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Impact of mine polymetallic Draa Sfar South on the aquifer of central Haouz (Morocco)

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Abstract

The residues of the activities of polymetallic mines can be a source of pollution by heavy metals in the water resource as a result of the phenomenon of acid mine drainage (AMD). In this context, the present study was designed to evaluate the impact of the mining activity of DraaSfar South on the groundwater table of the Haouz Central, based on the study of the physico-chemical parameters and elements metal traces Fe, Zn, Pb, and Cu. The chemical analyzes show that the waters are of types Mg-Cl, Ca-Cl and Mg-HCO_3, with an electrical conductivity ranging from 1100 to 5000 µs/cm. The main source of the mineralization of waters is likely related to the dissolution of evaporite minerals, and in the process of exchange of bases. The concentrations of trace elements of metal Zn, Pb, Cu and Fe of the waters of the groundwater table of the Haouz Central are below the standard of the WHO for drinking water. These results reflect the obviousness of the good to average quality of these waters. This allows us to conclude that the operation of the elements metal traces Zn, Pb, Cu and Fe at the level of the mine DraaSfar South has no noticeable effect on the aquifer of the Haouz Central. But following the mining discharges, we can sound the alarm of the pollution of these surface waters after mining discharges, and the danger of their reuse whether for irrigation or other field.

1. Introduction

Water resources in Morocco are confronted with problems of quantity and quality. On the one hand, these resources are limited due to the semi-arid to the arid climate in most of the territory, with episodic droughts. On the other hand, they can undergo a deterioration in their quality by different types of pollution, in particular, metallic pollution due to metals emanating from industrial activities, mainly mining operations. The latter affect water basins through the use of water for the treatment of ore and by the phenomenon of acid mine drainage (AMD). The region of Marrakech (Central Morocco) is one of the main metallogenic regions of the country. There are several mining sites currently in operation or currently abandoned. The main sites are located in the Jebilet including the Kettara mine [1-3], DraaSfar [4, 5] and Sidi BouOthmane [6]. It is essentially a mineralization of sulphide clusters with base metals (Fe, Pb, Zn and Cu) [7]. The mine of DraaSfar and of Hajjar are the main base metal mines still in operation in the Marrakech region, both of which are generators of AMD [8]. Mining activities generate large amounts of discharges, which could have negative impacts on the environment: pollution of soils, surface and groundwater, destruction or disturbance of natural habitats and visual impact on the landscape [1].

The DraaSfar mine is a former mining exploitation of Zn, Pb, and Cu which has resumed his activities by CompagnieMinière des Guemmassa. This polymetallic deposit consists essentially of pyrrhotite ($Fe_{1-X}S_2$) (75 to 95%) with other accessory sulphides and sulfo-arsenides, such as sphalerite (ZnS) (the most abundant mineral phase after pyrrhotite), gallium (PbS), pyrite (FeS_2), chalcopyrite ($CuFeS_2$), arsenopyrite (FeAsS) and stannite (Cu_2 (Fe, Zn)SnS4) and oxides (magnetite ($Fe^{2+}Fe_2^{3+}O_4$) and cassiterite (SnO_2)) [9]. This mine is located a few hundred meters from River of Tensift. These drainage waters are also conveyed, without any purification, to this river whose waters are reused by the local residents for irrigation. They are characterized by high values of electrical conductivity which is expressed by very high levels of major ions and quite high in heavy metals. This effluent exceeds the limit values of the proposed Moroccan Standards for direct discharges and therefore requires treatment before its spreading in the receiving media [8]. The objective of this study is to evaluate the impact of the DraaSfar South mining activity on the groundwater resource of the central Haouz groundwater, based on the study of physicochemical and metallic parameters.

2. General Framework

The DraaSfar South mine site is part of the Haouz plain. It is the subject of several studies [4, 5, 9-14]. This mine is located about of 13km in the north-west of Marrakech (Figure 1) in a rural village with an agricultural vocation. It is a municipality with a surface area of 5790 ha, whose main activity is the agriculture (65% of the area is occupied by agricultural land). These lands are irrigated from the surface water coming from the River of Tensift (perimeter of the Regional Agricultural Development Office (ORMVA) and groundwater (private pumping). The mine is located a few hundred meters from the River of Tensift (~550 m). The latter constitutes the mainstream of the Haouz plain, with a very irregular hydrological regime [15]. The width of the minor bed and that of the major bed vary widely depending on the periods of low water, high water and flood periods.

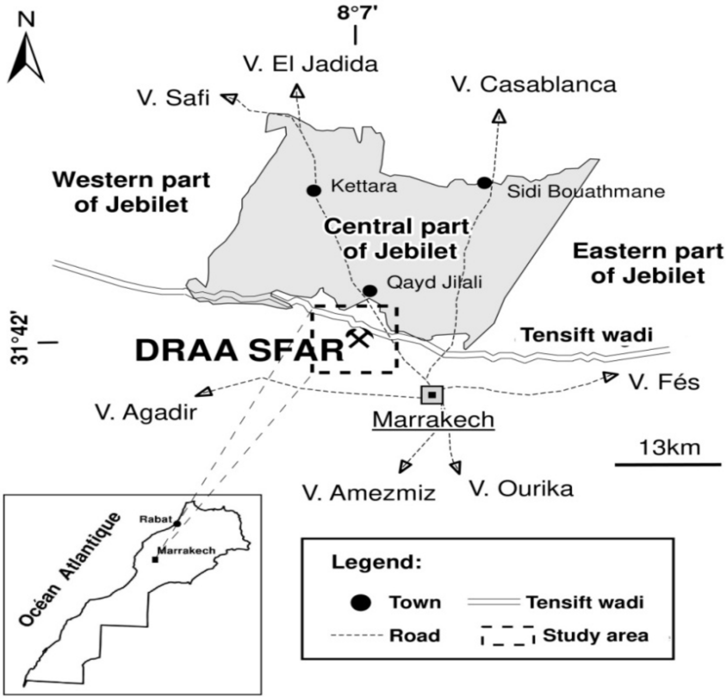

Figure 1: Geographical location of the study area.

The climate governing the study area is a semi-arid climate, with average of rainfall about of 223 mm/year and temperatures of around 19 °C (Figure 2). The piezometric map compiled from the data of the companion of April 2016 shows a direction of flow towards the northeast (Figure 3a). Geologically and hydrogeologically, the DraaSfar region is made up of primary schists covered by the Haouz alluvium (Ministry of Energy and Mines, 1996).

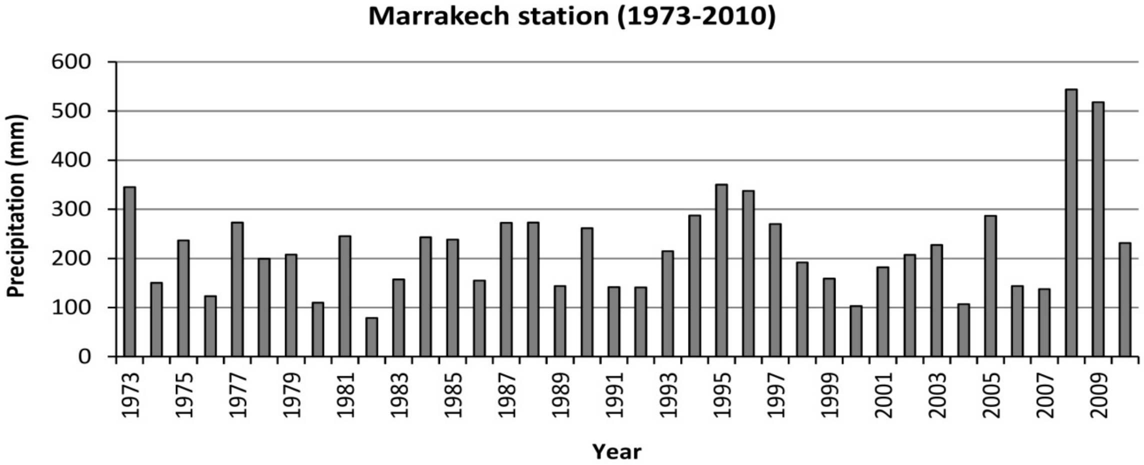

Figure 2: Precipitation evolution at the resort of Marrakech for the period 1973-2010.

The aquifer flows largely in lacustrine limestones and marl-limestones intercalated at alluvial levels. The mining sector appears as a spike of about 2 Km/700 m which emerges from the Mio-Pliocene and quaternary cover. The sulphide deposit of the mine is cashed in the Sarhlef series which characterizes the central part of the Jebilet (Sarhlefshales) whose lands are of Visean-Namurian age [9]. The lithostratigraphy of DraaSfar (Figure 3b) shows two units separated by a horizon with sulphide mineralization [9]. The first is calcarenitic represented by a sandstone-peliticfacies with an intercalation of the limestone levels. The second is a volcanic and volcano-sedimentary unit with a thickness ranging from 50 to 100 m. It consists of a sandstone-peliticfacies at the base surmounted by vesiculated tuffs, pyroclastites and rhyolites.

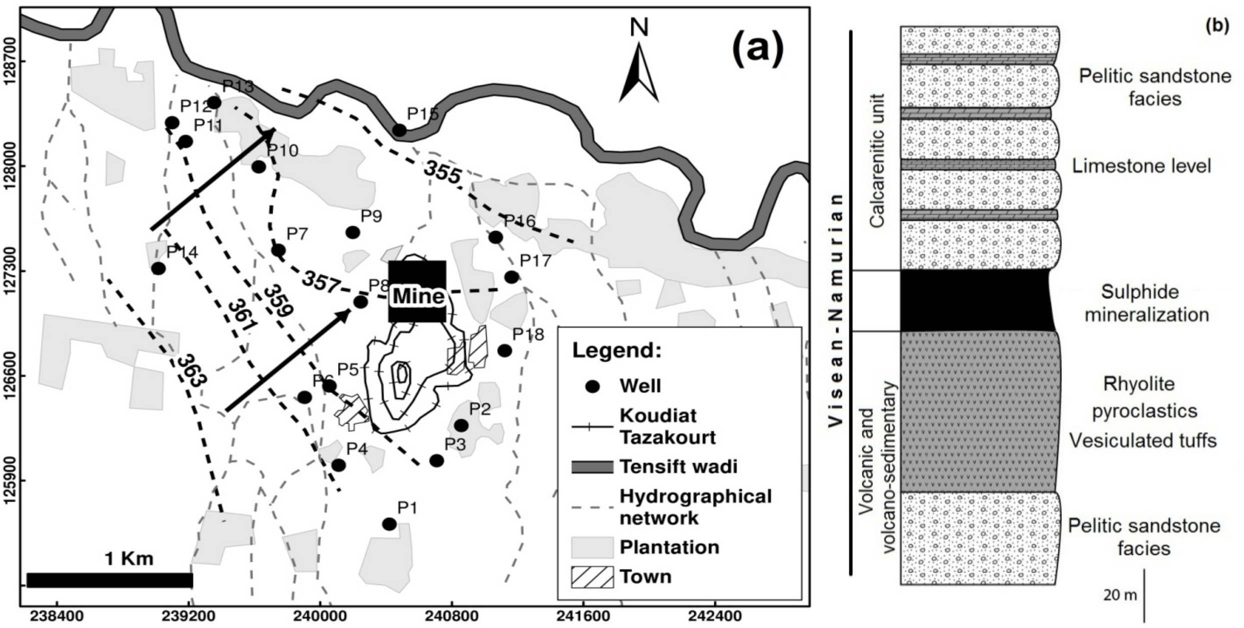

Figure 3:(**a**)Piezometric map of the study area (campaign of April 2016) and (**b**)Stratigraphic log of the DraaSfar South (modified from [9]).

3. Materials and methods

A total of 18 samples were taken from 17 wells capturing the water table of Haouz and one of the surface water (TensiftWadi) during the month of April 2016. In the field, were measured the physical parameters and the depth of the water table: (1) pH and temperature by a pH/mV/°C meter type ADWA AD111, (2) Conductivity by a conductivity meter type HANNA HI 8733, (3) The depth of the water level via a sound piezometric probe of 200 m. The major chemical elements are determined by ion chromatography, using DIONEX ICS-1100 at the Center of Analysis and Characterization (CAC) at the Sciences Faculty of Semlalia, UCA, Marrakech. The metallic trace elements (ETM) (Fe, Cu, Pb and Zn) were determined by an inductive coupled plasma atomic emission spectrometer (ICP-AES) of the Perkin Elmer Optima 3100RL type at the REMINEX laboratory of Guemessa (MANAGEM Group) . Alkalinity was determined in situ by titration. This evaluation was approached by the study of physicochemical parameters (major elements and metallic traces).

4. Results and discussions

4.1. *Mineralization and chemical facies*

The results of the chemical analyzes are shown in Table 1. The water from the study area have generally a neutral pH of between 6.76 and 8.21 and temperatures ranging from 19.5 °C to 24.4 °C. The electrical conductivity is 1100 to 5000 µs/cm. The water have generally three chemical facies types: Mg-Cl, Ca-Cl and Mg-HCO_3 (upstream) (Figure 4). This transition from one facies to another emphasizes the complexity of the hydrogeochemical processes that govern the mineralization of this aquifer.

In order to trace back to the origin of the groundwater mineralization of the Haouz basin, a first approach consists of presenting the existing relationships between the major elements (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-,SO_4^{2-}) (Figure 5) and the correlations between these elements and the saturation indices (Figure 6).

The correlation diagram Na^+*vs.*Cl^- (Figure 5a), shows the presence of a strong positive correlation between these two elements ($R^2 = 0.91$), this reflects that they come from the same origin, which could be the dissolution of the halite. This dissolution is supported by the parabolic proportional relationship of the [Na^++ Cl^-]*vs.* SI_{HALITE} (Figure 6a). All of the sampled points are below the halite dissolution line (line 1: 1), with Na^+ deficiency. This deficit could be explained by the ion exchange process where the Na^+ ions are released and are replaced by the Ca^{2+} and/or Mg^{2+} ions of the confining formations [16, 17] (Figure 5d). The Ca^{2+}-SO_4^{2-} diagram shows a significant positive correlation ($R^2 = 0.85$) and a scattering of points around the 1: 1 line (Figure 5b) with a slight excess of Ca^{2+}. This dispersion reflects the contribution of gypsum dissolution, probably of Permo-Triassic age, to the mineralization of the water, confirmed by the parabolic proportional relationship of the [Ca^{2+}+ SO_4^{2-}]*vs.* SI_{GYPSE} (Figure6a).

Table 1: Physicochemical parameters of groundwater in the study area.

Sample	T	pH	CE	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	HCO_3^-	SO_4^{2-}	NO_3^-
	°C		µs/cm	mg/L							
P1	23.3	6.76	1962	232.5	55.9	67.8	2.3	315.2	384	323.7	9.0
P2	21.6	7.59	2670	212.4	116.7	71.8	2.4	501.6	360	243.8	55.9
P3	22.6	7.66	1785	106.1	112.5	53.8	1.9	357.5	336	160.3	25.0
P4	23.8	7.63	1224	60.1	111.8	40.9	1.5	172.6	318	139.8	17.5
P5	23.3	7.6	1356	92.2	109.4	44.2	1.6	193.1	348	158.3	21.0
P6	23	7.62	1238	34.1	109.3	43.6	1.5	161.4	354	140.6	8.0
P7	24.4	7.66	1231	60.1	111.2	43.2	1.6	141.6	362	156.1	8.4
P8	22.5	7.55	2310	120.3	155.3	72.8	2.6	458.4	348	339.7	16.8
P9	23.6	7.6	1790	85.3	120.1	67.1	2.1	316.7	384	235.9	10.4
P10	22.6	7.21	4250	445.6	168.7	105.5	3.3	1089.0	380	559.3	40.1
P11	24.4	7.54	1350	62.3	102.6	48.6	2.3	248.0	402	100.9	15.5
P12	23.5	7.74	2100	158.4	127.8	71.6	2.4	492.5	414	221.8	15.2
P13	23.5	7.38	4400	401.3	180.6	141.7	4.5	1180.4	440	402.1	6.9
P14	23.4	7.4	2100	172.3	121.6	71.3	2.5	498.0	336	291.7	28.8
P15 (O.T)	24.2	7.69	4000	267.4	184.6	15.2	15.7	977.7	546	292.7	0.4
P16	21.9	7.88	3100	315.2	90.3	108.6	3.2	720.2	438	300.0	20.0
P17	195	7.65	5000	420.6	270.5	113.2	6.2	1564.7	372	33.6	4.8
P18	21.3	8.2	1100	115.3	62.3	46.5	6.2	113.9	422	97.4	-

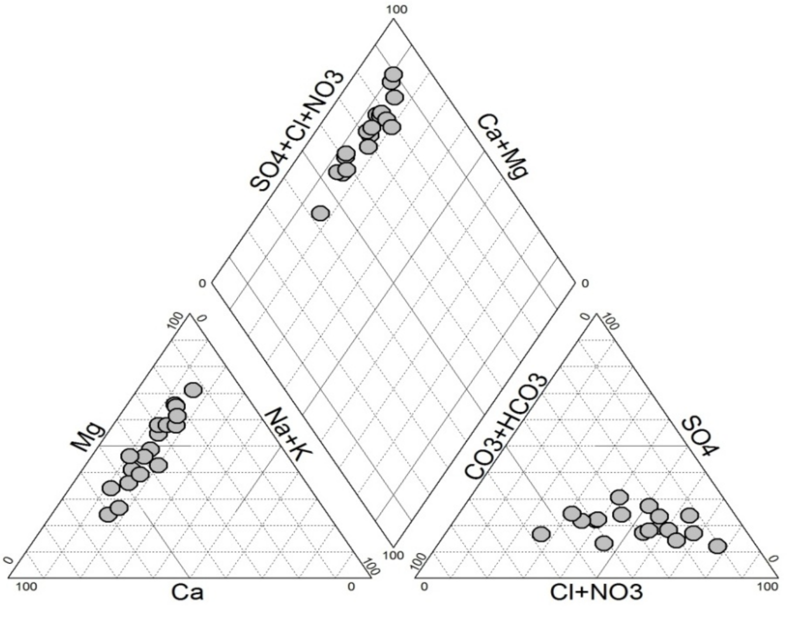

Figure 4: Piper diagram of groundwater from the study area.

The correlation between Ca^{2+}-Mg^{2+} (Figure5c) has a low coefficient ($R^2 = 0.60$), which makes it difficult to assume the participation of dolomite dissolution,probably of Cretaceous age, in the water mineralization. This hypothesis is supported by the low coefficient of correlation ($R^2 = 0.22$) between [Ca^{2+}+Mg^{2+}] and $SI_{DOLOMITE}$.

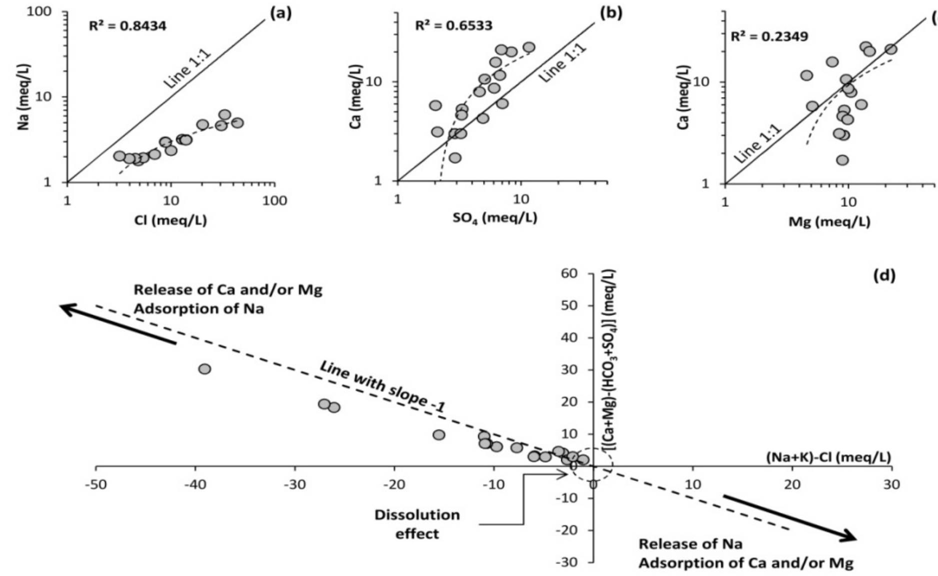

Figure 5: Relationship between the major elements of the sampled waters, : (**a**) Na/Cl; (**b**) Ca/SO_4; (**c**) Ca/Mg and (**d**) [(Ca+Mg)-(HCO_3+SO_4)]/(Na+K)-Cl)

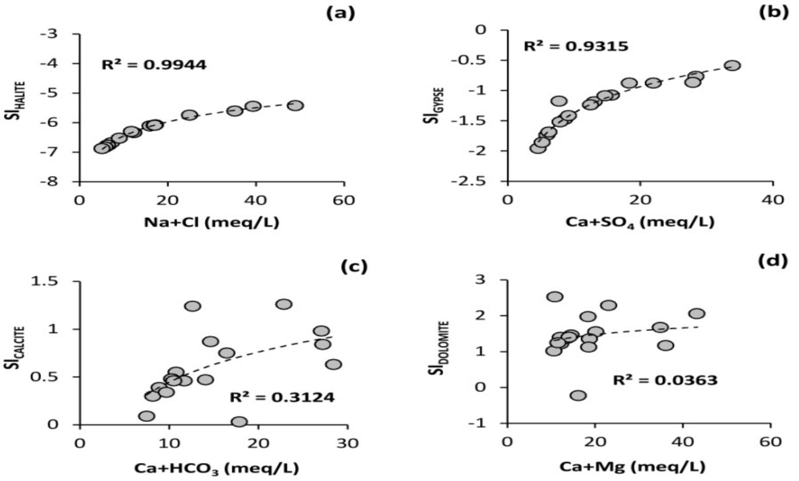

Figure 6: Correlation diagrams, (**a**) Na+Cl*vs* IS_{HALITE}; (**b**) Ca+SO_4*vs* IS_{GYPSE}; (**c**) Ca+HCO_3*vs* $IS_{CALCITE}$ and (**d**) Ca+Mg*vs* $IS_{DOLOMITE.}$

4.2. *Assessment of the average contents of metallic trace elements in the water around the mine*

The metal trace element contents of the sampled water points, as well as the recommended threshold for each element, are summarized in Table 2.

The iron is one of the most abundant metals in the earth's crust. It is found in fresh natural waters at levels ranging from 0.5 to 50 mg/L. With the exception of the two points P18 and P15 (surface water), all the points display iron contents lower than 20 µg/L and therefore below the threshold of 50 mg/L. Well P18 has iron concentrations of 97.4 mg/L, which may be due to the direct oxidation of pyrite in the presence of oxygen and water with a neutral pH as follows [18]:

$$FeS_2 + 7/2\, O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^{+} \qquad (1)$$

The surface water represented by the point P15 has a content of 45.2 mg/L close to the threshold of 50 mg/L.

The zinc is an essential trace mineral found in almost all foods and drinking water in the form of salts or organic complexes. Although zinc levels in groundwater normally do not exceed 0.05 mg/L [19]. In the case of this study, with the exception of the well P8, all analyzed wells have zinc concentrations below the 5 mg/L threshold. Well P8, the nearest water point to the mine, shows zinc content of 0.058 mg/L slightly above the standard. This could be an indication of the mine effect on groundwater. As for copper, all the points have concentrations lower than 3.6 µg/L and which do not exceed the standards fixed by WHO (2 mg/L). With regard to lead concentrations, all points have levels below the threshold determined by WHO.

Table 2: Metallic trace element content of the groundwater in the study area and potability standards according to [19].

	Metallic trace element (µg/L)								
	Cu	Fe	Pb	Zn		Cu	Fe	Pb	Zn
Normes WHO	2000	500-5000	50	4000					
P1	<3.6	<20	31.6	<2	P10	<3.6	<20	21.9	<2
P2	<3.6	<20	<11	35	P11	<3.6	<20	31	<2
P3	<3.6	<20	<11	<2	P12	<3.6	<20	<11	<2
P4	<3.6	<20	<11	14.4	P13	<3.6	<20	<11	<2
P5	<3.6	<20	<11	4.7	P14	<3.6	<20	<11	<2
P6	<3.6	<20	<11	<2	P15	<3.6	45.2	<11	<2
P7	<3.6	<20	20.5	<2	P16	<3.6	<20	21.1	<2
P8	<3.6	<20	<11	58.1	P17	<3.6	<20	<11	<2
P9	<3.6	<20	<11	<2	P 18	<3.6	97.4	37.7	<2

Conclusion

This study has made an original contribution to the evaluation of the impact of DraaSfar South mining activity on the central Haouz plain aquifer. The chemical analyzes show that the water are of Mg-Cl, Ca-Cl and Mg-HCO_3 types. The main origin of water mineralization is likely to be related to the dissolution of evaporite minerals, such as halite and gypsum, and the cation exchange phenomenon. With the exception of the P8 well, the closest to the mine, which may be a warning sign that may worsen in the future, the rest of the wells catching the water table of the central Haouzhavecontents of metallic trace elements below the WHO standard for drinking water. This situation reflects the evidence of the good to average quality of these waters. this situation can be explained by the fact that the direction of flow is towards the waditensift and the mining discharges are directed towards this one. This situation reflects the evidence of the good to average quality of these waters. This leads to the conclusion that the exploitation of trace metal elements Zn, Pb, Cu and Fe at the DraaSfarSud mine has no noticeable effect on the waters of the shallow aquifer of central Haouz. But following the mining discharges, we can sound the alarm of the pollution of these surface waters after mining discharges, and the danger of their reuse whether for irrigation or other field.

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