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Assessment of the Physico-Chemical Quality of Waters in the Canton of Bangeli

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Abstract: Drinking water requires an acceptable physico-chemical quality in relation to water quality standards. They may not contain any substance which is harmful or which may harm the health of the consumer. In order to contribute to the control of water quality intended for human and animal consumption in the canton of Bangeli (in Togo), our study focused on the physico-chemical quality and the state of chemical pollution of the waters of this canton by using the water quality index (WQI) because of its usefulness in understanding water quality issues. A total of 28 points were selected, sampled and analyzed. The analyses are carried out in the dry and rainy seasons and focused on parameters such as pH, conductivity (EC), temperature, NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, SO_4^{2-}, TH, Ca^{2+}, Na^+, K^+, Fe et Cl^-. These results show that all the surface water and 66.66% of groundwater have an iron content greater than 0.3 mg/L. All the other parameters meet the standards except for one well where the nitrate content exceeds the standard value (50 mg/L). The calculated quality indices made it possible to realize that surface waters and 42% of groundwater analyzed are of poor quality (WQI > 100), so they require treatment before using as drinking water.

Keywords: *Canton of Bangeli, physico-chemical, water quality, quality index, poor quality*

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1. Introduction

Water is a natural resource essential to life. Maintaining its quality is a major concern for a society that has to meet ever-increasing water needs. It plays a very important role in the socio-economic development of a country. Thus, water resources are a major concern in countries with arid or semi-arid climates as they are absolutely essential for the development of human, economic and social activities [1]. Groundwater provides excellent sources of drinking water supply. However, the use of these water resources and the increase in human activities have caused serious problems due to a lack of environmental protection [2,3]. In addition, water quality is affected by natural factors, including geological structure and mineralogy, precipitation and runoff [4,5,6,7,8]. Groundwater contamination has therefore become one of the most serious problems in the world in recent decades [9]. In the canton of Bangeli, the drinking water supply is provided by groundwater. Studies were conducted from 2015 to 2017 to assess the chemical quality of these waters [10]. These authors found that the iron and nitrite content exceeded the drinking water standard. The levels were from 3.62 to 6.47 mg/L for iron and those of nitrites exceeded the WHO guideline value which is 0.2 mg/L. This work was carried out at a time when iron mining was taking place. But since 2017 when iron extraction work in the area stopped, no research has focused on assessing the physico-chemical quality of the waters in this area. In addition, mining waste abandoned on the site is subject to bad weather (wind, rain, etc.). It is therefore necessary to assess the physico-chemical quality of these post-mining waters in order to see whether the water quality is getting worse or not. Several methods are used to assess the physico-chemical quality of water. These methods include the one using the Water Quality Index (WQI) [9,11,12]. This method is used for groundwater quality assessment over the world due to its ability to fully express water quality information and is one of the most effective tools and one important parameters for the assessment and management of groundwater and surface water quality. In other words, the WQI summarizes large amounts of water quality data in simple terms (Excellent, Good, Poor, Very poor, etc.). This work consists of analyzing the global parameters of surface and underground waters and calculating the quality index of these waters in order to prioritize the areas at risk. It is necessary to carry out preventive detections and effective studies on health risks in specific areas where contamination issues may arise due to anthropogenic activities such as mining

2. Material and Methods

2.1. Study area

Bangeli is a canton of Bassar prefecture and located about 36 km west of the city of Bassar (Figure 1). It is located between 09° 42 min 19´ North latitude and 0° 62 min 43´ East longitude. This canton, which is home to rich deposits of iron ore in the form of hematites, allowed a vast iron production industry to develop there from the beginning of the Iron Age [13]. Iron working had been done for decades. The Bangeli iron mine is operated by MM Mining SA on the basis of an investment agreement dated August 7, 2006 with the Togolese State. Mining activities could cover an area of approximately 3708 km² in the Buem structural unit and approximately 11621 km² in the Atakora structural unit. Around the mine, there are large amounts of waste and abandoned ores since the cessation of activities in 2017 [14]. This waste is dispersed in the environment under the action of natural factors; downstream of the site, there is a water reservoir built on the stream called "Ledjole River" by the natives. The overflow of this reservoir flows into the stream. The waters of this reservoir were used to wash the ore before transporting them. Today, this water is used for animal consumption. The reserve is estimated at 500 million tons and is located at a depth of about 10 to 30 meters from the ground surface. Iron ore is mainly concentrated over a length of 50 km at Bangeli hill with iron proportions varying between 35 and 55% [14]. The region benefits from a Guinean tropical type climate with two seasons: a dry season dominated by the northern trade winds (the harmattan) which lasts from November to March and a rainy season dominated by the southern trade winds (the monsoon) which lasts from April to October. The annual thermal averages vary from 26.4°C to 28.3°C and the average annual precipitation varies between 1000 and 1800 mm.

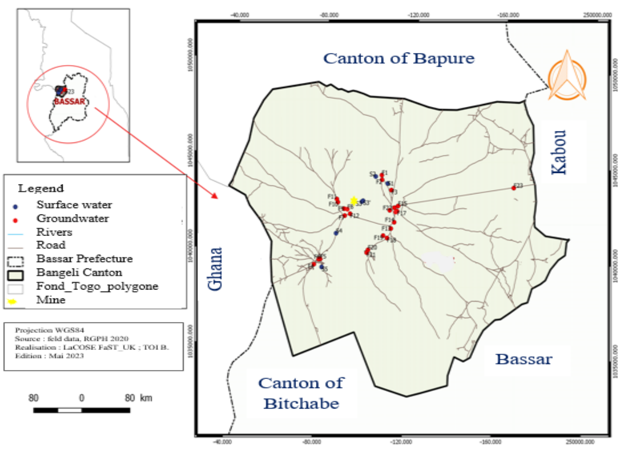

Figure 1. Map of Bangeli Canton

2.2. Methodology and Data Used

2.2.1. Sampling

A total of 28 water samples per season (in April and in August, 2020) were taken, including 4 surface waters, 2 wells and 22 boreholes. The sampling points were chosen according to the different activities identified in the study area (farming, mining and domestic wastewater), to their frequentation by the population, to their accessibility, their position in relation to the abandoned mining (Upstream, downstream, less than 2 km or more) and the availability of water in all seasons (Figure 2).The samples were collected in polyethylene bottles after pumping for 5 to 10 min. The bottles were previously washed and then rinsed with distilled water. At each sampling point, the bottle is rinsed three times with water from the sampling point before sampling. These bottles are filled to prevent oxidation of some elements in the presence of oxygen and then taken to the laboratory at 4° C. Several physico-chemical parameters were determined in situ: pH, temperature and conductivity. pH is determined using a Sartorius brand pH meter PT-10 and conductivity using an ELMETRON type CC – 411 conductivity meter. Phosphorus, nitrogen and sulphate compounds are determined by the colorimetric method described [15] total iron is determined by the orthophenanthroline method using a GENESYS 10S UV-VIS brand spectrophotometer. Chlorides and permanganate index are determined by volumetric methods. The concentration of the major elements (Na, K, Mg and Ca) was determined using an iCE 3000 SERIES THERMO FISCHER flame atomic absorption spectrophotometer (AAS).

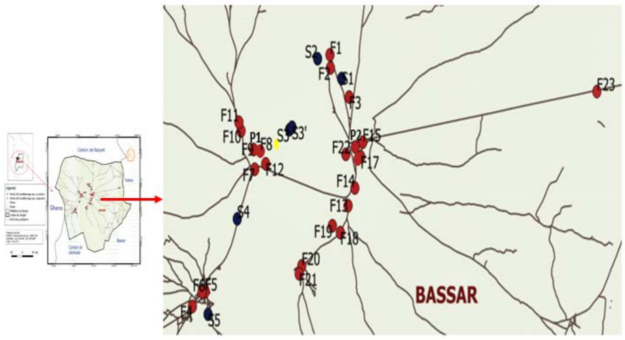

Figure 2. sampling points distribution

2.2.2. Water Quality Index

Water Quality Index (WQI) is an effective tool for communicating water quality information to concerned citizens and decision makers [16]. It is applied in this study to assess groundwater and surface water quality due to its usefulness in understanding water quality issues [17]. Its purpose is to give a single value to the quality of water. The quality of the different samples can then be compared on the basis of the index value. To determine the potability of groundwater and surface water, equation 1 was used for the calculation of the water quality index [18,19]

$$WQI = \frac{\sum_{i=1}^{n} W_i * q_i}{\sum_{i=1}^{n} W_i} \qquad (1)$$

Where, W_i is a weighting factor calculated using equation (2);

$$W_i = \frac{K}{S_i} \quad (2)$$

Where, S_i is normal value of water quality parameter i, for our study these are the [20] standards

K: is a proportionality constant, which is taken as 1.0 [2], n is the total number of water quality parameters. The quality evaluation index of each parameter used (qi) (Equation 3)

$$q_i = \frac{V_a - V_i}{S_i - V_i} * 100 \quad (3)$$

Where, q_i is the quality rating index for water quality parameter i, V_a is the Actual value of the i th water quality parameter obtained from the results obtained, V_i is the Ideal value of the water quality parameter i^{th} obtained from standard tables, V_i for pH = 7 and for the other parameters it equals to zero[2,18]

In this study, for the calculation of the water quality index, the weighting factor W_i of each parameter analyzed is first calculated and then the evaluation index q_i is evaluated on the basis of the results of 'analysis. A classification of WQI will be made according to Table 1. WHO standard values, ideal values and weighting factors of water quality parameters are listed in Table 2

Table 1. Water quality status based on WQI [16]

Class	Quality index	Definition of the quality class
01	< 50	Excellent quality
02	50 - 100	Good quality
03	100 - 200	Poor quality
04	200 -300	Very poor quality
05	> 300	unfit for human consumption

Table 2. Ideal values and water weight factors [21]

Parameters	Ideal value (Vi)	Standard Value (Si)	Relative weight (Wi)	Constant (K)
pH	7	6,5 à 9	0,1111	1
EC (mg/L)	0	1000	0,001	1
Cl^- (mg/L)	0	250	0,004	1
Iron (mg/L)	0	0,3	3,3333	1
SO_4^- (mg/L)	0	250	0,004	1
Ca^{2+} (mg/L)	0	75	0,0133	1
Na^+ (mg/L)	0	200	0,005	1
K^+ (mg/L)	0	12	0,0833	1
Mg^{2+} (mg/L)	0	30	0,0333	1
TH (mg/L)	0	300	0,0033	1
HCO_3^- (mg/L)	0	400	0,0025	1
NO_3^- (mg/L)	0	50	0,02	1
NH_4^+ (mg/L)	0	1,5	0,6666	1
NO_2^- (mg/L)	0	3	0,3333	1
PO_4^{3-} (mg/L)	0	5	0,2	1
IP (mg/L)	0	5	0,2	1

In addition to the above,

- Acknowledge any limitations or uncertainties associated with the data collection and analysis process. Discuss potential sources of error and their potential impact on the results.
- Explain how the sampling locations were selected to ensure representativeness of the study area. Discuss the rationale behind the choice of sampling points and how they reflect the diversity of water sources in the Canton of Bangeli.

3. Results and Discussion

This part presents the results of the physico-chemical analyzes carried out on the samples as well as the water quality index

Physicochemical quality assessment of waters may widely reflect the pollution load and anthropogenic pressure on water systems. Figures 3, 4, 5, 6 and 7 present the mean values of physicochemical water quality parameters for the samples to reveal spatial variation. Table 3 shows the means, max and min values of other physico-chemical parameters and Tables 4 and 5 show the correlation coefficients of physicochemical water quality parameters. Figures 8 and 9 present results of WQI calculate for each sampling point.

3.1. Water Quality

The pH values show that waters are moderately neutral (Figure 3). Except Points P1, P2, S1 and S3, the pH respects the WHO guideline value. Apart from these 4 points, the pH is almost neutral. Indeed, the pH of drinking water is normally between 6.5 and 9 according to WHO recommendations [20]. Waters of these 4 samples are acid (pH range between 5.5 to 6.5). These are well and surface water from the abandoned mine site and downstream from the Ledjole stream. The contact of these waters with the metals would lead to the dissolution of the latter and can lead to acid mine drainage.

Electrical conductivity is the ability of water to pass electrical current and is expressed in microsiemens per centimeter (µS/cm). Bangeli groundwater mineralization is relatively high. The values oscillate between 2863 ± 3 µS/cm and 842 ± 2 µS/cm (Figure 2). Points F4, F5, F6, F10, F11 and P2 show values above 1100 µS/cm which is the WHO guideline value. The results of this study are partially in contradiction with those of [10]. Indeed, the previous study gave values between 34 ± 26.9 and 385 ± 63.9 µS/cm. This strong mineralization of groundwater could be explained by the fact that they had to cross several geological layers by causing the dissolution of minerals. Unlike groundwater, surface water has low mineralization (electrical conductivity less than 250 µS/cm (Figure 3)). Low conductivity is synonymous with low mineralization of the salts present in the environment [3,22,23]

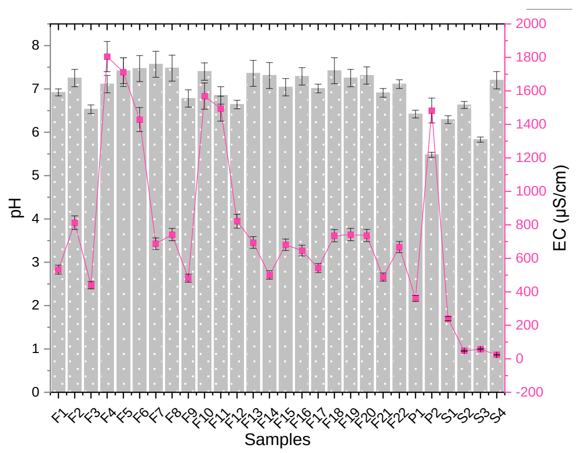

Figure 3. Variation of conductivity and pH according to sampling points

Figure 4 presents the results of the calcium and magnesium contents and the hardness of the waters of the samples. The analysis of Figure 3 shows that all the waters sampled have low hardness values, these are soft waters (TH < 70mg/L) [24]. The variations in total hardness (TH) observed in the waters of the different points can be linked to the geological nature of the land crossed. The values recorded vary from 2.7 ± 0.5 mg/L to 30 ± 0.1 mg/L (Figure 3). According to [20] relating to the potability of water, the total hardness must not exceed 300 mg/L. The results obtained therefore comply with WHO guidelines for this parameter. Analysis of the results in Figure 3 also shows that the calcium and magnesium contents are lower than [20] guide values. Indeed, the calcium contents vary from 1.3 ± 0.01 mg/L to 17.8 ± 0.2 mg/L and those of magnesium oscillate between 0.75 ± 0.01 and 13.15 ± 0, 2mg/L (Figure 4).

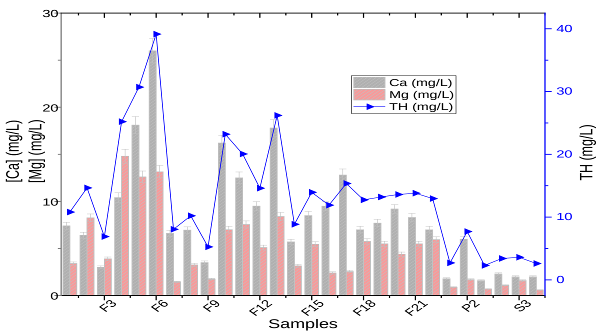

Figure 4. Calcium, magnesium and total hardness content of water

Figure 5 shows the variations in ammonium, nitrite and ortho-phosphate levels in Bangeli waters. An analysis of Figure 5 shows that the waters of the study area have low levels of ammonium, nitrites and ortho-phosphates. All the waters analyzed comply with [20] directives concerning these parameters. Indeed, [20]recommends levels lower than 1.5 ± 0.1 mg/L for ammonium, 3 mg/L for nitrites and 5 mg/L for ortho-phosphates.

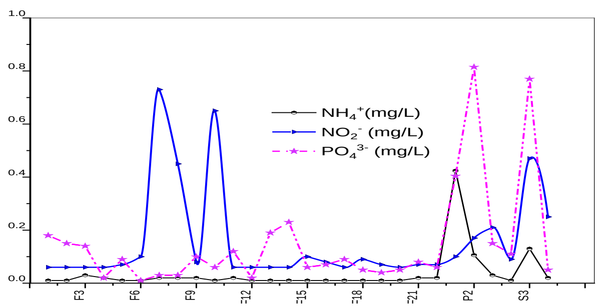

Figure 5. Variations in the ammonium, nitrate and nitrite contents of the different points sampled

Figure 6 represents the variations of the total iron content in the waters of Bangeli. The analysis of Figure 6 shows on the one hand that the total iron content varies between 0.02 ± 0.01 and 5.5 ± 0.3 mg/L at groundwater level. 50% of the points sampled (12 points out of the 24) show levels that greatly exceed the WHO recommendation of 0.3 mg/L. These are points F5, F6, F7, F8, F9, F12, F13, F18, F19, F21, P1 and P2 (Figure 2). These points are mainly located downstream of the mine site and less than 2 km from the site. This pollution would originate from the infiltration or the transport by the wind of the iron coming from the waste abandoned on the site or from the transport by the wind during the extraction works. Another source would be the recharge of the water table by water from the reservoir built on the site and which was used to wash the ore. Concordant and very similar results were also observed in the study area by other researchers [10]. On the other hand, all the surface water points sampled have iron levels well above the WHO recommendations. This pollution would be linked to the mining waste abandoned on the site. Indeed, the highest concentration is observed at S3 (12.84 ± 0.4 mg/L), the water reservoir built downstream of the mine site. This water reservoir is surrounded by piles of waste coming from the mine and which are driven by runoff towards the water reservoir. Similarly, point S4 (6.19 ± 0.3 mg/L) has a very high total iron content. It is a point located on the Ledjole stream; downstream of the dam. This river collects excess water from the dam during periods of flooding. The geological nature of the soils in the study area is another probable cause.

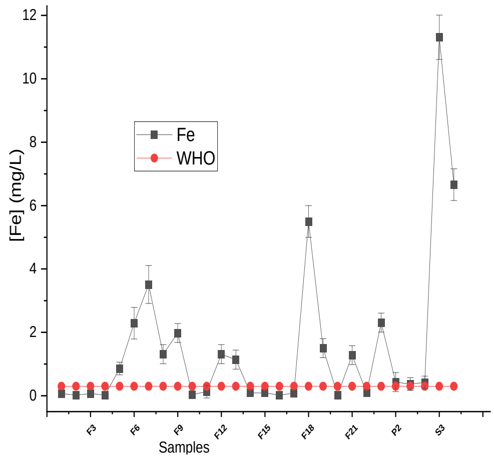

Figure 6. Variations in iron content according to water points

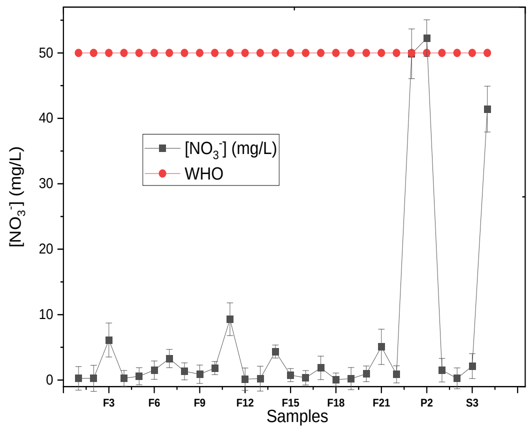

Figure 7. Variations in nitrate content according to water points

Figure 7 shows the variations in nitrate levels as a function of the points sampled. The presence of nitrates in water can be of natural or anthropogenic origin. An analysis of Figure 6 shows that the waters of the study area with the exception of point P2 (52.25 ± 0.3 mg/L) have nitrate levels that meet WHO recommendations (50mg/L). The high value at this point would be linked to anthropogenic activities. Indeed, point S4 is in an agricultural area where the local population practices market gardening. The nitrates present in this water come either from agricultural inputs, manure or decomposing plant matter [25].

In All figures, it is important to note that the results obtained from the different sample locations are not interconnected, as these locations are sporadic and unrelated. Therefore, attempting to establish connections or patterns between their results would be misleading and unnecessary.

Table 3 presents the results of the maximum, minimum, mean and mean deviation values of the different contents of ions: sulphates (SO_4^{2-}), chlorides (Cl^-), sodium (Na^+), potassium (K^+), bicarbonates (HCO_3^-) and the permanganate index (PI). Analysis of this table shows that the waters of Bangeli have normal sulphate levels. Indeed, the sulphate content values oscillate between 3.61 ± 0.1 mg/L (point S2) and 46.63 ± 0.2 mg/L (point S4). These values are significantly lower than the WHO recommendation. Similarly, Table 3 shows great variability between the chloride contents in the waters. The values oscillate between 21.30 ±0.2 mg/L to 83.43 ±0.4 mg/L; this variability is mainly linked to the nature of the terrain crossed. According to WHO recommendations, chlorides do not exceed the limit value (250 mg/L). The analysis of the sodium and potassium ions of the water samples shows that their values are lower than the guideline values of the WHO with the exception of points S1, S3 and P2 where the potassium exceeds the limit value. The potassium content at these points are respectively 12.08 ± 0.2 mg/L, 22.61 ± 0.3 mg/L and 17.36 ± 0.1 mg/L mg/L.

Using the measured complete alkalimetric (TAC) values, we determined the bicarbonate content in the water samples (Table 3). According to [20] value, is set at 400 mg/L for this element, but a very high concentration of bicarbonates gives the water a salty taste. The contents vary from 17.5 ± 0.23 to 210.5 ± 0.3 mg/L; they are particularly high at point F2 (210.5 ± 0.46mg/L)

Permanganate index (PI) refers to the mass of oxygen consumed by the oxidizable organic matter contained in 1L of water. The results show that PI compline between 0.37±0.1 and 2.75±0.2. According to the WHO, the permanganate index must have a content of less than 5 mg/L in drinking water. Analysis of the results in Table 3 revealed normal amounts ranging from 0.75 ± 0.1 to 2.75 ± 0.2 mg/L.

Table 3. Mean, minimum and maximum values of SO_4^{2-}, Cl^-, K^+, Na^+, HCO_3^- and PI

	SO_4^{2-}	Cl^-	Na^+	K^+	HCO_3^-	PI
Unit	mg/L					
Max	46.63 ±0.2	83.43 ±0.4	42.29 ±0.3	22.61 ±0.3	370.00 ±0.4	2.75 ±0.2
Minimum	3.61 ±0.01	21.30 ±0.2	7.18 ±0.1	1.81 ±0.1	17.50 ±0.1	0.75 ±0.1
Average	16.81 ±0.1	41.22 ±0.3	29.20 ±0.2	7.94 ±0.2	68.21 ±0.2	1.51 ±0.2
Medium	6.44 ±0.1	12.55 ±0.2	6.39 ±0.1	3.40 ±0.2	44.31 ±0.2	0.37 ±0.1
n	56	56	56	56	56	56
WHO	250	250	200	12	400	5

3.2. Water Quality Index

After calculating the quality index (WQI) using the results of physico-chemical analyzes and the standard values of the WHO drinking water standard [20], the water quality classes are determined for the 24 groundwater points (Figure 7) and for the 4 surface water points (Figure 8). The analysis of figures 7 and 8 makes it possible to define Five (5) water quality classes in the study environment.

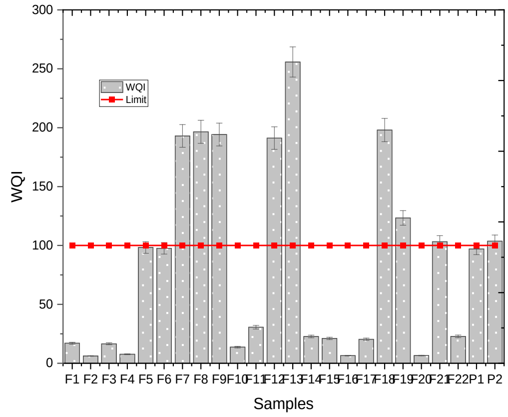

Figure 8. Groundwater quality index

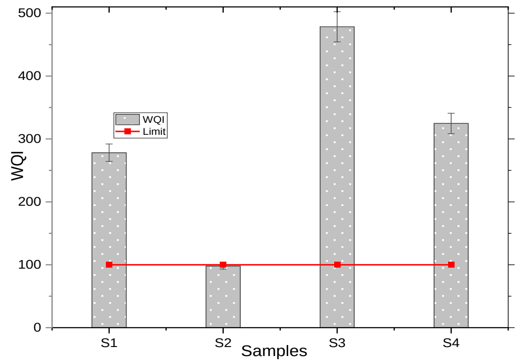

Figure 9. Surface water quality index

Thus, we have excellent quality water (WQI < 50) which represents 50% of the groundwater sampled. These are boreholes F1, F2, F3, F4, F10, F11, F14, F15, F16, F17, F20, and F22. Good quality waters represent only 14.28% of the samples (F5, F6, P1 and S2). Poor quality waters represent 33.3% of all the samples (F7, F8, F9, F12, F18, F19, F21, and P2). Very poor quality water (F13 and S1) and water unfit for consumption S3 and S4) occupy 7.14% each, or 75% of surface water. These surface waters are located downstream of the mining site: point S3 is a water reservoir on the site, in the open air, this water was used to wash the ore, while point S4 is a stream which results from runoff and overflow of water from the mining site during the flood period. Point S4 can therefore constitute a danger for the population of Bangeli; its surroundings showed that its waters are used for market gardening. The significant degree of degradation of waters quality of Bangeli in general and above all of the surface waters in particular would be linked to the impact of the mining activity. Indeed, the results of physico-chemical analyzes have shown that these waters are very rich in iron. The iron content is well above the WHO guideline value, thus increasing the WQI at these points. Also, the geological nature of the land crossed by the water can also influence its quality.

3.3. Correlation between the Different Parameters

Tables 4 and 5 are the correlation matrices between the different parameters analyzed

Table 4. Correlation matrix for groundwater

	pH	EC	Fe	SO_4^{2-}	Cl^-	Ca^{2+}	Na^+	K^+	Mg^{2+}	TH	HCO_3^-	NO_3^-	NH_4^+	NO_2^-	PO_4^{3-}	IP
pH	1,00															
EC	0,01	1,00														
Fe	**-0,54**	0,20	1,00													
SO_4^{2-}	0,33	0,75	-0,15	1,00												
Cl^-	-0,23	-0,05	-0,13	-0,05	1,00											
Ca^{2+}	0,28	0,36	-0,23	0,41	-0,26	1,00										
Na^+	0,22	**0,89**	0,07	**0,85**	-0,07	0,34	1,00									
K^+	-0,33	**0,68**	**0,75**	0,28	-0,11	0,02	**0,52**	1,00								
Mg^{2+}	0,37	**0,71**	-0,24	**0,62**	0,03	0,30	**0,72**	0,21	1,00							
TH	0,41	**0,70**	-0,29	**0,65**	-0,11	**0,72**	**0,69**	0,16	**0,88**	1,00						
HCO_3^-	**-0,50**	**0,58**	**0,64**	0,15	0,20	0,02	0,40	**0,80**	0,19	0,15	1,00					
NO_3^-	**-0,77**	0,05	**0,63**	-0,28	0,12	-0,37	-0,28	0,43	-0,37	-0,46	0,49	1,00				
NH_4^+	-0,47	-0,18	0,22	-0,34	0,18	-0,47	-0,47	-0,03	-0,32	-0,47	0,04	**0,81**	1,00			
No_2^-	0,28	0,15	0,14	0,25	-0,11	-0,13	0,18	0,29	-0,20	-0,21	0,05	0,01	-0,03	1,00		
PO_4^{3-}	**-0,79**	0,06	**0,70**	-0,28	0,07	-0,29	-0,20	**0,52**	-0,36	-0,41	**0,65**	**0,88**	**0,53**	-0,10	1,00	
IP	-0,08	0,00	0,07	-0,03	0,23	-0,39	0,02	0,08	0,02	-0,18	-0,11	0,13	0,22	0,06	0,06	1,00

Table 5. Correlation matrix for surface waters

	pH	EC	Fe	SO_4^{2-}	Cl-	Ca	Na	K	Mg2+	TH	HCO_3^-	NO_3^-	NH_4^+	NO_2^-	PO_3^-
pH	1,00														
EC	-0,14	1,00													
Fe	**-0,73**	0,18	1,00												
SO_4^{2-}	**0,75**	-0,19	-0,11	1,00											
Cl^-	**0,66**	**0,63**	-0,31	**0,54**	1,00										
Ca^{2+}	0,20	-0,03	**0,52**	**0,79**	0,29	1,00									
Na+	**-0,91**	0,43	**0,50**	**-0,89**	-0,42	-0,45	1,00								
K^+	0,00	**0,82**	0,43	0,30	**0,71**	**0,54**	0,10	1,00							
Mg^{2+}	**-0,82**	-0,39	**0,75**	-0,39	**-0,86**	0,11	**0,51**	-0,27	1,00						
TH	-0,49	0,15	**0,95**	0,20	-0,12	**0,75**	0,24	**0,55**	**0,60**	1,00					
HCO_3^-	0,15	0,32	**-0,71**	**-0,52**	0,20	**-0,88**	0,22	-0,22	**-0,56**	**-0,85**	1,00				
NO_3^-	**0,91**	-0,25	-0,41	**0,95**	**0,58**	**0,57**	**-0,98**	0,12	**-0,57**	-0,12	-0,27	1,00			
NH_4^+	**-0,68**	-0,01	**0,98**	-0,02	-0,40	**0,58**	0,39	0,31	**0,81**	**0,96**	**-0,81**	-0,32	1,00		
No_2^-	-0,38	0,03	**0,90**	0,32	-0,12	**0,83**	0,09	0,49	**0,58**	**0,99**	**-0,92**	0,02	**0,93**	1,00	
PO_4^{3-}	**-0,75**	-0,10	**0,96**	-0,12	**-0,54**	0,47	0,44	0,17	**0,89**	**0,90**	**-0,77**	-0,40	**0,99**	**0,87**	1,00

Analysis of Table 4 shows that electrical conductivity (EC) is strongly correlated with sodium, potassium, magnesium and bicarbonates (0.89; 0.68; 0.71 and 0.58 respectively). This very high correlation is in perfect harmony with the theory. Indeed, conductivity is intrinsically linked to the presence of ions in solution. The high concentration of these ions in the water therefore increases this conductivity. Similarly, calcium and magnesium are highly correlated with total hardness (0.72 and 0.88 respectively). This strong correlation is explained by the fact that the TH is the sum of the calcium and magnesium. Nitrates are also very strongly correlated with ammonium and sulphates.

Analysis of Table 5 shows that electrical conductivity (EC) is strongly correlated with chloride and potassium (0.63 and 0.82 respectively). This very high correlation is in perfect agreement with the theory because the conductivity is intrinsically linked to the presence of ions in solution. The high concentration of these ions in the water therefore increases this conductivity. Similarly, iron, sulfate, calcium, magnesium ions and hydrotimetric title are strongly negatively correlated with carbonates. Calcium and magnesium are highly correlated with hydrotimetric title, nitrates, nitrites and ammonium. This strong correlation is explained by the fact that the TH is the sum of the calcium and magnesium. Nitrates are also very strongly correlated with ammonium and sulfates.

4. Conclusion

The study of the water quality of Bangeli canton shows that all surface waters as well as the majority of underground waters are all polluted with iron. The total iron concentration of these waters largely exceeds the WHO guideline. The assessment of the physico-chemical quality of the waters showed that the canton experiences significant iron pollution, which is clearly felt, especially in the surface waters and in the groundwater in the vicinity of the mine. The water quality index applied to these waters made it possible to realize that these waters are generally of good quality with the exception of surface waters. The most probable sources of this pollution would be the waste abandoned on the site and the geological nature of the soils. An analysis of heavy metals (ETM), soils and mining waste will be the subject of a future study in order to better understand the origin of this pollution.

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