World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Assessment of surface water quality in mining area: A case study of the southwest region of Burkina Faso

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World Journal of Advanced Research and Reviews, 2025, 25(01), 1097-1107

Publication history: Received on 06 November 2024; revised on 13 January 2025; accepted on 15 January 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.25.1.0073

Abstract

Mining activities, whether industrial or artisanal, are often responsible for the pollution of water resources, leading to significant degradation of water quality. This study aims to assess the quality of surface waters in three out of the four provinces of the South-Western region of Burkina Faso, an area known for its numerous mining sites. To evaluate the water quality in the study area and to assess the importance of each parameter in influencing this quality, we applied Weighted Arithmetic Water Quality Indices (WAWQI) and Hierarchical Cluster Analysis. These analyses were based on data obtained from the measurement of various physicochemical parameters (pH, electrical conductivity, total hardness, calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulphate, nitrate, phosphate) and heavy metals (total iron, manganese, lead, cadmium, chromium, copper, zinc, arsenic) collected at the end of 2020. Samples were taken from a variety of sources: four rivers and five reservoirs. This approach provided a comprehensive assessment of the surface water quality in the study area.

The results indicated that, of the twenty parameters analysed, only total iron consistently exceeded the World Health Organization (WHO) standards across all samples, while bicarbonate exceeded the standard in three instances and calcium-phosphate in one. The water quality index values ranged from 8.18 to 165.85, with an average of 46.84. Only one river sampling point, situated at the Poni province (SW4 at Poniro River), exhibited "poor" water quality, while all other water bodies exhibited water quality ranging from "good" to "excellent." The dendrogram analysis confirmed this finding by showing that total iron is separated from the other parameters, highlighting its negative role in the deterioration of water quality, whereas the other parameters play a positive role.

Keywords: Surface water; Water quality index (WQI); Southwest region; Burkina Faso; Mining activities

1. Introduction

The mining sector in Burkina Faso has experienced significant growth over the past few decades. Once dominated by large-scale mining industries, the sector is now characterized by the proliferation of artisanal mining operations. Indeed, more than 1,000 gold mining sites have been identified across the national territory [1]. This mining activity has seen particular development in the South-Western region, where 74 sites have been identified [2].

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Gold is the most sought-after mineral in mining activities and constitutes a major source of income for both the state and the local populations [3]. Whether artisanal or industrial, the methods used for mineral extraction in general, and gold extraction in particular, present significant risks of environmental pollution. [4] stated that the exploitation of mining products is one of the practices causing the most damage to the environment, especially in Africa's producing countries. A study conducted by [2] revealed that in 44 gold panning sites, significant pollution risks affected nine rivers in the Mouhoun basin. The pollution generated by small-scale mining sites leads to significant environmental consequences, notably due to the transportation of pollutants by waterways [5]. Various chemicals are used at artisanal gold extraction sites, including mercury, cyanide, sulfuric acid, nitric acid, zinc, motor oils, and detergents [3], [6], [7], [8]. These substances are likely to contaminate surface or groundwater [9]. The release of these chemicals into the environment or the runoff of polluted water from these substances affects the spring waters and the hydrographic network of the Poni Province, in the South-Western region of Burkina Faso [10]. [11] highlighted the pollution of surface waters by metallic elements such as mercury, arsenic, iron, and lead, linked to mining activities in the commune of Meguet, located in the Central Plateau region of Burkina Faso.

Evaluating water quality from a large number of samples, each containing many parameters, can be challenging [12]. To simplify this process, researchers developed the concept of the Water Quality Index (WQI), which has been used in many countries for several decades. Horton [13] was the first to apply a method for calculating the WQI, considering ten water quality parameters. In recent times, methods for calculating the Water Quality Index (WQI) have significantly simplified the process of assessing water quality, as well as its monitoring and evaluation over both time and space. As a result, it is important to recognize that WQI calculation techniques provide considerable value in decision-making regarding water quality management and control. This approach has been widely adopted by researchers to assess the quality of surface water [14], [15], [16], [17], [18]. Surface waters in the locality play a crucial role for local populations, particularly in rural areas. They are used for market gardening, livestock watering, and sometimes even for domestic purposes within households. Therefore, in the context of mining activities, it is essential to assess the quality of these waters, which are vulnerable due to their easy accessibility. This study aims to evaluate the quality of surface waters in the provinces of Poni, Bougouriba, and Ioba, located in the South-Western region of Burkina Faso.

2. Material and methods

2.1. Study area overview

The study area covers the provinces of Poni, Bougouriba, and Ioba, located in the South-Western region of Burkina Faso. It spans between latitudes 9°50' and 11°22' North and longitudes 2°42' and 4°42' West, with a total area of 13,598 km^2. The area is bordered to the east by the Republic of Ghana and the Centre-East region, to the west by the Cascades and Hauts-Bassins regions, to the north by the Hauts-Bassins and Mouhoun regions (to a lesser extent), and to the south by Côte d'Ivoire (Figure 1).

The climate of the region is of the Sudanian-Guinean type. Rainfall typically lasts for an average of six months per year, which can extend to seven months in the southern part of the area. The average annual precipitation ranges between 900 and 1200 mm.

The region is drained by the Mouhoun and Comoé-Léraba river basins. The hydrographic network of the area is also characterized by the presence of non-permanent secondary rivers, as well as surface water storage structures such as dams, lakes, and ponds.

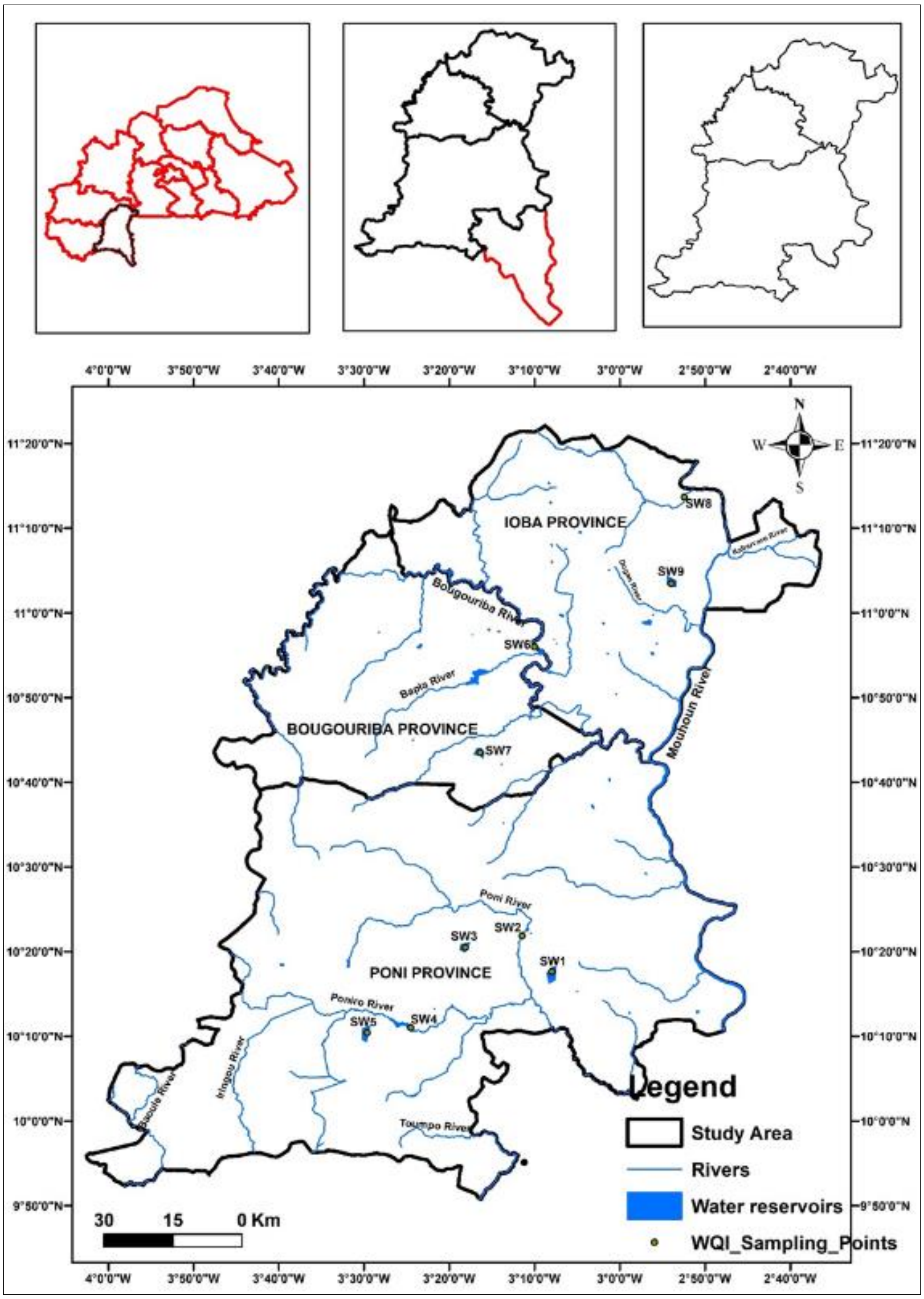

Figure 1 Geographical Location of the Study Area

2.2. Sampling

In the study area, surface water sampling was conducted at the end of 2020. In the Poni province, five samples were collected, three from water reservoirs (SW1, SW3 and SW5) and two from rivers (Poni: SW2 and Poniro: SW4). In the Bougouriba province, two samples were taken: one from a water reservoir (SW7) and the other from the Bougouriba River (SW6), which marks the boundary between this province and Ioba province, where two additional samples were collected, one from the river (SW8) and the other from a water reservoir (SW9). In total, nine samples were collected and analysed by the General Directorate of Water Resource (Fig. 1).

For each sample, physicochemical and metallic analyses were conducted. pH, temperature, and electrical conductivity were measured in situ using the WTW MULTILINE P4 device. The following chemical parameters: nitrate (NO_3), nitrite (NO_2), phosphate (PO_4), and sulphate (SO_4) were analysed using ion exchange chromatography. Chloride (Cl^-) ion concentration was determined by titrimetric method. The concentration of calcium and magnesium ions was determined volumetrically using an EDTA (Ethylene Diamine Tetra-Acetic Acid) solution. Sodium (Na), potassium (K) ions, and heavy metals (Fe, Cu, Mn, Zn, As, Pb, Cr, Cd) were quantified by atomic absorption spectroscopy using the Perkin Elmer Pin AAcle 900T.

3. Method

3.1. The Weighted Arithmetic Water Quality Index

In this study, the Weighted Arithmetic Water Quality Index (WAWQI) method was employed to determine the water quality index of the surface water. This technique reduces multiple water quality parameters results to a single, easily interpretable value, facilitating straightforward evaluation. The weighted arithmetic WQI values were determined based on the following procedure:

In the first step, the physicochemical parameters (pH, electrical conductivity, total hardness, calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulphate, nitrate, phosphate) and the heavy metals (total iron, manganese, lead, cadmium, chromium, copper, zinc, arsenic), which are to be used in the calculation of the water quality index, are identified. The guideline values for each of these parameters, as per the World Health Organization (WHO) standards, are then determined (Table 1).

Table 1 WHO Drinking Water Standards, Weights, and Relative Weights used in the calculation of the surface water quality index

Parameters	Units	WHO (2011)	Weight (wi)	Relative weight (Wi)
pH	-	6,5-8,5	4	0,06
CE à 20°C	(µS/cm)	2500	5	0,07
TH	(°F)	500	2	0,03
Ca	(mg/L)	75	2	0,03
Mg	(mg/L)	50	2	0,03
Na	(mg/L)	200	2	0,03
K	(mg/L)	12	2	0,03
Fe	(mg/L)	0,3	3	0,04
HCO3	(mg/L)	120	1	0,01
Cl	(mg/L)	250	3	0,04
SO4	(mg/L)	250	4	0,06
NO3	(mg/L)	50	5	0,07
PO4	(mg/L)	1	4	0,06
Mn	(mg/L)	0.4	3	0,04
Pb	(mg/L)	0.01	5	0,07
Cd	(mg/L)	0.003	5	0,07
Cr	(mg/L)	0.05	5	0,07
Cu	(mg/L)	2	4	0,06
Zn	(mg/L)	5	3	0,04
As	(mg/L)	0.01	5	0,07
Total	-	-	69	1,00

During the second step, a weight (wi) is assigned to each selected parameter based on its influence on health and its relative importance for drinking water quality, according to WHO standards. The weights range from 1 to 5, depending on the parameter's relevance in determining the overall water quality for consumption (Table 1).

In the third step, the relative weight of each parameter was determined (Table 1) using Equation 1.

$$W_i = \frac{w_i}{\sum_{i=1}^{n}(w_i)} \quad \text{Equation 1}$$

Wi represents the relative weight of each parameter, while wi refers to the assigned weight. The total number of parameters considered is denoted by n (5). In this context, Table 1 provides the standard values based on WHO guidelines, along with the assigned and relative weights for each parameter, which are used in calculating the WQI. A weight of 5 was assigned to NO_3, EC [14], [19], Pb, Cd, Cr and As; 4 to pH, SO_4, [20], PO_4 [14], and Cu; 3 to Fe [14], [20], Zn and Mn; 2 to TH, Ca, Mg, Na, and K [20], and 1 to HCO_3 [19; 20], according to their relative importance (Table 1).

In the fourth step, the quality-rating scale (Qi) for each parameter was determined using Equation 2.

$$Q_i = \frac{(C_i - V_i)}{(S_i - V_i)} \times 100 \quad \text{Equation 2}$$

Where **Ci** represents the estimated concentration of each parameter and **Si** denotes the recommended value according to WHO drinking water quality standards, the value of **Vi** is set to zero for all parameters, except for pH, which is set to 7 [19], [21].

In the fifth step, the sub-index value for each parameter is calculated using Equation 3.

$$SI_i = Q_i \times W_i \quad \text{Equation 3}$$

Finally, the WQI for each groundwater sampling point is determined using Equation 4.

$$WQI = \sum_{i=1}^{n}(SI_i) \quad \text{Equation 4}$$

The calculated WQI values were compared to the levels provided in Table 2 to determine the water quality class. Based on the results, spatial variations in the WQI can be easily observed. This allows for the quick identification of critical points, enabling the implementation of protective and/or remedial measures. When the WQI value is below 50, from 50 to 100, 100 to 200, 200 to 300, and above 300, the water is classified as excellent, good, poor, very poor, and unsuitable for consumption, respectively.

Table 2 Classification of water according to the WQI

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

3.2. Hierarchical Cluster Analysis

Hierarchical Cluster Analysis (HCA) is a statistical technique employed to categorize various parameters according to their similarities. This method operates on the principle that the assignment of objects to specific groups is not predetermined, making HCA an unsupervised learning approach [22]. The primary objective of HCA is to generate a tree diagram, or dendrogram, where parameters that share greater similarities are grouped together in closely related branches. This technique is applied in this study to group physicochemical parameters and heavy metals based on their impact on the overall water quality index. To achieve this, after calculating the global index with all parameters (a total of 20), additional indices were calculated by excluding each of these parameters. The resulting set, along with the global index, was then used for Hierarchical Cluster Analysis to assess their similarities. This analysis was conducted using SPSS software (version 25, 2017).

4. Results

4.1. Physicochemical Characteristics of Surface Water

The results of the physicochemical parameter analyses were first processed to determine the descriptive statistical characteristics, namely the maximum and minimum values, mean, and standard deviation (Table 3). These results were then compared with the reference values provided by the World Health Organization.

Table 3 Descriptive statistics of the physicochemical parameters

Parameters	Maximum	Minimum	Average	Standard Deviation
pH	7,67	6,54	6,968	0,330
EC	367	38,2	90,09	98,965
TH	46,74	11,9	25,579	10,426
Ca	100,0397	4,16832	21,706	30,452
Mg	33,264	0,34	6,579	9,788
Na	12,86	0,776	3,728	3,575
K	3,43	0,206	1,877	0,820
Fe	11,08	0,05	2,438	3,148
HCO3	376,98	2,928	132,077	142,096
Cl	2,8	0,082	1,002	0,766
SO4	1,003	0,007	0,302	0,293
NO3	15,073	0,015	1,676	4,715
PO4	2,034	0,057	0,644	0,643
Mn	0,25	0,05	0,133	0,080
Pb	0,003688	0,0005	0,002	0,001
Cd	0,00069	0,00005	0,0001	0,000
Cr	0,004586	0,000046	0,001128	0,001
Cu	0,122	0,05	0,057	0,023
Zn	0,249	0,045	0,069	0,063
As	0,001783	0,000423	0,0009	0,000
WQI	165.85	8.18	48.23	46.50

Except for pH, which has no units, total hardness measured in °F, and electrical conductivity in µS/cm, all other parameters are expressed in mg/L. Std. dev. Means Standard deviation.

The results show that the surface waters in the Southwest region generally exhibit a neutral pH. Specifically, the measured pH values range from 6.54 to 7.67. The electrical conductivity values, ranging between 38.2 µS/cm and 367 µS/cm, with a mean of 90.09 µS/cm, indicate a relatively low mineralization of these waters. The total hardness (TH), representing calcium and magnesium content, varies between 1.98°F and 26.02°F, with a mean of 7.69°F, classifying the waters as generally soft. The average concentration of bicarbonate ions is 132.08 mg/L, with a standard deviation of 144.79 mg/L. The maximum and minimum concentrations of bicarbonates fluctuate between 376.98 mg/L and 2.93 mg/L, with three sampling points exceeding the threshold recommended by the World Health Organization (WHO).

The maximum and minimum concentrations of sodium are 12.86 mg/L and 0.78 mg/L, respectively, while potassium concentrations range from 3.43 mg/L to 0.21 mg/L. These values are well below the thresholds recommended by the WHO, suggesting good organoleptic water quality.

Regarding nitrates and nitrites, the maximum and minimum concentrations are 15.07 mg/L and 0.02 mg/L for nitrates, and 0.08 mg/L and 0.02 mg/L for nitrites. All these concentrations are below the limits prescribed by the WHO. For sulphates, the maximum and minimum concentrations are 1.00 mg/L and 0.01 mg/L, respectively, also complying with WHO standards.

As for phosphates, the maximum measured concentration is 1.01 mg/L, slightly exceeding the WHO standard. However, among the nine sampling points, only one (located in the municipality of Kampti) exceeds the threshold recommended by the WHO. The average phosphate concentration is 0.65 mg/L, with a standard deviation of 0.30 mg/L. High phosphate concentrations can lead to the risk of water eutrophication [23].

4.2. Descriptive Statistics of Heavy Metal Concentrations

The descriptive statistics for heavy metals focused on the concentration of the following metallic elements: iron, manganese, lead, cadmium, chromium, copper, zinc, and arsenic (Table 3).

Total iron, which includes both ferric and ferrous iron, exhibits concentrations ranging from 11.08 mg/L to 0.05 mg/L, with a mean of 2.44 mg/L and a standard deviation of 3.22 mg/L. For this parameter, except for a single sample collected in the municipality of Tiankoura, the other eight sampling points exceed the threshold value of 0.3 mg/L.

The concentrations of other metallic elements are below the World Health Organization (WHO) threshold values for each parameter: lead (3.69 µg/L), manganese (250 µg/L), cadmium (0.69 µg/L), chromium (4.59 µg/L), copper (120 µg/L), zinc (250 µg/L), and arsenic (1.78 µg/L). Thus, except for iron, the concentrations of the other heavy metals comply with WHO standards and remain within acceptable limits.

4.3. Water Quality Indices

To obtain an overview of the surface water quality in the study area, the results of the analyses of physicochemical and metallic parameters were used to calculate the Water Quality Indices (Fig. 2).

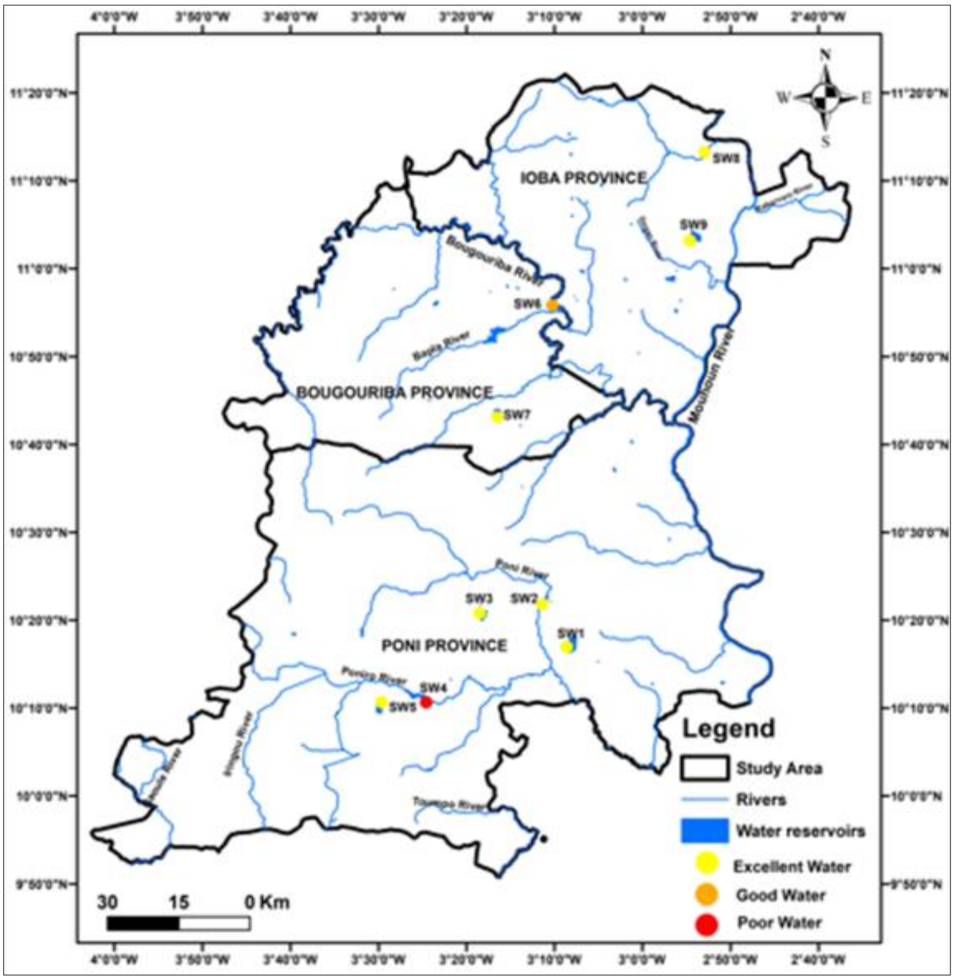

Figure 2 The different classes of surface water in the study area

The analysis of the results shows that the water quality indices range from 8.18 to 165.85 (Table 3). The maximum index was observed in a sample from the Poni province (SW4, Poniro River), while the minimum index was recorded in the same province (SW1, Water reservoir). The average of the calculated indices was 48.23, indicating that, overall, the water quality is excellent. Among the nine sampling points, seven indicate excellent water quality. The standard deviation of 46.50 indicates a slight variation in the Water Quality Index (WQI) across the sampling points.

In order to highlight the role of the various parameters used in the calculation of water quality indices, hierarchical cluster analysis was performed (Fig. 3). The resulting dendrogram reveals two distinct groups: the first group includes the overall index, i.e., the one calculated using all 20 parameters, as well as the indices calculated after excluding each of the other 19 parameters (except for iron); the second group consists solely of the index calculated without iron. This analysis shows that iron behaves quite differently from the other parameters.

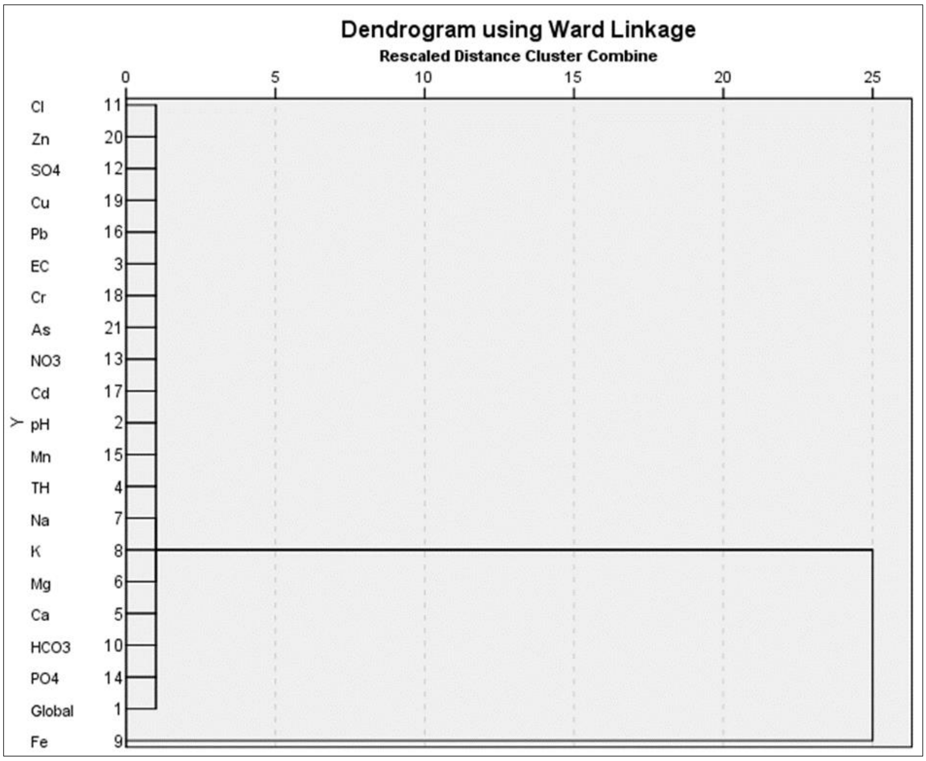

Figure 3 Cluster analysis based on sampling points of surface water

5. Discussion

This study has allowed for the assessment of water quality and the level of surface water pollution in the Southwest region of Burkina Faso. In general, the physicochemical results indicate that the water is relatively neutral, soft, and low in mineral content. The analysis of chemical parameters reveals that, overall, the water meets the standards of the World Health Organization (WHO). Dianou et al. [24] also observed in a study on the surface waters of the Sourou valley that the water quality was satisfactory. Similarly, [25] drew a similar conclusion in a study conducted on the surface waters of the Central-North region of Burkina Faso. However, the presence of heavy metals in these waters, including iron, lead, arsenic, zinc, cadmium, and manganese, is a warning sign for various stakeholders, especially the government. The presence of these elements in surface waters can be attributed to mining activities, which promote their release and dissolution into the water [26], [27], [28]. Iron, in particular, shows very high concentrations at almost all sampling points (Fig. 4). High levels of iron have also been reported in the surface waters of the gold-bearing area in the Central Plateau region, specifically at the Méguet site in Burkina Faso [11]. High iron concentrations may also result from the leaching of lateritic soils [29], [30]. In fact, this element can have either a natural origin (such as the leaching of lateritic soils) or an anthropogenic origin (due to mining activities).

The quality index provides an overall overview of water quality by considering all measured parameters and combining the influence of all parameters. Regarding the overall water quality, the WQIs for the Southwest region, except for point SW4, are satisfactory. Since the other metallic elements present in the water did not have a significant impact on water quality due to their low concentrations, it is important to emphasize that the presence of mining activities does not necessarily lead to a degradation of water quality [31]. However, regular monitoring of water quality is necessary to assess the evolution of their presence and anticipate potential pollution risks.

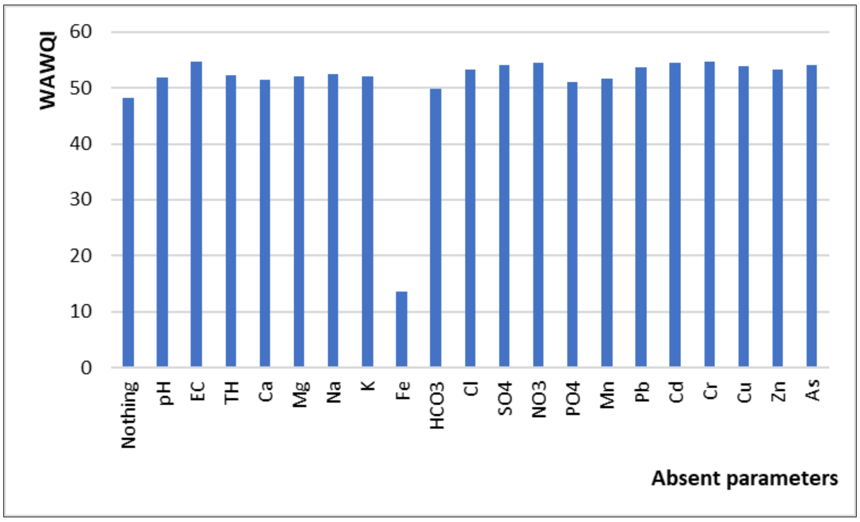

Figure 4 The average of the WQIs calculated with all the parameters and the absence of each of them

The absence of iron resulted in the highest quality indices across all nine sampling points, demonstrating that this parameter is the primary factor contributing to surface water pollution in the area (Fig. 4). [18] emphasized the importance of physicochemical parameters through this type of analysis. Their study identified two main groups, one of which was further subdivided into two subgroups, distinguishing parameters with positive, negative, and neutral effects. In our study, the absence of the other 19 parameters led to indices that were significantly different from the overall index, with each absence leading to a distinct index, which explains the absence of subgroups in this dendrogram (Fig. 3). This allows us to conclude that all the parameters used in this study are essential for determining water quality.

6. Conclusion

This study allowed for the assessment of surface water quality in the Southwest region of Burkina Faso, an area characterized by the continuous growth of mining activities. In general, the analysed waters are soft and low in mineral content, which is one of the characteristics of surface waters. Most of the physicochemical parameters measured are below the threshold values recommended by the World Health Organization (WHO). The water quality indices revealed a quality ranging from good to excellent for the majority of the sampling points, except for one point, which showed a quality considered poor. Hierarchical cluster analysis classified the parameters into two groups: one group contributes positively to the surface water quality of the locality, while the other, consisting of iron, contributes negatively, thus highlighting the importance of each parameter in the accurate definition of water quality.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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