

# Heavy metals concentrations and usability of groundwater at Mahd Adh Dhahab gold mine, Saudi Arabia

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**Abstract** The purpose of this study is to evaluate the environmental and social impact and operational water quality in the Mahd Adh Dhahab gold mine area and its surroundings in the central part of the Arabian Shield, Saudi Arabia. This study investigates the distribution of heavy metals in the groundwater from the Mahd Adh Dhahab gold mine area and its surroundings to examine the contamination level of heavy metals in this water due to mining activities. Analytical results of 23 samples from different drains and Wadis of the study areas indicated that water has relatively high concentrations of Na (average 1,916 ppm), Al (average 1.2 ppm), Fe (average 1.2 ppm), and B (average 2.9 ppm). Other elements exist in very low concentrations (less than 0.5 ppm). The heavy metals distribution shows no specific patterns in the studied wells. Although the concentrations of some heavy elements such as Cu, Zn, and Pb are high due to their abundance in the exposed mineralized veins in the Mahd Adh Dhahab gold mine, no abnormally high concentrations of these elements were found in the studied water samples. This suggests no obvious pollution effects of the mining activities on the groundwater. Except Fe and Mn contents, the groundwater in the Mahd Adh

Dhahab mine area and its surroundings have lower metals concentrations compared to the World Health Organization guidelines for drinking water quality and water quality criteria for livestock set by the Ontario Ministry of Environment, which can indicate the validity of such water as drinking water after treatment for Fe and Mn. The concentrations of heavy metals in the studied water samples also have very low values compared to the Desirable Contaminant Concentration and Acceptable Contaminant Concentration values suggesting no pollution effect of the mining processes on the water quality. This in turn indicates the validity of the water in the mine area as well as the surrounding areas for agricultural uses.

**Keywords** Mahd Adh Dhahab · Saudi Arabia · Heavy metals · Groundwater · Pollution

## Introduction

The pollution of the water bodies with toxic metals has been attracting considerable public attention over the past few decades. Heavy metals are added to an aquatic system by natural or by anthropogenic sources (Suthar et al. 2009). Groundwater is an important source of water supply in many parts of the world. The sources of components that determine groundwater quality are numerous and diverse. According to Davis and DeWeist (1966) the dissolved inorganic constituents in groundwater are grouped into major (>5 mg/l), minor (0.01–10 mg/l), and trace (<0.01 mg/l) levels, based on their concentrations. These constituents can enter groundwater through many different routes (Barcelona et al. 1990; Salomons 1995) including: (1) interactions with geologic formations, (2) interactions of groundwater with surface water bodies, (3) percolation of precipitation water containing dissolved, colloidal, and suspended materials, (4) cross-flow between aquifers through natural fractures across the contact between the two aquifers and man-made boreholes

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open to more than one aquifer, (5) direct entry from the land surface through wells, and (6) flow from adjacent aquifers caused by pumping. It is apparent that groundwater can contain hazardous components to human health which is derived from various naturally occurring sources, and it is necessary to evaluate the quality of the groundwater under pristine conditions before assessing the contamination of the groundwater caused by human intervention (Al-Awadi et al. 2003; E-Tech International 2010).

The delivery of mining-derived contaminants to streams and rivers can lead to a significant environmental impact on sediment and water quality in downstream reservoirs; the concentrations of trace metals in most natural water are controlled by adsorption or co-precipitation processes and by contamination of environmental ecosystems by trace elements derived from mining activities (e.g., Plumlee et al. 1993; Caritat et al. 1998; Williams 2001; Martin and Calvert 2003; Fang, et al. 2003; E-Tech International 2010). Moreover, the environmental effects of past mining activities can be observed in receiving water bodies several decades after mine closure (Azcue and Nriagu 1993). Abandoned mining sites contain wastes from processing operations that are a potentially important source of toxic elements (e.g., As, Ba, Cd, Cu, Pb, and Zn) and could have significant impacts on the surrounding environment (Salomons 1995; Piatak et al. 2004). The mineralogical composition of the rocks is the main factor in the development of environmental pollution (Dinelli et al. 2001; Milu et al. 2002).

Due to the increasing of mining activities in the Saudi Arabia during the last few decades, the environmental impact assessment of these mines has attracted many studies in order to preserve the environment around these mines. Al-Hobaib et al. (2010) studied the pollution effect of mining activities in the Mahd Adh Dhahab mine on the soils, dusts, and plants from inside and outside the mine. They found that the pollution effect of some heavy metals is limited to the soils and dusts inside the mine. There were no abnormal concentrations of heavy metals in the soils and dusts from outside the mine as well as the plants. The current study tries to illustrate the pollution effect of the Mahd Adh Dhahab gold mine on the water resources of the mine area and its surrounding areas through detailed analyses of water samples represent a number of drains and Wadis. The obtained results were compared with the standard values and upper limits of the concentrations of these metals in the drinking and irrigation water to examine the possibility of using of this water for human activities.

### Location and water resources of the study site

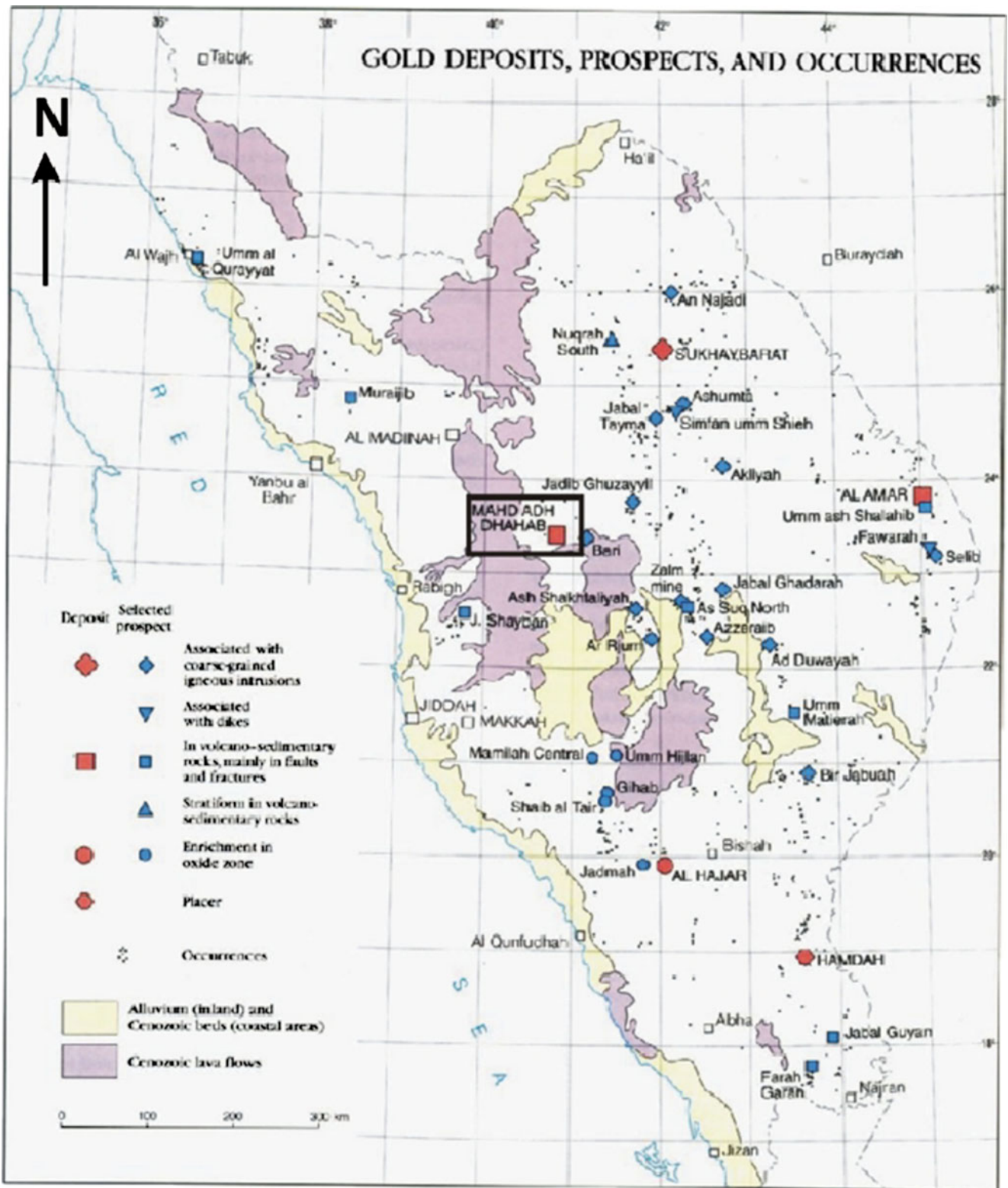
Many gold deposits, prospects, and occurrences are found in Saudi Arabia (Fig. 1). Mahd Adh Dhahab, Sukhaybarat, and

Al Amar deposits are the most important and currently working mines in Saudi Arabia (Fig. 1), some other prospects are still under explorations. The Mahd Adh Dhahab gold mine is located 380 km northeast of Jeddah and 275 km southeast of Al-Madana Al-Munawara between latitude 23°30'30" N and longitude 40°51'30" E in the west-central part of the late Proterozoic Arabian Shield (Fig. 1).

The Mahd Adh Dhahab gold mine belongs to the middle and western parts of the Western Arabian Shield where the gold deposit is hosted in rocks of the late Proterozoic Mahd group; a bimodal basalt-rhyolite volcanic-volcaniclastic sequence of rocks that rest nonconformably on the basement of metamorphosed tonalite of the Dhukhur batholith (Kemp et al. 1982; Afifi 1990). The gold of Mahd Adh Dhahab mine occurs in the quartz veins and is associated also with silver, zinc, copper, and other metals. The water resources of Mahd Adh Dhahab area and surroundings are considered as secondary resources since there is no large groundwater aquifers in these areas. The occurrence of water in these areas is limited to the Wadi sediments and rock fractures and their quantities and qualities are affected by the rainy seasons and precipitation rate. In the seasons of heavy rains, the amount of groundwater increases and salinity decreases and vice versa.

Like many parts of Saudi Arabia, the Mahd Adh Dhahab area is located in the dry to semi-dry climate region. Studies during the period from 1985 and 2007 indicated that the rain in these areas ranges from light to medium with an average precipitation rate of 94 mm per year and average humidity is 14% and 35% in the winter and summer, respectively, with an average of 22% (e.g., Abouammoh 1991; Abdullah and Al-Mazroui 1998; Taher and Alshaikh 1998; Al-Mazroui 2010).

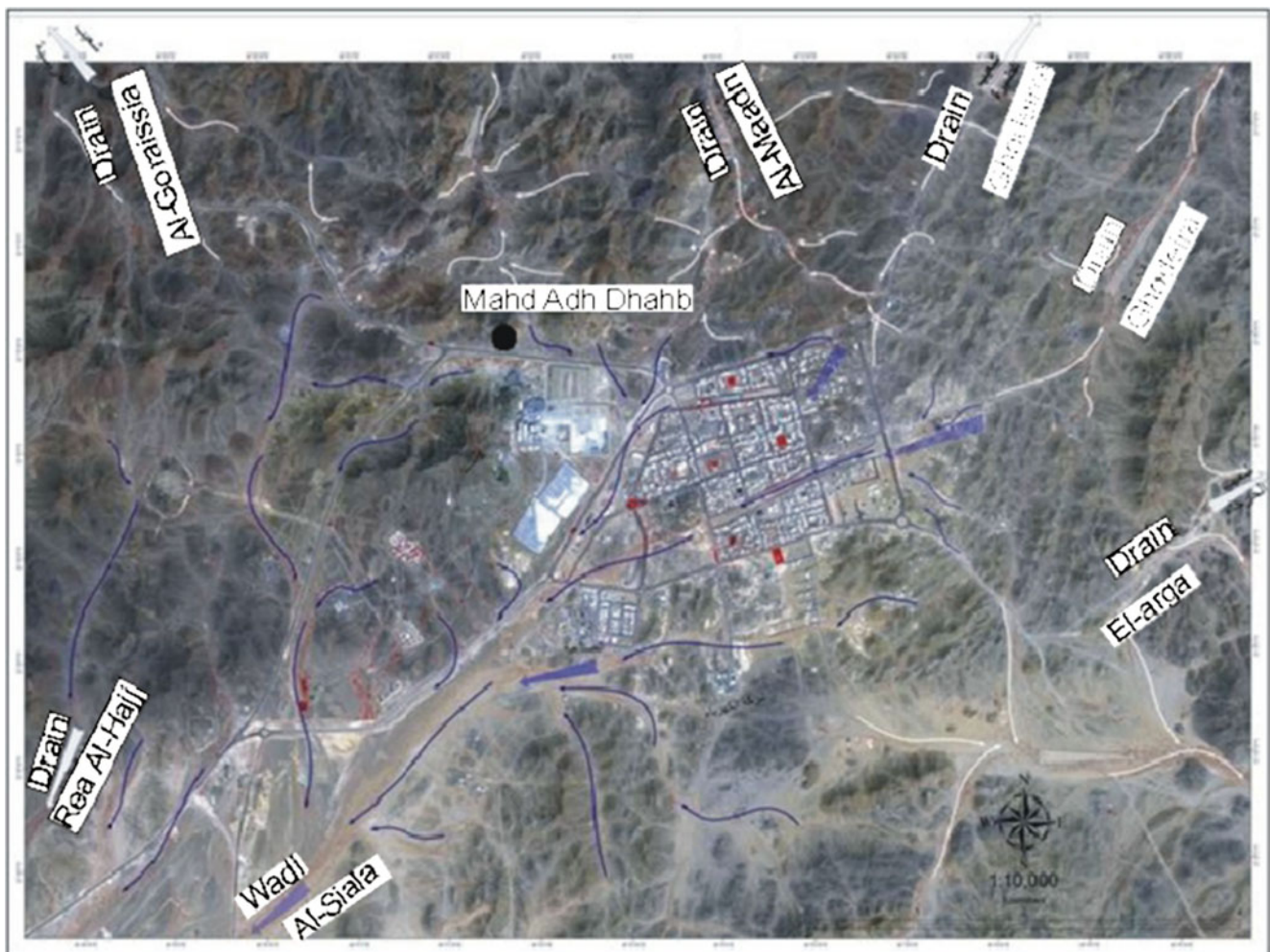
A number of drains and Wadis occur in the study area (Fig. 2). Some of them run away from the mine area (drains run to the north and east) and many others run through the mine area itself towards the southwest such as (1) Al-Maadan drain that is sourced from the mountains located north of the Mahd Adh Dhahab City and runs northward to drainage in Wadi El-Arg, (2) Ghodeira drain, which runs through Mahd Adh Dhahab City northward to drainage in Wadi El-Arg as well, (3) Ghodairra drain, which runs in its northern part parallel to the former drain and drainage in Wadi El-Arg. In its southern part, it runs to the west and southwest directions through Mahd Adh Dhahab City and meets with the drains from the south and north of the mountain and mine to drain in the Wadi Al-Siala (Fig. 2), (4) Rea Al-Hajj drain that runs from north to southwest of the mine mountain to meet with the floods drained from Al-Mahd City and drainage in Wadi Al-Siala, (5) Al-Goraissia drain that runs from the root of Al-Mawqea Mountain to the northwest direction in a braded path close to the mine then it changes to be straight before its drainage in Wadi El-Arg, (6) Wadi Al-Siala to which water comes from the western and southern mountains parallels to the Mahd City and



**Fig. 1** Distribution of gold deposits and prospects in the Arabian Shield including the Mahd Adh Dhabab area (from Colletette and Grainger 1994). *Solid rectangular* indicates the study area

from the eastern and western mine mountains to run in the southwest directions with slight slopes, and (7) Wadi Al-Gharga, in which the Al-Gharga wells are located and road

to Afif area passes through it. It runs east and northeast directions from mountains east to the Mahd City to drain in Wadi Al-Arg.



**Fig. 2** Distribution of drains and Wadis in the Mahd Adh Dhahab mine area and its surroundings. *Solid circle* indicates the study area

The distribution of drains and Wadis systems around the Mahd Adh Dhahab gold mine indicates that the possible pollution effect of mining activities on the surface and groundwater will be limited to the surface and groundwater of drains and Wadis around Al-Mahd Mountain as well as Wadi Al-Siala. Thus, the assessment of the pollution effect of the mining activities in Mahd Adh Dhahab area can be examined by the analyses of number of groundwater samples that were collected from a number of drains and Wadis around the Mahd Adh Dhahab gold mine.

### Samples and analytical procedures

To examine the contamination level of heavy metals caused by the mining activities in Mahd Adh Dhahab gold mine on the groundwater of the mine and its surrounding areas, 23 water samples were collected to represent eight drains and Wadis from inside and outside the Mahd Adh Dhahab mine area. The samples cover approximately 30 km around the

Mahd Adh Dhahab mine area and represent (1) the drains that run from northeast to southwest of the mine area passing through the Mahd City, (2) drains inside the Mahd City and around its industrial area, (3) drains and Wadis that run away from the Mahd area, (4) water stock of the Mahd area, and (5) water from other mining areas (e.g., Sayed Mountain area) for comparison. Sample numbers and locations were cited in Table 1 and Fig. 3. Water samples were analyzed for their heavy metals concentrations by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) at the ALS laboratory group (Analytical Chemistry and Testing Services), Canada.

### Results and discussion

#### Distribution of heavy metals

The concentrations of heavy metals in the water samples are shown in Table 1 and the averages of metals concentrations in different areas in Fig. 4. The distribution

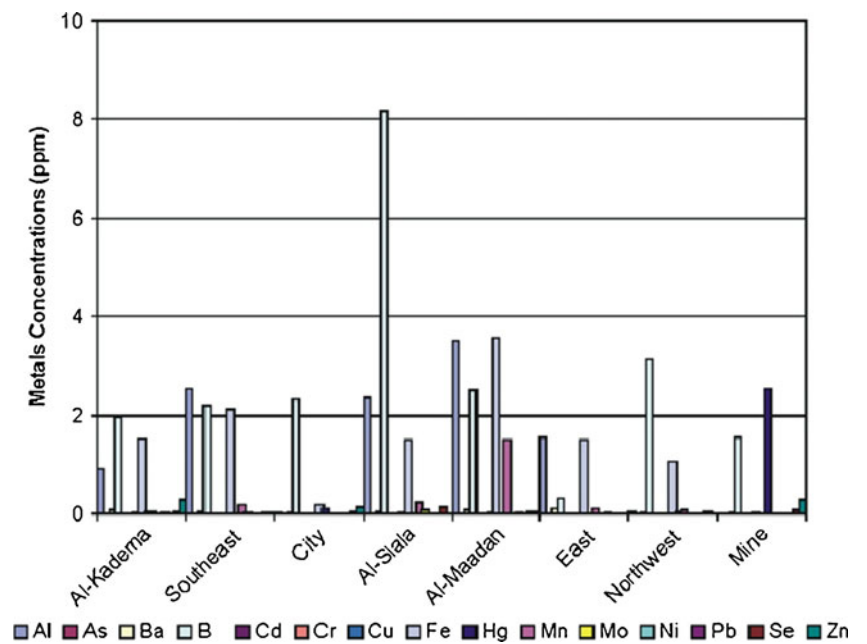
**Table 1** Concentrations of heavy metals (in parts per million) in the water samples collected from the Madh Adh Dahab mine area and surrounding areas

Samples	Al	As	Ba	B	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Na	Ni	Pb	Sb	Se	Zn
Wadi Al-Kadema	1	0.01	0.006	0.07	1.48	0.0011	0.001	0.003	1.850	0.066	0.064	0.002	0.017	0.005	0.01	0.064	0.229
	2	0.01	0.005	0.08	1.56	0.0004	0.001	0.019	0.030	0.062	0.004	0.002	0.006	0.008	0.01	0.041	0.565
	3	2.73	0.005	0.11	2.83	0.0004	0.005	0.025	2.680	0.000	0.125	0.002	0.021	0.010	0.01	0.069	0.047
Southeast of Mahod City	5	1.53	0.005	0.03	4.27	0.0004	0.003	0.009	1.680	0.000	0.075	0.021	0.004	0.005	0.01	0.050	0.006
	6	3.55	0.005	0.07	0.10	0.0004	0.007	0.015	2.580	0.000	0.261	0.007	0.012	0.005	0.01	0.010	0.020
	7	0.01	0.005	0.02	2.34	0.0004	0.006	0.003	0.536	0.300	0.003	0.008	0.003	0.005	0.01	0.041	0.012
Mahd Adh Dahab City	8	0.07	0.005	0.02	2.86	0.0004	0.002	0.004	0.227	0.140	0.015	0.006	0.004	0.005	0.01	0.060	0.002
	14	0.01	0.005	0.04	1.36	0.0004	0.001	0.003	0.070	0.046	0.001	0.002	0.003	0.005	0.01	0.027	0.020
	15	0.01	0.005	0.03	1.04	0.0004	0.001	0.002	0.009	0.019	0.001	0.002	0.005	0.005	0.01	0.010	0.046
	17	0.01	0.005	0.02	3.98	0.0004	0.001	0.004	0.121	0.035	0.002	0.005	0.022	0.005	0.01	0.118	0.565
Wadi Al-Siala	9	4.64	0.008	0.03	2.82	0.0004	0.002	0.019	2.650	0.000	0.589	0.012	0.003	0.006	0.01	0.052	0.016
	10	1.86	0.005	0.06	9.26	0.0004	0.002	0.012	1.410	0.000	0.114	0.034	0.027	0.005	0.01	0.174	0.002
	11	0.59	0.005	0.04	12.40	0.0004	0.001	0.015	0.400	0.000	0.018	0.166	0.006	0.005	0.01	0.146	0.002
Wadi Al-Madina	12	2.10	0.006	0.11	3.78	0.0004	0.003	0.012	2.790	0.000	3.550	0.015	0.041	0.009	0.01	0.017	0.018
	13	0.48	0.007	0.06	2.95	0.0004	0.001	0.014	0.591	0.000	0.083	0.005	0.004	0.005	0.01	0.136	0.002
	19	7.98	0.005	0.05	0.76	0.0004	0.013	0.041	7.320	0.026	0.888	0.007	0.030	0.020	0.01	0.011	0.108
East of Mahd city	16	1.54	0.005	0.11	0.30	0.0004	0.003	0.011	1.500	0.000	0.100	0.002	0.016	0.005	0.01	0.012	0.009
Northwest Mahd City	4	0.01	0.005	0.02	2.67	0.0004	0.001	0.003	0.173	0.099	0.003	0.002	0.005	0.005	0.01	0.048	0.002
	18	0.10	0.007	0.02	3.59	0.0004	0.003	0.007	1.940	0.010	0.136	0.013	0.002	0.005	0.01	0.052	0.015
Mahd Ahd Dahab mine	20	0.01	0.005	0.03	0.91	0.0004	0.001	0.002	0.028	9.990	0.017	0.002	0.007	0.005	0.01	0.137	1.050
	21	0.01	0.005	0.02	1.43	0.0004	0.001	0.003	0.004	0.106	0.006	0.002	0.002	0.005	0.01	0.023	0.002
	22	0.01	0.005	0.03	1.54	0.0004	0.002	0.003	0.002	0.022	0.001	0.002	0.004	0.005	0.01	0.056	0.002
	23	0.01	0.006	0.02	2.30	0.0004	0.001	0.081	0.002	0.045	0.009	0.002	0.003	0.005	0.01	0.095	0.132



Fig. 3 Locations of the analyzed water samples

Fig. 4 Average concentrations of metals in water samples from different wells on the Mahd Adh Dhahab mine and its surrounding areas



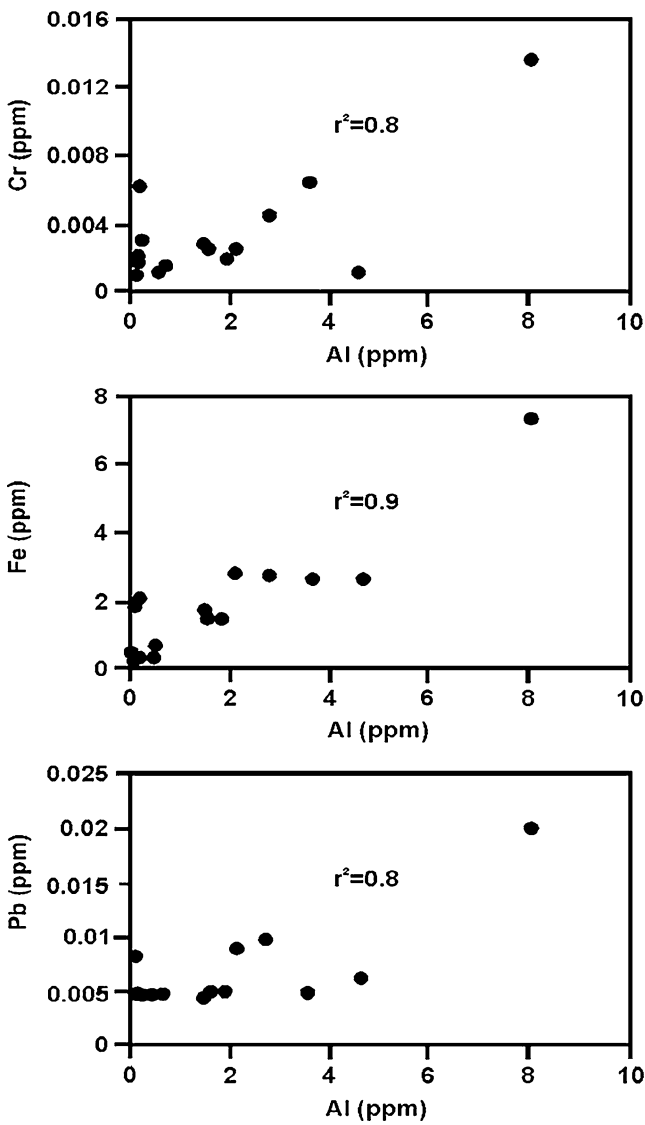


Fig. 5 Positive correlations between Al and Cr, Fe, and Pb in water samples

of metals especially heavy metals and those of harmful effects in the analyzed water samples will be discussed below.

*Aluminum*

Al contents range between 0.01 and 8 ppm with an average of 1.2 ppm. Water from the wells of Wadi Al-Siala and Al-Madina areas have relatively higher Al contents compared to other areas in the study site with averages of 2.4 and 3.5 ppm, respectively. Al shows positive correlations with Cr, Fe, and Pb (Fig. 5) suggesting common sources and/or mode of occurrences of these elements. Interactions with geologic formations that are composed mainly of aluminum silicate minerals could be a probable source of Al in the

studied wells. The Al concentration in the studied water samples is relatively higher than the permissible concentration in the safe drinking water (0.05–0.2 mg/L, US EPA 2009) compared with the concentration mentioned by World Health Organization (WHO) for drinking water (WHO 2008).

*Total iron*

Iron contents range between 0.002 and 7.3 ppm with an average of 1.2 ppm. Water from Al-Madina area and wells from southeast Mahd Adh Dhahab City have relatively high Fe contents compared to other areas with averages of 3.6 and 2.1 ppm, respectively. Fe shows positive correlations with Cr, Pb, and Ni (Fig. 6) suggesting common sources and/or mode

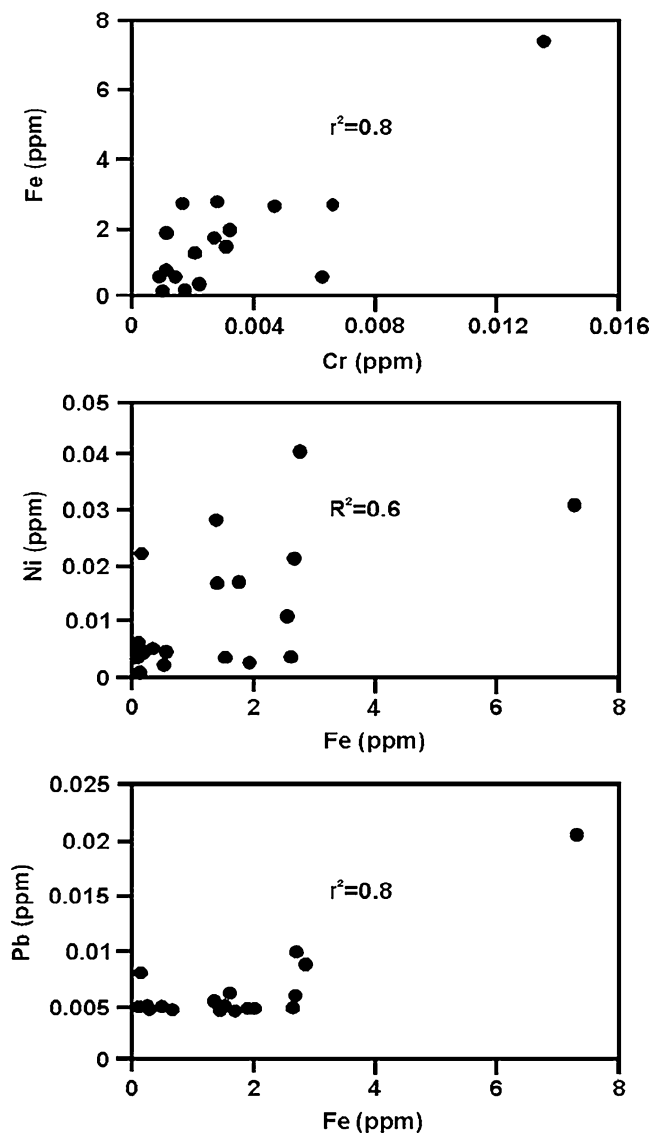


Fig. 6 Positive correlations between Fe and Cr, Pb, and Ni in water samples

of occurrences of these elements. The positive correlation between Fe and Al (Fig. 5) indicates that the aluminum silicate minerals, which compose the host rocks, could be a possible source of the iron in the study water. Like Al, the Fe concentration in the studied water samples is also relatively higher than the permissible concentration in the safe drinking water determined by some organizations (WHO 2008; US EPA 2009).

#### Boron

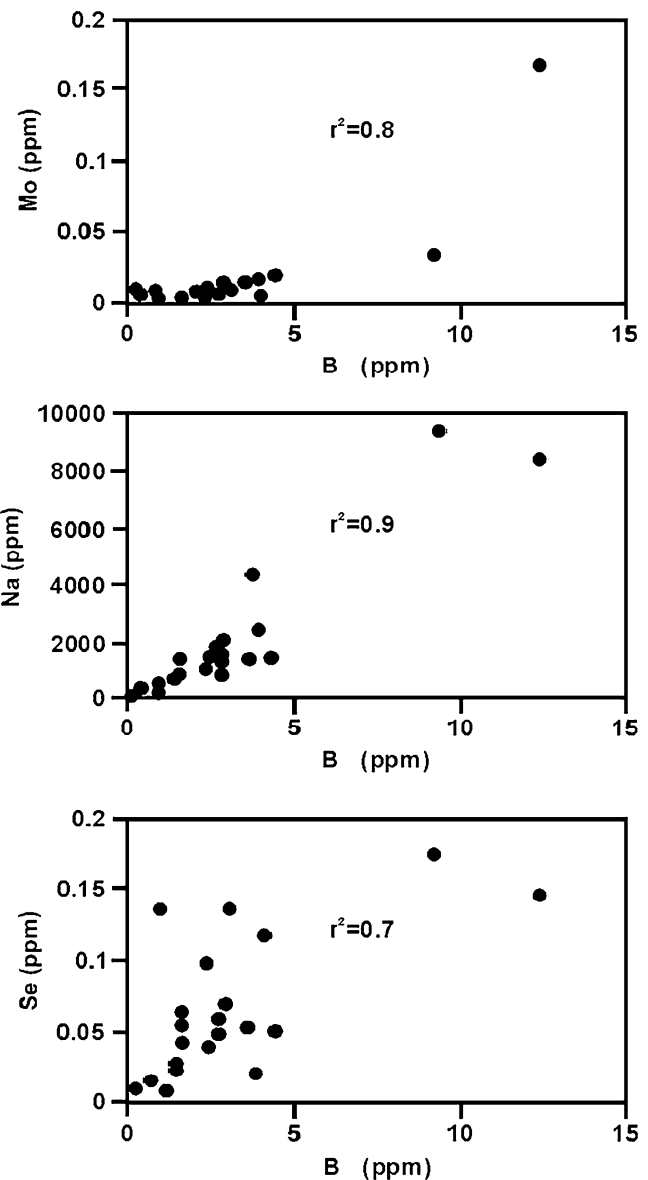
Boron (B) contents range between 0.1 and 12.4 ppm with an average of 2.9 ppm. Water from the wells of Wadi Al-Siala have the highest B contents (average of 8.2 ppm), while water from the wells of east of Mahd Adh Dhahab City have the lowest B contents (average of 0.3 ppm). Other areas have comparable B contents. The relatively high contents of boron in all water samples that collected from Mahd Adh Dhahab and surrounding areas could be attributed to the interaction between groundwater and sulfide-bearing veins and their host volcanic basaltic rocks which are very common in the area of Mahd Adh Dhahab gold mine (Senior and Sloto 2006). B shows positive correlations with Mo, Na, and Se (Fig. 7) suggesting common sources and/or mode of occurrences of these elements. The source of these elements could be the sulfide-rich veins and host basic to intermediate volcanic rocks.

#### Lead

The Pb contents range between 0.005 and 0.02 ppm with an average of 0.006 ppm. The Pb contents in most of the samples are less than the detection limits of the ICP-MS (<0.005 ppm), which are also ten times lower than the allowed limit of Pb in the drinking water of WHO (<0.05 ppm) and very low compared with the concentration of Pb in the safe drinking water (0.3 mg/L) determined by the US EPA (2009). The maximum Pb content (0.02) was found in a well near Jabal Said mine at El-Ghafra drain that is located 35 km from the Mahd City is still less than the allowed limit of Pb in the drinking water. Pb shows positive correlations with Al (Fig. 5), Fe (Fig. 6), Cr, and Ni (Fig. 8) suggesting common sources and/or mode of occurrences of these elements.

#### Cadmium

Cadmium is one of the harmful contents for the drinking water. No results were detected in the studied water samples since the concentrations of Cd in all analyzed samples were under the detection limits of the ICP-MS (<0.0004 ppm). These values are also less hundreds times lower than the



**Fig. 7** Binary plots between B and Mo, Na, and Se. Positive correlations are observed

allowed limit of Cd in the drinking water (<0.01 ppm) according to the Saudi standard for unbottled water (SASO//701/2000) and based on the data of WHO (2008).

#### Mercury

In many samples, Hg was recorded in concentration higher than the allowed contents in the drinking water (<0.05 ppm) but without systematic patterns of distribution in all wells. These differences in the distribution patterns of Hg suggest different sources of the Hg in different wells and can indicate local sources of Hg rather than one general source. This in turn regrets any role of mining activities in the Mahd Adh Dhahab gold mine in the concentration of



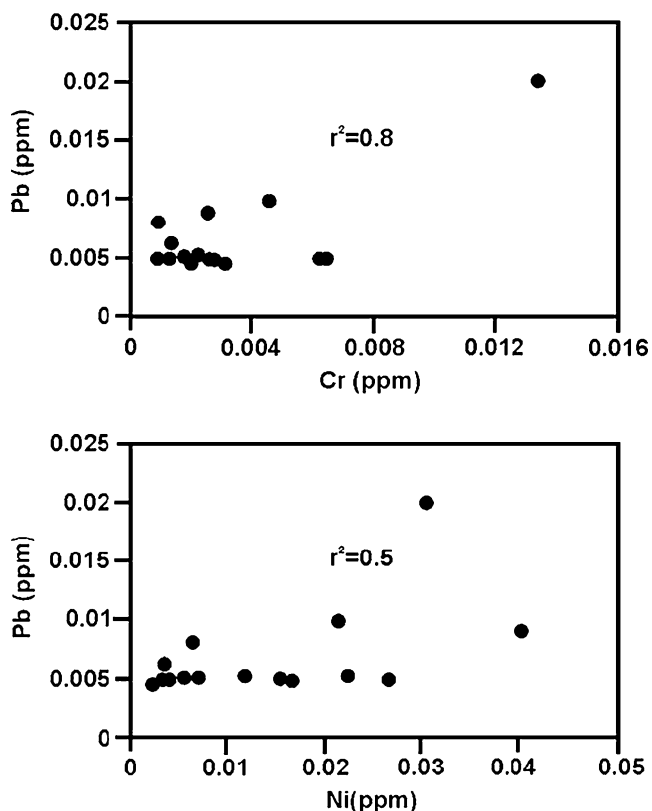


Fig. 8 Positive correlations between Pb and Cr and Ni in water samples

Hg in the studied wells. The following notes can be drawn about the distribution of Hg:

1. No analytical signal of Hg was detected in water from the wells of Wadi Al-Siala, which receive water from the drains of the Mahd Adh Dhahab mine. It means that the concentration of Hg in this water is less than the detection limit of the ICP-MS (<0.01 ppm).
2. Hg occurs in concentrations slightly higher than the allowed values in the water of downstream of El-Madina drains but it occurs in lower concentrations in the water of upstream of El-Madina drains, which is very close to the mine.
3. Hg displays similar concentrations in wells down to El-Ghoderia drain, which runs in the northeast part of the Mahd area and its water does not connect to the drain of the mine area, while no Hg was recorded in El-Ghodeera drain, which runs parallel to the former drain eastward.
4. No analytical signal of Hg was detected in water from the wells of Al-Goraisia drain. This is more or less logic since this drain runs northeast to the Mahd area and no connections between the water in this drain and drain water from the mine.
5. The maximum Hg content (9.99 ppm) was detected in well number 20, which is hundreds times higher than

the allowed values in drinking water. On the other hand, the Hg values vary in the other three wells although all wells are located on the same line. The relatively high Hg contents in well # 20 compared to other wells can be attributed to the occurrence of Hg in the mineralization zones and/or the use of Hg in the extraction processes of gold.

6. Hg contents vary among the wells from the Mahd City. For example, well # 15 has Hg contents lower than the allowed limit although it is located close to well # 20 with the maximum Hg content. In the mean time, well # 7 and 8 southwest the industrial area have Hg ten times higher than the allowed Hg content in the drinking water. They have Hg contents of 0.14 and 0.30 ppb for wells 7 and 8, respectively.

### Selenium

The Se contents range between 0.01 and 0.17 ppm with an average of 0.063 ppm. Although the Se shows relatively high concentration in all wells from the Mahd City and its drains and Wadis (except Wadi El-Kharga), no systematic patterns can be noticed for its distribution. These differences in the distribution patterns of Se also suggest different sources of the Se in different wells and can indicate local sources of Se rather than one general source. This in turn regrets any role of mining activities in the Mahd Adh Dhahab gold mine in the concentration of Se in the study wells. Se shows positive correlations with B (Fig. 7) and Na (Fig. 9) suggesting common sources and/or mode of occurrences of these elements. High Se contents are attributed to its presence in meteoric water in the pore spaces of sandstones and shales as well as the volcanic basaltic rocks especially those associated with B-, Se-, and As-rich solutions. This can be evident from the different distributions of these elements from well to the others and absence of uniform distributions of these elements in the studied water samples.

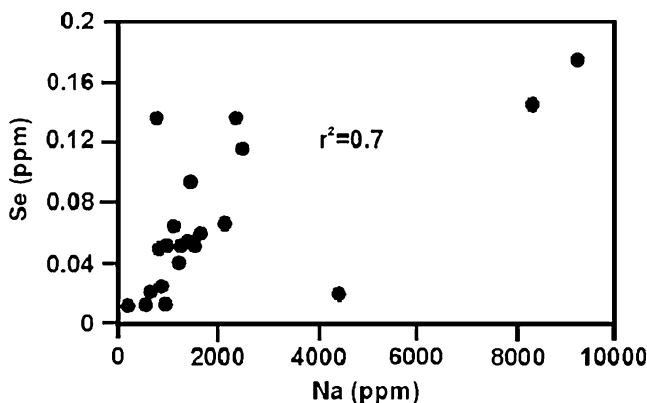
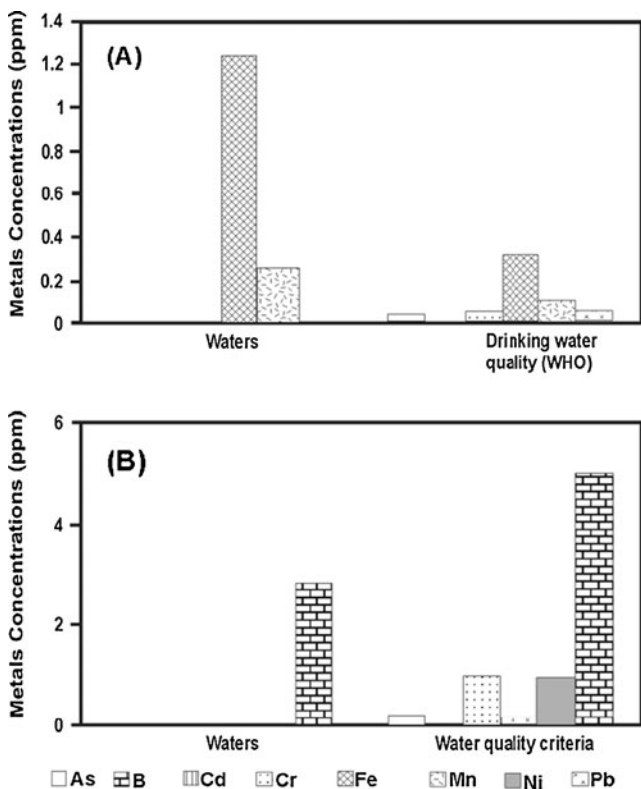


Fig. 9 Positive correlations between Se and Na in water samples



**Fig. 10** Comparisons of heavy metals in the water samples in the study area to that of the safe drinking water quality guidelines (WHO) (a) and water quality criteria for livestock (Ontario Ministry of Environment) (b)

*Sodium*

Sodium, as indicator of water salinity of the analyzed water samples, ranges between 16 and 9,360 ppm with an average of 1,916 ppm. Water from the wells of Wadi Al-Siala and Al-Madina have the highest Na contents (averages of 6,277 and 2,277 ppm, respectively), while water from wells east of Mahd Adh Dhahab City has the lowest Na contents (average of 48 ppm). Other areas have more or less comparable Na contents. The positive correlation between Na and Se (Fig. 9) suggests the common origin of both elements in the meteoric water in sandstones and shales as well as the volcanic basaltic rocks which are very common in the study area.

*Zinc*

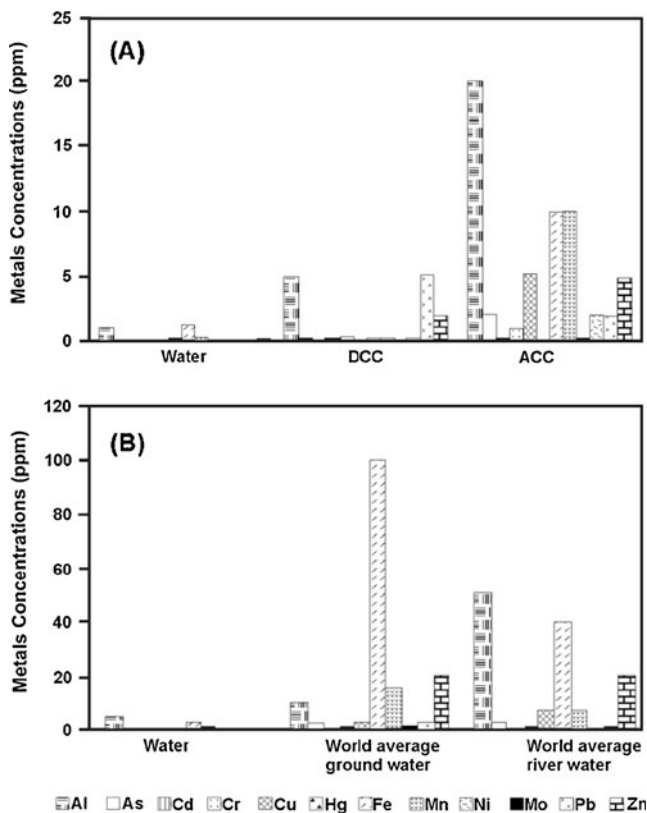
The Zn contents range between 0.002 and 1.1 ppm with an average of 0.13 ppm. Almost all the studied samples show Zn contents lower than the allowed limit value in a safe drinking water (5 ppm). Presence of Zn in rainwater collected at Wadi El-Kharga east to the mine (0.0199 ppm) may indicate the presence of Zn mineralization exposed to the mountain surface that was washed by rainwater.

Contamination level and usability of water

The distribution of heavy metals in the water samples from Mahd Adh Dhahab mine area and surroundings shows that although the concentrations of some elements such as Zn and Pb are high in the rocks of the mine (Al-Hobaib et al. 2010), there is no effect of these high concentrations on the water compositions either inside or outside the mine area.

Comparisons of metals concentrations in the groundwater from Mahd Adh Dhahab mine and its surrounding areas with the WHO guidelines for drinking water quality and water quality criteria for livestock set by the Ontario Ministry of Environment as quoted by Van der Leeden et al. (1990) are shown in Fig. 10a, b, respectively. Except Fe and Mn concentrations, the groundwater from Mahd Adh Dhahab mine and its surrounding areas has lower concentrations of almost all other elements. Therefore, after treating this water to reduce Fe and Mn contents, water from Mahd Adh Dhahab mine area and surroundings can be used as drinking water or in the agricultural activities of the Mahd City.

Figure 11a shows a bar chart of average concentrations of these metals in the water samples in comparison to the



**Fig. 11** Distributions of heavy metals in the water samples in comparison to that in the water with the DCC and ACC (a) as well as the world average ground (Rose et al. 1979) and river (Faure 1998) waters (b)

guideline contaminant concentrations in irrigation water for agricultural use as detailed in the NWQMS WQC including the Desirable Contaminant Concentration (DCC) which is the threshold value for prolonged use on soil (up to 100 years) and Acceptable Contaminant Concentration (ACC) which is the threshold value for short-term use (<20 years). The figure illustrates clearly that the analyzed water samples have lower metal concentrations compared to the DCC and ACC values. Compared to the world average groundwater (Rose et al. 1979) and world average river water (Krauskopf 1979; Faure 1998), the analyzed water samples showed lower concentrations in all metals (Fig. 11b). This indicates no pollution effect of the mining activities in the quality of groundwater, which in turn suggests the validity of the water in the mine area as well as the surrounding areas for agricultural uses.

### Conclusions and recommendations

Water samples collected from a number of drains and Wadis from the Mahd Adh Dhahab mine area and its surroundings were subjected to detailed chemical analyses. Distributions of heavy metals in these samples indicate that the mining activities did not systematically contribute to the heavy metal concentrations of the groundwater of the study area.

The groundwater in the Mahd Adh Dhahab gold mine and its surroundings is valid as drinking water after treatment for Fe and Mn due to the lower heavy metals concentrations compared to the WHO guidelines for the safe drinking water quality and water quality criteria for livestock set by the Ontario Ministry of Environment. The use of groundwater in the mining area and its surroundings for agricultural applications can be also recommended based on their low heavy metals contents compared to the DCC and ACC.

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