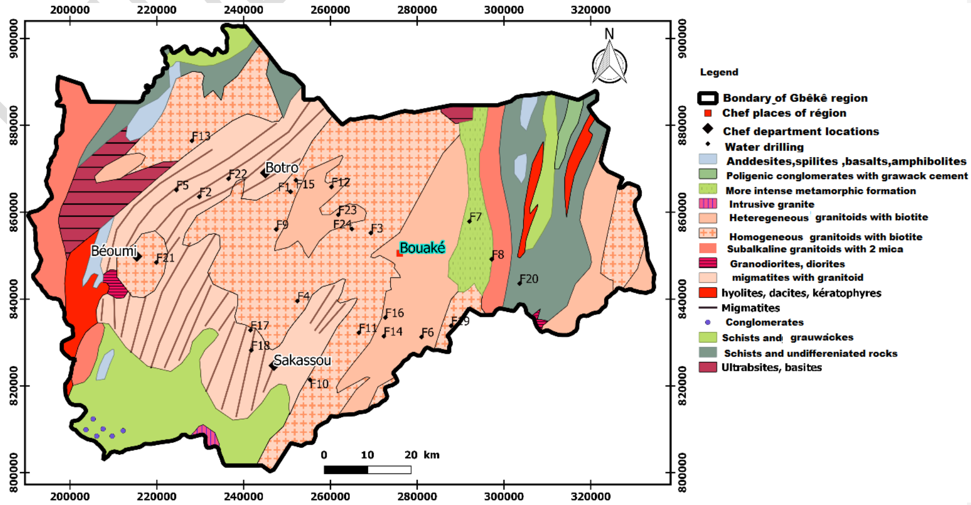

Fig. 1. Study area

2.2. Groundwater samples and data collection

Groundwater was sampled from 24 boreholes during the long dry season of 2015 (Fig. 1). Water sample collection from boreholes was carried out according to the procedures described by Lamrani et al. (2008) and Tayfur et al. (2008). 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 bottles. Once collected, all samples were stored on ice and immediately transported to the laboratory. Chemical analyses were processed within 6 hours after collection.

2.3. Physico-chemical analyses

Water temperature (T˚), electrical conductivity (EC), pH, dissolved oxygen (DO), Groundwater temperature (T), dissolved oxygen, pH and electrical conductivity were measured in situ using the Hach Model 44600 Meter and the Multi 340i Handheld.

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Chemical parameters were determined at the laboratory according to the methods presented in Table 1

Correlation studies were carried out using focused principal components analysis (PCA) to determine the relationships between physicochemical parameters. Focused PCA is a special type of PCA designed to describe and understand relationships between a set of quantitative variables, with a particular interest in the dependencies of one variable with the others. The relationships between nondependent variables are interpreted as in a PCA. Correlated variables are close or diametrically opposite (for negative correlations). Independent variables make a right angle with the origin. Focused PCA was conducted using R 3.4 software, module PSY.

Table 1. Analysis methods of chemical parameters

Elements	Analysis methods
Ca^{2+}. Mg^{2+}	Atomic absorption spectrometry (NF EN ISO 7980)
K+	Atomic emission spectrometry (AFNOR NF EN ISO 11885)
NO_3^-	Molecular absorption spectrometry (AFNO R standards NFT 90-045)
Cl^-	Liquid phase chromatography (AFNOR NF EN ISO 10304-3)
NH_4^+	Titrimetry method (AFNOR NF T90-015-1)
SO_4^{2-}	Chromatography of ions in the liquid phase (NF EN ISO 10304-1)
PO_4^{3-}	Molecular absorption spectrometry (AFNO R standards NFT 90-023)
Al^{3+}	Atomic absorption spectrometry (NF EN ISO 12020)
Fe, Mn^{2+}, Cu^{2+}, Zn^{2+}	Atomic absorption spectrometry (AFNO R standards FDT 90-112)

2.4. Groundwater pollution evaluation

Groundwater quality index (*GWQI*) method reflects the composite influence of the different water quality parameters on the suitability for drinking purposes. The standards for drinking purposes as recommended by WHO (2011) have been considered for the calculation of *GWQI*. For computing *GWQI* three steps are followed as described by Vasanthavigar et al. (2010). In the first step, Seventeen physicochemical parameters (pH, EC, Temperature, NO_3^-, NO_2^- , NH_4^+, SO_4^{2-}, PO_4^{3-}, K^+, Ca^{2+}, Mg^{2+}, Mn^{2+}, Cl^-, Fe^{2+}, Cu^{2+}, Zn^{2+}, Fer total) has been assigned a weight (*wi*) according to its relative importance in the overall quality of water for drinking purposes (Table 2). The maximum weight of 5 has been assigned to the parameters like nitrate, nitrite and phosphate due to their major importance in water quality assessment. Other parameters were assigned weight between 1 and 4 depending on their importance in water quality determination. In the second step, the relative weight (*Wi*) is computed as follows (Equation 1) :

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \quad (1)$$

Where $\boldsymbol{W_i}$ is the relative weight, ***wi*** is the weight of each parameter, ***n*** is the number of parameters.

In the third step, a quality rating scale $\boldsymbol{(q_i)}$ for each parameter is assigned by dividing its concentration in each water sample by its respective standard (Equation 3) according to WHO acceptability and health-based of drinking-water guidelines or limit values defined by Vasanthavigar et al. (2010) and Bhuiyan et al. (2016).

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \quad (2)$$

Where, $\boldsymbol{q_i}$ is the quality rating ; $\boldsymbol{C_i}$ is the value or concentration of each parameter in each water sample ; $\boldsymbol{S_i}$ is the drinking water standard for each parameter.

For computing the *GWQI*, the ***SI*** is first determined for each parameter (Equation 3), which is then used to determine the *GWQI*. *GWQI* is defined as (Equation 4):

$$SI_i = W_i \times q_i \quad (3)$$

$$GWQI = \sum SI_i \quad (4)$$

Where ***SIi*** is the sub-index of *i*th parameter ; $\boldsymbol{q_i}$ is the rating based on value or concentration of *i*th parameter ; ***n*** is the number of parameters.

Table 2. List of parameters, weight factors, and limit values for the water quality index

Parameters	**WHO Standard (2011) (acceptability and health-based of drinking-water guideline values)**	**Weight (*wi*)**	**Relative weight ($\boldsymbol{W_i}$)**
pH	6.5 – 8.5[b]	4	0.073
EC		4	0.018
T	25 – 30°C[c]	2	0.036
$\boldsymbol{NO_3^-}$	50 $mg.L^{-1}$[a]	5	0.091
$\boldsymbol{NO_2^-}$	3 $mg.L^{-1}$[a]	5	0.091
$\boldsymbol{NH_4^+}$	1.5 $mg.L^{-1}$[b]	3	0.055
$\boldsymbol{SO_4^{2-}}$	250 $mg.L^{-1}$[b]	4	0.073
$\boldsymbol{PO_4^{3-}}$	5 $mg.L^{-1}$[c]	5	0.091
$\boldsymbol{K^+}$	12 $mg.L^{-1}$[c]	2	0.036
$\boldsymbol{Ca^{2+}}$	100 $mg.L^{-1}$[c]	2	0.036
$\boldsymbol{Mg^{2+}}$	50 $mg.L^{-1}$[c]	2	0.036
$\boldsymbol{Cl^-}$	250 $mg.L^{-1}$[b]	3	0.055
$\boldsymbol{Fe^{2+}}$	0.3 $mg.L^{-1}$[b]	4	0.073
$\boldsymbol{Fe_{total}}$	0.3 $mg.L^{-1}$[b]	3	0.055
$\boldsymbol{Mn^{2+}}$	0.4 $mg.L^{-1}$[a]	2	0.073
$\boldsymbol{Zn^{2+}}$	3 $mg.L^{-1}$[b]	3	0.055
$\boldsymbol{Cu^{2+}}$	2 $mg.L^{-1}$[a]	3	0.055
		∑wi = 55	∑ ***Wi*** = 1

[a]health-based of drinking-water guideline value
[b]acceptability and health-based of drinking-water guideline value

[c]limit values defined by Vasanthavigar et al. (2010) and Bhuiyan et al. (2016)

The *GWQI* range and type of water are classified as follows (Bhuiyan et al. 2016) (Table 3):

Table 3. *GWQI* range and type of water

Range	Type of water
< 50	Excellent water
50-100	Good water
100.1-200	Poor water
200.1-300	Very poor water
> 300	Water unsuitable for drinking Purposes

3. RESULTS AND DISCUSSION

3.1. General characteristics of groundwater quality

General characteristics of groundwater physicochemical parameters for the study area are summarized in Table 4. pH values varied from 3.06 to 8.36 with a mean value of 5.98 ± 1.25. But 70.8% of all pH values of groundwater samples had their pH below 6.5 during the period of study, indicating acidic nature of the samples. This effect is explained by the CO_2 production in the topsoil under the action of the biological activities. Indeed, the study area abounds many primary forests in protected forest areas. The presence of these forests promotes the abundance of plant organic matter. Its mineralization releases CO_2 which is dissolved in groundwater as follows:

$$CH_2O + O_2 \longleftrightarrow CO_2 + H_2O \longleftrightarrow H^+ + HCO_3^-$$

For Goné et al. (2014) and Brindha et al. (2019), acidic water (pH below 6.5) is corrosive causing leaching of metals from piped water supply and is disagreeable in taste. Though health issues due to direct consumption of acidic water is not reported as the human body is capable of adjusting the acidic nature of drinking water, it increases chances of heavy metal contaminant exposure that leads to other diseases.

EC values ranged from 105 to 632 $\mu S.cm^{-1}$ with a mean value of 266.9 ± 129 $\mu S.cm^{-1}$ (Table 4). These values show that the prospected boreholes were weakly to fairly mineralised. In agreement with Goné et al. (2014), this may be related to the nature of silicate rocks within the groundwater from the studied aquifers. It is established that the geochemical processes occurring within the groundwater and the reaction with aquifer minerals have a profond effect on water mineralisation. The low mineralization of the groundwater samples observed may be explained by water in contact with hardly alterable acid rocks.

Compared with the acceptability of drinking-water guideline proposed by WHO (2011), the groundwater samples presented low concentrations of major elements (Ca^{2+}, Mg2+, Cl^-. $SO_4^{2-}$and K^+). According to WHO (2011), the health-based guideline for nitrate in drinking-water is 50 $mg.L^{-1}$. NO_3^- concentrations of all the samples were below the permissible limit. The implication of this is that the water had very little contamination with landfill leachate, domestic sewage and other sources of pollution.

All the samples except three had the concentrations of iron within the suitable level of 0.3 $mg.L^{-1}$. According to WHO (2011), there is usually no noticeable taste at iron concentrations below 0.3 mg/l, although turbidity may develop. The sampling sites that had concentrations of iron above 0.3 $mg.L^{-1}$ were F3, F4 and F8. At levels exceeding 0.3 $mg.L^{-1}$, iron in waters of these boreholes stains laundry and cause taste.

Health-based of drinking-water guideline value established by WHO (2011) for copper is 2 $mg.L^{-1}$ and all groundwater samples were within limit. But, staining of laundry and sanitary ware may occur below

Comment [N6]: superscript the charge value guideline value (WHO, 2011). Aluminium concentrations of all the samples ranged from 0.001 to 0.011 mg.L^{-1}. There is no health-based of drinking-water guideline value established by WHO, but a health-based value derived from the JECFA PTWI would be 0.9 mg/l (rounded value), based on an allocation of 20% of the PTWI to drinking-water and assuming a 60 kg adult drinking 2 litres of water per day.

We noted a dominance of the major ions Cl^-, NO_3^-, Ca^{2+} and Mg^{2+} in these groundwater samples while other ions such as K^+ and SO_4^{2-} are comparatively less represented. Concentrations of major cations and major anions were classified as : $Ca^{2+} > Mg^{2+} > K^+$ and (Cl^- + NO_3^-) > SO_4^{2-}. Thus, majority of groundwater samples fell in mixed Mg-Ca-Cl type.

Table 4. Descriptive statistics of physicochemical parameters in the study area

Parameters	Unit	Min	Max	Mean	Std.Dev.
pH		3.06	8.36	5.98	1.30
T	°C	27.40	31.00	29.05	0.87
DO	mg.L^{-1}	6.60	7.10	6.81	0.09
EC	µS.cm^{-1}	105.00	632.00	266.87	128.70
NO_3^-	mg.L^{-1}	0.50	20.00	4.20	5.20
NO_2^-	mg.L^{-1}	0.00	1.80	0.08	0.40
NH_4^+	mg.L^{-1}	0.00	0.05	0.01	0.02
SO_4^{2-}	mg.L^{-1}	0.00	30.00	2.1	6.6
PO_4^{3-}	mg.L^{-1}	0.2	2.38	0.7	0.5
Mn^+	mg.L^{-1}	0.00	0.20	0.03	0.05
K^+	mg.L^{-1}	0.80	3.600	1.90	0.90
Ca^{2+}	mg.L^{-1}	8.02	48.10	25.31	12.50
Mg^{2+}	mg.L^{-1}	1.46	8.75	4.60	2.30
HCO_3^-	mg.L^{-1}	11.100	2013.000	204.598	297.28
Cl^-	mg.L^{-1}	3.50	60.30	13.70	12.80
Fe^{2+}	mg.L^{-1}	0.00	0.40	0.02	0.08
Fe_{TOT}	mg.L^{-1}	0.00	3.86	0.30	0.76
Al^{3+}	mg.L^{-1}	0.001	0.01	0.004	0.003
Cu^{2+}	mg.L^{-1}	0.00	0.08	0.015	0.02
Zn^{2+}	mg.L^{-1}	0.00	0.10	0.03	0.033
SiO_2	mg.L^{-1}	3.50	18.20	9.60	5.27

3.2. Groundwater quality for drinking purposes

Table 5 shows groundwater quality types determined on the basis of *GWQI* for assessing the suitability of groundwater quality for drinking purposes. *GWQI* values varied from 11.69 to 119.37. The critical limit (100) for drinking water purposes has been proposed by Vasanthavigar et al. (2010) and Bhuiyan et al. (2016). Table 5 shows that all groundwater samples did not exceed the critical limit (100) of *GWQI*s and belonged to excellent water quality except for one sample (sample from Borehole F8).

Table 5. Pollution potential of groundwater samples of the study area based on *GWQI*

***GWQI* values**	**Groundwater quality types**	**Number of samples**	**% of samples**	**Samples**
< 50	Excellent water	23	95.83	1-7 ; 9-24
50-100	Good water	0	0	
100.1-200	Poor water	1	4.17	8
200.1-300	Very poor water	0	0	
> 300	Water unsuitable for drinking purposes	0	0	

3.3. Relationships between groundwater physicochemical quality

Statistically significant relationships (p < 0.05) between physicochemical parameters were found in groundwater boreholes (Fig. 2). Ca^{2+} Mg^{2+}, K^{+}, Cl^{-}, NO_3^{-} and NH_4^{+} concentrations showed a positive correlation with EC. These parameters were also positively correlated with each other. On the other hand, Al^{3+} and DO showed a positive correlation with SiO_2 (Fig. 2). These associations indicate mixed sources of geogenic / anthropogenic origin. Ca^{2+}, Mg^{2+}, K^{+}, Al^{3+}, Cl^{-} are the main constituents of groundwater as a result of interaction with minerals in aquifers and chemical weathering of catchment rocks. The acidic nature of groundwater was due to leaching of altered rocks and anthropogenic sources. Anthropogenic pollutions were derived from the use of chemical fertilizers in agricultural fields. Our findings are in agreement with those reported by Ligban et al. (2017) in Daloa (Côte d'Ivoire) and Bhuiyan et al. (2016) in Lakshimpur district of Bangladesh.

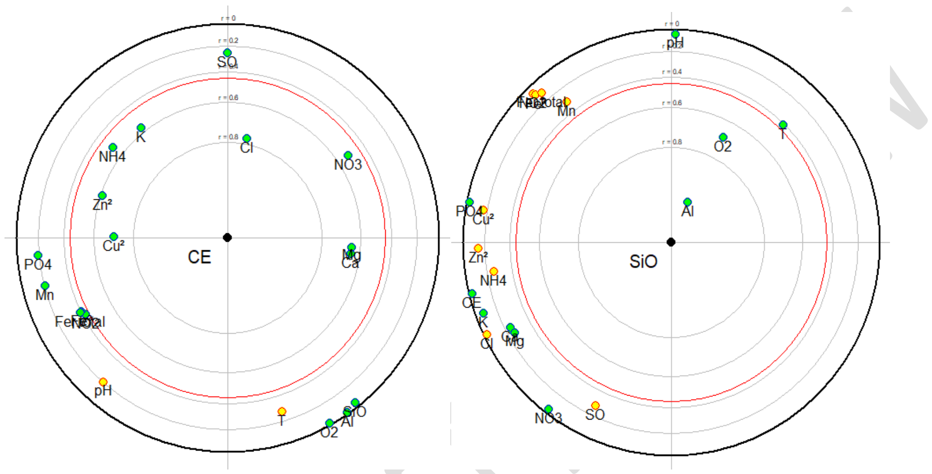

Fig. 2. Focused principal components analysis of physicochemical parameters and Electrical conducyivity and Silice (SIO_2). As the rings get closer to the center they reflect a higher correlation with EC and SIO_2

4. CONCLUSION

This study presented integrated approaches for characterizing geochemistry and suitability of groundwater quality in Gbêkê region of central Côte d'Ivoire. The groundwater samples fell in mixed Mg-Ca-Cl type. Based on GWQI; about 96% of the samples (23 sampling sites) belonged to excellent water quality type, whereas 4 % (1 location) exhibited very poor water quality for drinking purposes in the study area. The Focused PCA demonstrated that anthropogenic and natural/geogenic sources (rock–water interaction) were responsible for variation of physicochemical parameters in groundwater aquifer. This paper is expected to help water resource planners taking adaptive measures for groundwater quality monitoring in Gbêkê region.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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