**Physicochemical characterization and determination of scaling and corrosion sources in the groundwater of Tillabery, Niger**

**Abstract**

In Niger, in the Tillabéry region, despite surface water, groundwater constitutes the major source of drinking water supply for various populations. This study aims to assess the quality of groundwater in some villages in the Tillabéry region to understand the source of scaling and corrosion of some boreholes. Thirty-one samples were taken and then analyzed using *in situ* and conventional methods according to French AFNOR standards based on thirteen physicochemical parameters. The results of these analyses were processed with the Diagram and XLSTAT software. The physicochemical analyses of the waters show that their quality is mainly linked to the geogenic source of the soil and to human activities. Piper diagram analysis results show that these waters are all sulfated, with values ranging from 270 to 1528 mg/L, sodic from 5.3 to 1189 mg/L and potassic from 2.8 to 98, 7 mg/L, with the exception of Guemé water, which is bicarbonated at 1342 mg/L, Boukanda2 water, which is chloride-rich at 2083 mg/L, and Fanaka Koira1 and Lallé Tondi water, which are calcium-rich at 236 mg/L and 145.01 mg/L respectively. The principal component analysis with XLSTAT shows that the Na+, Cl-, K+ ionsgovern the mineralization of the water. The Mg2+, Ca2+, Fe 2+, SO42- , F- ionshave a geogenic source while the NO2- , NO3- ionshave an anthropogenic source. The results of the corrosion indices calculated from the modified Larson index formula showed that 97% of the analyzed waters have a tendency to corrosion. The highest value (191.68) belongs to the village of Gabdey Bangou. Several equations are described to justify the various scaling and corrosion mechanisms that occur, leading to a proposal for simple, less costly water treatment methods to limit these problems.

**Keywords:** Physicochemical, Scaling, Corrosion, Geogenic, Tillabéry, paramount importance

**Introduction**

Water is of paramount importance because it remains essential for the survival of all living beings [1]. This is why the question of the potability of water has become one of the world's concerns. Studies that characterize the physicochemical quality of borehole water are booming, especially in the Sahel of West Africa, a region with contrasting socio-economic characteristics. Indeed, Water is a composition of several ions, the chronological order of the main ions of which has been described by some authors [2]. It depends mainly on the geogenic nature of the soil and also on the reactive substances it encounters during its flow and during its stay in the reservoir [3, 4]. The problems of corrosion and scaling encountered at the level of equipment installations come from the results of many complex reactions involving multiple parameters [5]. Corrosion is one of the main processes that contribute to the rupture of cast iron drinking water pipes. It is the result of an exchange and movement process of ions that occurs either between two sites of the pipe having different potentials or between the soil and the external wall of the pipe [6].The aim of this work is to assess the physicochemical quality of water from certain boreholes in Tillabéry, to determine the origin of corrosion and scaling of equipment in order to propose solutions to the problems encountered.

**Materials and methods**

**Presentation of the study area**

The study area, the Tillabéry region, is located in the southwest of Niger. It is a plateau at an altitude of about 250 m, cut by temporary or permanent watercourses [7]. It is characterized by a climate of the sahelian tropical zone with a short rainy season (less than four months) and a long dry season. The temporal variability of precipitation is indeed quite high in the region [8]. The extreme averages of daily temperatures are from 18°C to 38°C, but they can vary between 9°C in January and 45°C in April during the day. The description of the soils shows slightly leached sandy formations and slightly evolved soils of erosion with a ferruginous facies [9, 10]. The Tillabéry region has the hydrographic network consisting of the Niger River, the only permanent watercourse, and its tributaries. In the north of the region, the depth of the groundwater table is 40 to 60 m and can reach 90 m on the plateaus. In the south, the areas near the river and those of Dallol Bosso are at most only about ten meters with alkaline soils. In the east, the depth is generally variable from 15 to 50 m and in the west between 20 and 35 m [7].



**Figure 1**: Location of the study area [7].

**Sampling and analysis**

The principles and methods of sampling, physicochemical analyses described by the French Association for Standardization (AFNOR) on water quality and analysis were used [11, 12]. The samples were taken in sterilized polypropylene plastic bottles rinsed several times with water from the boreholes filled to the brim for physicochemical analyses. Physical parameters such as conductivity and pH were measured *in situ* using a Palintest pH meter and an EUTECH INSTRUMENTS conductivity meter (Ciber Scan Com.110). All water samples were labeled and stored at 4°C until the water analysis laboratory of the regional directorate of hydraulics and sanitation of Tillabéry. Chemical parameters namely F - , SO 4 2- , total Fe, NO 3 - and NO 2 - were analyzed using a DR-3900 spectrophotometer. K+ and Na+ by atomic absorption using a JENWAY flame spectrophotometer. Ca2+ and Mg2+ were determined by EDTA complexometric, HCO3- by sulfuric acid titrimetric using a Hach Digital Titrator and Cl- by the Mohr method [12]. The data from these analyses were processed using diagram software for a global visualization of the hydro chemical facies and the XLSTAT 2014 software for the determination of the correlations between the different parameters [13, 14]. The axes whose values are greater than 1 are used for the choice of the factorial axes. The modified Larson formula was used for the determination of the corrosion indices. Larson was one of the first to be interested in the effect of certain ions present in water which influence the corrosion rate and proposes the following index (IL) [15]:

$$IL=\frac{\left([Cl^{-}\right] + [SO\_{4}^{2-}])}{[HCO\_{3}^{-}]} (1)$$

Chloride and sulfate ions have a very important complexing effect. It is therefore logical that these two ions are considered very corrosive and appear in the numerator of the expression of the Larson index from which the corrosion index (Ic)can be expressed as:

$$I\_{c}=\frac{\left([Cl^{-}\right] + 2[SO\_{4}^{2-}])}{[HCO\_{3}^{-}]} \left(2\right)$$

Concentrations are expressed in mol/L. Larson and Skold estimated that this index should not exceed 0.2 or 0.3. Other works show an acceptable value of up to unity [16].

**Results and discussion**

The results of the physicochemical analysis of the water are presented in Table 1

**Table 1:** physicochemical parameters of the waters analyzed from the Tillabéry region in mg.L-1 except (CE and pH)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Works | CE (µS.cm-1 ) | pH | Cl- | F- | NO2- | NO3- | HCO3- | SO42- | Ca2+ | Mg2+ | K+ | Na+ | Fe2+ |
| Dantiandou | **1863** | 7.9 | 85.2 | 0.75 | 0.01 | 3.52 | **282** | **300** | 32 | 2.42 | 6 | 126 | 0.13 |
| Dey Tegui | **1350** | 7.47 | 71.5 | 1.47 | 0.042 | 1.76 | **299.51** | **270** | 34 | 15.69 | 8 | **238** | 0.09 |
| Boundou | **1330** | 7.48 | 47 | **1.57** | 0.003 | 5.28 | **301.34** | **310** | 42 | 32.92 | 9.44 | **215.5** | 0.15 |
| Guilleyni | **1350** | 7.46 | 250 | **1.56** | 0.072 | 3.52 | **268.4** | **300** | 49 | 21.26 | 8 | **283** | 0.12 |
| Ayorou | **2420** | 8.81 | 228.25 | 1.2 | 0 | 0 | **207.4** | **1528** | **103.2** | 29.76 | 2.8 | 165 | 0.063 |
| Lallé Tondi | **1269** | 7.9 | 54.04 | 0.05 | 0.024 | 3.5 | **226.35** | **485.5** | **145.01** | 3.36 | 6.03 | 22.25 | 0.25 |
| Camp BF1 | **1250** | 7.2 | 68 | 0.97 | 0.06 | 11.88 | 109.8 | **345** | 45 | 40.7 | 6.89 | 94.85 | 0.11 |
| Camp BF4 | **1240** | 7.8 | 93 | 0 | 0.01 | 9.24 | 170.8 | **340** | 48 | 7.29 | **16** | 110 | 0.13 |
| Displaced Camp | **1210** | 7.6 | 63.5 | **1.72** | 0.006 | 1.76 | 152.5 | **370** | 24 | 7.29 | **16.45** | **213.3** | 0.27 |
| Borgan Golay | **3180** | 6.4 | 187 | 0.38 | **0.35** | **157.52** | 122 | **480** | **246** | **64.39** | **16.65** | 95.4 | **0.43** |
| Gueme | **1510** | 7.51 | **368** | 0.18 | 0.007 | 1 | **1342** | **510** | **144.7** | **142.94** | **26.65** | **424.4** | **1.25** |
| Fanaka koira 1 | **1737** | 6.35 | 74 | 0.74 | 0.029 | **52.8** | **307.44** | **530** | **236** | 38.39 | 7 | 65 | 0.04 |
| Kalbiri | **1230** | 7.48 | 9.6 | 0.19 | **0.231** | **53.68** | 16.47 | **275** | **82** | 37.66 | 3.5 | 5.3 | 0.06 |
| Manda Peulh | **1847** | 6.19 | 36 | 0.16 | 0.023 | 22 | 65.88 | **875** | **300** | 36.4 | **53.57** | 53.13 | 0.08 |
| Gabdey Bangou | **2790** | 6.8 | 202 | 0.76 | 0.033 | 13.2 | 21.96 | **1300** | **210** | **88.69** | **15** | **266** | 0.16 |
| Banned Kaina | **1180** | 7.2 | 110 | 0.83 | 0.02 | 4 | 151.28 | **430** | **94** | 6,075 | 11.7 | 182.4 | 0.01 |
| Haro Tondo | **1251** | 7.1 | 9.7 | 0.6 | **0.25** | 29.04 | **228.75** | **800** | **128** | **74,115** | 10.4 | 157 | **0.58** |
| Algouré Sounna | **3100** | 8.7 | **546** | **3.6** | **5.24** | 22 | 30.5 | **660** | **226** | 37.66 | **35** | **245** | 0.05 |
| Simiriko | **1275** | 6.41 | 72 | 1.02 | 0 | 5.28 | 176.9 | **510** | **106** | **62.57** | 6 | 88.25 | **1.2** |
| Hari Tchirey | **1610** | 7.53 | 4.4 | 0.78 | 0.042 | 22 | 12.2 | **700** | **108** | **68.04** | 3.3 | 65 | 0.07 |
| Banna Beri | **1953** | 7.6 | 50 | 0.72 | 0.116 | **61.6** | 87.88 | **920** | **182** | **97.69** | 11.7 | 113 | 0 |
| Fanaka koira 2 | **1406** | 6.95 | 5 | 1.35 | 0.059 | 50.6 | **202.52** | **580** | **254** | 23.09 | 4 | 26 | 0.03 |
| Fanaka Koira 3 | **2860** | 6.95 | **280** | 1.19 | 0.1 | **246.4** | **285.49** | **750** | **168** | **105.71** | **30** | **250** | 0.03 |
| Balley Do | **1315** | 6.85 | 53 | 0.57 | 0.04 | 8.36 | 191.54 | **410** | **116** | **61.36** | 6 | 38.5 | 0.03 |
| Boukanda 2 | **8060** | 6.33 | **2083** | 0.55 | 0.013 | 23.32 | 133.22 | **350** | **114** | **57.11** | **98.7** | **1189** | 0.06 |
| Sikou koira | **3230** | 6.6 | **439** | 0.93 | 0.13 | 19.8 | **433.83** | **640** | **249** | **62.94** | 7.69 | **283.51** | 0.01 |
| Tolboye Hodobo | **1243** | 7.7 | 150 | 0.98 | 0.93 | 3.96 | 200.08 | **310** | 46 | 20.65 | 10.3 | 192 | 0.11 |
| Talfaga | **1296** | 7.6 | 138 | 0.96 | 0.02 | 4.4 | **258.64** | **285** | 49.6 | 29.88 | 10.4 | 183.2 | 0.13 |
| Tamare | **1355** | 7.7 | 190 | 0.84 | 0.026 | 3.96 | **256.2** | **280** | 48 | 24.3 | 12 | 209 | 0.19 |
| Mondolo Wali koira | **1597** | 6.79 | 130 | 0.49 | 0 | 10.56 | **237.9** | **460** | **105** | 47.97 | 11.5 | 157 | 0.17 |
| Guessed Sisam | **1321** | 7.7 | 165 | 0.74 | 0.017 | 2.64 | **264** | **300** | 40 | 27.94 | 11.4 | **206** | 0.13 |

It is clear from this Table that the water is of notable mineralization with high CE electrical conductivities which largely exceed the WHO guide value of 250µS/cm [17]. This high mineralization can be explained by the shallow depths of the groundwater [7] likely to receive the hydrolyzed ions following the leaching of rocks and the residence time of the major ions. The pH values of the water from the various boreholes tend towards a pH of drinking water. However, acidic pH values were recorded on some boreholes studied which exceed the WHO guide value. This could be due to the decomposition of organic matter which uses the oxygen in the air to produce carbon dioxide. In water, the latter produces carbonic acid. In the presence of calcium carbonate compounds in the environment, the carbonic acid thus formed will dissolve them to produce calcium and then bicarbonate ions likely to increase the pH of the water. Concerning anions (Cl- , F- , NO2- , NO3- , HCO3- , SO42- ) whose guide values are respectively (250, 1.5, 0.15, 50, 200, 250) mg/L; for Cl- ions, five villages have values exceeding 250 mg/L. For fluoride ions, four villages have values exceeding 1.5 mg/L. With nitrite ions, five villages record values exceeding 0.15 mg/L. Regarding nitrate ions, five villages have levels above 50 mg/L. Regarding bicarbonate ions, sixteen villages have values exceeding the normal. Regarding sulfate ions, all levels exceed the WHO guide value. The WHO guideline values for cations (Na+ , Ca2+ , Mg2+ , K+ , Fe2+ ) are respectively (200, 70, 50, 12, 0.3) mg/L. Concerning calcium ions, twenty villages have levels higher than 70 mg/L. Concerning sodium ions, 12 villages have levels higher than 200 mg/L. For magnesium ions, 11 villages have a level higher than 50 mg/L. For potassium ions, 7 villages record values exceeding 12 mg/L and finally for ferrous ions, only 4 villages have levels higher than 0.3 mg/L. Thus, the consumption of water with values largely exceeding the WHO guideline values could cause health problems among consumers. It is very important to seek an adequate solution before supply.

**Descriptive analysis**

Table ***2*** presents the results of the descriptive analysis.

**Table 2**: Descriptive statistics of the results of physicochemical analyses:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable | Observations | Minimum | Maximum | Average | Standard deviation |
| THIS | 31 | 1180,000 | 8060.000 | 1923.484 | 1311.206 |
| pH | 31 | 6,190 | 8.810 | 7.292 | 0.642 |
| Cl- | 31 | 4,400 | 2083.000 | 202.006 | 372.160 |
| F- | 31 | 0.000 | 3.600 | 0.898 | 0.673 |
| NO2- | 31 | 0.000 | 5.240 | 0.255 | 0.942 |
| NO3- | 31 | 0.000 | 246.400 | 27.696 | 50.911 |
| HCO3- | 31 | 12.200 | 1342.000 | 227.251 | 229.831 |
| SO42- | 31 | 270.000 | 1528.000 | 535.597 | 300.794 |
| Ca2+ | 31 | 24.000 | 300.000 | 121.758 | 80.486 |
| Mg2+ | 31 | 2.420 | 142.940 | 44.395 | 33.031 |
| K+ | 31 | 2.800 | 98.700 | 15.551 | 18.749 |
| Na+ | 31 | 5.300 | 1189.000 | 192.322 | 207.883 |
| Fe2+ | 31 | 0.000 | 1.250 | 0.198 | 0.300 |

It is clear from this Table that the pH values are between 6.19 and 8.81 with an average of 7.29 which are close to the pH value of gypsiferous soils rich in coarse sand [18]. Concerning the anions (Cl- , F- , NO2- , NO3- , HCO3- , SO42-), the Cl- ions are predominant and range between 4.4 mg/L and 2083 mg/L with an average of 202.006 mg/L and a standard deviation of 372.160 mg/L. Then come the SO42- ionswhose values are from 270 to 1528 mg/L with an average of 535.597 mg/L and a standard deviation of 300.794 mg/L. In third place are the HCO3- with values between 12.2 and 1342 mg/L with an average of 227.251 mg/L and a standard deviation of 229.831 mg/L. In fourth place are the NO32- with values between 0 and 246.4 mg/L with an average of 27.696 mg/L and a standard deviation of 50.911 mg/L. In last place are the nitrite ions with values between 0 and 5.24 mg/L with an average of 0.255 mg/L and a standard deviation of 0.942 mg/L and fluorides with values between 0 and 3.6 mg/L with an average of 0.898 mg/L and a standard deviation of 0.673 mg/L. Regarding the major cations, Na+ are the most abundant with values between 5.3 and 1889 mg/L and an average of 192.322 mg/L with a standard deviation of 207.883 mg/L. Then come the Ca2+ ionswith values between 24 and 300 mg/L with an average of 121.758 mg/L and a standard deviation of 80.486 mg/L. In third place are the magnesium ions with values between 2.42 and 142.94 mg/L with an average of 44.395 mg/L and a standard deviation of 33.031 mg/L. In fourth place, the K+ ionswith values between 2.8 and 98.7 mg/L with an average of 15.551 mg/L and a standard deviation of 18.749 mg/L. Fe2+ cations are in last position and range from 0 to 1.25 mg/L with a mean of 0.198 mg/L and a standard deviation of 0.3 mg/L.

**Piper diagram of the analyzed waters**

The results obtained show on the ternary diagram of the anions, the majority of the water points analyzed are oriented towards the sulfate pole, while that of the cations is oriented towards the sodium and potassium pole with the exception of the water of Guemé which is bicarbonated, of Boukanda 2which is chlorinated and then that of Fanaka Koira 1 and Lallé Tondi which are calcic as shown in ***Figure 2.*** The abundance of these ions in the aquifers is confirmed by several studies which have led to chlorinated and sodium sulfated waters concerning certain areas of the Tillabéry region [19, 20, 21, 22]. It should be noted that the ion concentration of water does not always remain static, it is likely to change over time and space; an evolution which can be explained by the nature of the infiltrations and the exchanges between the water and the nature of the soil [23].



Piper diagram waterwater

**Figure 2**: Piper diagram of the analyzed waters.

**Principal component analysis PCA**

This analysis allows calculating the eigenvalues, the variances for each factorial axis, their accumulation to understand the participation of each parameter in the constitution of the factorial axes (***Figure 3***). The total variance of two factorial axes F1 and F2 is 48.97% and is insufficient to provide information on the different interactions that take place in the aquifer of the study area, hence the continuation of the analyses up to three factorial axes. Table ***3*** shows that the first three axes express 65.06% of the total variance including 29.91% for the first axis, 19.06% for the second axis and 16.09% for the third axis.

**Table 3**: Eigenvalues:

|  |  |  |  |
| --- | --- | --- | --- |
|  | **F 1** | **F 2** | **F 3** |
| Eigenvalue | 3.889 | 2.477 | 2.092 |
| Variability (%) | 29.917 | 19.058 | 16.094 |
| % cumulative | 29.917 | 48.975 | 65.069 |

**Table 4**: Eigenvectors:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **THIS** | **pH** | **Cl-** | **F-** | **NO2-** | **NO3-** | **HCO3-** | **SO42-** | **Ca2+** | **Mg2+** | **K+** | **Na+** | **Fe2+** |
| **F1** | **0.945** | -0.404 | **0.914** | -0.003 | 0.129 | 0.28 | 0.081 | 0.152 | 0.373 | 0.436 | **0.896** | **0.86** | 0.025 |
| **F2** | 0.179 | **0.568** | 0.27 | **0.679** | **0.6** | -0.313 | -0.462 | -0.202 | -0.34 | **-0.634** | 0.148 | 0.206 | **-0.542** |
| **F3** | 0.04 | -0.048 | -0.252 | 0.317 | 0.425 | **0.529** | -0.455 | **0.641** | **0.716** | 0.215 | -0.102 | -0.408 | -0.333 |

It is clear from this Table that the factor F1 is defined by CE, Na+, Cl- and K+. This axis reflects the natural overall mineralization of the waters. The grouping of these elements around this axis (F1, ***Figure 3***) shows that they would be dissolved by the same phenomenon. These elements could come from soil leaching, particularly the lateritic plateaus encountered south of Tillabéry. Conductivity describes the inorganic salts dissolved in the water [24] and the correlations of Cl- ions with Na+ and K+ ions (respectively 0.86 and 0.89) could be the cause of the salty taste of the water. Cl- ionscould come from human waste to pollute the water table because they do not combine easily with chemical elements and remain very mobile [25, 26]. The factor F 2 describes the pH, NO2- , F- which are diametrically opposed to Mg2+ and Fe2+ (***Table 3*, *Figure 3***). The hydrolysis of certain rocks such as muscovite, tourmaline could constitute the origin of fluoride ions following water-rock contact. Thus, Mg2+ ionscome mainly from the alteration of ferromagnesian minerals (migmatites and dolerites) [7, 21]. The factor F3 shows a correlation of NO3-, Ca2+ and SO42-. The study area being subject to significant evaporation due to the high temperatures it records during dry seasons, this phenomenon can promote the formation of gypsum (CaSO4, 2H2O) which can be dissolved by the infiltration water leading to their migration towards the water table [27]. NO3- and NO2- could have a purely anthropogenic source following human discharges and fertilizers used during agriculture and for which water has become the receptacle [28].

**Figure 3**: Correlation circles of the studied parameters

**Corrosive effect of the waters analyzed**

The classification of water obtained from the Piper diagram and the principal component analysis (PCA) led to the study of the mechanism of scaling and corrosion of the pipes of the different boreholes. Being practically sulfated, these sulfate-rich waters induce the proliferation of sulfate-reducing bacteria in the stagnation zones of the water distribution network [29]. Thus, the results of the calculated corrosion indices I C showed that 97% of the villages studied have a clear tendency towards corrosion and only 3% have an average tendency as shown in Figure 4 below:



**Figure 4**: Distribution of corrosion indices in the study area.

The values of the different indices according to the villages are illustrated in Figure 5:



**Figure 5**: Values of corrosion indices according to the villages studied.

The highest IC index is that of Gabdey Bangou with a value of 191.68. The water of Guessé Sisam has the lowest value with an IC of 0.72. It has been noted that the value of these indices is linked to the level of bicarbonate ions present in the water. According to Pierre (2012), alkaline earth ions such as calcium and magnesium can capture peroxide radicals when these cations are associated with hydrogen carbonate ions [16] according to the following reactions (3) and (4):

$$CaHCO\_{3}^{+}+ HO\_{2}^{.}+ H\_{2}O \rightarrow CaHCO\_{3}O\_{2}^{.}+ H\_{3}O^{+} (3)$$

$$MgHCO\_{3}^{+}+ HO\_{2}^{.}+H\_{2}O \rightarrow MgHCO\_{3}O\_{2}^{.}+H\_{3}O^{+} (4)$$

The radical thus formed then reacts with the hydroxide radicals to form solid calcium carbonate which is stable as long as the water is calcifying by the process of radical precipitation equation (5):

$$CaHCO\_{3}O\_{2}^{.}+ OH^{.} \rightarrow CaCO\_{3}+ H\_{2}O+ O\_{2} (5)$$

One of the essential factors in the development of a corrosive attack is the presence of dioxygen in the water. Corrosion by dissolved oxygen results in more or less deep pitting of the metal. Thus, electrochemical corrosion in a soil results from the activity of corrosion piles. Equation (6) explains the oxidation of iron which is equivalent to a loss of electrons:

$$Fe\rightarrow Fe^{2+}+ 2e^{-} (6) $$

The phenomenon of reduction of the solvent which is water is equivalent to the gain of electrons and a loss of an oxidation state is described by equation (7):

$$2H\_{2}O +2e^{-} \rightarrow H\_{2} +2OH^{-} (7)$$

Sulfated waters produce a significant amount of sulfide, especially hydrogen sulfide, which gives the water an unpleasant odor and taste, accelerates biological corrosion, and impairs its disinfection in distribution networks [30]. For this reason, the dihydrogen obtained in equation (7) combines with sulfate ions to produce hydrogen sulfide as shown in equation (8):

$$H\_{2} +SO\_{4}^{2-} \rightarrow H\_{2}S + 2O\_{2} +2e^{-} (8)$$

Some of the oxygen in the water produced in equation (8) will react with the hydrogen sulfide to give solid sulfur according to equation (9):

$$H\_{2}S + ^{1}/\_{2}O\_{2} \rightarrow S\_{solide } + H\_{2}O (9)$$

Sulfur is readily adsorbed on the surface of metals, reducing the effectiveness of natural or artificial protective layers. The dissolution of gases in water has very important consequences for natural waters, whether these gases are essential for aquatic life such as O2 or CO2 or whether they are toxic gases such as H2S.

Another part of the dioxygen still obtained in equation (8) will react with water to also give hydroxides as explained in equation (10)

$$^{1}/\_{2}O\_{2} +H\_{2}O +2e^{-} \leftrightarrow 2OH^{-} (10)$$

The Fe2+ obtained in equation (6) will react with the OH- of equation (10) to give ferrous dioxide Fe(OH)2 and is interpreted by equation (11):

$$Fe^{2+}+2OH^{-} \leftrightarrow Fe(OH)\_{2} (11)$$

Ferrous dioxide in the presence of oxygen is transformed into ferric hydroxide Fe(OH)3 insoluble in water and is described by equation (12):

$$2Fe(OH)\_{2}+ ^{1}/\_{2}O\_{2}+ H\_{2 }O \rightarrow 2Fe(OH)\_{3} (12)$$

Ferric hydroxide covers ferrous hydroxide and the whole gives a mushroom-shaped deposit [31].

As the temperature rises, some of the HCO3- in thewater is decomposed according to equation (13):

$ 2HCO\_{3}^{-} \leftrightarrow CO\_{3}^{2-}+ CO\_{2}^{\uparrow }+ H\_{2}O$(13)

The quantity then becomes sufficient to precipitate calcium carbonate which is the scale that can block the pipes according to equation (14):

$$Ca^{2+}+ CO\_{3}^{2-} \leftrightarrow CaCO\_{3 \left(solide\right)} (14)$$

Scale reduces the useful section of the pipes and can even obstruct them, altering the pressure losses and the flow rate of the water. Generally, carbonate scale causes the seals to harden and become brittle [32].

A part of the carbonates is hydrolyzed according to equation (15):

$$CO\_{3}^{2-}+ H\_{2}O \leftrightarrow CO\_{2}^{\uparrow }+ 2OH^{-} (15)$$

This equation is at the origin of the rise in the pH of water from boreholes with high bicarbonate ion contents (Ayorou, Algouré Sounna and Lallé Tondi).

**Conclusion**

The study of the physicochemical quality of groundwater from some boreholes in the Tillabéry region has highlighted their characteristics, their degree of drinkability and corrosion. It should be noted that these waters are of notable mineralization with conductivities far exceeding the standard recommended by the WHO. The use of the Piper diagram shows a diversity of facies with a predominance of sulfate, potassium and sodium. The PCA principal component analysis shows that the Mg2+, Ca2+, F-, SO42- ionscome from the water-rock contact and the dissolution of sedimentary rocks, while the NO2- and NO3- ionscome from leaching during the infiltration of water into the soil. The high sulfate ion contents give a medicinal taste to the water which causes the purgation of the digestive tract in humans with the production of sulfate-reducing bacteria likely to corrode the pipes. Thus, with the determination of corrosion indices, 97% of waters show a clear tendency to corrosion. In this case, it is important to propose a method of treating these waters with inexpensive materials that are accessible to all.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

.

**Details of the AI usage are given below:**

1. In the manuscript, the Piper diagram is used to identify the type of water, and XLSTAT to understand the origin of the various ions.
2. The DeepL and google translate are used to check the language used in the data.

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