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Fadila FEKRACHE[1*] and Khaled BOUDEFFA[2]

SURFACE WATER CONTAMINATION BY MINING WASTES: CASE OF THE SIDI KAMBAR REGION (SKIKDA NORTH-EAST ALGERIA)

Abstract: The objective of this work is to assess the contamination of the Essouk stream, under acid drainage from the Sidi Kambar mine (southwest of Skikda, Algeria), which has been widely exploited during the previous decades. The methodology was conducted to control the current state of water chemistry, its evolution in space and time according to the variation of water physicochemical parameters and the content of trace metals (Pb, Fe, and Zn). In general, Essouk stream are highly sulphated (reached 598.56 mg/L) and have an elevated salinity, resulting in a high conductivity (1925 µS/cm) and presented a low pH (3.01). In addition, Fe, Pb and Zn contents reached 5.17 mg/L, 2.05 mg/L and 4.05 mg/L, respectively. Such results were linked to the bedrock of Sidi Kambar that is composed of galena, pyrite and sphalerite.

Keywords: water, pollution, physicochemical parameters, trace metal elements, mineralisation

Introduction

Heavy metal pollution from mining is a widespread problem in the world [1]. Mining operations can have a huge local impact on the environment and population. They produce many types of air, water and soil pollutants that may ultimately affect human health [2]. Naturally, rocks containing sulphide minerals subjected to erosion for millions of years it is known as acid drainage of rocks [3]. However, this phenomenon is largely amplified by human activities and takes a considerable extent within the sites of mining activities that is called Acid Mine Drainage (*AMD*) [4].

AMD can occur at abandoned, inactive, and active mine sites, or around open pit mining operations and mine waste sites [5]. Thus, solid mine wastes can contain sometimes non-negligible quantities of non-exploitable metallic minerals, such as iron sulphides (pyrite). The existence of sulphide minerals (pyrite, galena, sphalerite, pyrrhotite, and chalcopyrite) exposed directly to atmospheric factors (water, air) leads to chemical and microbiological oxidation reactions of the residues. There is then production of sulphuric acid (H_2SO_4), which provoke a decreasing pH in the environment, leading to the formation of *AMD*. This phenomenon favours the leaching of metals by constituting an important source of pollution. As a result, it causes acidification of ponds and waterways,

[1] Laboratory of Research in Biodiversity Interaction, Ecosystem and Biotechnology (LRIBEB), Department of Natural and Life Sciences, Faculty of Sciences, University 20 August, 1955, P.O. Box 26, 21000 Skikda, Algeria, phone: +213657643755, ORCID: 0009-0007-1432-0565
[2] Department of Natural and Life Sciences, Faculty of Sciences, University 20 August 1955, P.O. Box 26, 21000 Skikda, Algeria, email: k.boudeffa@univ-skikda.dz, ORCID: 0000-0001-5581-1837
[*] Corresponding author: f.fekrache@univ-skikda.dz

compromising the life of plants and organisms living in water and on the banks. The surrounding soils become more loaded with certain heavy metals that are released and may become bioavailable to the food chains, thus threatening human, animals and vegetative health [6].

The mining activity in Algeria was very important since the middle ages and culminated in the 20th century, this activity has virtually ceased since the beginning of the 1990s, leaving many mine sites abandoned (so-called orphan mines) [7], such as the mine of Sidi Kambar where Zn/Pb are exploited. This mine, located 60 km from Skikda city, is one of the abandoned mining areas in northeastern Algeria for over 40 years. It is composed of a series of veins with sulphide mineralisation containing galena (PbS), sphalerite (ZnS), pyrite-marcasite and barite [8]. Today, after about half a century of cessation of all mining activities, Sidi Kambar mine still constitute a potential direct pollutant for the environment and for the health of the neighbouring populations [9]. Indeed, during its activities, it has generated several million tons of waste that have been abandoned without any preservation measures. The leaching of wastes by rainwater constitutes a serious source of contamination for waterways and agricultural land.

The current study investigates a typical case of the acid generating powers of the abandoned mining discharges by evaluating the physicochemical parameters (pH, electrical conductivity, total mineralisation, hardness, turbidity, total alkalinity and major elements) and trace metals. It is within this context to assess the impact of mine tailings on the quality of Essouk stream waters, which feeds the Guenitra dam.

Materials and methods

Study area

The old Zn/Pb mine of Sidi Kambar region is situated northeast of Algeria, 60 km from the Skikda province [10]. The mine site is in west Essouk sub-watershed, which feeds the Guenitra Dam (Fig. 1) and could affect its water quality [11]. It has a long mining history that begins in Roman times from the rediscovered deposit in 1879. Modern exploitation started in 1890 at the Dar El Hanout streams, with a very low production. From 1913 onwards the exploitation became regular [12, 13]. The management of the lead-zinc deposit was stopped in 1976; since then, baryte was exploited in the open pit until 1984, when the mine was closed. The mining waste from the Sidi Kambar mine stored on the surface is exposed to climatic conditions that favour the leaching of toxic metals into the environment. This poses serious risks to humans and ecosystems [14]. The extraction of ores has generated significant quantities of waste rocks that located near the laundry and are in direct contact with the Essouk stream. These discharges are considered a source of water pollution for their physicochemical instabilities [10].

Table 1

Main characteristics of Essouk stream [15]

Shape	Linear and sinuous
Length	4 km
Area	12.49 km^2

Essouk stream is feeding the Guenitra Dam from the western watershed, which runs through the mining area of Sidi-Kambar (Fig. 1, Table 1). Less than 30 km as the crow flies

from the Mediterranean coast between the cities of Skikda and Constantine [15]. It is one of the streams that fill the Guenitra dam (Fig. 1). Table 1 summarises the main characteristics of the stream.

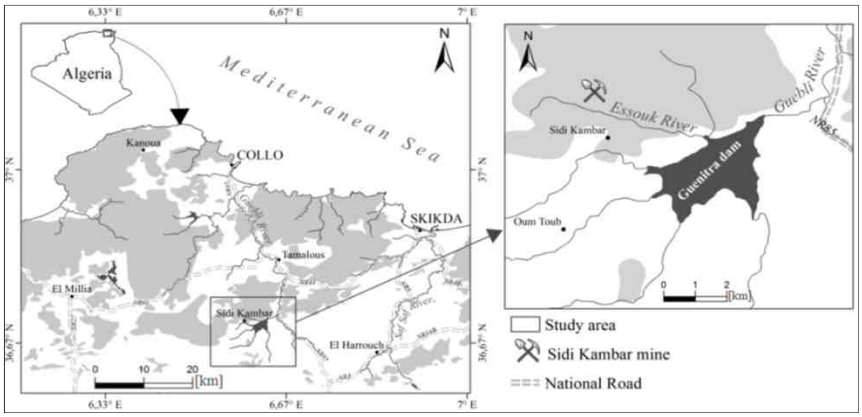


Fig. 1. Geographical location of the Sidi Kambar and Essouk stream

Water sampling and analysis

Surface water sampling was conducted during three campaigns in December 2019, February, and May 2020. The stations are located on the Essouk stream considered as the site of accumulation and sedimentation of mining effluents. The choice of stations took into account the upstream-downstream flow direction of the water and the proximity of the polluting discharges. Water samples were collected in 1 L polyethylene bottles, filled to the brim and rinsed with water and then stored at 4 °C until analysis. For the analysis of trace metals, samples were acidified to pH < 2 by adding a few drops of nitric acid. The measurements used to characterise the water quality included 13 variables (Table 2).

Table 2

Physicochemical parameters and water analysis method

Parameter	Method
Hydrogen potential (pH) [-]	Multi-parameter pH/Ion/Cond 750
Electrical conductivity (*EC*) [µS/cm]	Multi-parameter pH/Ion/Cond 750
Total hardness [mg/L]	EDTA Titrimetry
Turbidity [NTU]	Turbidimeter TurbiDirect
Total alkalinity [mg/L]	Titrimetric method
Sulphates (SO_4^{2-}) [mg/L]	Titrimetric method with $Ba(ClO_4)_2$
Calcium (Ca^{2+}) [mg/L]	EDTA Titrimetric method
Magnesium (Mg^{2+}) [mg/L]	Atomic absorption spectrometry (λ = 285.2 nm)
Chlorides (Cl^-) [mg/L]	Mohr's method

Table 3

Operating conditions for the determination of trace metals

Element dosed	Type of flame	Wavelength λ [nm]	Dosing range [mg/L]
Iron	Air-acetylene	248.3	0.05 to 4
Zinc	Air-acetylene	213.9	0.05 to 2
Lead	Air-acetylene	283.3	0.2 to 10

Metals are determined in the filtered water using a Perkin-Elmer Optima 5300 DV atomic absorption spectrometer (Table 3).

Results and discussion

Hydrogeochemical characterisation

The pH: The pH expresses the acidity or alkalinity depending on whether it is on the scale from 0 to 7 or 7 to 14 respectively, pH = 7 indicates neutrality. The pH is inseparable from the temperature of the dissolved oxygen and the total mineralisation. The pH values in the first campaign were between 3.94 and 6.91, but that of the second campaign were between 3.45 and 7.2, whereas the values fluctuate between 3.1 and 7.18 during the third campaign. The pH is close to neutral in the first three points during the three campaigns due to the water flow at the beginning of the valley and the lack of water accumulation. The acidity may have been neutralised by the dissolution of carbonate-rich minerals, possibly calcite and dolomite, which would explain, in part, the high Ca^{2+} and Mg^{2+} contents. In the points 4 to 8, the pH is acidic (varies between 3 and 4). This acidity would come from the oxidation of pyrite which is considered to be mainly responsible for the reduction in the pH of the waters of the mine and therefore causes an *AMD*.

AMD is the result of the exposure of sulfidic mine tailings (galena, pyrite) to oxygen and water [16]. The typical oxidation reactions of pyrite under the action of water and oxygen generating *AMD* are as shown in the reactions:

$$FeS_2 + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + 2H_2SO_4 \quad (1)$$

$$FeS_2 + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + {SO_4}^{-2} + 4H^+ \quad (2)$$

The pH becomes slightly acidic at point 10 (downstream); which is linked to the decrease in the effect of *AMD* of Essouk stream that is explained by the distance from the source of pollution as well as by the effect of dilution.

Electrical conductivity, *EC*: The conductivity values are sensitive to the variations of dissolved salts [17]. The *EC* values varied between 201 µS/cm and 1060 µS/cm during the first campaign, between 467 µS/cm and 1346 µS/cm during the second campaign and between 494 µS/cm and 1925 µS/cm for the last campaign. It is observed that *EC* values varied from point to point, where the highest values were observed in May. These conductivities are related to the high contents of chloride, sulphate, calcium and magnesium ions and can be explained by the dissolution of limestone and saline rocks (gypsum and halite) upstream of the study area and the leaching of mining discharges deposited nearby for decades. Sulphide oxidation reactions that generate acidity and its neutralisation by carbonates produce sulphates (SO_4^{2-}), metals (Fe, Pb, Zn) and ions (Ca^{2+}, Mg^{2+}). When pyrite is exposed to water and oxygen, oxidation and hydrolysis reactions produce sulfuric acid (H_2SO_4) and free hydrogen ions (H^+), acidifying the water. Lower acidities allow other metals which are associated with mining, such as lead and zinc, to enter the solution phase and be transported from the system. These metals precipitate from the water column as pH increases, however the pH at which there is a potential for complete precipitation varies for different metals [18].

Turbidity: The turbidity of water depends on the quantity of solid matter present in the suspended state. It is a measure of light emitting properties of water and the test is used to indicate the quality of waste discharge with respect to colloidal matter [19]. This parameter presents a large variation, the lowest rate was recorded in the third campaign (3.18 NTU)

and the highest rate was marked during the same campaign (61.1 NTU). On the spatiotemporal scale, the exceptionally high suspended matter load recorded in station 2 during the third campaign is probably the result of intense erosion of the watershed, following sudden stormy rains.

Total Dissolved Solids, *TDS*: The mineralisation, concentration of total dissolved solids (*TDS*, synonymous with mineralisation, salinity or total dissolved load). According to the results obtained in the 10 sampling stations, the values of *TDS* varied between 120.6 mg/L and 1132 mg/L. The minimum value was observed at station 1 during the first campaign, while the maximum was recorded at station 7 during the third campaign. This mineralisation was strongly related to sulphates. The surface waters at Essouk stream are characterised by a hydrochemical evolution resulting from the evaporation-dissolution cycle of secondary minerals (gypsum, anhydrite) present at the level of the tailings pond. This is confirmed by the high concentration of sulphates resulting from both the oxidation of pyrite and the dissolution of secondary sulphate minerals [20, 21].

Total Hardness, *TH*: The total hardness of water is produced by the calcium and magnesium salts it contains. It can be distinguished between carbonate hardness that corresponds to the content of carbonates and bicarbonates of Ca^{2+} and Mg^{2+} and a non-carbonate hardness [22]. The classification of water samples that based on *TH* values was as follows: very soft water (*TH* < 75 mg/L), soft water (*TH* between 75 mg/L and 150 mg/L), slightly hard water (*TH* between 150 mg/L and 300 mg/L), hard water (*TH* between 300 mg/L and 450 mg/L) and very hard water (*TH* > 450 mg/L) [23]. Generally speaking, the turbidity values obtained during our study are relatively high. These values varied between a minimum value of about 150 mg/L of $CaCO_3$ observed in station 5 during the first campaign, and a maximum concentration of about 900 mg/L of $CaCO_3$ reported at station 8 during the last campaign.

Total Alkalinity Content, *TAC*: In contrast to acidity, the alkalinity of water corresponds to the presence of bases and salts of weak acids. In natural waters, alkalinity is most often due to the presence of hydrogen carbonates, carbonates and hydroxides. The relative values of the *TAC* allow knowing the quantities of hydroxides, carbonates or alkaline or alkaline-earth hydrogen carbonates present in water. The *TAC* values ranged from a minimum value of about 10 mg/L observed at station 8 during the first campaign to a maximum value of about 90 mg/L, recorded at station 5 during the last campaign (Fig. 2).

Calcium: Calcium is an important nutrient for aquatic, organism and it is commonly present in all water bodies [24]. The recorded results of calcium content during the study period represent the importance of this element in Wadi Essouk waters with variable contents that oscillating between 30 mg/L and 450 mg/L during the first campaign and between 130 mg/L and 450 mg/L during the second campaign, and varies between 120 mg/L (station 1) and 700 mg/L (station 5) during the third campaign. The decrease in calcium content during the first campaign (30 mg/L) is explained by the precipitation of carbonate minerals (calcite, aragonite and dolomite).

Magnesium: Its origins are comparable to those of calcium; they come from the dissolution of carbonate formations with high magnesium contents. Magnesium also follows the same evolution as calcium and sulphates, where the lowest content was 50 mg/L at station 4 during the first campaign, while the highest content was recorded in station 8 during the last campaign (550 mg/L). The decrease in magnesium concentration indicates the precipitation of carbonate minerals (aragonite and dolomite).

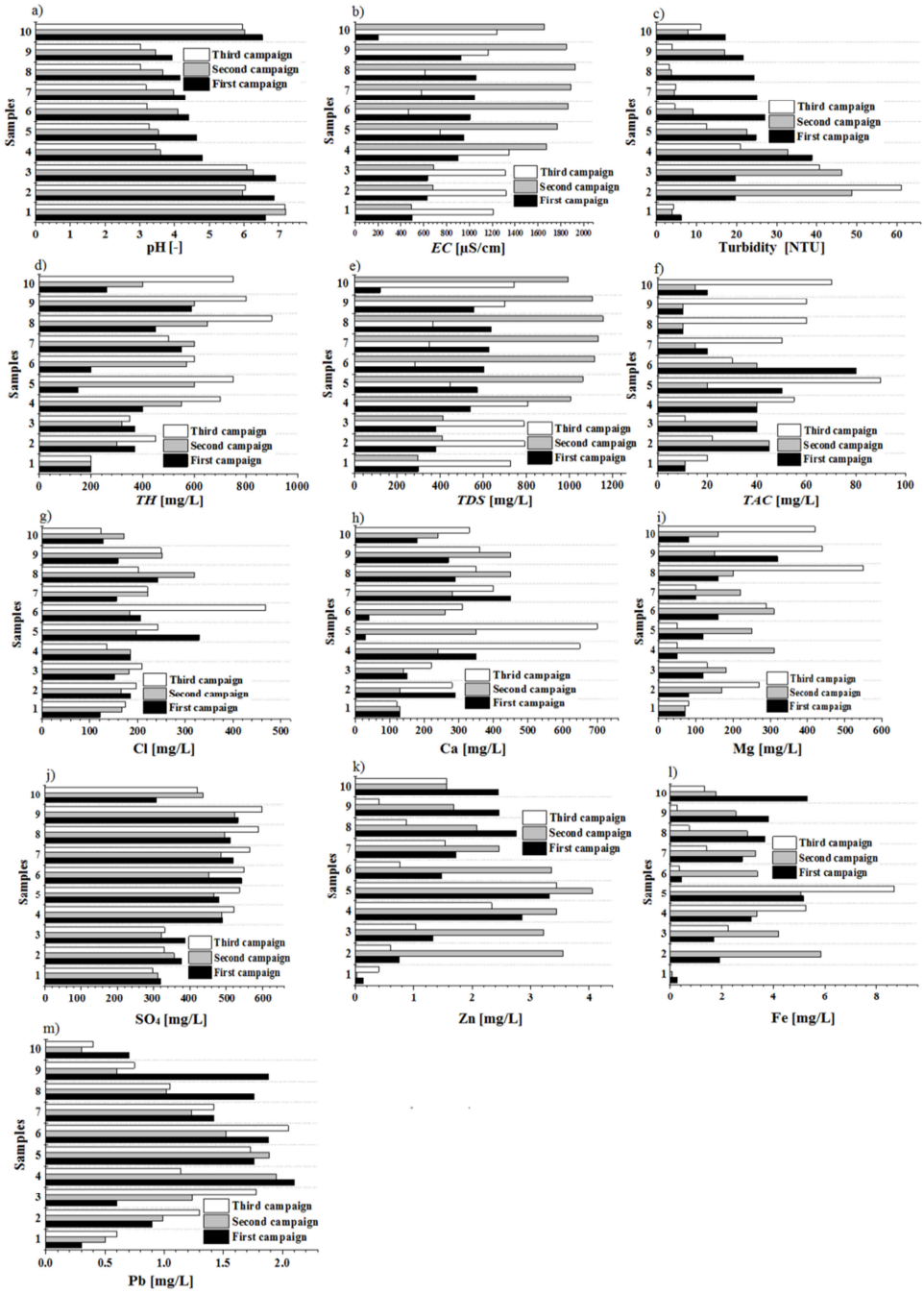


Fig. 2. Spatiotemporal variation of the physicochemical parameters along Essouk stream: a) pH, b) electrical conductivity, c) turbidity, d) total hardness, e) total dissolved solids, f) total alkalinity content, g) chlorides, h) calcium, i) magnesium, j) sulphates, k) zinc, l) iron, m) lead

Sulphates: *AMD*, water draining active and, in particular, abandoned mines is largely acid with elevated concentration of metals and sulphates. Sulphates may be present in *AMD* at concentration ranging from few hundred to several thousand mg/L [25]. The presence of sulphates in water is related to the dissolution of gypsum and the oxidation of sulphides (primarily pyrite FeS_2) [26], according to the following equations:

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 8{SO_4}^{-2} + 16H^+ \quad (3)$$

$$CaSO_4 \cdot 2H_2O \rightarrow Ca^{2+} + {SO_4}^{-2} + 2H_2O \quad (4)$$

Examination of Figure 2 classifies that sulphate contents are variable from station to station. The maximum value was 598.56 mg/L that recorded in station 9 during the third campaign. The minimum value was recorded in station 1 (298.69 mg/L) during the same campaign. The waters of Essouk stream are characterised by high levels of SO_4^{2-}.

Chlorides: Chlorides are important inorganic anions contained in variable concentrations in natural waters, generally in the form of sodium (NaCl) and potassium (KCl) salts. The monitoring of the evolution of chlorides in Wadi Essouk allows to detect important oscillations. Indeed, the extreme maximum and minimum levels were 468.6 mg/L (campaign 3) and 121.41 mg/L (campaign 1), respectively (Fig. 2). The temporal evolution was marked by a decrease in chloride contents during the last two campaigns compared to the third one resulting from the dilution by precipitation during the last two campaigns. Evaporated minerals (Cl^-) are thus formed on the surface of sulphate-rich discharges during the dry season. These dissolve during the wet season causing high *AMD* production [27].

Trace metals: Mining and its associated industries remain the major sources of heavy metals in the environment [28]. The average zinc content of the earth's crust is estimated to be between 70 mg/kg and 132 mg/kg [29]. According to Baize [29], the average lead concentration in the earth's crust is reported to be in the range of 13 mg/kg - 16 mg/kg. Lead is an element that can be found naturally in earth, but anthropogenic activities, including mines, can contribute to high concentrations of this metal [30]. The monitoring of the spatiotemporal evolution of metal pollution of water samples, taken at the different stations of Wadi Essouk showed variable contents of Fe, Zn and Pb. In Wadi Essouk the maximum concentrations of Fe and Zn were recorded in stations S5 and were respectively 5.17 mg/L, 3.32 mg/L for the first campaign, 5.05 mg/L, 4.05 mg/L during the second campaign and 8.69 mg/L, 3.44 mg/L for the third campaign. The Fe concentrations showed important variations; they fluctuate between 0.28 mg/L and 5.17 mg/L for the first campaign, between 0.087 mg/L and 5.05 mg/L for the second campaign and vary between 0 mg/L and 8.69 mg/L for the third campaign. In addition, the concentrations of Pb, Zn and Fe in the surface waters of Wadi Essouk were higher than the average levels of natural freshwater estimated at 0.05 mg/L for Pb, 0.1 mg/L for Zn and 0.3 mg/L for Fe. The levels of trace metals, Fe, Zn and Pb vary proportionally to the variation in pH of the water at each site. Pyrite (FeS), galena (PbS) and sphalerite (ZnS) are, respectively, the main sources of Fe, Pb and Zn contamination in this mining area. In the presence of oxygen, pyrite, galena and sphalerite can produce Fe^{2+}, Pb^{2+}, Zn^{2+} and SO_4^{2-}.

Statistical study

Statistical methods were used to establish correlations between the different chemical elements analysed and also to differentiate the origins of mineralisation, in which the

principal component analysis (*PCA*) was used. The advantage of this method is that it allows to reduce the information in a number of components more limited (group) than the initial number of variables, and thus to visualise the data in 2D, then to link the elements of the same character. It is therefore both a statistical and geometric approach (representation of variables in a space according to directions of maximum inertia).

In Tables 4, 5 and 6, we have reported the correlation matrix applied to the 10 points of Wadi Essouk surface water. Several remarks can be made about these tables:

The first campaign: pH is negatively correlated with major and trace elements (Mg^{2+}, Cl^{-}, SO_4^{2-}, Zn and Pb) and with *EC*, turbidity and *TDS*. Electrical conductivity correlates well with turbidity, *TDS*, sulphate and lead. Turbidity correlates with *TDS*, sulphate, zinc and lead. *TDS* is correlated to sulphate and lead. Lead correlates well with sulphates and zinc. Iron and zinc are well correlated.

Second campaign: pH is negatively correlated to major elements and lead. Electrical conductivity is well correlated with *TH* and *TDS*. Calcium correlates well with sulphates and chlorides. The strong correlation between sulphates and calcium indicates their common origin. *TH* is well correlated with calcium, magnesium, chlorides and sulphates. Magnesium is correlated with zinc and lead. Iron and zinc are well correlated.

Third campaign: pH is negatively correlated with major elements (Ca^{2+} and SO_4^{2-}) and with *EC*, *TDS*, *TAC* and *TH*. Electrical conductivity is well correlated with *TH* and *TDS*. Alkalinity (*TAC*) correlates with *TH*, calcium, sulphate, iron and zinc. Calcium correlates well with sulphate and iron. Iron and zinc are well correlated. The correlation between conductivity and sulphates is highly significant, this explains that the mineralisation of water is necessarily due to sulphate ions.

Table 4

Correlation matrix of physicochemical parameters (first campaign)

Variables	pH	*EC*	Turbi-dity	*TDS*	*TAC*	*TH*	Ca^{2+}	Mg^{2+}	Cl^{-}	SO_4^{2-}	Fe	Zn	Pb
pH	1												
EC	–0.85	1											
Turbidity	–0.58	0.61	1										
TDS	–0.85	1.00	0.61	1									
TAC	–0.04	0.20	0.40	0.20	1								
TH	–0.38	0.37	0.26	0.37	–0.51	1							
Ca^{2+}	–0.21	0.22	0.31	0.22	–0.49	0.83	1						
Mg^{2+}	–0.55	0.40	0.09	0.40	–0.17	0.46	–0.05	1					
Cl^{-}	–0.47	0.57	0.42	0.57	0.40	–0.29	–0.32	0.08	1				
SO_4^{2-}	–0.93	0.95	0.69	0.95	0.23	0.42	0.22	0.53	0.48	1			
Fe	–0.27	–0.03	0.26	–0.03	–0.29	0.14	0.12	0.14	0.37	0.76	1		
Zn	–0.61	0.37	0.64	0.37	–0.02	0.13	0.05	0.25	0.59	0.48	0.84	1	
Pb	–0.89	0.81	0.83	0.81	0.26	0.28	0.17	0.41	0.57	0.90	0.30	0.70	1

The correlation calculations show an increase in the concentration of sulphate ions with the increase in acidity (decrease in pH), confirming the origin of the sulphates. Concerning the evolution of the electrical conductivity, a good correlation with the sulphate contents is recorded. This implies the predominance of these ions in the mine effluent waters. Concerning the correlation of metals with iron, a good correlation of zinc is noted. For lead, the correlation coefficient is not significant; this can be attributed to the large difference in concentration.

Table 5

Correlation matrix of physicochemical parameters (second campaign)

Variables	pH	*EC*	Turbi-dity	*TDS*	*TAC*	*TH*	Ca^{2+}	Mg^{2+}	Cl^{-}	SO_4^{2-}	Fe	Zn	Pb
pH	1												
EC	0.54	1											
Turbidity	0.19	0.59	1										
TDS	0.54	1.00	0.59	1									
TAC	0.12	0.25	0.77	0.25	1								
TH	–0.96	–0.66	–0.34	–0.66	–0.23	1							
Ca^{2+}	–0.81	–0.50	–0.45	–0.50	–0.56	0.86	1						
Mg^{2+}	–0.68	–0.43	0.12	–0.43	0.50	0.64	0.21	1					
Cl^{-}	–0.60	–0.47	–0.40	–0.47	–0.53	0.67	0.84	0.03	1				
SO_4^{2-}	–0.92	–0.47	–0.40	–0.47	–0.34	0.94	0.86	0.51	0.62	1			
Fe	–0.30	–0.08	0.70	–0.08	0.62	0.21	–0.02	0.48	–0.05	0.54	1		
Zn	–0.44	–0.17	0.61	–0.17	0.70	0.35	0.01	0.76	–0.12	0.18	0.91	1	
Pb	–0.55	–0.30	0.33	–0.30	0.52	0.45	0.06	0.84	–0.04	0.25	0.59	0.81	1

Table 6

Correlation matrix of physicochemical parameters (third campaign)

Variables	pH	*EC*	Turbi-dity	*TDS*	*TAC*	*TH*	Ca^{2+}	Mg^{2+}	Cl^{-}	SO_4^{2-}	Fe	Zn	Pb
pH	1												
EC	–0.89	1											
Turbidity	0.47	–0.62	1										
TDS	–0.89	1.00	–0.62	1									
TAC	–0.57	0.74	–0.47	0.74	1								
TH	–0.72	0.83	–0.36	0.83	0.80	1							
Ca^{2+}	–0.64	0.59	–0.11	0.59	0.75	0.59	1						
Mg^{2+}	–0.18	0.34	–0.18	0.34	0.17	0.58	–0.28	1					
Cl^{-}	–0.41	0.28	–0.22	0.28	–0.17	0.02	–0.07	0.09	1				
$SO4^{2-}$	–0.97	0.95	–0.61	0.95	0.65	0.78	0.57	0.31	0.34	1			
Fe	–0.31	0.25	–0.04	0.25	0.59	0.28	0.86	–0.54	–0.15	0.72	1		
Zn	–0.34	0.37	–0.06	0.37	0.68	0.34	0.88	–0.48	–0.18	0.28	0.95	1	
Pb	–0.34	0.08	0.24	0.08	–0.20	–0.11	0.23	–0.36	0.67	0.15	0.32	0.26	1

Principal component analysis

In order to determine the impact of *AMD* on surface water quality, a Principal Component Analysis (*PCA*) was performed. In the present work, it was used to study on the one hand, the relationships between the different physicochemical parameters (pH, *EC*, *TDS*, *TH*, *TAC*, turbidity, Cl^{-}, SO_4^{2-}, Ca^{2+} and Mg^{2+}) and trace elements (Zn, Fe, Pb) on the other hand, the origin of these elements. The *PCA* was elaborated with the XLSTAT 2021 software.

First campaign: The *PCA* correlating the physicochemical parameters of the waters, allowed us to retain two main axes since they present more than 68 % of the total variance (Fig. 3a). The F1 axis which presented 49.19 % of this variance was strongly correlated on the positive side with electrical conductivity, *TDS*, turbidity, Cl^{-}, SO_4^{2-}, Mg^{2+}, Zn and Pb ion concentrations and negatively with pH. The factor F1 opposes most of the dissolved ore to the pH: when the mineral concentration increases the pH decreases. These conditions are mainly observed in the context of *AMD* contamination. Consequently, the F1 factor is considered as an indicator of *AMD* contamination. The F2 axis (19.65 % of variance) was

positively correlated to calcium and TH and negatively to *TAC*. This axis was considered as an indicator of dissolution of calcium and carbonate minerals.

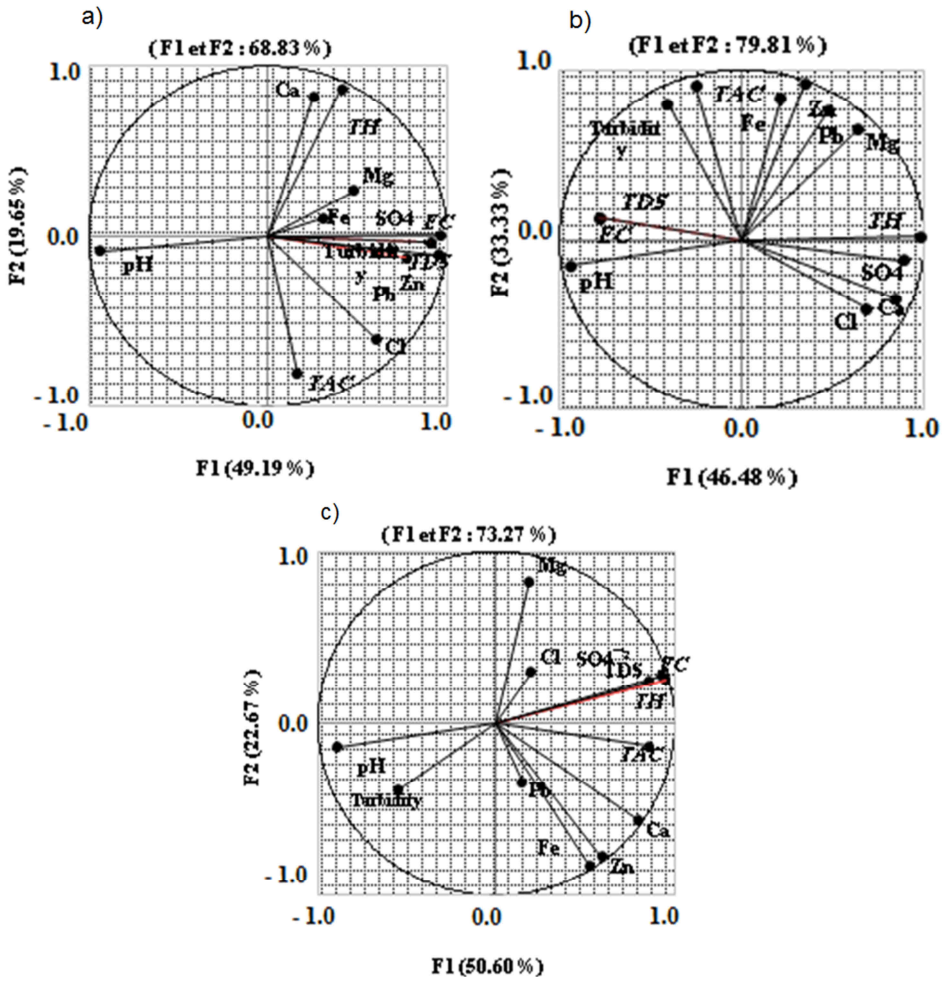


Fig. 3. Correlation circles showing the distribution of parameters along the F1 and F2 axes: a) first campaign, b) second campaign, c) third campaign

Second campaign: Figure 3b shows the distribution of the analysed parameters along the two main axes (F1 and F2), explaining 79.81 % of the total variance. The contributions are as follows: F1 (46.48 %) and F2 (33.33 %). Analysis of the graphs of the space of variables in the F1-F2 factorial plane shows that the F1 factor is strongly correlated on the negative side with pH, *EC*, *TDS*, and negatively with *TH*, SO_4^{2-}, Cl^-, Mg^{2+} and Ca^{2+}. This grouping is dominated by the major elements that come from the dissolution of secondary minerals (gypsum, anhydrite). The F2 factor is determined by metallic elements (Fe, Zn and Pb), turbidity and alkalinity (*TAC*). The F2 factor is considered as an indicator of *AMD* contamination.

Third campaign: The two axes (F1-F2) considered to describe the correlations between the variables related to spatial structures, hold alone 73.24 % of the total information with respectively 50.60 % for axis 1 and 22.67 % for axis 2 (Fig. 3). The pH, *EC*, *TDS*, *TAC*, *TH*, Ca^{2+}, SO_4^{2-}, Fe and Zn are included in the F1 factor; this axis is considered as an indicator of *AMD* contamination. The F2 factor is determined by Mg^{2+}, Fe and Zn ions.

Conclusion

The mining discharges of Sidi Kambar have led to a clear physicochemical modification of surface waters that is due to a probable contamination following the leaching of the mining discharges deposited in the vicinity of the stream, thereby; it reflects the oxidation of metal sulphides contained in the mining waste. The decrease in this impact further downstream from the mine is explained by the distance from the source of pollution as well as by the effect of dilution. In general, water discharges at Sidi Kambar is highly sulphated with elevated salinity resulting in a high conductivity. The production of *AMD*, in addition to the decrease in pH, inevitably led to the leaching of various metals and high concentrations of sulphates, which can be explained by the presence of secondary minerals (gypsum, anhydrite). The values of major ions upstream of the mine discharges are much higher than those found in the points located downstream of the mine. These waters are highly acidic and rich in metals. The acidity may have been neutralised by the dissolution of carbonate-rich minerals, possibly calcite and dolomite, which would explain, in part, the high Ca^{2+} and Mg^{2+} contents.

The preliminary results obtained within the framework of this study open up certain prospects for study that it would be wise to undertake:

- Study of the available fraction of heavy metals and the impact of certain Metallic Trace Elements on fauna (bioindication).
- Continue this study over several cycles in order to gather as much information as possible on the levels of contamination by Metallic Trace Elements in sediments and living organisms.

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