Assessment of mining activity impact on the surface water quality of Beht watershed (Sebou hydraulic basin), Central Morocco

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Abstract. Mining activities have a long history of contributing in the metallic trace elements (TME) contamination of surface waters. This contamination can be related to the mine water discharge from the exploitation of geo-chemically different deposits. The purpose of the present work is to evaluate the punctual and potential mining impact on the quality of the Haut Beht mine surrounding waters, through physico-chemical and bacteriological characterization of these waters, as well as their contamination degree in metallic trace elements (arsenic, lead, cadmium, zinc, copper), through monitoring during two analysis campaigns in 2014 (C1) and 2015(C2). The analyzes were performed by ICP-MS. The water overall quality results showed no visible impact of mine water discharges. At the Es6 and Es7 points there was organic contamination, which is linked to the resident's domestic discharges and grazing activities. The comparison of surface water quality at the upstream and downstream mine water discharges points showed sulfate contamination at Es8 during C1 and C2. While the lead (Pb), arsenic (As), cadmium (Cd), zinc (Zn), and copper (Cu) elemental concentrations remain consistent and very low compared to the limit values set by the surface water quality standards, the irrigation water standards, the drinking water standards, and the OMS standards, with the exception at point Es8 that showed As contamination during C1. The monitoring of the mine surrounding surface water quality has shown an improvement over time.
Key Words: Beht, metal trace elements, mine.

Introduction. Mining activities have contributed for a long time to the contamination of the surface water and the groundwater with trace metal elements (TME). The oxidation of sulfides such as pyrite releases dissolved metals into the environment and acidify the water by the formation of sulfuric acid forming acid mine drainage (AMD) (Goix 2012). Indeed the pH drop in these waters leads to a drastic increase in the heavy metals solubility and their mobility (Moran 1974), their concentrations can then reach levels above drinking standards (Amacher et al 1995). However there are natural systems where the mining activity does not cause acid drainage, but it hase an important impact on the affected waters chemical composition (MIW, mining influence waters) (Amacher et al 1995).

Complicated geological processes cause metallic or mineral raw materials concentrations in the earth's crust, forming deposits. Mineral deposits erosion and natural weathering can disperse its components in the surrounding environment (water, sediments and soil) (Plumlee & Nash 1995). The metal insoluble in the environment rush into the river bottom and stays there for a long time, becoming a long-term pollution source for the aquatic insects living there and the fish that feed on these insects (Goix 2012).

The Haut Beht mine is located in the Beht watershed, which is part of the Sebou basin (sub-basin). The waters of Sebou have experienced a significant deterioration in their quality for several years (Derwich et al 2010). This decline in quality is the direct

result of various emissions (industry, agriculture, cities etc.) being discharged into the river. The Sebou basin, which is considered a very important socio-economic area, is one of the most affected sectors of Morocco by pollution, due to the existence of two of the main agricultural plains of the country as well as the multitude and the diversity of industrial units in the big cities of the basin (Fes, Meknes, Kenitra, Sidi Kacem) (Azzaoui et al 2002).

Previous studies have treated the characteristics of the Sebou river water and its affluent Beht river (Azzaoui et al 2002; Benaabidate 2000; Derwich et al 2010; Lakhili et al 2015; Lakhili et al 2017; Qaouiyid et al 2016), but no study, to our knowledge, has evaluated the mining activities impact on the quality of these waters. It is to highlight that studies conducted near the mining centers of Aouli and Mibladan in High Moulouya have shown a negative mining activities impact on the surface waters, sediments, soil and plants quality (El Hachimi et al 2005), and the pollution of Moulouya surface waters by heavy metals (Baghdad et al 2009).

It is in this perspective and in a global study context of the mining impact on the environment at the Sebou watershed that we have chosen a mine among the four mines that include the basin (Ahmedat et al 2018; DEM 2011; Onhym 2020). We proposed to study the mine water discharges impact on the quality of surface water surrounding the mine through two sampling and analysis campaigns in 2014 and 2015. This is to assess the mining impact on the quality of surface waters surrounding the Haut Beht mine through the physico-chemical and bacteriological characterization of these waters, as well as the evaluation of the degree of their contamination in traces of metal elements.

Material and Method

Presentation of the study area. ***Geographical and hydrological context***. The area that is the subject of this study is located in the Beht watershed, which is located in the north-west of Morocco. It occupies the southwestern part of the Sebou basin and covers an area of 4,603.75 km2 (Figure 1). The Sebou River takes its source under the name Oued Guigou near the Zad Valley in the Middle Atlas mountains, it crosses a length of around 615 km before reaching its outlet in the Atlantic Ocean. The Sebou watershed water resources are estimated around the average of 6900 million m^3 per year. The surface water resources are estimated at 5600 million m^3, which represent 30% of the surface water of all Morocco. They are characterized by a very strong irregularity during the same year and from one year to another (Azzaoui et al 2002).
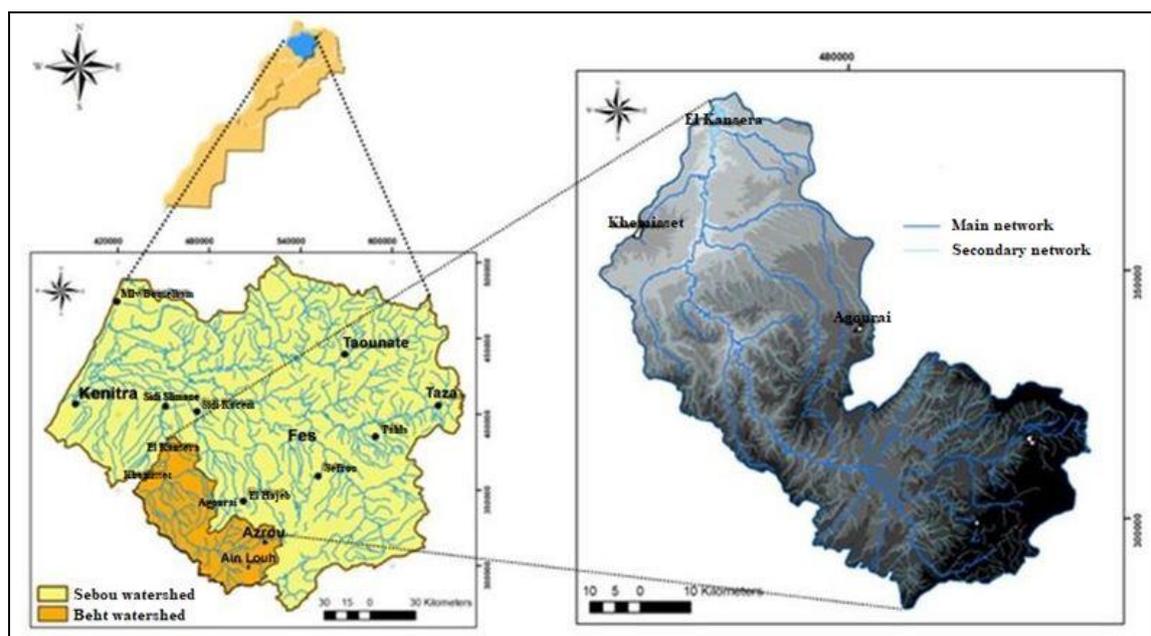

Figure 1. Geographical location of the study area: the Beht watershed in the context of the Sebou watershed (Lakhili et al 2017).

Climatic context. The Beht watershed is subject to a Mediterranean climatic stage, with a semi-arid climate (temperate and humid winter with hot and dry summer) in a semi-continental regime. This situation means that the rainfall year is made up of two seasons, a rainy season which runs from October to May and a dry one from June to September. The average annual rainfall of the basin does not exceed 700 mm, varying between 400 mm in the Haut-Beht deep valley of the central plateau, and 1000 mm in the humid high reliefs of the Middle Atlas north (Mint Chevie 2010). The geographical location of the Beht watershed between two mountainous areas, put the basin under the influence of oceanic currents from the Atlantic Ocean and continental currents from the Saharan area. The precipitation gradient is affected by the distance from the ocean (decrease in precipitation towards the interior basin), and the exposure degree of the slopes to the sea or inlets. Indeed, the geographical distribution of precipitation in the Beht basin depends on several factors such as altitude, latitude, slope exposure and continentality. (Laabidi et al 2014; Mint Chevie 2010).

Sampling stations. To evaluate the situation (2014-2015) of the surface water physico-chemical quality and to identify the metallic contamination evolution of the rivers surrounding the study area by certain toxic heavy metals such as lead (Pb), zinc (Zn), copper (Cu), cadmium (Cd) and arsenic (As), 9 sampling and analysis stations were chosen in 2014 and 6 stations in 2015 (Figure 2).
• Station 1 (Es1): surface water sampling point on the Beht River, located upstream the mine water discharge point (Ex1).
• Station 2 (Es2): surface water sampling point on the Beht River downstream the mine water discharge point (Ex1) and upstream the mine water discharge point (Ex2).
• Station 3 (Es3): surface water sampling point on the Beht River downstream the mine water discharge point (Ex2).
• Station 4 (Es4): surface water sampling point on the Beht River downstream intersection with its affluent 1 and downstream the mine water discharges points (Ex3) and (Ex4).
• Station 5 (Es5): surface water sampling point on the Beht River downstream its intersection with its intersection with its affluent 2, downstream the mine.
• Station 6 (Es6): surface water sampling point on the affluent 1 of the Beht River, this point is located upstream of the mine water discharge point (Ex 3).
• Station 7 (Es7): surface water sampling point on the affluent 1 of the Beht River downstream the mine water discharge point (Ex3) and upstream the mine water discharge point (Ex4).
• Station 8 (Es8): surface water sampling point on the affluent 1 of the Beht River, located downstream the mine water discharge point (Ex 4).
• Station 9 (Es9): surface water sampling point on the affluent 2 of the Beht River downstream the mine.
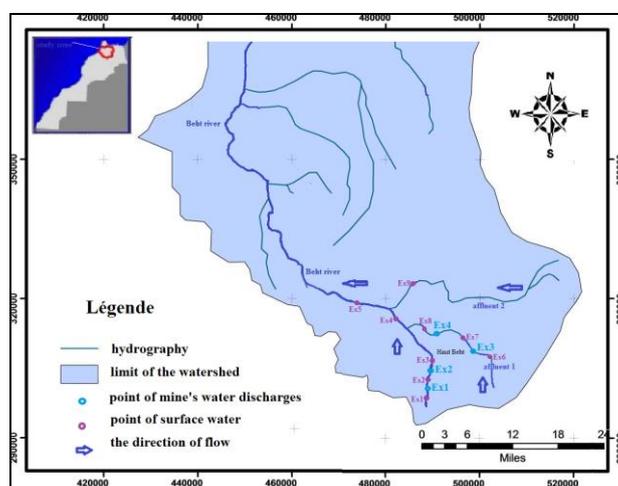

Figure 2. Geographic location map of the study area and surface water sampling stations surrounding the mine.

Analysis methods. Surface water samples were taken from the Beht River and its two affluents during the rainy period in 2014 and 2015 because during the dry period the streams sampled are not permanent. With each sample, water temperature, air temperature, electrical conductivity, pH, and dissolved oxygen were measured in situ. Water samples were taken using sterilized polyethylene vials, avoiding samples degassing by filling to the top the vials while minimizing the effects of turbulence. Sample vials were stored at 4°C during transport to the laboratory. The water samples were analyzed within 24 hours of collection to avoid any changes in the chemical composition of the water following degassing and photo-lytic or microbial reactions. Surface water samples are acidified by adding 4% nitric acid (HNO_3) to avoid changes in the concentration of metal trace elements (TME). According to standardized methods (Table 1), 36 variables were the subject of physicochemical and bacteriological monitoring.

The analyzes of heavy metals were carried out by ICP-MS (inductively coupled plasma mass spectrometry) to follow the evolution of the surface water metallic contamination with five elements in particular: lead (Pb), zinc (Zn), copper (Cu), cadmium (Cd) and arsenic (As). The two surface water sampling and analysis campaigns (C1: 2014 campaign and C2: 2015 campaign) were carried out by a laboratory approved by the state. Samples were taken following the AFNOR NF EN 25667 (ISO 5667) standard.

Table 1

The references for the basic analysis methods adopted by the analytical laboratory

Tests	Reference methods	Tests	Reference methods
Accredited tests in chemistry		*Accredited tests in chemistry and bacteriology*	
PH	NF T 90-008 / NMISO10523	As	FD T 90-119
Temperature	NF EN 25667 (ISO 5667) /NM 03.7.008	As	NF EN ISO 11885
Chlorides	NFISO9297/NM03.07.024	Nitrates	RODIER
Total phosphorus	NFENISO6878/ NM ISO6878	Chemical Oxygen Demand (DCO)	NF T 90-101 / NM03.7.56
Biochemical Oxygen Demand (BOD)	NF EN 1899 / NMISO03.7.056	V	NF EN ISO 11885
MES	NF EN 872/ NM03.7.052	CYANIDE	RODIER
Fluorides	NF T 90-004	Mo	FD T 90-119
Hg	RODIER / NFT 90-131	Be	NF EN ISO 11885
Color	NF EN 25667 (ISO 5667)	Ammonium	NF EN ISO 11885
Mo	NF EN ISO 11885	Total hydrocarbons C10-C50	Method CPG
Sulfates	NF T 90-040 / NM ISO 9280	Al	NF EN ISO 11885
Pb	FD T 90-112	Al	FD T 90-119
Pb	FD T 90-119	Zn	FD T 90-112
Pb	NF EN ISO 11885	Zn	NF EN ISO 11885
Cd	NFENISO5961	Cu	FD T 90-112
Cd	NF EN ISO 11885	Cu	NF EN ISO 11885
Fe	FD T 90-112	Cr	NF EN1233
Fe	NF EN ISO 11885	Cr	NF EN ISO 11885
Mn	NF EN ISO 11885	Turbidity	NF EN 7027/NM 03.7.010
Mn	FD T 90-112	Ni	FD T 90-119
Co	NM 03-7-022	Ni	NF EN ISO 11885

Co	NF EN ISO 11885	Se	NF EN ISO 11885
O2 dissolved	NF EN 25-813 /NM03-7-029	Se	Se FD T 90-119
Conductivity at 25°C	NF EN 27888/NM ISO 27888	Escherichia coli	NF EN ISO 9308-1/NM ISO 9308-1

Results and Discussion

Physico-chemical characterization of surface water in the vicinity of the mine.
To assess the overall quality of the surface water in the study area, all the analysis results obtained are compared to the Moroccan surface water quality grid (Order no 1275-01 of 17-10-02). This grid is based on the assessment of the physico-chemical and biological quality of the water and divided into 5 classes:
• Class I: Excellent quality water, used without special requirements, it is represented graphically by blue color.
• Class II: Good quality water, used after a simple treatment, shown in green.
• Class III: Medium quality water, can only be used after very thorough treatment, it is shown in yellow.
• Class IV: Poor quality water, polluted, can only be used after specific treatment, it is shown in purple.
• Class V: Very poor quality water, excessive pollution, it is represented in red.
The surface water quality grid has been simplified into parameters relating to indicators of organic, nitrogen, phosphorus, and bacterial pollution. The values obtained made it possible to classify the waters of the Beht river and their two affluents (Table 2 and Table 3) into five pollution levels ranging from the least polluted (class I) to the most polluted (class V).

Table 2

Surface water quality during C1

	Sampling point	O2 dissolved mg O2/l	BOD5 mg O2/l	COD mg O2/l	NH4+ mgNH4+/l	PT mgP/l	CF UFC/100 ml	Global Quality
Beht River	ES1	8,52	1,7	29	0,037	0,45	65	Medium
	ES2	9,40	1,3	27	0,012	0,109	70	Medium
	ES3	8,75	0,8	17	0,006	0,12	310	Good
Affluent 1	ES4	8,03	0,7	25	0,013	0,099	135	Good
	ES5	8,10	0,7	27	0,018	0,15	225	Medium
	ES6	5,62	0,7	19	0,019	0,061	2900	Medium
	ES7	7,95	0,5	19	0,005	0,132	50000	Poor
Affluent 2	ES8	8,5	0,4	21	0,366	0,236	105	Good
	ES9	8,44	0,5	15	0,011	0,061	700	Good

Surface water quality during C2

	Sampling point	O2 dissolved mg O2/l	BOD5 mg O2/l	COD mg O2/l	NH4+ mgNH4+/l	TP mgP/l	FC UFC/ 100 ml	Global Quality
Beht River	ES1	8,40	0,232	6,84	0,085	0,03	12	Excellent
	ES3	9,00	0,232	11	0,067	0,03	5	Excellent
	ES5	8,8	0,9	9	0,015	0,013	34	Good
Affluent 1	ES6	6,30	0,4	12	0,040	0,012	140	Good
	ES7	8,40	0,3	13	0,006	0,042	58	Good
	ES8	8,2	0,6	11	0,018	0,079	680	Good

Temperature and pH. The water temperature values of the Beht river and its two affluent vary from the upstream to the downstream of the rivers and from one campaign to another. They vary between 27.5 C and 17.6°C during C1 and between 18.2°C and 9.2°C during C2. The surface water temperature varies according to the seasons and can pass from 2°C in winter to 30°C in summer (Potelon & Zisman 1998). However, the rise of temperature in July and August promotes the self-purification phenomenon and increases the sedimentation rate of suspended matter (Djermakoye 2005). The pH of all surface water samples collected is greater than 7, suggesting the existence of a slightly alkaline environment. The extreme values are between 7.65 and 8.7 during C1 and between 7.45 and 8.65 during C2. The pH between 5 and 9 allows the normal development of fauna and flora (Blinda 2007).

Dissolved oxygen, BOD, and COD. Oxygen is an essential element for aquatic life, in particular for organisms ensuring the self-purification of rivers, it is a good pollution indicator of rivers and the monitoring of self-purification (Derwich et al 2008). For the present study, the dissolved oxygen contents vary between 9.4 mg/l and 5.62 mg/l during C1 (Table 2), and between 9 mg/l and 6.3 mg/l during C2 (Table 3). The two minimum values recorded during the two surface water sampling campaigns C1 and C2 are noted at the same point Es6 located upstream of the mining activities (Figure 1).

BOD (biochemical oxygen demand) allows the evaluation of biodegradable organic matter present in water (Makhoukh et al 2011). The values found for the BOD parameter of water are not uniform and vary between 0.4 mg/l and 1.7 mg/l during C1 and between 0.23 mg/l and 0.9 mg/l during C2, but they remain below the limit value set at 3 mg/l, which makes it possible to classify all the water sampled in the category of excellent quality from a BOD point of view.

Chemical oxygen demand (COD) represents the amount of oxygen consumed by chemically oxidizable materials in water. It is representative of the majority of organic compounds and oxidizable mineral salts (sulfides, chlorides etc.) (Makhoukh et al 2011). The COD recorded values of the surface water sampled vary between 15 mg/l and 29 mg/l during C1 and between 6.84 mg/l and 13 mg/l during C2. The grid of Moroccan standards then makes it possible to classify these waters in the category of excellent quality (Es3, Es6, Es7 and Es9), good (Es4, Es8) and average (Es1, Es2 and Es5) during C1 (Table 2), and in class of excellent quality for all the water sampled during C2 (Table 3). The points of average quality during C1 are Es1 which is located upstream the mine and far from its activities, Es5 which is downstream the mine but far from its activities and Es2 located downstream the mine water discharge (Ex1). Under the effect of the dilution, the COD value at the point Es2 is slightly lower compared to the value recorded at the Es1 point (Figure 2).

Ammonium and total phosphate. In natural waters, the detection of ammonium in large quantities is a pollution criterion (Dussart 1966). In fact, the water sampled has ammonium (NH_{4+}) contents which vary between 0.005 mg/l and 0.36 mg/l during C1 and between 0.006 mg/l and 0.085 mg/l during C2. All the ammonium values obtained in the

waters of the Beht Rver and its two affluents during C1 and C2 are lower than the excellent quality standards of surface water set at 0.1 mg/l (Table 2, Table 3), except in the Es8 point, where we noted a slightly elevated value of 0.36 mg/l (Table 2). This allows the water to be classified at this point in the category of good quality water in terms of ammonium.

Generally, phosphates come from leaching and they take part in the first line of the eutrophication process which is a phenomenon with environmental (algal development) and health consequences (release of algal toxins) (Kachi et al 2015). The total phosphate (TP) contents recorded during the two measurement campaigns vary between 0.061 mg/l and 0.45mg/l during C1 and between 0.012 mg/l and 0.079 mg/l during C2. Referring to the grid of Moroccan standards, the waters of the Beht River and its two affluents during C1 are of excellent quality (Es4, Es6, Es9), of good quality (Es2, Es3, Es5, Es7, Es8) and average quality at point Es1 (Table 2), located upstream of the mining operation. During C2 all the sampled waters are classified as excellent waters (Table 3).

Fecal coliforms. Fecal coliforms (FC) are indicators of fecal contamination, in the case of water contaminated with fecal pollution germs, as almost all surface waters (Uzoigwe et al 2007), it is not a warning signal, but an assessment of the fecal pollution extent. Most of these permanent contaminations come from urban wastewater discharges, the concentration of fecal coliforms of which is relatively constant and of the order of 106 to 107 per 100ml (Rodier 1996). The fecal coliform concentrations vary between 65 UCF/100ml and 50,000 UCF/100ml during C1, and between 5 UCF/100ml and 680 UCF/100ml during C2 (Table 2, Table 3). This makes it possible to classify according to the Moroccan surface water quality grid, the waters of the Beht River and its two affluents during C1 in the class of water of good quality which has as limit value of 2000UCF/100ml, apart from the two points Es6 and Es7, which respectively show average quality and poor quality (Table 2). However, during C2 the quality of the water became excellent at the points Es1 and Es3 (<20 UCF/100ml) and good in the rest of the points (Es5, Es6, Es7, and Es8) (Table 3).

The presence of fecal coliforms in the surface water sampled with high concentrations at two stations Es6, located upstream of the mine, and Es7 located downstream the mine water discharge Ex3 on the affluent 1, shows that there is fecal contamination of this river linked on one hand to the presence of numerous farm animals (sheep, cattle, goats etc.) and on the other hand, to the discharge of domestic wastewater from residents living near this non-permanent river (affluent 1 of Beht River).

Impact of the discharge of mine water on the quality of surface water. To assess the impact of mining and have more visibility of the mine water discharge impact on the surface water quality, we carried out a comparative approach between the quality of water upstream and downstream each discharge point of this mine water (Figure 2) (Table 4).

Table 4

Comparison between the contents of elements recorded in exceedances in the mine water discharges and their concentrations in the surface water upstream and downstream of the discharge points during C1

Discharge	Elements in excess	Unit	Excess value	Industrial discharge limit value	Upstream Point	Downstream point	Limit value	Water category
Ex1	Sulfate	mg/l	777	500	28,4	28,4	100	Excellent
	Sulfate	mg/l	974	500	28,4	29,5	100	Excellent
	Aluminium	mg/l	14,1	10	0,011	0,025	0,2	Excellent
Ex2	Iron	mg/l	25,5	5	0,0056	0,0056	0,5	Excellent
	Manganese	mg/l	8,78	1	0,0029	0,0029	0,1	Excellent
	Arsenic	mg/l	0,083	0,05	0,0025	0,0026	0,01	Excellent
Ex4	Sulfate	mg/l	1413	500	132	1957	400	very poor

The comparison between the qualities of surface waters upstream and downstream the mine water discharges points showed an absence of visible impact in terms of the elements recorded in excess in the mine water discharges. This may be related to the effect of dilution, since the flow of rivers is much greater than the quantities of mine water discharges. The sulfate concentrations recorded at the surface water points upstream and downstream of the mine water discharge point Ex1, and the iron, aluminum, sulfate, manganese, and arsenic concentrations recorded upstream and downstream the mine water discharges point Ex2 (Table 5), do not exceed the limits recommended by the surface water quality grid and they are classified in terms of these elements in the excellent water category. Except the Es8 point located downstream the mine water discharge point Ex4 and at the downstream limit of the mine on the affluent 1 of the Beht River (Figure 2) which shows an excess in sulfate.

Table 5

Comparison between the content of elements recorded in exceedances at the level of mine water discharges and their concentrations in the surface water upstream and downstream of the discharge points during C2

Discharge	Elements in excess	Unit	Excess value	Industrial discharge limit value	Upstream Point	Downstream point	Limit value	Water category
Ex1	Sulfate	mg/l	710	500	25,36	21,56	100	Excellent
	Manganese	mg/l	7,35	1	0,0071	0,0065	0,1	Excellent
Ex2	Sulfate	mg/l	586	500	25,36	21,56	100	Excellent
Ex4	Sulfate	mg/l	1310	500	120	1587	400	very poor

The comparison between the qualities of surface waters upstream and downstream the mine water discharges points showed an absence of visible impact in terms of the elements recorded in excess in the mine water discharges, with the exception in the Es8 point. The sulfate and manganese recorded values at the surface water points located upstream and downstream the mine water discharge point Ex1, and those of sulfate recorded upstream and downstream the mine water discharge points Ex2 and Ex4, do not exceed the limits recommended by the Moroccan surface water quality grid and according to these elements the surface waters are classified in the excellent water category. This classification does not include the Es8 point located at the downstream limit of the mine, which has an excess in sulfate.

These high sulfate concentrations recorded at the Es8 point during C1 and C2 can be linked to the exploitation of sulfide ore (Taltasse 1953) because the oxidation of mineral sulfides produces heavy metals and sulfate (Repeta et al 2002). Despite the sulfate exceedances recorded at the majority of the analyzed mine water discharges, the impact of these discharges at the downstream points remain invisible following the phenomenon of dilution, which is not the case at the Es8 point, because the water of the affluent 1 is not permanent year round and has a low flow rate, with limited accessibility given its geographical location in a valley between two mountains.

Metal contamination of surface water. Several studies have shown that mining is a major source of water contamination, due to the release and dispersion of metals contained in mine tailings (Davies & Bailinger 1990; Fuge et al 1989; Merrington & Alloway 1994). Generally, the concentrations of TME in natural waters are very low, due to their low solubility in the aquatic environment (Jung 2001). Thus the typical concentrations of arsenic (As) in uncontaminated fresh water are less than 10 µg/l (Smedley & Kinniburgh 2002), and 0,1 µg/l for cadmium (Cd), 3 µg/l for copper (Cu), 3µg/l for lead (Pb), and 15 µg/l in zinc (Zn) (Bowen 1979). However, these concentrations can be found ten to a hundred times in water contaminated by various sources (Fergusson 1990).

To determine the degree of surface water metallic contamination in the study area, the results of analyzes of samples taken from stations located at the Beht River and its two affluents during C1 and C2, are compared to:

• Moroccan surface water quality standard: the surface water quality grid (Order no°1275-01 of 17-10-02); class 1: Excellent quality;
• Moroccan standards (MS) for the quality of water intended for irrigation (Joint order No. 1276-01 of October 17, 2002);
• Potable water quality standards: the Moroccan standard (MS) for water intended for human consumption (NM 03.7.001);
• World Health Organization standards: WHO and the Food and Agriculture Organization of the United Nations: FAO (Lauren Posnick et al 2011; Serghini et al 2003).
The TME limit values in surface waters according to the above standards are presented in Table 6.

Table 6

The limit values in TME (mg/l) in surface waters

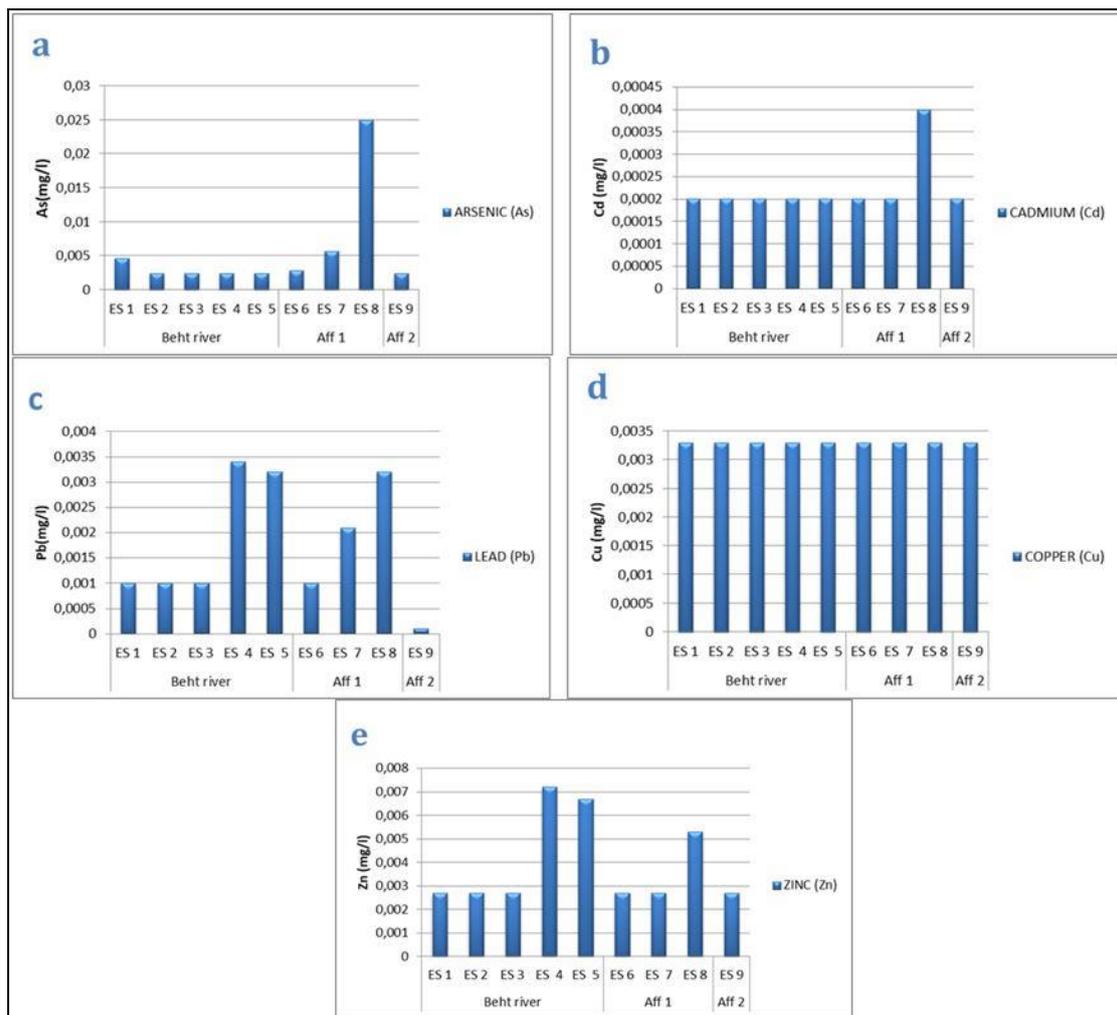|	Arsenic (As)	Cadmium (Cd)	Copper (Cu)	Lead (Pb)	Zinc (Zn)
Excellent Quality Grid	0,01	0,003	0,02	0,01	0,5
MS irrigation	0,1	0,01	2	5	2
MS potable	0,01	0,003	2	0,025	3
WHO	0,01	0,003	1	0.01	3

Surface water contamination in TME during C1.

Figure 3. Evolution of As (a), Cd (b), Pb (c), Cu (d) and Zn (e) concentrations in the water of the sampling stations at the Beht River and its two affluents during C1.

The TME concentrations of all the C1 samples (Figure 3) comply with the limit values of the Moroccan surface water quality grid, thus the surface water sampled from the Beht River and its two affluents are classified in the excellent water category. Except the waters of the Es8 point which are classified in the average water category, because of the concentration of As (0.025 mg/l), exceeding the limit value of the class of excellent waters set at 0.01 mg/l (Table 6).

All the TME concentrations of the surface water sampled during C1 comply with the limit values set by the quality standard of water intended for irrigation, the limit values of the standards for drinking water intended for human consumption, and the standards of the World Health Organization. Except for the Es8 point, where the arsenic concentration is 0.025 mg/l, exceeding the limit value set at 0.01 mg/l by the two standards of drinking waters and WHO (Table 6). The point Es8 is located downstream the mine water discharge Es4 and downstream the mine on the affluent 1 of the Beht River (Figure 2). The water at this point is not used either for irrigation (absence of agricultural land) or for drinking water supply (presence of wells and springs which are used for drinking water), because this point is located in a valley with difficult access.

The origin of arsenic in the waters surrounding a mining site comes mainly from two main sources, either a geochemical background rich in arsenic or the leaching of mine waste rock, as well as the remobilization of arsenic linked to mining activities through the opening of galleries and thus increasing the contact surfaces of the mine water with the bedrock, which enriches the water with arsenic (Bossy 2010).

Arsenic input can come from river bottom sediments highly enriched in arsenic and which are forcefully carried downstream the mining district (Bril & Floc'h 2001). These sediments constitute a potential stock of arsenic which, by leaching and disturbing environmental conditions, can easily be transferred to the aqueous fraction and contaminate surface water (Bossy 2010). The point Es9 is the only sampling point located on the affluent 2 of Beht River (Figure 2) downstream the mine, which may explain the considerable difference in TME concentrations at this point.

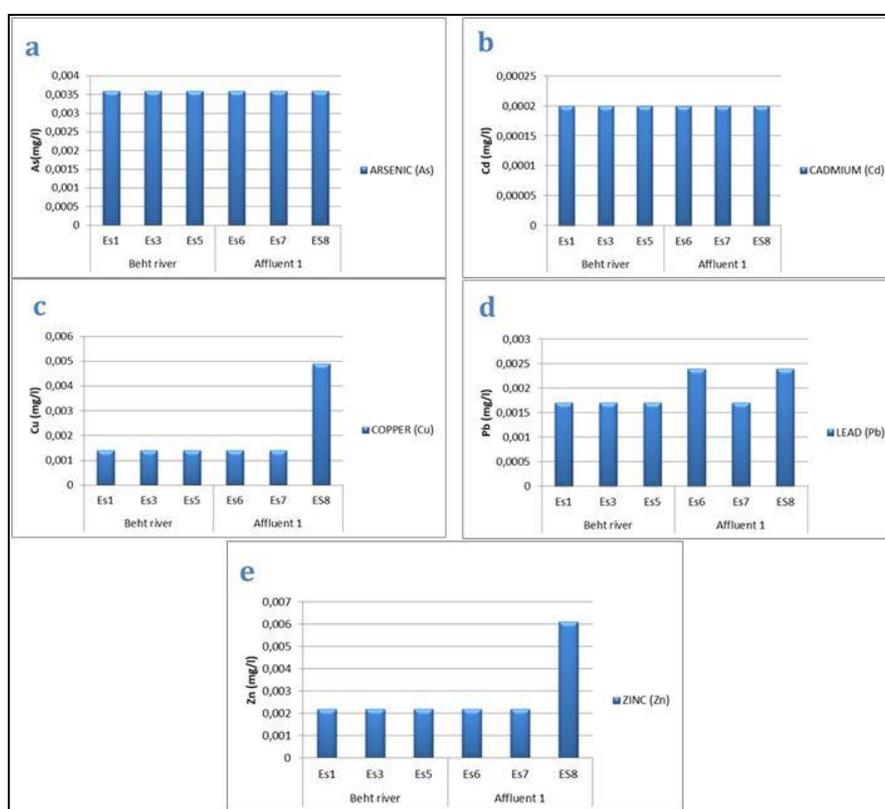***Surface water contamination in TME during C2****.*

Figure 4. Evolution of the concentrations of As (a), Cd (b), Cu (c), Pb(d) and Zn (e) in the water of the sampling stations at the Beht River and affluent 1 during C2.

All the concentrations of TME recorded in the surface water sampled during C2 (Figure 4) comply with the limit values set by the quality standard of water intended for irrigation, the limit values of the standards for drinking water intended for human consumption, and the standards of the World Health Organization. They also comply with the limit values of the Moroccan grid for the quality of surface water. The surface water sampled at Beht River and its affluent 1 are thus classified in the excellent water category.

Although the values of the TME concentrations have become conform and do not exceed the limit values set by the quality standards for water intended for irrigation or human consumption, a slight increase is recorded at the Es8 point in terms of lead, zinc, and copper, but the concentrations remain well below the limit values. This change over time of TME concentrations in surface waters is due to the change in the geochemical background, to the change in seasons, and the release of TME contained in river sediments under the effect of erosion (Bossy 2010; Bril & Floc'h 2001).

Conclusion. According to the Moroccan surface water quality grid, all the results of the quality analysis of the surface water of the Beht River and its two affluents, in the vicinity of the Haut Beht mine, showed organic contamination at two points. These two points (Es6 and Es7) are located upstream of the mine and their organic contamination can only be linked to domestic waste from local residents and to grazing activities and not to the mine water discharges, due to the organic nature of pollution.

The comparative analysis of the concentrations of elements recorded in excess in the mine water discharges compared to their concentrations in the surface water situated upstream and downstream the points of this mine water discharges showed contamination in sulfate at the Es8 point during the 2014 campaign (C1) and the 2015 campaign (C2). The hydrochemistry of the river's waters in the vicinity of the Haut Beht mine varies over time thanks to several factors, but the TME concentrations remain largely below the standards concerning the acceptable chronic concentrations in surface water at all the sampling stations, except the Es8 point which was non-compliant in terms of arsenic concentration during C1. The TME contents recorded in the other stations studied of surface water surrounding the mine do not show any contamination.

The results of the quality analysis of the surface water surrounding the Haut Beht mine during C1 and C2 made it possible to draw up a first observation on the occasional impact of mine water discharges on the quality of the surface water of Beht River and its two affluents. These results also show that the quality of the majority of watercourses, at the sampled points, complies with the standards in force and waters are not contaminated as the case of the surrounding waters of other industrial sites, which they have succeeded in making the Sebou hydraulic basin the most polluted basin in Morocco.

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