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Evaluation of the Physico-Chemical Quality and Potability of Groundwater Consumption in Department of Collines at Benin

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Abstract

The purpose of this study is to assess the physical and chemical quality of borehole water intended for consumption in the collines department in Benin. At the end of a sampling campaign, twenty-one (21) drinking water points were sampled. Different physico-chemical parameters were measured using standard analysis methods. The results of the analysis of the samples, showed that the groundwater of the department of the hills is characterized by a neutral pH and an average electrical conductivity in accordance with the WHO and Benin standard relating to the potability of groundwater. With this pH neutrality which would be linked to the nature of geological formations made up of crystalline rocks, the water in the hills is moderately hard with hardness values of 208 mg/L on average for magnesium ions of 22.54 mg/L on average and calcium ions of the order of 46.03 mg/L on average at the scale of the various localities and an alkalinity is of 43.81 mg/L on average. The NO_3^- values between 0 and 163.91 mg/L are low in the South-East and very high, even exceeding the standard accepted by WHO in the West and North-East of the study area. This nitrate pollution and the fairly high levels of organic matter in total nitrogen observed in the groundwater of the hills could also have an impact on the vulnerability of the water table. And this pollution with nitrates associated with electrical conductivity and chloride levels modifies and degrades from one drinking water point to another the potability of underground water in the hills.

Keywords

Collines Department, Physico-Chemical Parameters, Groundwater, Physico-Chemical Parameters, Potability of Underground Water

1. Introduction

Benin has a significant renewable water resource potential estimated on average at 13 billion cubic meters per year for surface water and an average annual recharge of about 2 billion cubic meters for groundwater (Azonsi et al., 2009). In terms of uses, around 90 million cubic meters of water are currently withdrawn from available groundwater resources, it's mean less than 5% of the potential, while surface water reservoirs can only store one around thirty million cubic meters, or less than 0.3% of surface water resources drained by the country's hydrographic network (Directorate General for Water, DG Eau 2006). In basement regions, groundwater resources are the most in demand for the DWS because of their technically favorable and financially less costly operating conditions. Suddenly, there is strong pressure on this component that can affect its availability in quantity and quality in the medium and long term (Tossou, 2016).

In the Collines department in Benin, a region known to be hydrogeologically difficult where the drinking water supply sector is dependent on groundwater, the excessive use of chemical fertilizers and pesticides to increase agricultural yields constitutes a danger for the quality of groundwater. It should be remembered that the quantitative and qualitative composition of groundwater in dissolved and suspended matter, of mineral or organic nature, determines its quality (Jain et al., 2005) and this quality can be altered when external substances enter in contact with the aquifer. This is the case with undesirable or even toxic substances which make groundwater and surface water unsuitable and toxic for various uses, in particular for the use of drinking water (Méhounou et al., 2016).

The poor quality of drinking water is a public health problem (WHO, 1981; World Health Organization, 2006). Thus, since the different water user and consumer sectors can induce more or less negative effects on the quality of groundwater resources, it is important that this water be subject to systematic and regular analyzes of its quality. This reflects the objective of this study, which is to assess the physical and chemical quality of borehole water intended for consumption in the hills Department in Benin.

2. Materiel and Methods

2.1. Hydrogeological Framework of the Study

The Hills Department, which covers an area of 13,931 km^2, is located between 7˚27'' and 8˚46'' North latitude and between 1˚39'' and 2˚44'' East longitude. Rainfall and temperature are two factors that influence the availability of water in hill towns. The rainfall regime follows a bimodal distribution in the South and unimodal distribution in the North (Bokonon-Ganta, 1987; Boko, 1988; Afouda, 1990; Houssou, 1998; Ogouwalé, 2006). And despite the amount of water flowing and seeping in, drinking water supply remains problematic due to the geological nature of the subsoil.

Geologically, the department of hills is located on the scale of the structural unit of the plain of Benin and presents a great complexity of geological formations affected by several phases of deformation, metamorphism and magmatism (Boukari, 1982). **Figure 1** shows outcropping lithological formations. In the southern part, migmatitic and gneissic formations are exposed, intruded by granitic plutons in circumscribed masses and a volcano-sedimentary series (Breda, 1989; Adissin, 2012). These outcrops have a general north-south direction (Dubroeucq, 1967). In the Northeast, we observe in places, plutons of porphyroid granite with biotite appearing in the form of plissote massifs placed in the host gneissic to migmatitic, the North-West being dominated by migmatites and gneiss of the Pira group.

Studies (Kamagaté, 2006; Kamagaté et al., 2007; El-Fahem, 2008; Kamagaté et al., 2008) on the hydrogeology of the basement aquifers of Benin, particularly in the upper valley of the Ouémé and on the characteristics of the aquifers in the study area, particularly in its southern part in Dassa-Zoumé and its surroundings (Boukari, 1982; 2007) have shown the existence of two main reservoirs,

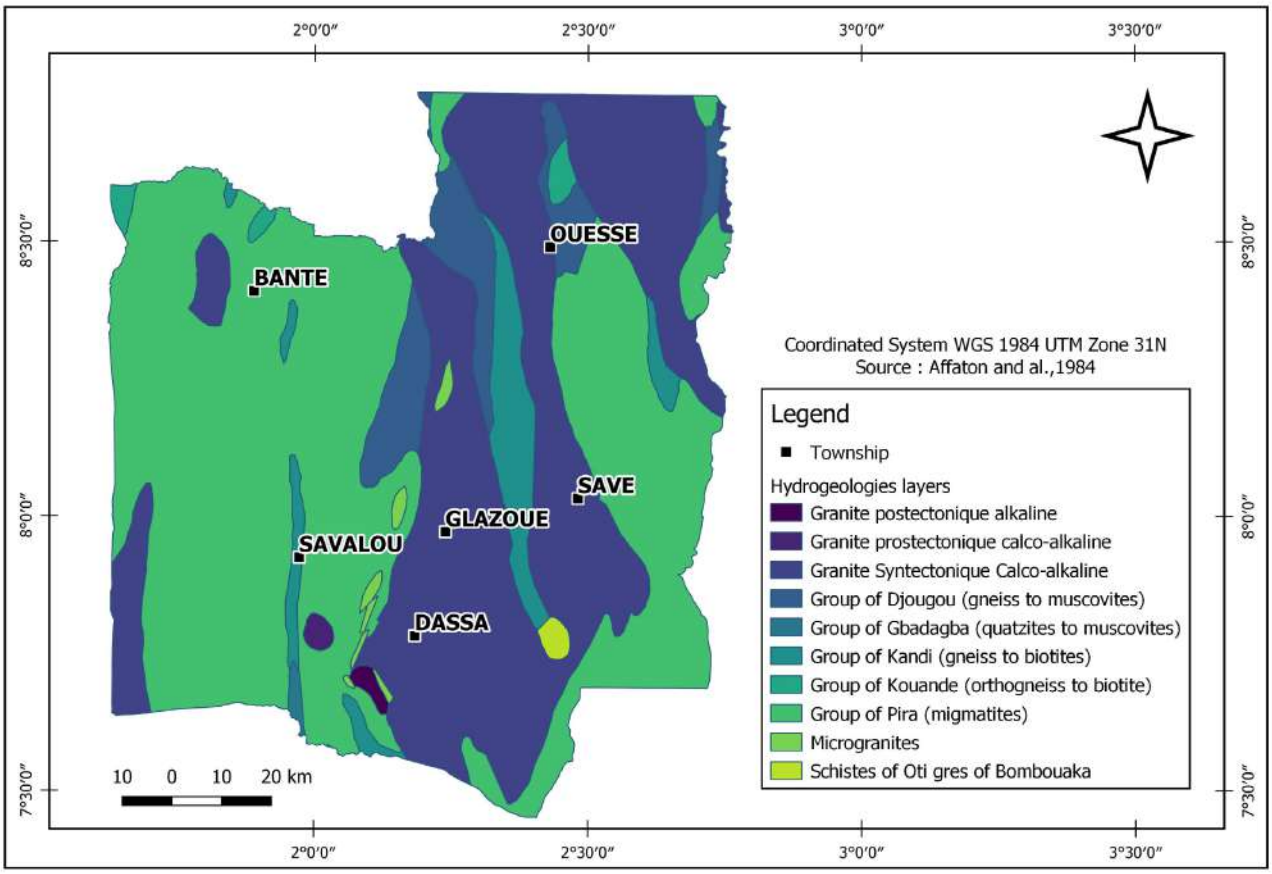


Figure 1. Geological map at the scale of the hills department.

superimposed and in permanent contact, which characterize the study area. According to the authors, these aquifer systems are made of a superficial alterite reservoir made up of the semi-permeable alteration product of the underlying healthy rock, characterized by a good capacitive function and whose water table is fed from the surface by rainfall recharge; and an underlying reservoir of cracks and fractures allowing drainage of the upper loose cover with interstitial porosity.

2.2. Sampling and Assay Methods

The assessment of the physico-chemical quality of groundwater in the hills was possible using water sampling taken during a campaign in October 2019. Thus, the physico-chemical parameters measured in situ and at laboratory, were used to assess the quality of this drinking water.

- **Sampling**

Sampling was done at 21 water points which are boreholes intended for the drinking water supply (DWS). Figure 2 shows the spatial distribution of the sampling points. The size of the sample covers the south of the department widely. To do this, 1.5 liter plastic bottles previously washed and rinsed in the laboratory were completely filled with water. These are then hermetically sealed to prevent any gas leakage. At the same time, a 250 ml glass beaker rinsed with

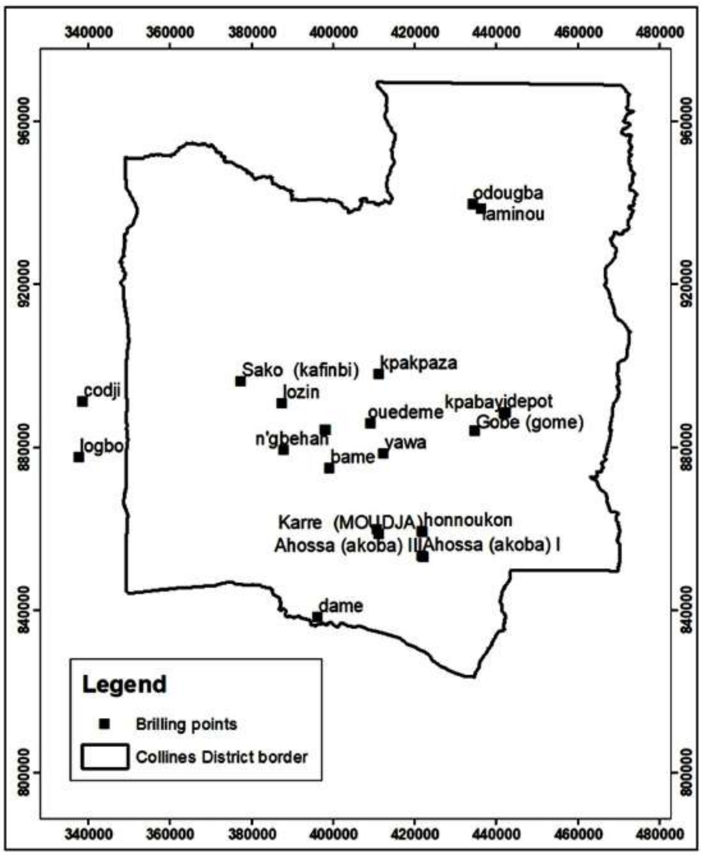


Figure 2. Spatial distribution of sampling points in the Hills.

the water to be analyzed (before taking measurements) and with distilled water (before any new sampling) was used for in situ measurements of pH, conductivity and TDS. Once the samples have been taken, the vials of bottles are placed in a cooler containing ice to be stored at a temperature of 4˚C until the Central Laboratory for Water Analysis (LCAE) of the Directorate General for Water (DG-Eau); where they are kept at the same temperature until the date of analysis.

- **Assay methods**

The pH, the temperature (T˚C), the total dissolved salt (TDS) and the Electrical Conductivity (CE) were measured by a pH/Oxi meter WTW 340i whose probe rinsed and immersed in a beaker containing the sample displays on the screen and after stabilization, the relative values of the three parameters *in situ*.

Chemical parameters such as calcium (Ca^{2+}), magnesium (Mg^{2+}) and chloride (Cl^-) are measured by the volumetric method. Other parameters including color, sulfate (SO_4^{2-}), nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), fluoride (F^-), iodide (I^-), Ammonium (NH_4^+) and iron (Fe^{2+}) are made by the method of spectrometry. The assay protocols for these parameters were made by standard analysis methods as described by Rodier et al., (2009) or according to the catalogs of the equipment used.

3. Analysis Results

3.1. Normalized Principal Component Analysis (ACPN)

The statistical study carried out by ACPN gives numerous results which are presented in Table 1 and Table 2. In Table 1, are recorded the eigenvalues, the variances expressed for each factor and their accumulations. The factor F1, with an expressed variance of 47.58% is the most important of all, then the factors F2, F3, F4 and F5 with respectively 13.06%; 10.33%; 7.36%; and 6.07% of the expressed variance.

These five factors reflect most of the information sought and make it possible to represent the cloud of points in a significant way because the sum of the variance expressed by these factors is 84.40%. The contribution of the different variables in the definition of the main factors is given in Table 2. Each factor is defined by a certain number of essential variables in the demonstration of the mechanism of water mineralization. This table shows that the factor F1, the most important is defined by the electrical conductivity, the hardness, the alkalinity and the ions Cl^-, Mg^{2+}, Ca^{2+}, HCO_3^-, NO_3^-, SO_4^{2-} in opposition to the ions Fe^{2+}, NH_4^+, NO_2^- and I^-.

Table 1. Eigenvalues and percentages expressed for the main axes.

	F1	F2	F3	F4	F5
Own value	9.04	2.48	1.96	1.40	1.15
Variance expressed (%)	47.58	13.06	10.33	7.36	6.07
Cumulative variance expressed (%)	47.58	60.64	70.97	78.33	84.40

Table 2. Correlations between variable and factor.

	F1	F2	F3	F4	F5
Ph	−0.04	0.67	0.46	−0.35	0.11
TDS	−0.91	0.30	0.01	0.21	−0.02
CE	−0.92	0.29	−0.02	0.21	0.01
T, ˚C	−0.29	0.67	0.43	−0.09	0.10
Color	0.60	0.18	−0.46	0.13	0.31
Mg	−0.88	0.18	−0.30	−0.11	0.01
Ca	−0.89	−0.10	−0.18	−0.04	−0.02
Cl	−0.90	0.31	−0.11	0.20	0.11
HCO_3	−0.71	−0.17	−0.36	−0.42	−0.16
NH_4	0.62	0.58	−0.35	−0.14	−0.27
NO_3	−0.75	0.12	−0.05	0.11	0.20
NO_2	0.63	0.53	−0.37	−0.09	−0.33
PO_4	−0.03	−0.22	0.16	0.46	−0.73
Fe	0.71	0.00	−0.18	0.23	0.39
SO_4	−0.56	0.37	0.09	0.57	−0.07
F	−0.28	−0.10	0.74	−0.33	−0.12
I	0.65	0.58	−0.14	−0.10	−0.21
Hardness	−0.93	0.05	−0.26	−0.08	0.00
Alcalinity	−0.71	−0.17	−0.36	−0.42	−0.16

Significant links existing between the different parameters are given by the correlation matrix. These links reflect the different correlations that exist between the parameters analyzed. Based on the critical correlation coefficient r = 0.64 (Mangin, 1970), electrical conductivity is strongly correlated with the majority of ions (r > 0.5). Note that electrical conductivity (EC) describes the inorganic salts present in solution in water. The space of the variables of the factorial plane F1 - F2 (**Figure 3**) shows that this plane expresses 60.64% of the expressed variance. Factor F1 (47.58%) is determined by EC, hardness, alkalinity and Cl^-, Mg^{2+}, Ca^{2+}, HCO_3^-, NO_3^-, SO_4^{2-} ions, as opposed to Fe^{2+}, NH_4^+, NO_2^- and I^- ions. The elements which define this factor come from a long duration of solution following the water-rock contact. These elements come from the hydrolysis of minerals present in the rocks which constitute the bedrock of the aquifers which shelter the waters of the region. Indeed, hydrolysis being a slow process, factor F1 therefore expresses the phenomenon of mineralization-residence time. The grouping of the majority of the variables supported by mineralization, around this axis shows the influence of alteration-hydrolysis in the dissolution of ions. The presence of NO_3^- on this axis reveals that the mineralization of water is accompanied by anthropogenic pollution.

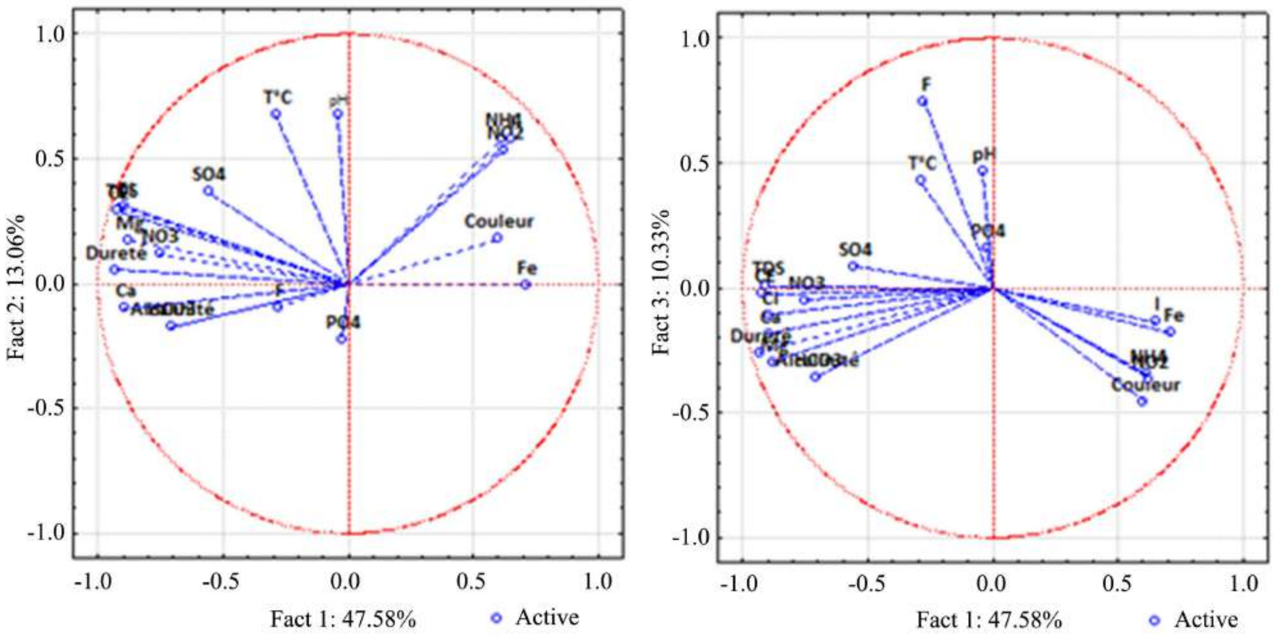


Figure 3. Analysis of variables in the factorial plane F1 - F2 and F1 - F3.

The opposite ions of Fe^{2+}, NH_4^+, NO_2^- et I^- drain the pole of colored waters rich in Fe^{2+}, NH_4^+, NO_2^- et I^-. Factors F2 and F3 respectively explain 13.06% and 10.33% of the inertia of the cloud of representative points of the structures and are determined by the temperature, the pH and the PO_4^{3-} and F^- ions. Nitrogen compounds come from the degradation of organic matter by microorganisms in the surface layers of the soil, with the production of CO_2 which is then carried away in depth with the seepage water (Ahoussi et al., 2008). Better still, the naturally occurring NO_3^- ions which are part of the nitrogen cycle represent the most soluble form of nitrogen. Mainly used as inorganic fertilizers for plant growth and the synthesis of organic nitrogen compounds, excess nitrates can be found quickly in groundwater. Waste containing organic nitrogen also represents a source of nitrates obtained from various biochemical processes (ammonification and nitrification) (Aghzar et al., 2001; Amadou and al., 2014). This plan highlights the superficial exchanges that take place between the site's water and runoff from precipitation and soil drainage.

The graphic representation in space of the statistical units of the factorial plane F1 - F2 and especially F1 - F3 highlights three main groupings of water points (**Figure 4**). Class 1 gathers waters of medium to high electrical conductivity, the ionic acquisition of which is under the control of mineralization-residence time accompanied by anthropogenic pollution. Class 2 contains colored waters with high and natural concentrations of Fe^{2+}, NH_4^+, NO_2^- and I^- without anthropogenic input. These are waters with low electrical conductivity. Class 3 is much more distinct on the statistical units of the factorial plane F1 - F3. This class includes much more fluorinated and phosphated waters.

The Dendrogram (**Figure 5**) from the Ascending Hierarchical Classification (CAH) highlights three main groupings of variables. The 1st grouping consists

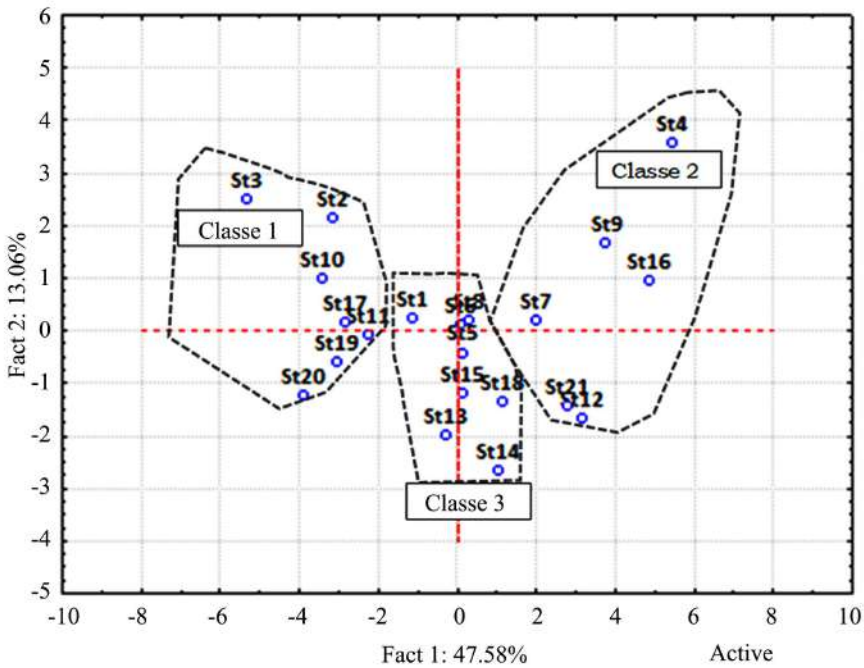


Figure 4. Space of the statistical units of the factorial plane F1 - F2.

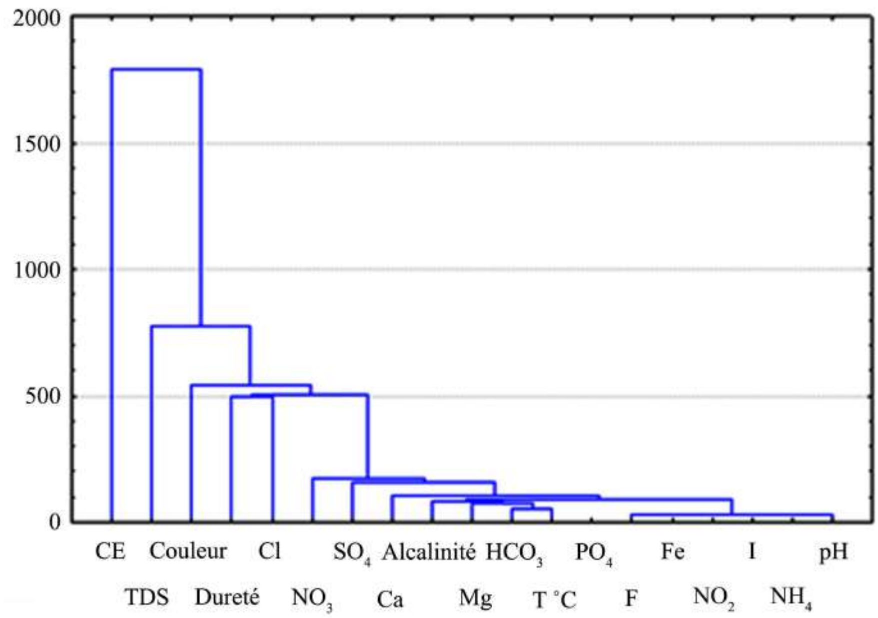


Figure 5. Dendrogram of the waters studied in the Hills department.

of CE, TDS and color. This group reports on the mineralization-residence time. The second group consists of chlorides and hardness. The 3rd group includes alkalinity, HCO_3^-, Ca^{2+}, NO_3^-, PO_4^-, SO_4^{2-}, Mg^{2+}, F^-, Fe^{2+}, NH_4^+, NO_2^-, pH and the temperature indicate the hydrolysis of minerals and the contribution of human activities in the mineralization of water from the study area. This group also highlights the phenomenon of mineralization governed by the infiltration of rainwater into aquifers.

3.2. Variation of pH and Temperature (T ˚C)

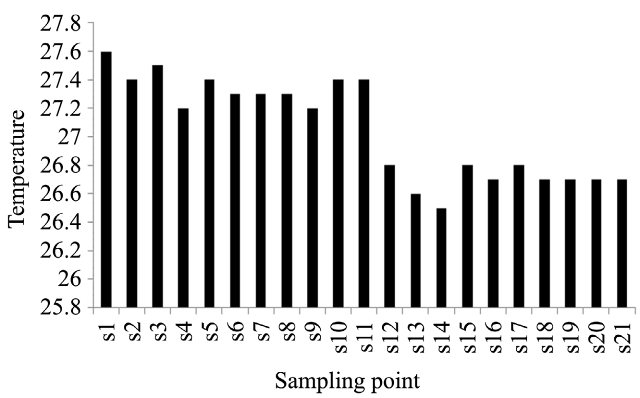
The pH of water provides information on its acidity and alkalinity. The pH of natural waters is generally between 6.6 to 7.8 (Nisbet et al., 1970) and it varies from 7.2 to 7.6 (Rodier, 1984). Usually, pH values are between 6 and 8.5 in natural waters (Chapman & Kimstach, 1996). The nature of the land crossed by the water is the natural cause, causing significant variations in pH. The analysis of these waters revealed that the pH is close to neutral, at the level of all the water points (**Figure 6**), the average pH values at the level of the study area were within the drinking water standards of groundwater (6.5 - 8.5 according to WHO standards).

Water temperature is an important factor in the aquatic environment as it governs almost all physical, chemical and biological reactions (Chapman & Kimstach, 1996). In the study area, the measured temperature shows almost no variation (**Figure 6**). The observed value is around 29.5˚. These values remain acceptable for drinking water standards.

3.3. Study of the Spatial Distribution of Chemical Parameters

The electrical conductivity of the water in the department of the hills varies from 56 to 1735 µS/cm for an average value of 612 µS/cm. The low values of CE are observed in the localities of Soclogbo and Torto in the South-East and in Dame while the high values are observed in the localities of Yawa and Kpakpaza (**Figure 7**).

The spatial distribution of magnesium in this department shows values between 1.95 and 69.06 mg/L for an average value of 22.54 mg/L. The low Mg values are observed in the localities of Soclogbo and Torto in the South-East and in Agbomadin, Dame, Missi, Logbo, Agbado and in Honnonkon while the high values are observed in the East of the localities of Yawa and Kpakpaza (Figure of Mg). Calcium varies from 4.81 to 97 mg/L for an average value of 46.03 mg/L. The low Ca values are observed in the localities of Soclogbo and Torto in the south-east and west of the localities of Yawa and Kpakpaza while the high values are clearly observable in Gbedje, north of Karre and on both sides other from Ouedeme.



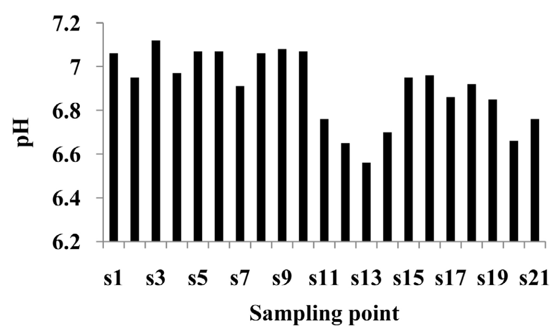


Figure 6. Variation in the Ph and temperature of groundwater in the Hills.

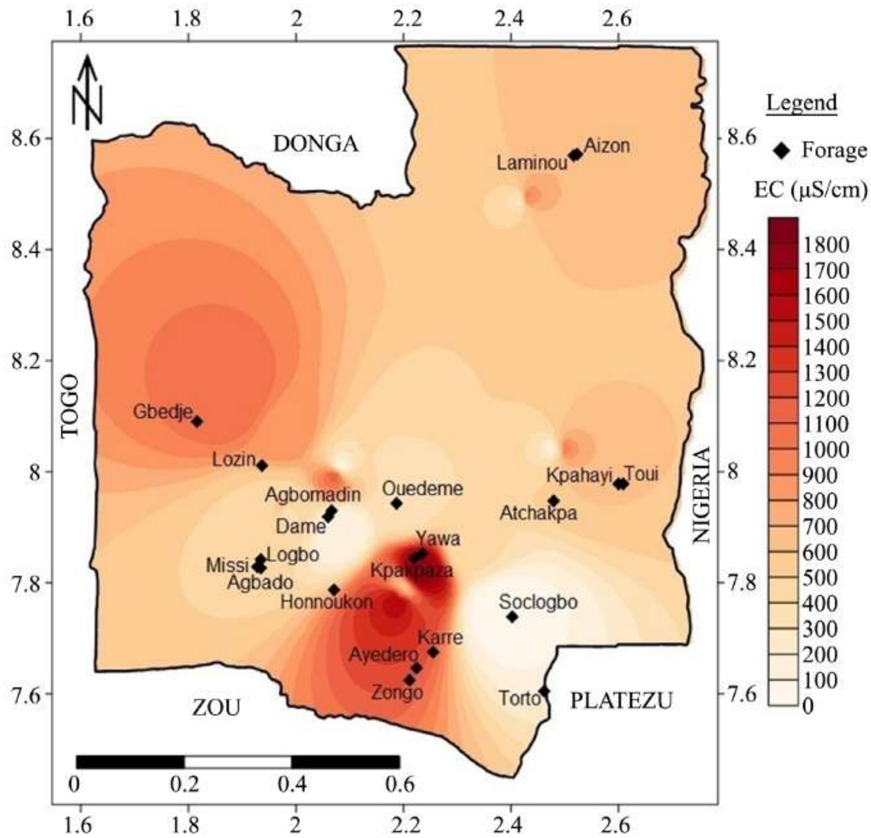


Figure 7. Spatial distribution of electrical conductivity.

It follows from variations in calcium and magnesium, a similar distribution with hardness, a function of Ca^{2+} and Mg^{2+}. Then its values are between 24 and 498 mg/L with an average value of 208 mg/L. As a result, groundwater is less hard in the localities of Soclogbo and Torto in the south-east while it is distinctly hard in Gbedje, west of Ouedeme, Yawa and Kpakpaza (**Figure 8**).

The alkalinity in the hills department shows values between 10 and 80 mg/L for an average value of 43.81 mg/L. The low values of alkalinity are also observed in the localities of Soclogbo and Torto in the south-east while the high values are observed in the localities of Yawa and Kpakpaza (**Figure 9**).

The spatial distribution of chlorides in the department shows values that are between 14.2 and 335 mg/L for an average value of 134.89 mg/L. The low values of Cl^- are observed in the localities of Soclogbo and Torto in the south-east and in Dame, Missi, Logbo, Agbado and in Honnonkon while the high values are in Gbedje, Agbomadin and in Karre (**Figure 10**). With regard to fluoride ions, they vary from 0 to 1.1 mg/L for an average value of 0.49 mg/L. Non-flowered waters are found in the localities of Soclogbo and Torto in the south-east and west of the localities of Yawa and Kpakpaza while those strongly fluorinated are clearly observed in the south of the localities of Atchakpa and Kpakpaza (**Figure 10**). It should also be noted that these values are lower than the WHO guide value which is set at 1.5 mg/L.

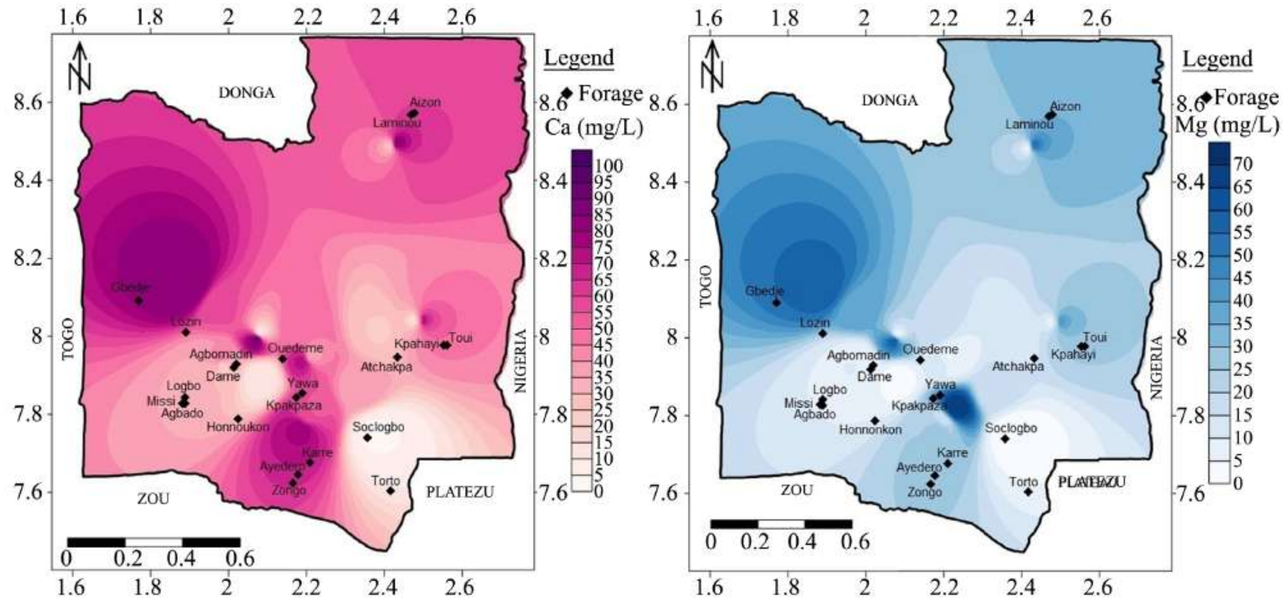


Figure 8. Spatial distribution of calcium and magnesium levels.

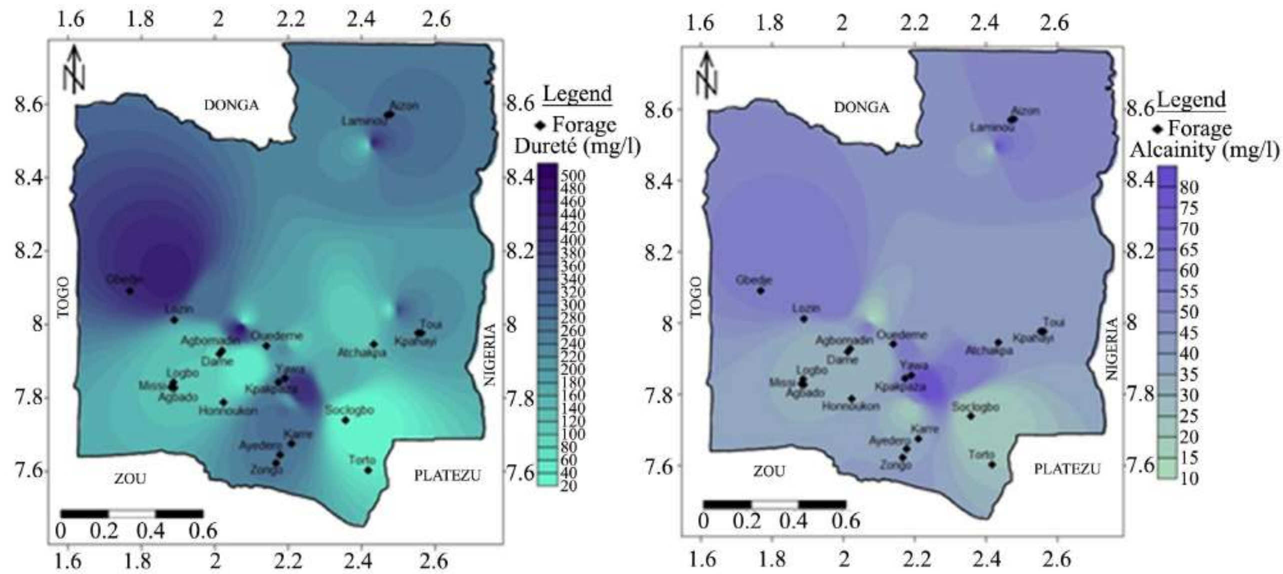


Figure 9. Spatial distribution of hardness and alkalinity rates.

For iodide ions, its values are between 0.09 and 2.09 mg/L with an average value of 0.39 mg/L. The iodides are strongly observed in the localities of Soclogbo and Torto in the south-east and north-west of Ouedeme while its values are very low in the north and west in the department (**Figure 11**).

The spatial distribution of iron in the waters of the Collines department shows values which are between 0 and 1.25 mg/L for an average value of 0.28 mg/L. Low Fe values are observed in the west and in the center of the department. High iron values are observed north of Honnoukon precisely between the localities of Agbomadin and Dame on the one hand and those of Yawa and Kpakpaza on the other hand (**Figure 11**).

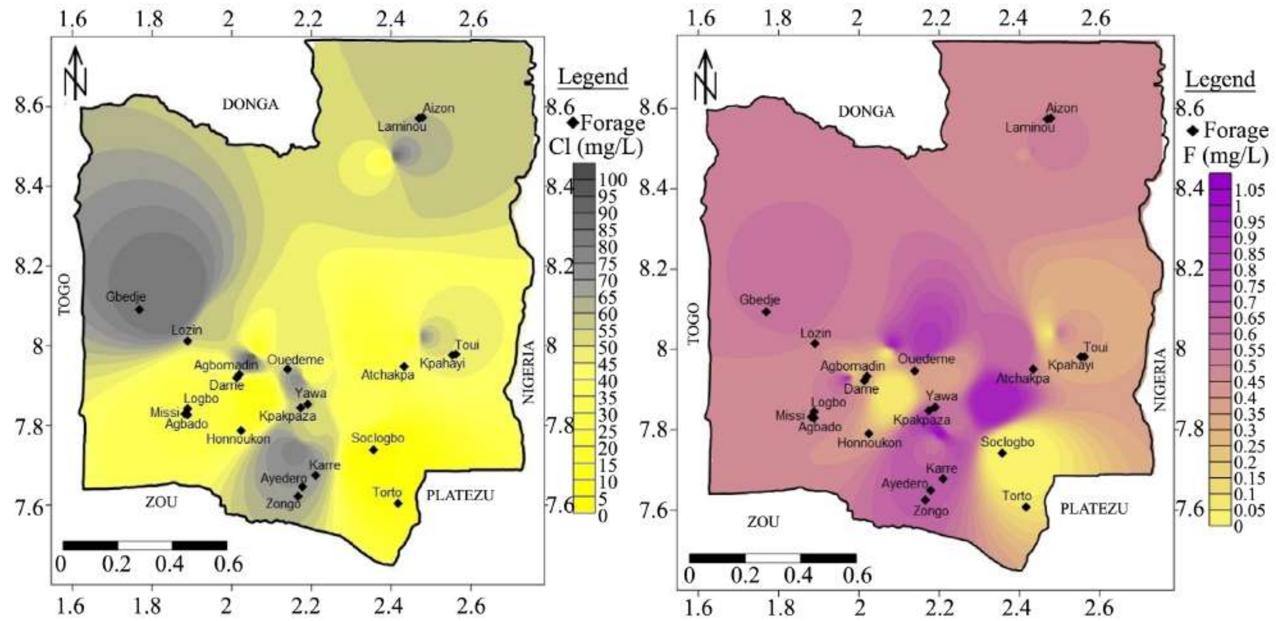


Figure 10. Spatial distribution of the levels of chlorides and fluorides.

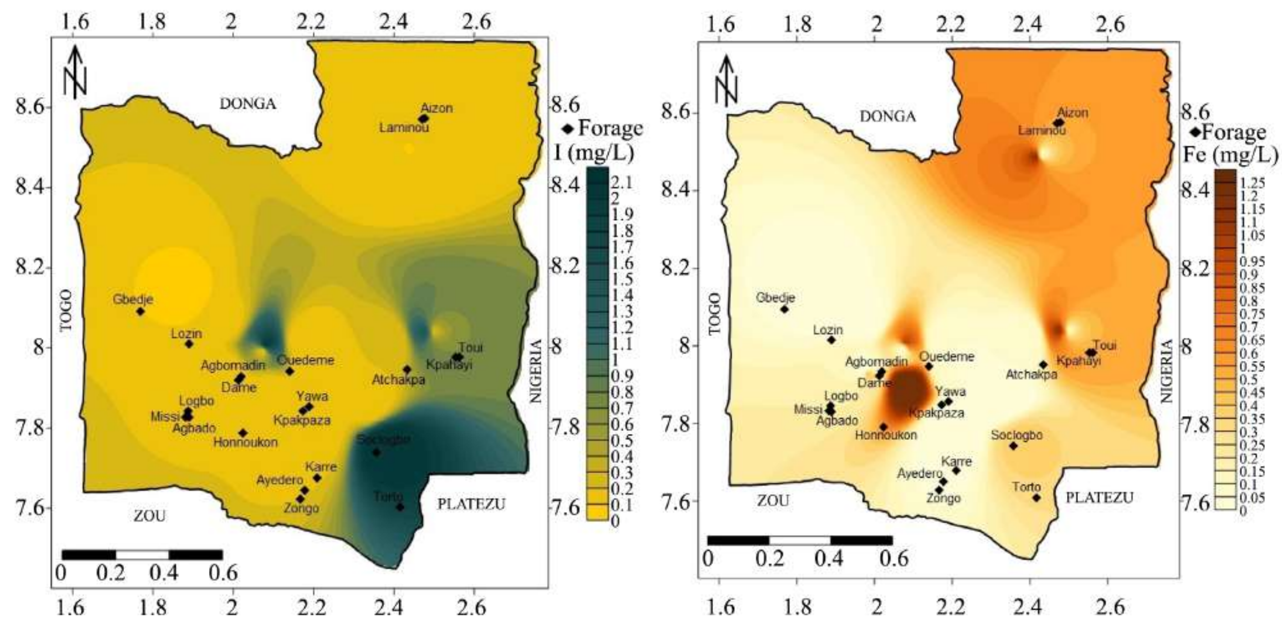


Figure 11. Spatial distribution of iodide and iron levels.

The bicarbonates in the waters of the department of the hills vary from 6.1 to 48.8 mg/L with an average value of 26.72 mg/L. The low values of HCO_3^- are observed in the localities of Soclogbo and Torto in the south-east while the high values are in the south-east of the localities of Yawa and Kpakpaza (Figure 12). The spatial distribution of ammonium in the department's groundwater shows values between 0 and 2.12 mg/L with an average value of 0.24 mg/L. NH_4^+ values are high in the localities of Soclogbo and Torto in the south-east and almost zero in the localities of Gbedje and Lozin in the west of the study area and in the

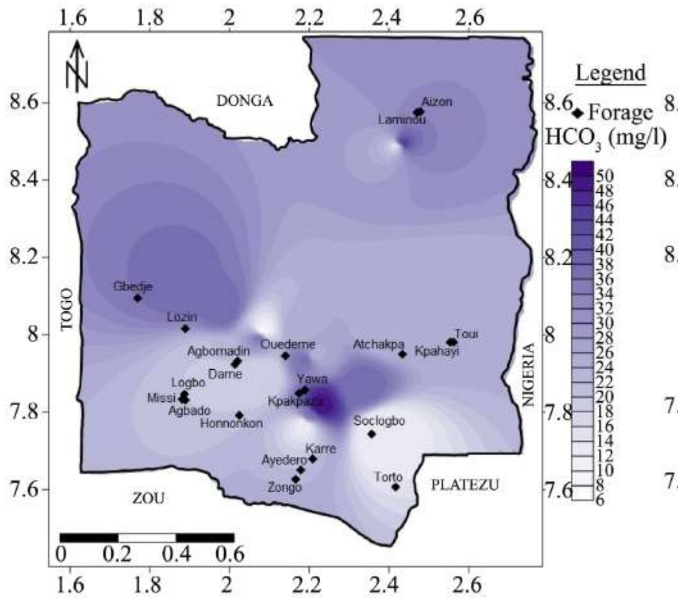


Figure 12. Spatial distribution of bicarbonate and ammonium levels.

center in the localities of Yawa, Kpakpaza, Karre, Ayedero, Zongo and Ouedeme (Figure 12).

Like ammonium, the spatial repair of nitrites is similar to it. Nitrites in the waters of the department are generally low with slightly higher values in the south-east, in the localities of Soclogbo and Torto. The values are between 0 and 0.27 mg/L for an average value of 0.03 mg/L (Figure 12). Unlike the two previous ions, nitrates are heterogeneous and vary between 0 and 163.91 mg/L for an average value of 53.07 mg/L. The values of NO_3^- are low in the South-East in the localities of Soclogbo and Torto or even Yawa, Honnoukon, Ouedeme, Agbomadin, Dame and Atchakpa. They are very high, exceeding the standard (50 mg/L) accepted by the WHO in the localities of Gbedje, Lozin, Missi and Logbo in the West, Aizon in the North-East, Karre and Zongo in the South of the zone d. study (Figure 13).

Phosphates in the waters of the Collines department are homogeneous and low throughout the department, with slightly higher values at the east of Ouedeme. The values are between 0.09 and 2.82 mg/L for an average value of 0.40 mg/L (Figure 14). Regarding the sulfate ions, they vary from 0 to 128 mg/L for a mean value of 25.9 mg/L. Waters very low in SO_4^{2-} are found in the localities of Soclogbo, Atchakpa and Torto in the south-east, while those strongly sulphated are clearly observed in the South in the localities of Yawa, Kpakpaza, Karre, Ayedero and Zongo (Figure 14).

3.4. Assessment of the Quality of Drinking Water

The quality of groundwater intended for consumption in the Hills was assessed following the study of the pollution parameters and the interpretation of a simplified grid (Table 3) namely the electrical conductivity and the chloride ions

Table 3. Simplified grid for the assessment of the overall quality of groundwater.

	Settings		
	Electrical Conductivity µS/cm	Chlorides mg/l	Nitrates mg/l
Excellent	<to 400	<to 200	<to 5
Good	400 - 1300	200 - 300	5 - 25
Average	1300 - 2700	300 - 750	25 - 50
Bad	2700 - 3000	750 - 1000	50 - 100
Very bad	>to 3000	>1000	>100

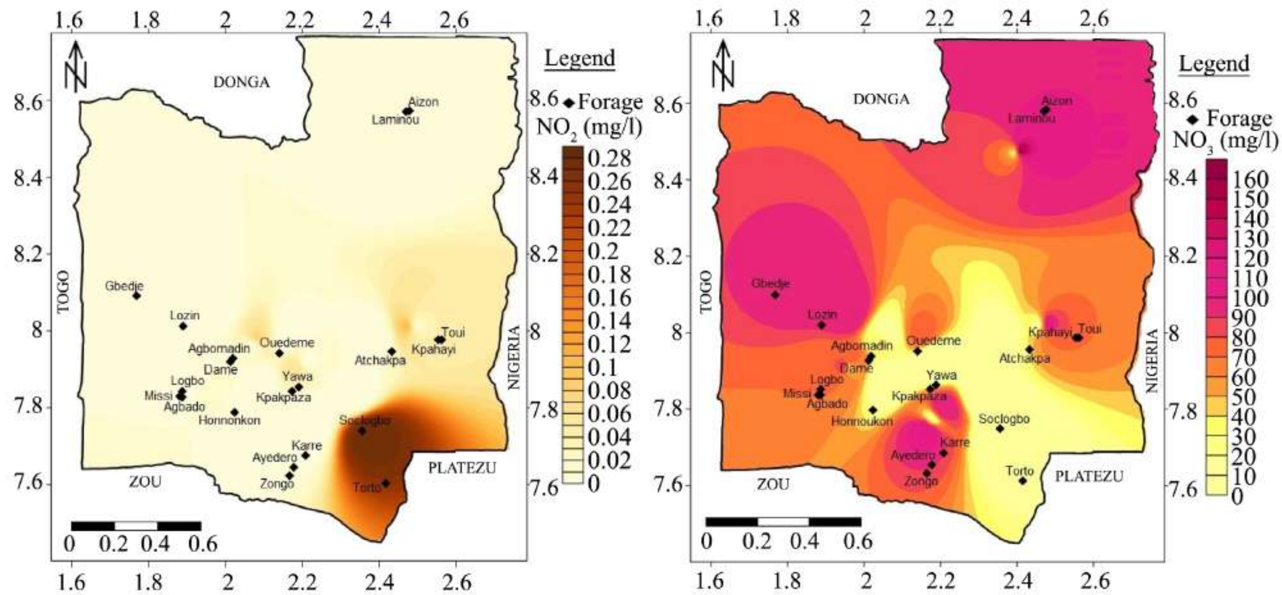


Figure 13. Spatial distribution of the rates of nitrites and nitrates.

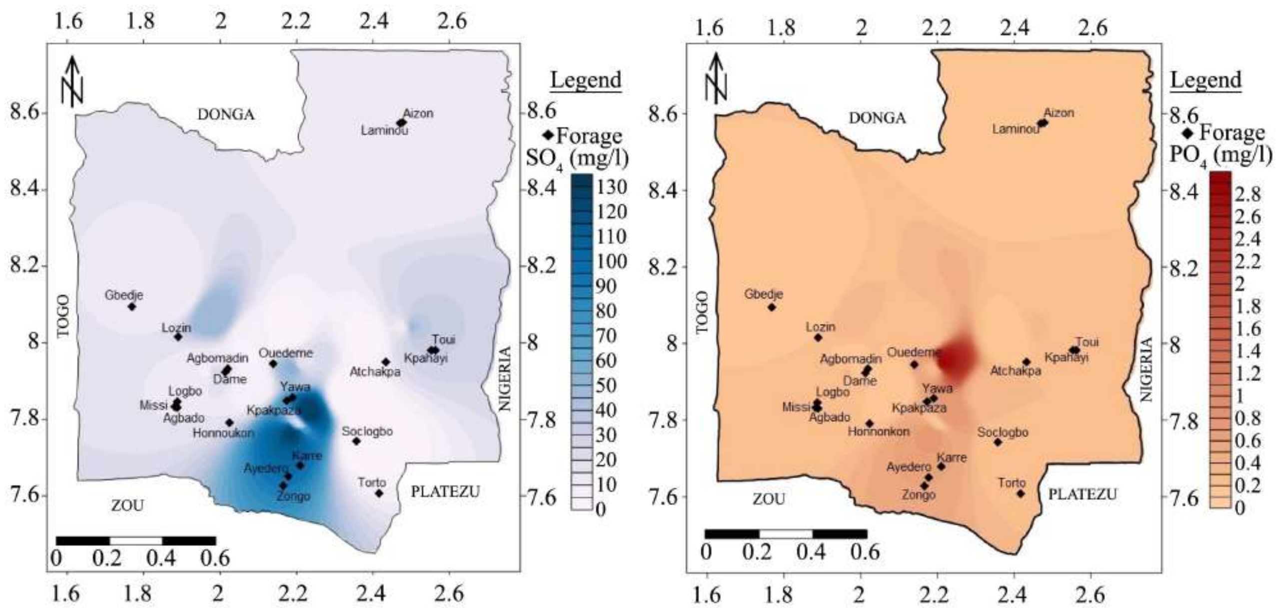


Figure 14. Spatial distribution of the levels of sulfates and phosphates.

which provide information on the mineralogical quality of water then nitrates which are indicators of groundwater pollution (Nouayti et al., 2015).

Analysis of the samples has shown that the water quality is generally good or even excellent (**Table 4**). However, a cross-reading shows very poor-quality waters (zongo, toui and Aizon) of poor quality (karré, Missi, Logbo, Lozin, Ouédemè and Gbedjè) given the nitrate contents.

4. Discussion

The quality of water depends above all on its physicochemical parameters. The groundwater of the Collines Department is characterized by a neutral pH that meets WHO and Beninese standards for groundwater potability. These values are contrary to the values obtained in the municipality of Pobè (Lagnika et al., 2014) and in the district of Dêkin in Dangbo (Adéké, 2017), where they obtain acidic pH despite the significant presence of limestone in the area southern Benin. However, similar results have characterized the groundwater of Ulmès in Morocco (Dadi et al., 1997). The decomposition of organic matter in the surface layer of the soil produces the CO_2 responsible for the acidity of groundwater in humid tropical environments (Ahoussi et al., 2010). The neutrality of the pH values obtained could therefore be linked to the nature of the geological formations made up of crystalline rocks, where certain rocks by dissociation in water release carbonate ions CO_3^{2-}.

The pH of water depends on the temperature. The temperatures obtained are almost invariant and higher than the value allowed by the WHO standard. These values are slightly lower than those found by Lagnika et al. (2014), Adéké (2017) and Tossou (2016). The latter give this rise to the influence of the ambient temperature and by the geothermal gradient mentioned by Degbey et al., 2010 in Maoudombaye, 2015. The slight decreases in temperature observed in our study could be explained by the period and the time of sampling.

Table 4. Overall quality of groundwater in the hills.

	CE	Cl^-	NO_3^-	**Overall quality**		CE	Cl^-	NO_3^-	**Overall quality**
Ayedero	657	159.75	24.808	GOOD	Lozin	850	198.8	99.232	GOOD
Zongo	1574	298.2	119.61	AVERAGE	Honnoukon	147	46.15	0.886	EXCELLENT
Karré	1735	355	99.232	AVERAGE	kpakpaza	348	81.65	1.329	EXCELLENT
Torto	56	24.85	4.873	EXCELLENT	Yawa	388	49.7	7.531	EXCELLENT
Soclogbo	405	28.14	0	EXCELLENT	Ouédemè	399	60.35	72.652	EXCELLENT
Missi	532	110.05	98.346	GOOD	kpabayi	65	14.2	1.772	EXCELLENT
Agbado	323	106.5	34.554	EXCELLENT	Toui	1052	301.75	124.04	GOOD
Logbo	517	113.6	79.74	GOOD	Atchakpa	311	63.9	14.176	EXCELLENT
Agbomadin	57	35.5	1.772	EXCELLENT	Gbedjè	1046	227.2	95.942	GOOD
Damé	1198	284	45.186	GOOD	Aizon	983	227.2	163.91	GOOD
					Laminou	207	46.15	24.808	EXCELLENT

Groundwater has an average electrical conductivity in accordance with the standard. These values are higher than those recorded in the municipality of Pobè by Lagnika et al. (2014) 236.62 µS/cm on average, as well as that obtained by Adejuwon and Mbuk in Ikorodu in Nigeria. This comparison shows that the waters of the department of hills are mineralized.

The ions responsible for the mineralization of water can be of natural or anthropogenic origin; the concentration of magnesium (Mg^{2+}) and calcium (Ca^{2+}) ions determines the hardness of the water. It is 22.54 mg/L on average for magnesium and 46.03 mg/L for calcium. The latter lead to a hardness of 208 mg/L on average. It follows from these results that the water in the hills is moderately hard. But, the different concentrations of Mg and Ca comply with the WHO and Beninese standard. By comparison, the recorded magnesium concentration is higher than that of water from wells in the commune of Pobè (13.63 mg/L), water from boreholes in the village of Dêkin (0.17 mg/L) in the commune of Dangbo (Adéké, 2017). According to Oga Ca^{2+} and Mg^{2+} ions could come from basic magmatic rocks, more or less metamorphosed. The significant presence of Mg^{2+} ions in the groundwater of the Collines department may be of natural origin, because their soil is made up of migmatitic and gneissic rocks intruded by granitic plutons in circumscribed massifs and a volcano-sedimentary series (Breda, 1989; Adissin, 2012).

The anions associated with these cations are Cl^-, I^-, SO_4^{2-}, HCO_3^-, chloride ions are strongly present with average concentrations of 134.89 mg/L but located below the standards admissible by WHO. The concentration of sulfate ions is 25.9 mg/L on average. There is a low content of fluoride ions (0.49 mg/L). All these values meet the standards for the quality of drinking water. The concentration of chlorides recorded in this study exceeds that obtained in the groundwater of Pobè (17.75 - 7.26 mg/L) (Lagnika et al., 2014), in the groundwater of Dêkin (6.3 mg/L) (Adéké, 2017) as well as that obtained by Dadi in 1997 (11.15 - 24 mg/L) in the aquifers of the crystallophyllian Massif of Oulmès (Morocco), Aka et al. (2013) (33.33 mg/L) in the department of Abengourou (south-east of the Ivory Coast). The significant presence of chloride ions could be of anthropogenic origin because the water table is fed from the surface by rainfall recharge (Kamagaté, 2006; Kamagaté et al., 2007; El-Fahem, 2008; Kamagaté et al., 2008).

The alkalinity of water is the concentration of carbonate, bicarbonate and hydronium ions it contains. It is 43.81 mg/L on average. The average concentration of bicarbonate in groundwater in the department of hills is 26.72 mg/L. This value is lower than that obtained by Lagnika et al., (2014) (37.87 mg/L) in the boreholes of the municipality of Pobè, Dadi et al., 1997 (23.13 - 192 mg/L) in the water underground of the Ulmès plateau and its surroundings in Morocco. This observed difference confirms the neutral nature of the groundwater in the department of hills. The pH being neutral, the concentration of hydronium ions is equal to that of hydroxide, which leads to an average concentration of 17.09 mg/L of carbonate ions (CO_3^{2-}) responsible for the neutralization of its acid coming from the decomposition of organic matter in the surface layer of the soil (Ahoussi et al., 2010).

The Collines department in Benin is a region recognized for its agricultural activity which is based on the misuse of chemical fertilizers and pesticides to increase agricultural yields. This constitutes a danger for the quality of groundwater caused by the presence of nitrogenous derivatives (nitrite, nitrate, ammonium, phosphate). These waters are characterized by an average concentration of 0.24 mg/L of ammonium ion, 0.03 mg/L of nitrite ion and 53.07 mg/L of nitrate ion and 0.40 mg/L of phosphate ion. Generally speaking, these values comply with WHO and Beninese standards except for nitrate which is above standards. This nitrate value is higher than that found by Adéké (2017) (1.5 mg/L) in the district of Dêkin, Lagnika et al. (2014) (45.30 mg/L) in the town of Pobè as well as that obtained by Oga (2009) (0 - 10 mg/L) in the Tiassalé region in Côte d'Ivoire, Dadi, 1997 (1.48 - 36.17 mg/L) in the crystallophyllian massif of Oulmès (Morocco). This significant presence of nitrate confirms the oxygenation of the medium which ensures the transformation of ammonium ions into nitrates. The latter reaches the groundwater by filtration and may be the main factor in the deterioration of the quality of these waters (Aghzar et al., 2002). This pollution of groundwater in the department of hills by nitrates comes from human activities of agricultural origin. Likewise, the fairly high levels of total nitrogen in organic matter could also have an impact on the vulnerability of the water table to this pollution.

Iron is a trace element beneficial to the body at low concentrations. Its content in groundwater in the hills is 0.28 mg/L on average, below the norm. But it appears more at the level of Zoumè with contents higher than the standard. This value obtained is lower than the value recorded in the Tiassalé region in Côte d'Ivoire (1.38 - 8.75 mg/L) by Oga et al. (2009), in the district of Dêkin commune of Dangbo in Benin (5.49 mg/L) by Adéké (2017). The latter as well as the results of Ahoussi et al. (2013) attach the high iron content of drilling water to the ferralitic nature of the more or less leached soil. The soil of the region of the hills of Benin not being ferralitic, the presence of iron in the groundwater at this polluted point could be of anthropogenic origin because it is fed by rainfall recharge from the surface. Indeed, according to Oga, iron gives water an unpleasant metallic taste, and a reddish brown color. The coloring of the water obtained in the area is then due to the presence of iron. This statement is confirmed by the analysis of variables which shows a correlation between colored water and Fe^{2+} ions.

5. Conclusion

This study made it possible to assess the quality and potability of underground water resources in the hills. The analyzes carried out on twenty-one (21) drinking water points are carried out on physical (temperature, pH and electrical conductivity) and chemical (cations and anions) parameters. The results showed that the pH of water depends on the temperature; the values of these two parameters are higher than those of the WHO unlike those of the electrical conductivity which conform to it. The water sampled is highly mineralized in Mg^{2+} ions. These ions are suspected of natural origin. The strong presence of Cl^- and especially NO_3^- ions (a very good indicator of the vulnerability of aquifers) makes it possible to suspect the presence of derivatives of phytosanitary products and pesticides in drinking water. These products cause toxicity in the consumer. Likewise, the relatively high total nitrogen content of organic matter could also have an impact on the vulnerability of the water table to this pollution. It is urgent to conduct a study of the biological quality of its sampling sites to target localities exposed to a health risk. This study thus reveals the non-drinkability of water resources in the hills.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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