IJSRM
INTERNATIONAL JOURNAL OF SCIENCE AND RESEARCH METHODOLOGY
An Official Publication of Human Journals
HUMAN

Human Journals
Research Article
April 2022 Vol.:21, Issue:2

Assessment of Hydrogeochemical Properties and Evaluation of the Quality of Groundwater from Basement Aquifer: Case of Niamey Region

IJSRM
INTERNATIONAL JOURNAL OF SCIENCE AND RESEARCH METHODOLOGY
An Official Publication of Human Journals
HUMAN

Abdourazakou Maman Hassan*[1], **Moussa Dandibi Bachir**[2], **Mamane Imrana Chaibou Ousmane**[3], **Arzu Firat Ersoy**[4]

1. Karadeniz Technical University, Department of Geological Engineering, 61080, Trabzon, TURKEY
2. Head of Mining Environment / CEA Department Ecole Des Mines de l'Industrie et de la Géologie, Department of Geoscience, 732, Niamey, NIGER
3. Université Abdou Moumouni de Niamey, Laboratoire Matériaux-Eaux et Environnement, BP 10662 Niamey (Niger)
4. Karadeniz Technical University, Department of Geological Engineering, 61080, Trabzon, TURKEY

Submitted: 22 March 2022
Accepted: 27 March 2022
Published: 30 April 2022

HUMAN JOURNALS

www.ijsrm.humanjournals.com

Keywords: hydrogeochemical processes, basement aquifer, groundwater chemistry, Water quality index

ABSTRACT

This study aims to investigate the hydrogeochemical processes controlling groundwater chemistry from the basement aquifer of Peripheral areas of the Niamey region and to assess its quality for drinking. Therefore, 9 groundwater samples were taken in the right and left bank of Niger river ın the Niamey region and for these samples the physical parameters (TDS, pH and EC)), major ions (SO_4^{2-}, CO_3^-, Cl^-, HCO_3^-, Mg^{2+}, Na^+, K^+, Ca^{2+}) and water pollution parameters such as NH_4^+, NO_2^-, NO_3^- values were determined. Principal component analysis method, Piper, Shoeller and Chadha diagrams were used to determine the key hydrogeochemical process controlling the ***groundwater chemistry*** basement aquifer of Peripheral areas of the Niamey region. To evaluate the quality of water for drinking, water quality index method was used and the physico-chemical parameters were compared with the standards guideline values recommended by the World Health Organization. Principal component analysis showed that rock-water interaction is the main factor that impact the groundwater chemistry in the study area. According to ***Water quality index*** most of water samples are suitable for drinking. According to Piper diagram, calcium-magnesium bicarbonate facies ($CaMgHCO_3$) and calcium chloro-sulfate ($CaSO_4Cl$) facies are the most widespread in the study area. According to this diagram, four water facies were observed in the study area which are $CaHCO_3$, Ca-Mg-Cl, NaCl and $NaHCO_3$. Schoeller diagram showed that in the majority of the samples, the cations sequence of groundwater samples is $rMg^{2+} > rCa^{2+} > r(Na^+ + K^+)$ and the anions sequence is $r(HCO_3^- + CO_3^-) > rSO_4^{2-} > rCl^- > rNO_3^-$.

1. INTRODUCTION

The drinking water problem is acute in most countries of West Africa. The rainfall deficit due to insufficient and irregular rains remains one of the main causes of the water problem in these countries. In fact, in the Sahelian zones and particularly in the basement regions of southwestern of Niger, groundwater resources are increasingly faced with qualitative and quantitative degradation due to climatic and anthropogenic actions. In general, groundwater chemistry in crystalline basement aquifers is linked to the mineralogical composition of the bedrock and to the various weathering processes that affect it [1]. In the basement regions of southwestern of Niger characterized by a semi-arid climate, fissured aquifers remain the only recourse points during the long dry seasons [2]. In the basement area, groundwater often collects in the upper layers and or circulates along privileged conduits, which are essentially cracks or faults [3]. This situation makes it difficult to supply drinking water in quantity and quality in these regions. The difficulty of providing a water supply in a quantitative and qualitative manner for these populations living in the basement areas constitutes one of the primary constraints to the economic and social development of these regions [4].

Many types of researches have been realized throughout the world to determine the main hydrogeochemical processes controlling groundwater quality in crystalline basement aquifers in semi-arid regions. The work carried out by [5] in Bomboré gold mineralized zone of Burkina Faso highlighted that the weathering of carbonate and silicate minerals from metasedimentary bedrock is the main factor controlling groundwater chemistry in this region. The highs concentrations of NO_3^- and SO_4^- in some wells are caused by the low recharge rates and chemical weathering of sulfide minerals in this region. In addition, most of groundwater samples of this region were not suitable for drinking due to the highs concentration of Fe, As and Pb. In Burundi, the work realized by [6] to determine the hydrogeochemical evolution of groundwater in Precambrian basement aquifers of Bugesera region demonstrated that the aluminosilicates weathering is the main factor controlling the hydrogeochemical evolution of groundwater. The presence of $NaSO_4$, $NaNO_3$, KNO_3 and $CaNO_3$ facies indicated the harmful influence of anthropic activities on groundwater quality of this region. The work carried out in Tanzania by [7] to assess the groundwater geochemistry of fractured crystalline aquifer of Dodoma indicated that the groundwater chemistry of this area is mainly linked to the dissolution of sodic feldspars and amphiboles, the cation exchange and salt leaching. The quality of water in this region was affected by the process of nitrification of wastewater effluents which is the main sources of high nitrate concentration in some wells. In Nigeria the work realized by [8] to assess the hydrogeochemical process of groundwater in basement aquifer of Moro highlighted that the contribution of precipitation to the ionic inputs in the groundwater, the weathering and dissolution processes are the mainly factor controlling the groundwater chemistry of this region.

In the region of Niamey located in the southwest of Niger, the drinking water supply to the population is provided mainly by water from the Niger River. However, in most of the peripheral villages of this region, the basement aquifers are the main source of water for the rural population. These aquifers which have a limited extent and that quality remains to be desired depending on precipitation and very often run out during the dry season. The works carried out by [9], [10] and [11] in this region highlighted a deterioration of the quality of groundwater in this region caused by high nitrogen and bacteriological pollution which make the water unfit for consumption.

The purpose of this study is to investigate the hydrogeochemical processes controlling groundwater chemistry from basement aquifer of Peripheral areas of the Niamey region and to assess its quality for drinking.

2. MATERIALS AND METHODS

2.1. Study Area

The region of Niamey is located in the southwest of Niger between the parallels 13 ° 28 ’and 13 ° 35’ north latitude and the meridians 02 ° 03 ’and 02 ° 12’ east longitude. It covers an area of 239 km2. This region is located to the north by the municipalities of Karma and Hamdallaye, to the east by the municipalities of Liboré and Hamdallaye, to the south by the municipalities of Liboré and Bitinkodji and to the west by the municipality of Bitinkodji. The Niger River divides Niamey into two distinct parts (right bank and left bank) and two bridges currently connect the two banks. Most of the population is located on the left bank which totals 4 of the 5 districts of Niamey while the 5th district occupies the right bank (Figure 1). The climate of this region falls within the regional framework of that of the Sahelian tropical strip. In the Niamey region, more than a third of precipitation falls with an intensity greater than 50 mm.h-1, and more than half of the annual rainfall total falls in less than 5 hours [12]. The annual average temperature of this region is 29°C. The maximum temperature recorded during the day can reach 45°C in the shade at the end of the dry season (in April). As part of this work, groundwater samples were taken from wells located on the right and left banks of the Niger River.

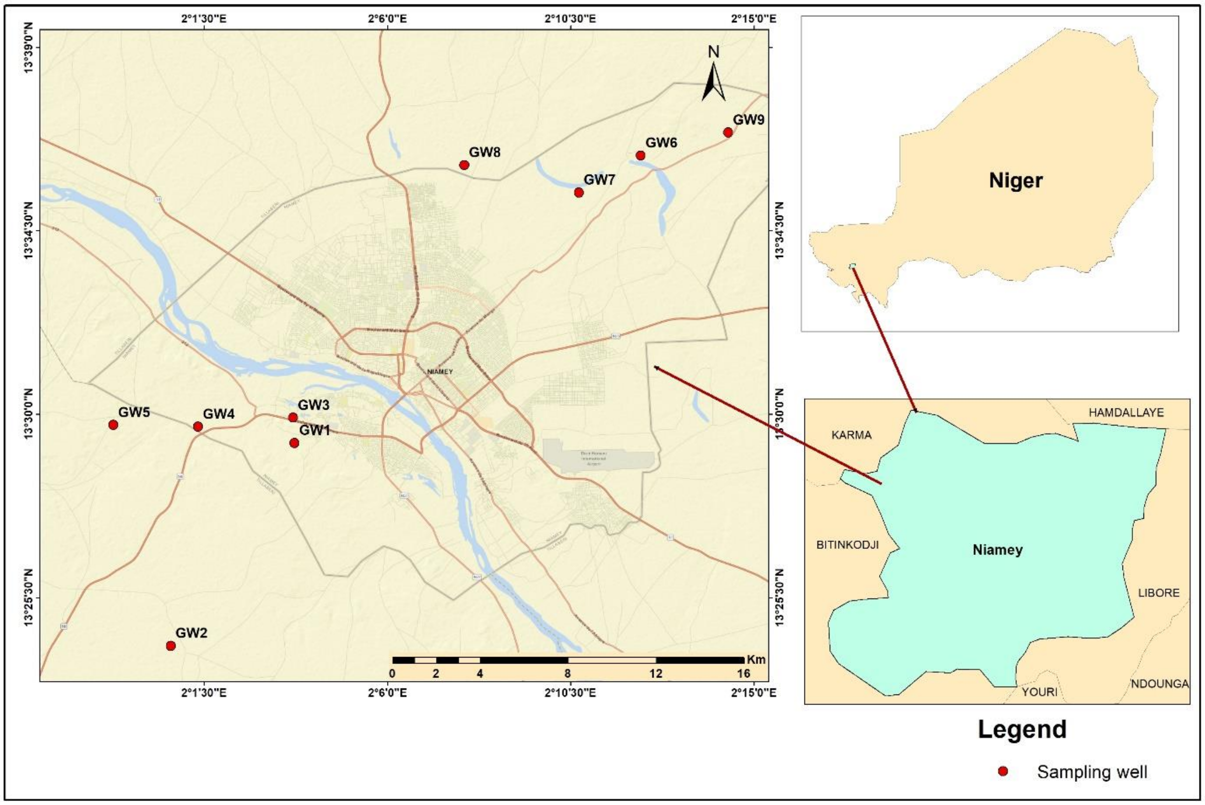

Figure No. 1: study area

The geological context of the Niamey region is characterized by three main types of formations which are the formations of the Meta-Liptako basement, the Sandstone of the Terminal Continental, and the Alluviums of the Niger River. The Meta-Liptako basement is the deepest geological formation in the region. This formation of the lower Proterozoic age belongs to the Birimian province of West Africa. It is composed of altered plutonic (granites, granulites) and metamorphic (gneiss, quartzites, schists) rocks. The Sandstone of Continental Terminal (CT) Formation, probably of Mid-Pliocene age is the youngest formation in the Iullemmeden basin [13]. In the region of Niamey, the Sandstone of Continental Terminal (CT) Formation corresponds to CT3 Formation [14] with a middle Eocene to Pliocene age. It consists of an alternation of more or less clayey sandstone and versicolored clays with intercalations of levels of ferruginous oolites and rests directly on the Birrimian basement of Liptako, or locally, on the sandstones of the Upper Proterozoic [15]. The alluviums of the Niger River are composed of loosely compacted sand (Figure 2). These formations are described as undifferentiated alluvium and valley bottom colluvium. They are the product of quaternary fluvial sedimentation of the Niger River, especially during its high water.

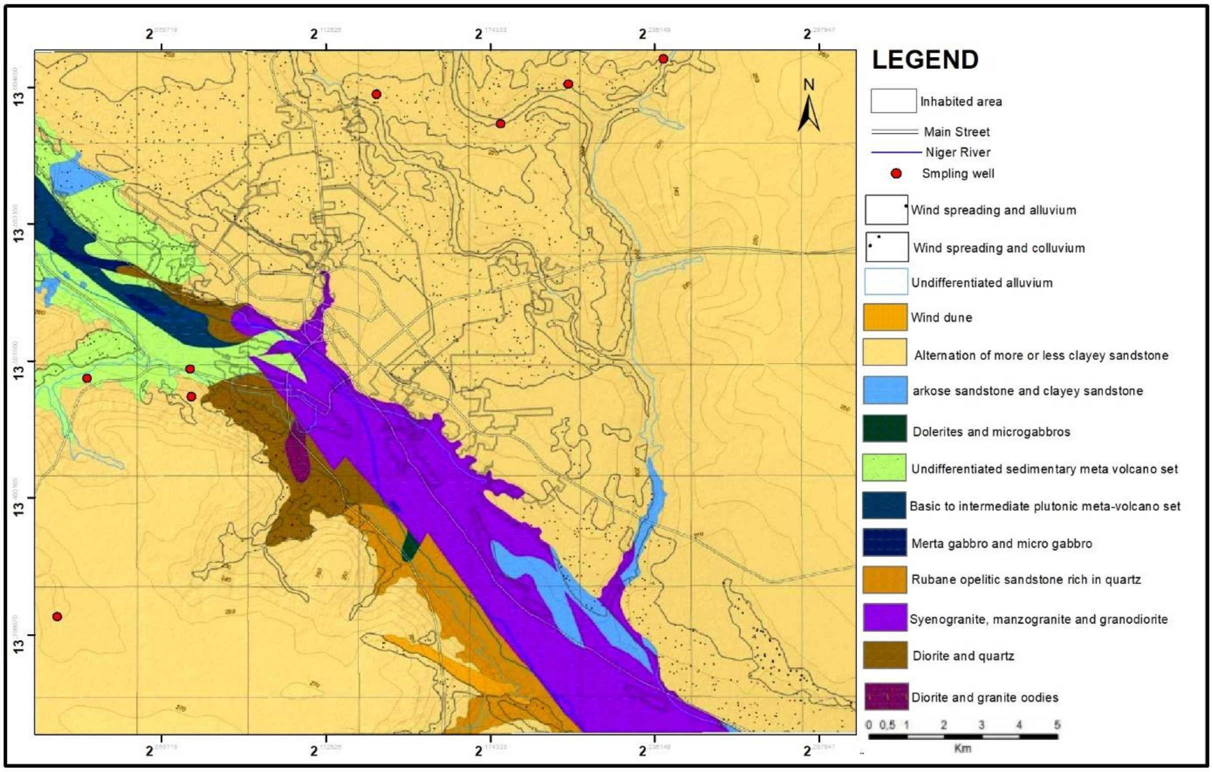

Figure No. 2: Geology of study area

2.2. Sampling and Analytical Methods

For this purpose, 9 groundwater samples were taken in the study area and for these samples the physical parameters (TDS, pH and EC)), major ions (SO_4^{2-}, CO_3^-, Cl^-, HCO_3^-, Mg^{2+}, Na^+, K^+, Ca^{2+}) and water pollution parameters such as NH_4^+, NO_2^-, NO_3^- values were determined. The coordinates of sampling points were taken and recorded by using the Global Positioning System (GPS) device. The physical parameters of collected samples were determined in situ by using HQD-Meter. The analysis of the physical and chemical parameters of groundwater samples was carried out at the chemical analysis laboratory of the AGRHYMET regional center of Niamey. The concentration of HCO_3^- and CO_3^- were determined by using titration method. The atomic absorption spectrometry method was used to determine the concentrations of Na^+, Ca^{2+}, K^+, Mg^{2+} while NH_4^+. NO_2^-, NO_3^- SO_4^{2-} and Cl^- analyses were carried out by using ion chromatography method.

In this study Piper diagram [16] and the Chadha diagram were used to determine the hydrochemical process that controls the groundwater chemistry in the study area.

To evaluate the quality of water for drinking, the physicochemical parameters of collected samples from the study area were compared with the standards guideline values recommended by the World Health Organization [17]. Then in this study, the weighted arithmetic water quality index method was used to classify groundwater samples according to its quality. The determination of Water Quality Index (WQI) is one of the methods used to assess the suitability of water for drinking [18]. The main advantage of this method is that it reduces the many physico-chemical parameters of water to a single number [19]. This method has the additional advantage of providing information to the concerned policymakers about the water quality of status of region [20]; [18]. For this study the weighted arithmetic WQI values were determined according to the following procedure:

In the first step, physicochemical parameters which will be used for WQI calculation were selected according to the WHO standards for drinking water. For this study the parameters considered for the calculation of the WQI are T, pH, TDS, Mg^{2+}, Na^+, NH_4^+, K^+, Ca^{2+}, SO_4^{2-}, Cl^-, HCO_3^-, NO_2^- and NO_3^-. In the second step, a weighted value (wi) is allocated for each selected parameter according to its perceived effects on health and its relative importance in terms of drinking water quality following WHO requirements. The values of different assigned weights vary between 1 and 5 depending on the importance of each considered parameter in determining of the water quality for drinking. In the third step, the relative weight of each parameter was calculated by using the following Eq. 1.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

Where w_i represents the assigned weight value for each parameter, Wi indicates the relative weight and n the total number of considered parameters.

The assigned weight values and relative weight values, the World Health Organization guideline and the relative weight (W) of each parameter considered in determining of the water quality index are given in Table 1. In this study, due to their importance for water quality 5 weighted values can be allocated to NH_4, NO_3, NO_2, TDS, Cl and SO_4 [21]; [18].

In the next phase, the quality-rating scale (Q_i) value of each parameter was determined by using the following Eq. 2.

$$Qi = \frac{(C_i - V_i)}{(S_i - V_i)} * 100$$

(2)

Where C_i represents the estimated concentration value of each parameter, S_i represents the recommended value according to the WHO standards for the quality of drinking water. Except for pH where it is equal to 7, the value of V_i is considered as zero for all other parameters [22]; [18].

In the fifth step, the sub-index value of each parameter is determined according to the following Eq. 3.

$$SI_i = Q_i * W_i$$

(3)

Finally, the Water Quality Index (WQI) for each station is calculated according to the following Eq. 4.

$$WQI = \sum_{i=1}^{n} SI_i$$

(4)

Multivariate analysis methods (Principal Component Analysis (PCA) method, Hierarchical Cluster Analysis (HCA) method and correlation analysis) were also used in this study for to examine the relationship between the hydrogeochemical parameters of samples and for to determine the main source of these parameters. Since almost all of the data collected in the study area does not have a normal distribution, the Spearman correlation analysis method was used to determine the relationships between the physical and chemical parameters of the groundwater sample collected in the study area. When the correlation coefficient is close to 0, there is no relationship between the variables. When this value is greater than 0,7 there is a strong correlation between the variables, when this value varies between 0,5 and 0,7 there is then a moderate correlation between the variables. A very high value (r = +1 or = -1) of the correlation coefficient reflects a strong relationship between the variables [23]; [24].

Principal component analysis used in this study is one of the most used multivariate statistical analysis methods. This method is used to measure and explain the relationships between many variables [25]. The main objective of the principal component analysis method is to reduce the large number of variables under a smaller number of components [18]. Cluster analysis is a multivariate statistical method that is used to classify objects into group based on their similarity. The use of this method in geology and hydrogeology is recent. This method is therefore commonly used to analyze the hydrochemical data of water and complements the principal component analysis method [18].

Table No 1: Assigned weight and relative weight of physicochemical parameters

Parameters	**WHO (2011)**	**Weight (wi)**	**Relative weight (W)**
Ca^{2+}	75	3	0,071428571
Mg^{+}	50	3	0,071428571
Na^{+}	200	4	0,095238095
K^{+}	12	2	0,047619048
Cl^{-}	250	5	0,119047619
HCO_3^{-}	120	1	0,023809524
SO_4^{2-}	250	5	0,119047619
NO_3^{-}	50	5	0,119047619
NO_2^{-}	0,5	5	0,119047619
pH	6,5 - 8,5	4	0,095238095
EC	2500	5	0,119047619
		∑wi = 42	∑Wi = 1

3. RESULTS AND DISCUSSSIONS

3.1 Groundwater suitability for drinking and Water Quality index

The Table 2 indicates the descriptive statistical analyses results of physico-chemical parameters of samples collected in the study area. The pH values varied from 6,90 to 7,5 with an average of 7,22. These pH values corroborate with those obtained by [26] on the aquifers of fissured horizon of the basement of the Niamey region where slightly acidic to neutral waters were observed. The pH values of all water samples were within permitted limit prescribed by [17]. The EC values ranged between 86 and 300 µS/cm with mean value of 154,33 µS/cm. According to WHO, all water samples were found within the acceptable limit of 2500 µS/cm. The Ca^{2+}, Mg^{2+} and K^{+} values are respectively between 5 – 24,68 mg/L, 3 – 16,56 mg/L and 1 – 2 mg/L. The concentrations of sodium varied from 1 to 4 mg/L with an average of 2,18 mg/L. The Na^{+} values of all water samples fall within the WHO guidelines of 200 mg/L. The SO_4^{2-} content varies from 2 to 35 mg/L with mean value of 13,11 mg/L. Based on SO_4^{2-} values, all groundwater samples were within the permissible limit prescribed by WHO guidelines. The concentrations of Cl^{-} are between 1 and 6 mg/L with an average value of 3,39 mg/L. Based on World Health Organization guidelines, all samples were suitable for drinking. The HCO_3^{-} values ranged from 25 to 105 mg/L with an average value of 44,22 mg/L. The concentrations of NO_2^{-} varied between 0,02 and 1,15 mg/L with average value of 0,36 mg/L. According to WHO, excepted water samples from well number GW1, all water samples were found within the acceptable limit of 0,5 mg/L. The NO_3^{-} values varied between 1,11 and 5,74 mg/L with a mean value of 3,21 mg/L. According to WHO guidelines, all water samples were found within the acceptable limit of 50 mg/L.

Table No 2 : Descriptive statistics for physicochemical parameters

Parameters	Minimum	Maximum	Mean	Std. Deviation
Ca^{2+}	5,00	24,68	10,01	6,15
Mg^{2+}	3,00	16,56	7,05	4,46
Na^{+}	1,00	4,00	2,18	0,87
K^{+}	1,00	2,00	1,22	0,44
Cl^{-}	1,50	6,00	3,39	1,32
SO_4^{2-}	2,00	35,00	13,11	10,80
HCO_3^{-}	25,00	105,00	44,22	25,96
NO_3^{-}	1,11	5,74	3,21	1,43
NO_2^{-}	0,02	1,15	0,24	0,36
EC	86,00	300,00	154,33	73,11
pH	6,90	7,50	7,22	0,20
T	30,90	31,90	31,27	0,35

The WQI values of collected groundwater samples are between 6,94 and 43,41 with an average of 21,80 (Table 3). The lowest value of WQI was observed in well number GW8 located in the right bank of Niger river. The highest values of WQI were observed in wells number GW1 located in left bank of Niger river. The Table 4 indicates the classification of water according to the water quality index values [27]. According to this classification all groundwater samples of study area fall in excellent water category class.

Table No. 3: The WQI values of the different water samples

Well number	WQI =∑Sii	Water class
GW1	43,41	Excellent
GW2	22,31	Excellent
GW3	40,38	Excellent
GW4	15,31	Excellent
GW5	13,20	Excellent
GW6	10,35	Excellent
GW7	33,03	Excellent
GW8	6,94	Excellent
GW9	11,26	Excellent
Max	43,41	
Min	6,94	
Mean	21,80	

Table No. 4: Classification of water according to the WQI

WQI level	Water type
< 50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
> 300	Inadequate for drinking

3.2. Hydrochemical Parameters of Groundwater Samples

3.2.1 Statistical analyzes

3.2.1.1 Correlation Analysis

The correlation coefficient matrices for physical and chemical parameters of groundwater samples collected in the study area are presented in Table 5. According to this table, strong correlation value was observed between Ca and Mg (0,979), Ca and K (0,881), Ca and HCO_3 (0,975), Mg and K (0,918), Mg and HCO_3 (0,956), Mg and EC (0,982), Na and Cl (0,998), K and HCO_3 (0,912), K and EC (0,963), HOC3 and EC (0,964), HCO_3 and pH (0,812) EC and pH (0,851). This strong correlation observed between Ca, Mg, K and HCO3 indicated that these ions have the same origin. These ions could all come from the incongruous dissolution of silicate minerals in the study area [26]. Moderate correlations were observed between Ca and Na^+ (0,775), Ca^{2+} and Cl^- (0,732), Ca^{2+} and SO_4^{2-} (0,644), Ca^{2+} and pH (0,751), Mg^{2+} and Na^+ (0,706), Mg^{2+} and Cl^- (0,661), Mg^{2+} and SO_4^{2-} (0,523), Mg^{2+} and pH (0,781), Na^+ and K^+ (0,729), Na^+ and Cl^- (0,681), Na^+ and SO_4^{2-} (0,681), Na^+ and HCO_3^- (0,747), Na^+ and EC (0,674), K^+ and Cl^- (0,693), K^+ and pH (0,782), Cl^- and SO_4^{2-} (0,669), Cl^- and HCO_3^- (0,701), NO_3^- and T (0,607) and NO_2^- and T (0,620).

Table No. 5: Spearman correlation analysis results

	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	HCO_3^-	NO_3^-	NO_2^-	EC	pH	T
Ca^{2+}	1	0,979	0,775	0,881	0,732	0,644	0,975	0,012	0,099	0,953	0,751	-0,145
Mg^{2+}	0,979	1	0,706	0,918	0,661	0,523	0,956	0,107	0,167	0,982	0,781	-0,056
Na^+	0,775	0,706	1	0,729	0,998	0,681	0,747	,056	-,014	0,674	,395	-,375
K^+	0,881	0,918	0,729	1	0,693	0,335	0,912	0,039	-0,017	0,963	0,782	-0,187
Cl^-	0,732	0,661	0,998	0,693	1	0,669	0,701	0,081	-0,010	0,628	0,351	-0,371
SO_4^{2-}	0,644	0,523	0,681	0,335	0,669	1	0,557	0,039	0,073	0,441	0,346	-0,202
HCO_3^-	0,975	0,956	0,747	0,912	0,701	0,557	1	-0,163	0,060	0,964	0,812	-0,244
NO_3^-	0,012	0,107	0,056	0,039	0,081	0,039	-0,163	1	0,314	0,029	-0,104	0,607
NO_2^-	0,099	0,167	-0,014	-0,017	-0,010	0,073	0,060	0,314	1	0,104	0,260	0,620
EC	0,953	0,982	0,674	0,963	0,628	0,441	0,964	0,029	0,104	1	0,851	-0,086
pH	0,751	0,781	0,395	0,782	0,351	0,346	0,812	-0,104	0,260	0,851	1	0,076
T	-0,145	-0,056	-0,375	-0,187	-0,371	-0,202	-0,244	0,607	0,620	-0,086	,076	1

3.2.1.2 Principal Components Analysis and R-mode Hierarchical Cluster Analysis

As part of this study principal component analysis and hierarchical cluster analysis methods have been used using the variables such as calcium, nitrate, magnesium, nitrite, potassium, sodium, bicarbonate, chloride, sulfate, pH, temperature and electrical conductivity.

The rotated factor loading values, the proportion of total variance of each component and their eigenvalues were summarized in Table 6.

According to Table 6, three principal factors with eigenvalues greater than one have been formed. These three factors alone explain 87,18 % of the total variance. Factor 1 accounts for 58,577%, Factor 2 accounts 17,91 % and Factor 3 accounts 10,698 % of the total variance (Table 6). These three principal components can help to determine the principal sources of hydrochemistry of groundwater in the study area. The spatial distribution of principal components is given in Fig. 3. According to Table 6 and Figure 3, the Factor 1 which represents 58,577 % of total variance is mainly linked with strong positive loading of pH (0,935), EC (0,935), EC (0,933), HCO_3 (0,898), Mg (0,879), K (0,867) and Ca (0,834). The elements which define this factor come from a long period of dissolution following the water-rock contact. The abundance of Ca, Mg, K and HCO_3 ions in basement aquifer of study area is confirmed by several studies carried out in West Africa [2]; [28]. These elements come from the hydrolysis of the minerals present in the rocks which constitute the reservoirs. Indeed, hydrolysis being a slow process, the factor 1 represents the phenomenon of mineralization-residence time. The presence in this group of the majority of variables supported by mineralization, shows the influence of alteration-hydrolysis in the dissolution of ions [29]. The higher levels of Ca compared to Na^+ observed in the groundwater samples of the study area indicate that these ions which constitute factor 1 come mainly from the hydrolysis of calcium plagioclases such as anorthite. Theses Calcium plagioclases such as anorthite appear to be the dominant feldspars in rocks in the area [26]. The score plot of the water samples (Fig. 4) showed that the samples which are more influenced by Factor 1 are wells number GW3 and GW7. The Factor 2 which represents 17,91 % of total variance is principally connected with positive high loading of Cl (0,884), Na (0,866) and moderate loading of SO_4 (0,762). The Cl, Na and SO4 observed in this group could be due to anthropic activities that taking place in the region of Niamey. In addition to anthropogenic activities the accumulation of these ions can be due to the process of intense evaporation which could result in the concentration of these ions in the crystalline basement aquifers [26]. The work carried out by [30] to assess the hydrogeochemistry of groundwater in Air crystalline aquifer suggested that the presence of Cl and SO4 in crystalline basement aquifer could be explained by the volcanic activities in the Air, likely to release chlorine and sulfides. The score plot of the water samples (Fig. 4) showed that the samples which are more influenced by Factor 2 are groundwater samples from stations number GW3, GW9 and GW6. The Factor 3 which represents 10,698 % of total variance is associated with strong positive loading of T (0,895), NO_3 (0,801) and moderate loading of NO_2 (0,764). The presence of NO_2 and NO_3 in this factor indicates the pollution of groundwater caused by anthropogenic activities that take place in the study area. The score plot of the water samples (Fig. 4) showed that the samples which are more influenced by Factor 3 are groundwater samples from stations number GW1 and GW2. The R-mode cluster analysis result that was realized in this study to determine the association of physico-chemical parameters based on their similarities and sources is given in Figure 5. According to the result of this R-mode cluster analysis, 3 principal groups of variables were formed. The first group includes Na, Cl and SO_4; the second group consists of Mg, EC, Ca, HCO_3, K and pH; and the third group includes T, NO_3 and NO_2. This R-mode cluster analysis method results confirm the results obtained in principal component analysis method where the same groups were observed.

Table No. 6: Rotated factor loading, total variance explained and eigenvalues of each factor

	Component		
	1	2	3
pH	**0,935**	0,008	0,094
EC	**0,933**	0,329	0,031
HCO_3^-	**0,898**	0,407	-0,126
Mg^{2+}	**0,879**	0,420	0,106
K^+	**0,867**	0,371	-0,059
Ca^{2+}	**0,834**	0,514	0,012
Cl^-	0,376	**0,884**	-0,092
Na^+	0,431	**0,866**	-0,105
SO_4^{2-}	0,252	**0,762**	0,019
T	-0,007	-0,325	**0,895**
NO_3^-	-0,162	0,279	**0,801**
NO_2^-	0,183	-0,076	**0,764**
Eigenvalues	7,029	2,149	1,284
% of variance	58,577	17,910	10,698

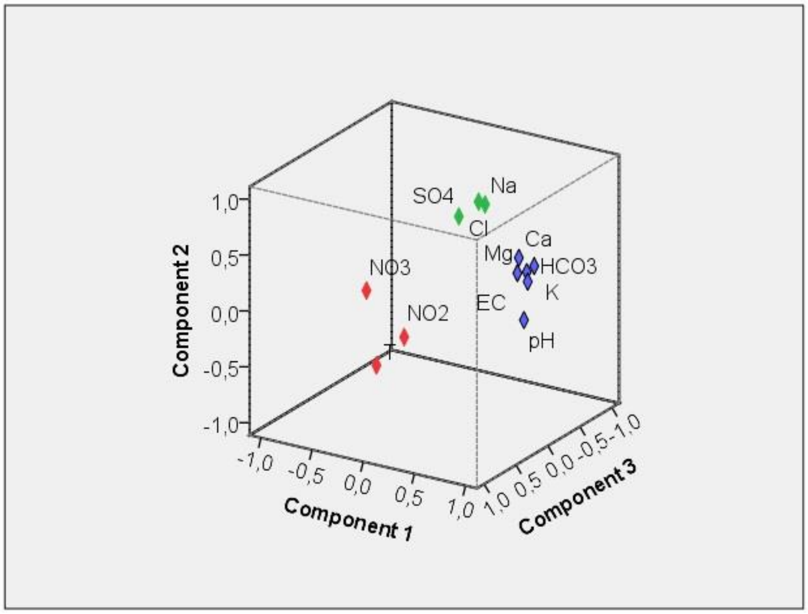

Figure No. 3: Spatial distribution of principal components

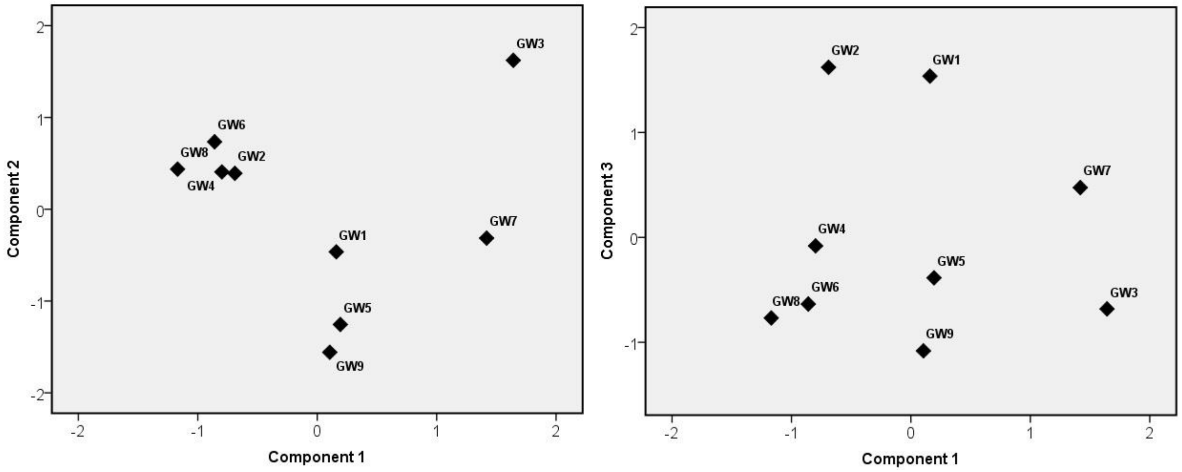

Figure No. 4: score plot of different water samples

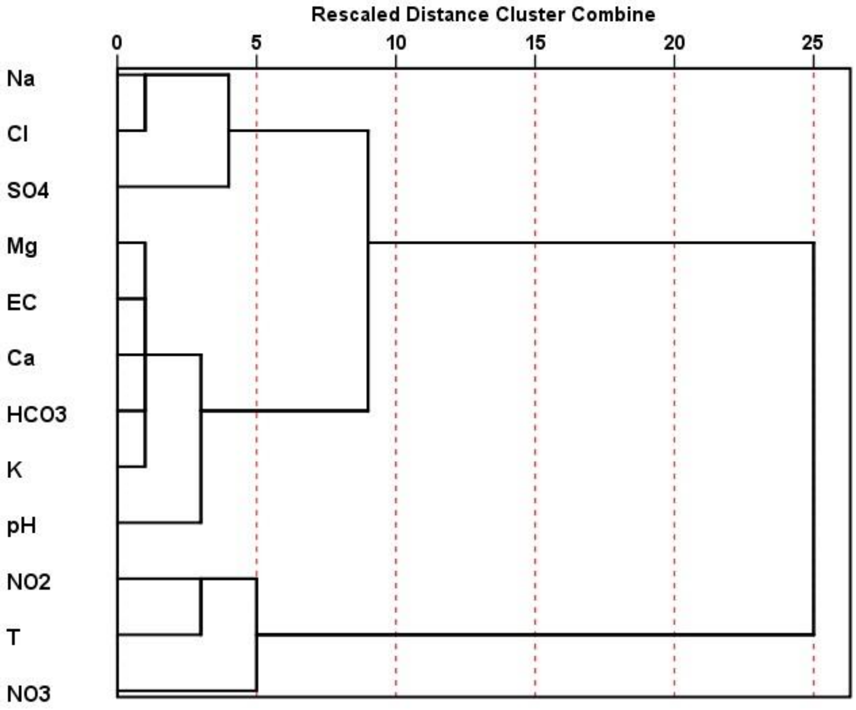

Figure No. 5: Dendogram of R-mode cluster analysis result

3.2.2 Piper, Shoeller and Chadha Diagrams

Piper classification diagram used in this study to determine the hydrochemical facies that control groundwater illustrated two different water types in the study area, which are calcium-magnesium bicarbonate facies ($CaMgHCO_3$) and calcium-chloro-sulfate ($CaSO_4Cl$) (Figure 6). The $CaMgHCO_3$ water type, which is dominant in the study area, represents around 78% of analyzed samples. This result is in agreement with that of several authors who have worked in West Africa and all of which have come to the conclusion that the bicarbonate facies is the most represented in basement aquifer waters [2]; [28]; [31]; [32]. The abundance in the study area of this water type that is characterized by the dominance of Ca and HCO_3 ions reveals a strong carbonate rock-water interaction and strong recharge process. The dominance of the bicarbonate facies in basement waters can be traced back to the origin of the production of bicarbonate ions. In fact, bicarbonates are mainly produced by the alteration of silicates during the acquisition of the saline load of water in the aeration zone [33]. The predominance of the calcium-magnesium bicarbonate facies indicates a homogeneous character to the waters of the study area. Indeed, the precambrian basement under Niamey region is mainly formed with granitoids (mainly granites and granito-gneiss), paraderivate schists (sericite-schists), metabasites (metabasalts) and amphibolites. Granitoids occupy the south-eastern half of the Niamey map while schists occupy the other half with a low proportion of metabasites. The alteration of silicate minerals of granites gives new silicate minerals, often of the clay family such as montmorillonite (smectite family) and kaolinite with the dissolution of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} [26].

The calcium chloro-sulfate water types represent 22% of analyzed samples and were observed in GW6, and GW2 wells number which are located in the right bank and left bank of Niger River, respectively. This facies indicated also the forte proportion of the sum of Cl, SO4 and NO3 in these samples compared to the sum of HCO_3^- and CO_3^{2-}. The forte proportion of sum of Cl, SO_4^{2-} and NO_3^- observed in these wells could be due to anthropic activities that take place in the region of Niamey. In addition to anthropogenic activities the accumulation of these ions can be due to the process of intense evaporation which could result in the concentration of these ions in the crystalline basement aquifers [26].

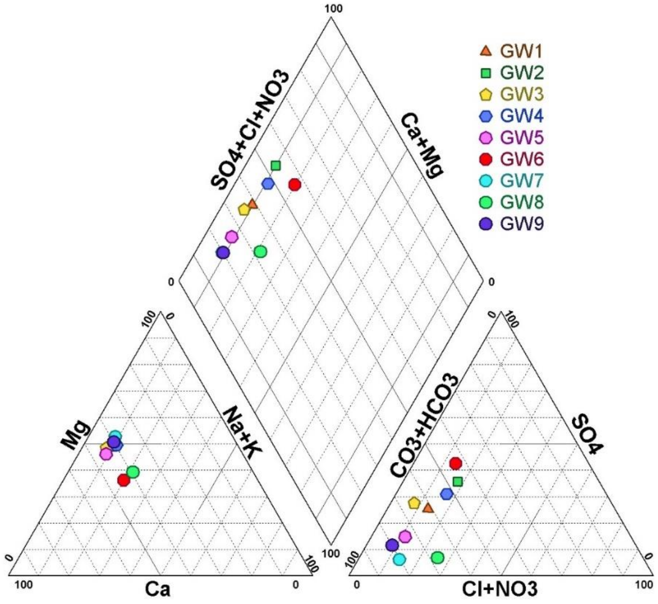

Figure 6: Piper diagram

According to the semi-logarithmic Schoeller diagram [34] (Figure 7), in the majority of the samples, the cations sequence of groundwater samples is $rMg^{2+} > rCa^{2+} > r\ (Na^{+} + K^{+})$ and the anions sequence is $r\ (HCO_3{}^{-} + CO_3{}^{-}) > rSO_4{}^{2-} > r\ Cl^{-} > r\ NO_3{}^{-}$. This diagram shows that the graphs are generally parallel to each other, suggesting that the proportions of the different major ions in the samples are the same, but the overall concentration differs.

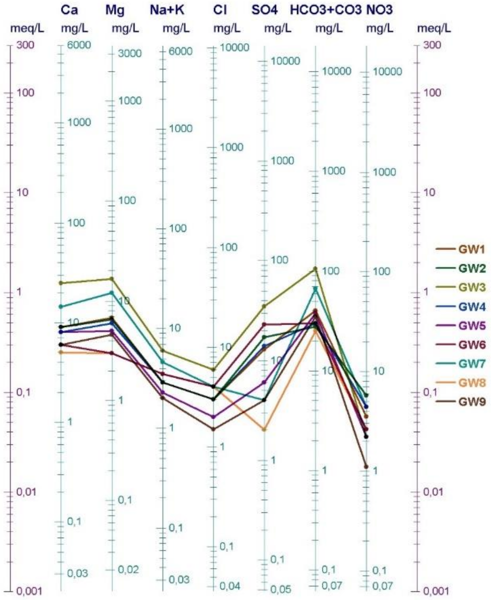

Figure 7: Shoeller diagram

In this study, Chadha diagram [35] is used in general for the classification of natural waters as well as the identification of hydrochemical process. This diagram is constructed by plotting on the X-axis the difference between earths and alkali metals ((Ca^{2+}+Mg^{2+}) – (Na^{+}+K^{+})) against weak acidic anions and strong acidic anions ((HCO_3^{-}+CO_3^{2-}) – (SO_4^{2-}+ Cl^{-})) on the Y axis, of water data expressed as milliequivalent percentage. The milliequivalent proportion differences from the axis X and Y are prolonged further into the principal study subfields of the proposed diagram, which defines the global character of water [35].

According to this diagram (Figure 8), four water facies were observed in the study area which are $CaHCO_3$, Ca-Mg-Cl, NaCl and $NaHCO_3$ (Figure X). The $CaHCO_3$ water type that falls in field 5 of diagram is the most widespread in the study area and represents around 88,89% of analyzed groundwater samples. This dominant water type reveals as in the piper diagram, principal component analysis and hierarchical cluster analysis methods that the weathering of host rocks and recharge process are most important in the study area [35]. However, the well number GW6 that falls in field 6 of diagram is Ca-Mg-Cl-SO_4 water type.

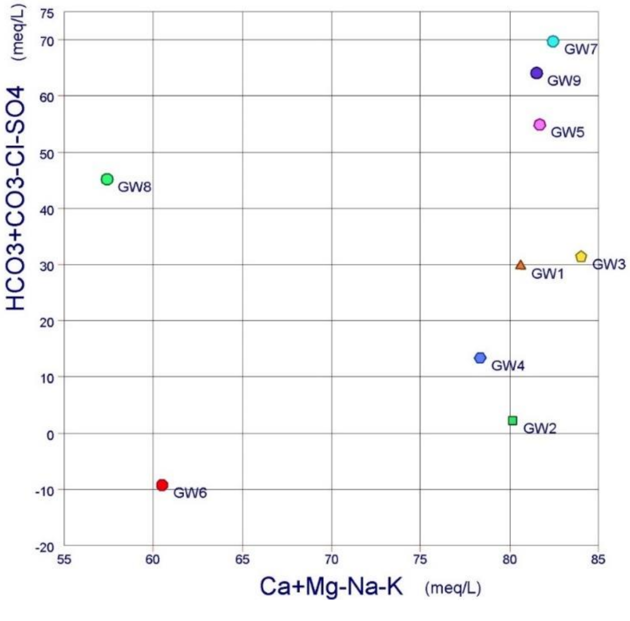

Figure 8: Chadha diagram

4. CONCLUSIONS

This study investigated the hydrogeochemical processes controlling groundwater chemistry from the basement aquifer of Peripheral areas of the Niamey region and assessed its quality for drinking. The WQI values of groundwater samples collected in the study area showed that all samples fall in excellent water category class. According to Principal component analysis method, 3 principal components which represent 87,18 % of the total variance. the Factor 1 which represents 58,577 % of total variance is mainly linked with strong positive loading of pH (0,935), EC (0,935), EC (0,933), HCO_3 (0,898), Mg (0,879), K (0,867) and Ca (0,834). The Factor 2 which represents 17,91 % of total variance is principally connected with positive high loading of Cl (0,884), Na (0,866) and moderate loading of SO_4 (0,762). The Factor 3 which represents 10,698 % of total variance is associated with strong positive loading of T (0,895), NO_3 (0,801) and moderate loading of NO_2 (0,764). According to correlation analysis, strong correlation value was observed between Ca and Mg (0,979), Ca and K (O,881), Ca and HCO_3 (0,975), Mg and K (0,918), Mg and HCO_3 (0,956), Mg and EC (0,982), Na and Cl (0,998), K and HCO_3 (0,912), K and EC (0,963), HOC3 and EC (0,964), HCO_3 and pH (0,812) EC and pH (0,851) indicating that these ions have the same origin. Piper diagram illustrated two different water types in the study area, which are calcium-magnesium bicarbonate facies ($CaMgHCO_3$) and calcium chloro-sulfate ($CaSO_4Cl$). According to the Chadha diagram four water facies were observed in the study area which are $CaHCO_3$, Ca-Mg-Cl, NaCl and $NaHCO_3$. Schoeller diagram demonstrated that in the majority of the samples, the cations sequence of groundwater samples is $rMg^{2+} > rCa^{2+} > r\,(Na^+ + K^+)$ and the anions sequence is $r\,(HCO_3^- + CO_3^-) > rSO_4^{2-} > r\,Cl^- > r\,NO_3^-$.

REFERENCES:

[1] J.D Hem, (1985). *Study and interpretation of the chemical characteristics of natural water* (Vol. 2254). Department of the Interior, US Geological Survey, vol 2254

[2] M.S. A. Babaye,I Sandao, M.B. Saley,I Wagani, and B. Ousmane, (2016). Comportement hydrogéochimique et contamination des eaux des aquifères fissurés du socle précambrien en milieu semi-aride (Sud-Ouest du Niger). International Journal of Biological and Chemical Sciences, 10 (6) 2728-2743.

[3] K.T. Yao, (2009). Hydrodynamisme dans les aquifères de socle cristallin et cristallophyllien du Sud-Ouest de la Côte d'Ivoire: cas du département de Soubré: apports de la télédétection, de la géomorphologie et de l'hydrogéochimie. Doctoral dissertation, Conservatoire national des arts et metiers-CNAM ; Université de Cocody-Côte d'Ivoir,.

[4] S.M. Rabilou, M.A. M. Mousbahou, M.S. Laouali, N. Ibrahim and I. Habou, (2018). Caractérisation Physico-Chimique Des Eaux Souterraines Du Socle De La Région De Zinder (Niger) Pendant La Saison Des Pluies Et La Saison Sèche.ESJ 14 (27).

[5] A. Sako, O. Bamba and A. Gordio, (2016). Hydrogeochemical processes controlling groundwater quality around Bomboré gold mineralized zone, Central Burkina Faso. *Journal of Geochemical Exploration, 170* 58-7.

[6] K. Walraevens,C. Bakundukize, Y.E. Mtoni and M. Van Camp, (2018). Understanding the hydrogeochemical evolution of groundwater in Precambrian basement aquifers: A case study of Bugesera region in Burundi. *Journal of Geochemical Exploration*, *188* 24-42.

[7] H. Nkotagu, (1996). The groundwater geochemistry in a semi-arid, fractured crystalline basement area of Dodoma, Tanzania. *Journal of African Earth Sciences*, *23*(4) 593-605.

[8] M.N. Tijani, (1994). Hydrogeochemical assessment of groundwater in Moro area, Kwara State, Nigeria. *Environmental geology*, *24*(3) 194-202.

[9] J.P. Chippaux et al., (2002). Etude de la pollution de l'eau souterraine de la ville de Niamey, Niger. *Bull Soc Pathol Exot* 94.2 119-123

[10] M. Lasagna, G.A. Dino, L. Perotti, F.Spadafora, D.A De Luca, G. Yadji and M. Konaté, (2015). Georesources and environmental problems in Niamey city (Niger): a preliminary sketch. *Energy Procedia*, *76* 67-76.

[11] A.B. Hassane, C. Leduc, G. Favreau, B.A Bekins and T. Margueron, (2016). Impacts of a large Sahelian city on groundwater hydrodynamics and quality: example of Niamey (Niger). *Hydrogeology journal*, *24*(2) 407-423.

[12] L. Le Barbé and T. Lebel, (1997). Rainfall climatology of the HAPEX-Sahel region during the years 1950–1990. *Journal of hydrology*, *188* 43-73.

[13] J. Lang, C. Kogbe, S. Alidou, K.A. Alzouma, G. Bellion, D. Dubois, A. Durand, R. Guiraud, A. Houessou, I. de Klasz, E. Romann, M. Salard-Cheboldaeff, J. Trichet, (1990). The continental terminal in West Africa. Journal of African Earth Sciences (and the Middle East). Volume 10 Issues 1-2 pages 79-99.

[14] J. Greigert, (1966). Description des formations crétacées et tertiaires du bassin des Iullemmeden (Afrique occidentale). Publ. Dir. Mines et Géologie Niger, Bur.Rech.Géol.Min, p. 234.

[15] J.P. Vicat, J.M. Leger, Y. Ahmed, L. Willems, (1994). Les indices de déformations plioquaternaire de la bordure occidentale du bassin des Iullemmeden dans la région de Niamey. Rev. Géographie Alpine, Au Contact Sahara-Sahel. Vol.1 15-25.

[16] A.M. Piper, (1944). A graphical procedure in the geochemical interpretation of water analysis. Trans Am Geophys Union, 25 914–923.

[17] World Health Organization, (2011). Guidelines for Drinking-Water Quality. Vol. 4 World Health Organization. WHO, Geneva

[18] A.M. Hassan and A. Fırat Ersoy, (2022). Statistical assseement of seasonal variation of groundwater quality in Çarşamba coastal plain, Samsun (Turkey). Environ Monit Assess 194 135.

[19] O. Arkoç, (2016). Application of Water Quality Index with the Aid of Geographic Information System in Eastern Thrace to Assess Groundwater Quality. Geological Engineering Journal/Jeoloji Mühendisligi.

[20] F.A Kondum, R.T Iwar and E.T Kon, (2021). A Comparison of Water Quality Indexes for an Inland River. *Journal of Engineering Research and Reports*, 1-14.

[21] C.B Karakuş, (2019). Evaluation of groundwater quality in Sivas province (Turkey) using water quality index and GIS-based analytic hierarchy process. International journal of environmental health research, 29(5) 500-519. https://doi.org/10.1080/09603123.2018.1551521.

[22] R.M. Chowdhur, S.Y. Muntasir and M.M. Hossain, (2012). Water quality index of water bodies along Faridpur-Barisal road in Bangladesh. Glob Eng Tech Rev, 2(3) 1-8.

[23] M. Kumar, A.L. Ramanathan, M.S. Rao and B. Kumar, (2006). Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi. India Environ Geol, 50(7) 1025–1039. https://doi.org/10.1007/s00254-006-0275-4

[24] A.M. Hassan and A.F. Ersoy and N.A. Turan, (2021). Assessment of heavy metal(loids) in groundwater by multivariate statistical analysis and metals pollution indices: a case study of Çarşamba coastal aquifer, North Turkey. Arab J Geosci 142658.

[25] F. Çakır, (1994). Karşılıklı Bağımlılığın Ölçüsünde Kümeleme Analizi ve Bir Uygulama. Master's thesis Marmara University. https:// katalog.marmara.edu.tr/eyayin/tez/T0041974.pdf

[26] A.B. Hassane, (2010). Aquiferes superficiels et profonds et pollution urbaine en Afrique: cas de la communauté urbaine de Niamey (Niger). Doctoral dissertation, Université Abdou Moumouni,.

[27] S.M. Yidana and A.Yidana, (2010). Assessing water quality using water quality index and multivariate analysis. Environmental Earth Sciences, 59(7) 1461-1473.

[28] T. Lasm, O. De Lasme, M.S. Oga, M.Youanta, D. Baka, F. Kouame and T.K. Yao, (2011). Caractérisation hydrochimique des aquifères fissurés de la région de San-Pedro (Sud-Ouest de la Côte d'Ivoire). International Journal of Biological and Chemical Sciences, 5(2).

[29] F. Chemseddine, B. Abderrahmane, R. Abdelkader and S. Elias, (2009). Caractérisation hydrogéochimique des eaux souterraines du complexe aquifère Morsott-Laouinet (Région Nord de Tébessa, Sud-Est algérien). Afrique Science : Revue Internationale des Sciences et Technologie, 5(2).

[30] I. Alhassane, A.B.M Sani, S. Issoufou and I.M.S Souleymane, (2019). Caractérisation Hydrogéochimique des Aquifères du Bassin de Timia (Massif de l'Aïr, Nord du Niger). ESJ, 15 (30).

[31] M.S. Oga, T. Lasm, K.T. Yao, N. Soro, M.B. Saley, D. Kouassi, F. Gnamba, (2009). Caractérisation chimique des eaux des aquifères de Fracture: cas de la région de Tiassalé en Côte D'ivoire. European Journal of Scientific Research, 31 (1) 72- 87.

[32] M.A. Kouassi, E.K. Ahoussi, B.Y. Koffi, Y.A. Ake and J. Biemi, (2012). Caractérisation hydrogéochimique des eaux des aquifères fissurés de la zone Guiglo-Duekoué (Ouest de la Côte d'Ivoire). *International Journal of Biological and Chemical Sciences*, *6*(1) 504-518.

[33] T.B.I.B. Bouazza, (2018). Caractérisation hydrogéochimique des aquifères fissurés de la région du Bélier (Centre de la Côte d'Ivoire). *Moroccan Journal of Engineering Sciences*, *1*(2).

[34] H. Shoeller, (1965). Quantitative evaluation of groundwater ressources. In: Methods and techniques of groundwater investigations and development, UNESCO, pp 54-83.

[35] D.K. Chadha, (1999). A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. Hydrogeol J, 7(5) 431–439. https://doi.org/10.1007/s100400050216

[36] A.M Hassan and A. Firat Ersoy, (2022). Hydrogeochemical and isotopic investigations on the origins of groundwater salinization in Çarşamba coastal aquifer (North Turkey). *Environmental Earth Sciences*, *81*(4) 1-19.