Int. j.econ. & environ. geol. vol:1(2) 35-42

Contamination of Potentially Trace Metals in Aqaba and Eshidiya Phosphogypsum in Jordan

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Abstract. Contamination of As, Cd, Cr, Cu, Hg, Pb, Se, Zn and V in Jordan phosphogypsum by product has been determined. The aim of this study is to assess the potential of trace metals contamination caused by production plant of Aqaba and Eshidiya. Arsenic, Cr, Hg, Pb, Se and V have exhibited normal abundances where Cd and U had the highest enrichment factors of 16 and 4, respectively in Aqaba phosphogypsum and 18 and 1, respectively in Eshidiya phosphogypsum. In addition, the elements geo-accumulation index factor were calculated and found that As, Cd, Cr, Cu, Hg, Pb, Se, Zn V are unpolluted to moderately polluted, with the exception of Cd, it shows highly polluted. Arsenic, Cd, Cr, Cu and Zn show immobility to low mobility, whereas Se exhibits intermediate to high mobility. The results obtained in this study can be not worrying from the point of view of environmental safe use of phosphogypsum.

Introduction

For every ton of phosphoric acid as P_2O_5 produced using the wet process, from 4.5 to more than 5.5 tons of phosphogypsum are generated, depending on the quality of the phosphate rock (FIPR, 1980; Anwar and Nadim, 1984; Michael and Lloyd, 1985). It is estimated that more than 22 million tons of phosphoric acid (as P_2O_5) are produced annually worldwide, generating in excess of 110 million tons of gypsum by product (Wissa and Fuleihan, 1993). Phosphogypsum consists primarily of calcium sulphate with small amount of silica, usually as quartz, and unreacted phosphate rocks. Radium and uranium, as well as toxic metals, namely, arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver also occur in phosphogypsum. The phosphate industry in Jordan annually produces 3 million tons of phosphogypsum stockpiled at Aqaba complex for fertilizer industry and Indo-Jordan fertilizer company. The Aqaba complex could accommodate over 30 million tons, while the Indo-Jordan factory at Eshidiya could accommodate 10 million tons (Fig.1). The continued accumulation of phosphogypsum has created urgent pressures to find useful applications for this by product. The U.S. Environmental Protection Agency (EPA) has identified phosphogypsum as a potential hazardous waste because of its radium-226 content and the large volumes produced (Berta, 1990; Rutherford et al., 1995 and Camplin et al., 1996). The main impurities considered as pollutants in gypsum are heavy metals, particularly cadmium (Fergusson, 1990; Van Kauwenberg, 1997; Al-Hwaiti, 2000; Brigden et al., 2002). May and Sweeney (1984) conducted research to determine if phosphogypsum is hazardous or toxic and, if so, to investigate means to mitigate the situation so that the phosphogypsum could be used in a variety of high volume applications. The results indicated that trace elements were uniformly distributed in phosphogypsum stacks and showed no significant difference in the concentrations of trace element with depth. Thus, phosphogypsum was not a corrosive hazardous waste, if the pH was greater than 2. The presence of heavy metal contaminants may pose a potential hazard to human health (Roessler et al., 1979; Taha and Seals, 1991; Cabrera et al., 1994; Davister, 1998; Al-Masri and Al-Bich, 2002). Furthermore, Anwar and Nadim (1984) investigated the groundwater environmental aspects of phosphogypsum disposal as a function of the hydrologic conditions at the disposal site, and of the metal attenuation characteristics of various soil strata. They suggested that a gypsum stack will continue to drain until it stops settling due to self weight

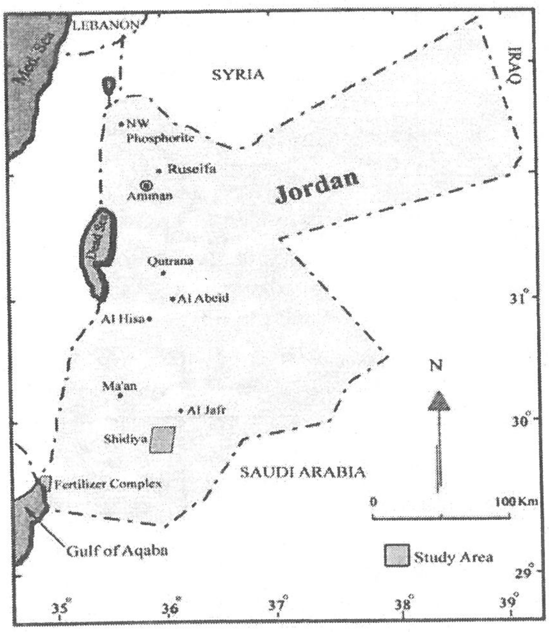

Fig. 1. Location map of the study area
Med. = Mediterranean

consolidation and creep, and until moisture in the gypsum pore reaches field capacity. The time required for a closed stack to stop draining depends on the dimensions and age of the stack, the properties of the gypsum and the hydrogeological setting. A stack on porous foundation will drain much more rapidly than one constructed atop a low permeability clay stratum. Al-Hwaiti et al. (2005a) studied the mobilization, redistribution and bioavailability of potentially toxic elements in Eshidiya phosphorites. They investigated the heavy metal distribution during the phosphate and phosphate fertilizer processing steps. All measured elements were enriched in phosphoric acid with the exception of As, which was enriched in phosphogypsum. Assessment of the availability of toxic elements to plants showed that Cd and Cr are not available for plant uptake, whereas Cu, Pb, V and Zn will be available upon direct application of phosphate to soil. Of the heavy metals present in the fertilizer, Cd is of greatest concern as a result of its toxicity, and ability to accumulate in soils, and its bioaccumulation in plants and animals (USPHS, 2000). In addition, the US Department of Health and Human Services in its 9th Report on carcinogens also lists cadmium and certain cadmium compounds as known human carcinogens (USPHS, 2000). There is a clear association between the cadmium concentration in soil and the plants grown on that soil (WHO, 1992; Carter and Scheiner, 1992; Elinder and Jarup, 1996). In 1989, EPA imposed a ban on phosphogypsum use under the National Emission Standard for Hazardous Air Pollutants (NESHAP) because of concern over radioactive elements and heavy metals in the phosphate used to manufacture phosphogypsum. The Florida Institute of Phosphate Research (FIPR, 1980) and other organizations believe they have demonstrated that phosphogypsum may safely and economically be used in building and road construction, agriculture and other applications. This concern over heavy metals concentration in phosphogypsum and the problem of its usage in industry has prompted this study. The main goals of this study are: Determine the heavy metal concentrations of phosphogypsum waste material, Evaluate enrichment and depletion factors of heavy metals, Calculate the geo-accumulation to assess the degree of waste contaminations and Assess the degree of mobility of heavy metals.

Materials and Methods

Sampling Collection

Twenty four samples were collected from the two plants, Aqaba and Eshidiya. The samples were selected from 12 sites corresponding to piles of different ages depending on their formation; 20 kg from each site were collected. All samples were dried, homogenized to determine the heavy elements concentrations in different ages.

Chemical Analysis

Extractions were performed on 12 composite samples. This method has been developed by Paul Briggs at the U. S. Geological Survey (USGS). Twenty mg of composite samples were put in Teflon beakers, with 3 ml HCl, 2 ml HNO_3, 1 ml $HClO_4$ and 2 ml HF added to each beaker. Samples were dried on a hot plate overnight. 1 ml $HClO_4$ was then added and allowed to dry. The dried samples were removed from hot plate and cooled, 1 ml Aqua Regia was then added. A pre-set volume of 1 % HNO_3 was added to each beaker. The solutions were analyzed for U and trace elements by ICP-MS at the Savannah River Ecology Laboratory, Aiken, SC.

Partial extractions were also used on 12 composite samples. Fifty mg of each dried sample was put in a 15 ml centrifuge tube and 5 ml of nitric acid and hydrochloric (Aqua Riga) were added, then shaken and left for 24 hours. Afterward, the tube also was shaken and left an additional 24 hours, then centrifuged for 10 minutes. The supernatant solutions were prepared for chemical analysis by ICP-AES at the Chemistry and Geochemistry Department, Colorado School of Mines.

Mineralogical Analysis

X-Ray diffraction Analysis (XRD)

X-ray diffraction analysis was carried out at the Geology and Geological Engineering Department, Colorado School of Mines. XRD analysis was performed on composite samples of Aqaba and Eshidiya in order to determine the mineral composition of phosphogypsum.

Scan Electron Microscope Analysis (SEM)

SEM analysis was also carried out at the Geology and Geological Engineering Department, Colorado School of Mines. SEM and SEM-EDS were performed on composite samples of Aqaba and Eshidiya in order to identify the texture, structure and map distributions of analyzed elements of phosphogypsum.

Results and Discussion

Mineralogical Approaches

Mineralogy was carried out to understand the inter-elemental relationships between the analyzed elements. The XRD detected gypsum and minor levels of quartz. X-ray diffraction of phosphogypsum was in agreement with the results of May and Sweeney (1984) confirming that the material is dominated by gypsum and quartz.

SEM confirmed the presence of gypsum and minor quartz (Fig. 2). These results showed that there are different crystal shapes like tubular, rhombic, cluster and aggregates. These results were also confirmed by (Doner and Lynn, 1989; Abdel-Al et al., 2004; Al-Hwaiti et al., 2005b). It is clear that with increasing sulfate concentrations, there is formation of crystals at high sulfate and thick crystals at low super-saturation ratio (Abdel-Al et al., 2004).

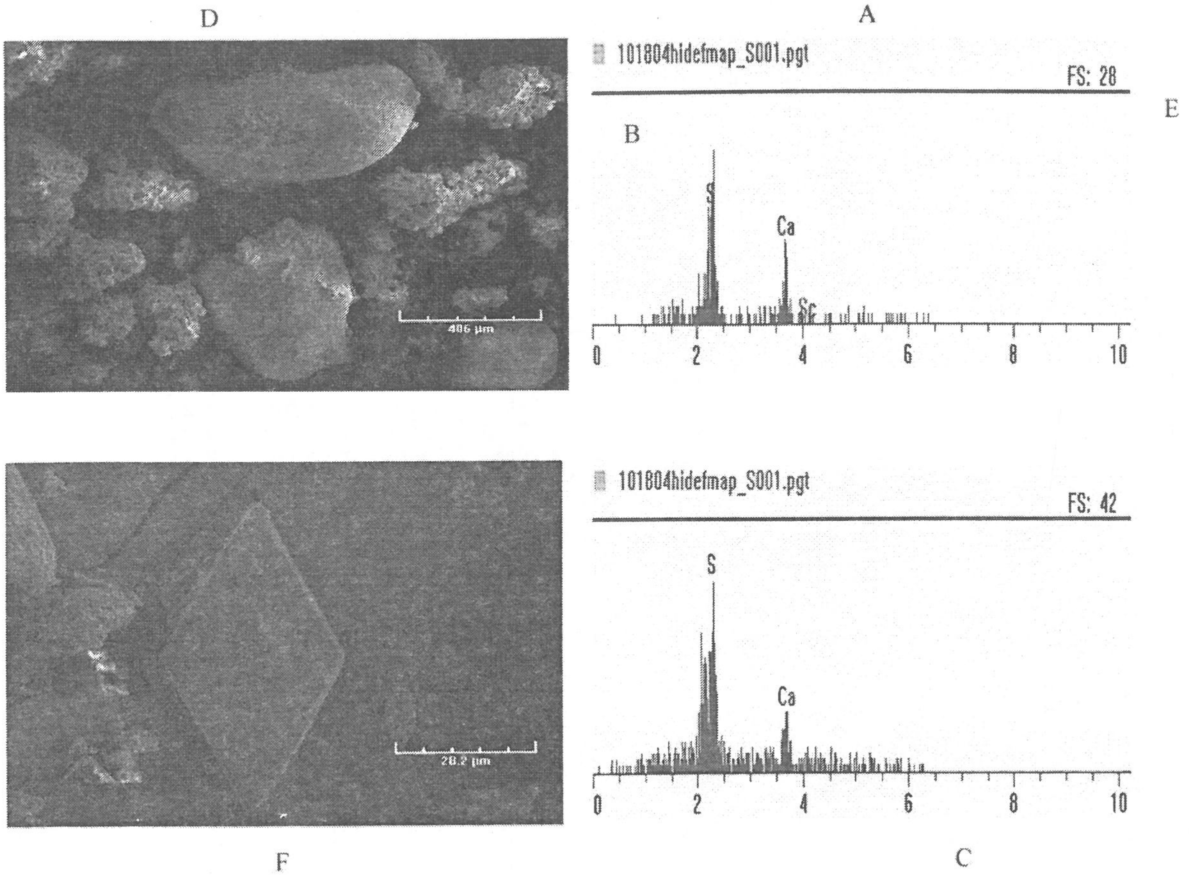

Fig. 2. SEM showing crystal varies in size and shape, overview (A); tabular and aggregates (B) and rhombic (C) . D, E and F show chemical compositions.

Geochemical Approaches

Descriptive statistical analysis involved the computation of basic statistics (e.g. minimum, maximum, mean and standard deviation) as shown in Table 1. These statistics are useful in the description of the distribution and abundances of elements in Aqaba and Eshidiya phosphogypsum.

Correlations between the analyzed elements are shown in the Table 2. Calcium correlates positively with Ba, Hg and Se in Eshidiya phosphogypsum with r = 0.55, 0.54 and 0.61, respectively. This indicates its association in gypsum mineral phase, as revealed by XRD, SEM and fraction size distribution (Al-Hwaiti et al., 2005b). In contrast, Ca shows strong negative correlation with Pb with (r = - 0.74). In addition to that, P has a positive correlation with Ba and Hg (r = 0.81 and 0.81) respectively, which might be attributed to these elements being associated with the phosphate mineral phase, as supported by XRD and SEM. The positive correlations between S and U (r = 0.87) and S and Zn (r = 0.54), suggest association in the gypsum mineral phase as are reported by XRD, SEM and particle size distribution. Furthermore, Ca is correlated positively with Cd and Zn in Aqaba phosphogypsum with r = 0.57 and 0.55, respectively due likely to these elements being associated with the gypsum mineral phase as detected by XRD and SEM. Sulfur correlates positively with As, Cd, U, Zn and Ca (r = 0.66, 0.81, 0.91, 0.92 and 0.70 respectively) (Table 2). It seems likely that these correlations can be attributed to associations in gypsum compounds as supported by XRD and SEM results.

Enrichment Factor

Altschuler (1980) compared the trace element composition of phosphorites with average shale through the use of concentration and depletion factors. Similar terminology is used in this study. When the average concentration of the element determined for phosphogypsum is greater than the values for standard shale, the average concentration of the element for phosphogypsum is divided by the concentration of the standard; the resulting value is termed the enrichment factor. Altschuler (1980) considered an element in phosphorites enriched or depleted if the enrichment or depletion factor compared with average shale is greater than two. Using the criteria that depletion and enrichment factor of less than two are normal abundances, As, Cr, Hg, Pb, Se and V are considered of normal abundances in phosphogypsum (Table 3).

Cadmium and U were considered enriched. Cadmium and U had the highest enrichment factors of 16 and 4, respectively in Aqaba phosphogypsum and 18 of Cd in Eshidiya phosphogypsum.

Table 1. Descriptive statistical analysis of Aqaba and Eshidiya phosphogypsum (ppm)

	Aqaba				**Eshidiya**			
Elements	**Min.**	**Max.**	**Mean**	**St.Dev.**	**Min.**	**Max.**	**Mean**	**St.Dev.**
As	7.67	10.15	8.81	0.39	5.88	9.32	7.81	0.64
Ba	7.94	360.95	250.85	51.96	182.35	1161.60	608.62	186.49
Cd	1.81	10.96	5.05	1.31	2.89	7.12	5.50	0.75
Co	1.31	7.81	5.03	0.88	4.01	6.78	5.37	0.40
Cr	0.26	1.56	1.01	0.18	0.80	1.36	1.07	0.08
Cu	0.21	1.81	1.17	0.22	0.97	1.54	1.15	0.08
Cs	9.87	19.51	12.90	1.51	7.73	23.25	12.54	2.28
Hg	0.03	0.07	0.06	0.01	0.05	0.10	0.07	0.01
Mn	87.58	267.40	145.58	31.03	46.12	135.14	101.15	13.15
Ni	15.36	24.10	18.24	1.39	11.78	21.87	17.61	1.42
Pb	1.95	9.86	5.58	1.04	3.55	11.65	6.50	1.21
Rb	2.77	29.73	17.11	3.64	12.10	21.59	16.97	1.34
Se	0.04	0.42	0.29	0.06	0.15	0.84	0.19	0.15
Sr	116.68	680.69	415.94	75.62	278.60	554.54	348.86	44.50
U	2.70	81.51	16.86	12.94	2.46	6.54	4.02	0.57
V	75.96	394.12	139.63	50.98	61.58	93.56	74.94	4.77
Zn	67.09	97.72	78.46	4.47	58.08	82.24	69.48	4.15

Table 2. Correlation coefficient matrix of Eshidiya phosphogypsum, bold coefficients are significant at the 95% level (n=12)

	As	Ba	Cd	Cr	Hg	Pb	Se	Sr	U	Zn	Ca	P	S	Si
As	1.00													
Ba	-0.44	1.00												
Cd	**-0.90**	**0.61**	1.00											
Cr	**0.89**	-0.31	**-0.94**	1.00										
Hg	-0.37	**0.99**	**0.53**	-0.23	1.00									
Pb	**0.82**	-0.21	**-0.52**	**0.51**	-0.20	1.00								
Se	0.04	-0.01	-0.31	0.40	-0.04	-0.21	1.00							
Sr	0.27	**-0.54**	**-0.53**	0.45	**-0.54**	0.05	**0.85**	1.00						
U	**-0.84**	-0.01	**0.66**	**-0.77**	-0.11	**-0.69**	0.18	0.19	1.00					
Zn	-0.46	-0.19	0.14	-0.21	-0.27	**-0.57**	0.74	0.72	**0.78**	1.00				
Ca	**-0.58**	**0.55**	0.35	-0.17	**0.54**	**-0.74**	0.61	0.16	0.41	0.35	1.00			
P	-0.09	**0.81**	0.34	-0.08	**0.81**	0.14	-0.12	-0.46	-0.28	-0.40	0.13	1.00		
S	**-0.68**	-0.28	0.36	**-0.53**	-0.33	-0.81	0.25	0.29	**0.87**	**0.54**	0.44	-0.60	1.00	
Si	0.30	**-0.86**	-0.49	0.23	**-0.91**	0.20	0.37	**0.80**	0.25	**0.72**	-0.35	**-0.68**	0.35	1.00

Table 3. Average content (ppm) of trace elements in Jordan phosphogypsum and reference values for shale and phosphate

	References		**Aqaba**		**Eshidiya**	
	shale[a]	**Phosphate[b]**	**Phosphogypsum**	**EF[c]**	**Phosphogypsum**	**EF[c]**
As	10	23	8.81	0.68	7.81	0.60
Cd	0.30	18	5.05	**16.83**	5.50	**18.33**
Co	20	7	5.03	0.25	5.37	0.27
Cr	100	125	1.01	0.01	1.07	0.01
Cu	50	75	1.17	0.02	1.15	0.02
Hg	0.40	*	0.06	0.15	0.07	0.18
Mn	850	1230	145.58	0.17	101.15	0.12
Ni	80	53	18.24	0.23	17.61	0.22
Pb	20	50	5.58	0.28	6.50	0.33
Rb	140	*	17.11	0.12	16.97	0.12
Se	0.60	4.6	0.29	0.48	0.19	0.32
Sr	400	184	415.94	1.04	348.86	0.87
U	3.50	120	16.86	**4.56**	4.02	**1.09**
V	130	110	139.63	1.07	74.94	0.58
Zn	90	195	78.46	0.87	69.48	0.77

[a] Karuskopf (1979), [b] Altschuler (1980)

[c] Enrichment factor= average phosphogypsum content/shale content

Geo-accumulation Index

The geo-accumulation index (Muller, 1979) was used to assess the degree of contamination. The index is calculated as follows:

$I_{geo} = \log_2 (C_g/1.5Cs)$

where $I\text{-}_{geo}$ is the geo-accumulation index, $\log_2$ is log base 2, C_g is the concentration in the phosphogypsum, and C_s is the background or reference. One of the commonly used references is average shale. Geo-accumulation and sediment quality (Table 4) was used to classify the phosphogypsum in terms of quality (Table 5). The results revealed that all the analyzed elements are unpolluted to moderately polluted, with the exception of Cd, which is highly polluted.

For comparison, the average concentrations of heavy metals in some World phosphogypsum and Jordan phosphogypsum are shown in Table 6. Obviously, most of the analyzed heavy metals like As, Cd, Co, Cr, Hg, Pb, Se and U are depleted in Aqaba and Eshidiya phosphogypsum, and their average concentrations are significantly lower in comparison with those reported for Florida Idaho, Alberta and Lebanon phosphogypsum.

Environmental Approaches

In this study, the extraction reagent aqua regia was used, to bring together information on the behavior of heavy metals in phosphogypsum stacks. In addition to that, Motuzova and Ngo (1999) emphasized the influence of soil forming processes on the migration of elements from soil plant using correlation techniques. This technique, most widely used for phosphate rock and fertilizer,

Table 4. Igeo classes and sediments quality (Muller, 1979)

Igeo values	quality
<0	Un polluted
0-1	Un polluted to moderately polluted
1-2	Moderately polluted
2-3	Moderately and highly polluted
3-4	Highly polluted
4-5	Highly to very highly polluted
5-6	Very highly polluted
6-7	Extremely polluted

Table 5. Geo-accumulation of average heavy elements in phosphogypsum and reference values for shale

	Aqaba			**Eshidiya**		**Overall Assessment**
	shale[a]	**PG**	**Igeo**[b]	**PG**	**Igeo**[b]	**Quality**
As	10	8.81	0.18	7.81	0.16	Un polluted to moderately polluted
Cd	0.30	5.05	3.38	5.50	3.68	Highly polluted
Co	20	5.03	0.05	5.37	0.05	Un polluted to moderately polluted
Cr	100	1.01	0.002	1.07	0.002	Un polluted to moderately polluted
Cu	50	1.17	0.005	1.15	0.005	Un polluted to moderately polluted
Hg	0.40	0.06	0.03	0.07	0.04	Un polluted to moderately polluted
Mn	850	145.58	0.03	101.15	0.02	Un polluted to moderately polluted
Ni	80	18.24	0.05	17.61	0.04	Un polluted to moderately polluted
Pb	20	5.58	0.06	6.50	0.07	Un polluted to moderately polluted
Se	0.60	0.29	0.10	0.19	0.06	Un polluted to moderately polluted
U	3.50	16.86	0.97	4.02	0.23	Un polluted to moderately polluted
V	130	139.63	0.21	74.94	0.12	Un polluted to moderately polluted
Zn	90	78.46	0.17	69.48	0.15	Un polluted to moderately polluted

[a]Karuskopf (1979); PG= phosphogypsum [b]Igeo value= *log₂* (average phosphogypsum content/shale content)

Table 6. Mean content (ppm) of some trace elements in Aqaba and Eshidiya phosphogypsum compared with World Phosphogypsum

	Florida[a,b]	**Idaho**[a], [b]	**Alberta**[b]	**Lebanon**[c]	**Aqaba**	**Eshidiya**
As	42	-	-	1.5	8.81	7.81
Cd	7	11	4	-	5.05	5.50
Co	6	<1-5	3	<2	5.03	5.37
Cr	4	48	12	8	1.01	1.07
Cu	3	11	<4	5	1.17	1.15
Hg	27	33	<50	-	0.06	0.07
Ni	2	-	9	<2	18.24	17.61
Pb	11	13	<5	4	5.58	6.50
Se	<0.5	9	<2	-	0.29	0.19
U	3	7	3	-	16.86	4.02
V	19	-	20	2	139.63	74.94
Zn	11	31	12	3	78.46	69.48

B.D.L. = below detection limit [a]May and Sweeney (1984) [b]Rutherford et al. (1995) [c]Brigden, and Stringer (2002) employs a single extraction whose content for one element correlates with plant available content and can be used to predict plant uptake or likelihood of deficiency or toxic symptoms occurring in soil, plants or animals (Johnston and Proctor 1977; Bryan and Langston 1992; He and Singh, 1994; Alloway, 1995; Piotrowska and Kabata–Pendias, 1997). Therefore, in this study, some correlations were carried out in the sense of Motuzova and Ngo (1999).

Extraction experiments in Aqaba and Eshidiya phosphogypsum are shown in Tables (7). In Aqaba phosphogypsum, a comparison of Cd values in the total extraction and the partial extraction at different age (1, 5, 10, 15, 20 and > 20) shows that Cd contents are 0.41 & 0.01, 0.34 & 0.01, 0.81 & 0.01, 1.48 & 0.01, 1.19 & 0.01 &1.43 and 0.01 ppm, respectively. Accordingly, the extracted Cd amounts represent approximately 2.44%, 2.94%, 1.23%, 0.68%, 0.84% and 0.70% of original Cd present in phosphogypsum stacks. The mobility of the analyzed elements, the calculated total element content (%) was used as a measure of the degree of mobility as shown in Table (8). Degree of element mobility based on aquaregia extracts for Aqaba and Eshidiya phosphogypsum are listed in Table 9. It illustrates that, all the analyzed elements exhibit immobility to low mobility with the exception of Se, which shows intermediate to high mobility.

Table 7. Extraction experiments in aqua regia extracts of Aqaba and Eshidiya Phosphogypsum

Aqaba	**As (ppm)**			**Cd (ppm)**			**Cr (ppm)**		
Age (year)	**T As**	**Cx As**	**% As**	**T Cd**	**Cx Cd**	**% Cd**	**T Cr**	**Cx Cr**	**% Cr**
1	17.07	0.12	0.70	0.41	0.01	2.44	7.22	0.04	0.55
5	21.81	0.22	1.00	0.34	0.01	2.94	7.19	0.04	0.56
10	16.00	0.08	1.28	0.81	0.01	1.23	5.93	0.02	0.33
15	19.70	0.13	0.66	1.48	0.01	0.68	9.47	0.03	0.32
20	14.15	0.20	1.41	1.19	0.01	0.84	9.46	0.04	0.42
>20	14.44	0.16	1.10	1.43	0.01	0.70	7.64	0.52	0.52
	Cu (ppm)			Se (ppm)			Zn (ppm)		
	T Cu	Cx Cu	% Cu	T Se	Cx Se	% Se	T Zn	Cx Zn	% Zn
1	9.90	0.06	0.67	0.87	0.18	20.69	24.02	0.09	0.37
5	5.12	0.03	0.59	1.58	0.14	8.86	23.90	0.02	0.34
10	1.25	0.01	0.80	1.47	0.11	7.48	15.93	0.02	0.13
15	2.51	0.01	0.40	1.25	0.09	7.20	16.51	0.03	0.18
20	2.47	0.01	0.40	1.73	0.10	5.78	20.22	0.03	0.15
>20	4.14	0.02	0.48	1.50	0.13	8.67	37.38	0.06	0.16
Eshidiya	**As (ppm)**			**Cd (ppm)**			**Cr (ppm)**		
	T As	Cx As	% As	T Cd	Cx Cd	% Cd	T Cr	Cx Cr	% Cr
1	5.58	0.13	2.33	3.30	0.02	0.61	14.20	0.05	0.35
2	3.58	0.14	3.91	2.98	0.02	0.67	16.37	0.07	0.33
3	8.32	0.13	1.56	3.48	0.02	0.29	15.36	0.05	0.33
4	4.93	0.13	2.64	2.28	0.02	0.88	15.00	0.10	0.67
5	4.49	0.11	2.45	2.74	0.02	0.73	15.79	0.11	0.70
>5	21.12	0.42	2.00	3.36	0.02	3.36	15.00	0.11	0.73
	Cu (ppm)			Se (ppm)			Zn (ppm)		
	T Cu	Cx Cu	% Cu	T Se	Cx Se	% Se	T Zn	Cx Zn	% Zn
1	7.26	0.04	0.55	0.63	0.21	33.33	32.06	0.12	0.37
2	2.91	0.01	0.34	0.28	0.22	78.57	32.60	0.16	0.49
3	2.83	0.01	0.35	0.30	0.22	73.33	24.98	0.10	0.40
4	2.81	0.01	0.36	0.39	0.20	51.28	24.60	0.08	0.33
5	2.99	0.01	0.33	0.27	0.19	70.73	29.91	0.06	0.20
>5	3.74	0.01	0.27	0.50	0.20	40.00	27.68	0.10	0.36

y= year; T= Total Cx.Ê: Extracted, , %TAs = (Cx As/ TAs) X 100%

Table 8. Total extractions (%) as measures of the degree of mobility

T-values (%)	**Degree of Mobility**
<0	Immobile (UM)
0-2	Immobile to low mobility
2-4	Low mobility (LM)
4-6	Low mobility to Intermediate mobility
6-8	Intermediate mobility (IM)
8-10	Intermediate to high mobility
>10	High mobility (HM)

T: total extracted (%)

Conclusion

Exception of Cd, it shows highly polluted. Mobility of the analyzed elements illustrates that, As, Cd, Cr, Cu and Zn show immobility to low mobility, whereas Se exhibits intermediate to high mobility. However, the amount of heavy metals released into the environment, connected with phsphogypsum stockpiled wastes seems to be not worrying from the point of view of environmental and human health protection, both due to all the analyzed elements relatively are unpolluted to moderately polluted, low concentration of heavy metals compared

Table 9. Degree of element mobility based on aqua regia extracts for Aqaba and Eshidiya phosphogypsum

	T-Values	Degree of Mobility	T-Values	Degree of Mobility
As	1.03	UM to LM	2.48	LM
Cd	1.47	UM to L M	1.09	UM to LM
Cr	0.45	UM to LM	0.52	UM to LM
Cu	0.56	UM to LM	0.37	UM to LM
Se	9.78	IM to HM	57.87	HM
Zn	0.22	UM to LM	0.36	UM low LM

As, Cr, Hg, Pb, Se and V are considered in normal abundance in phosphogypsum. Cadmium and U were considered enriched. Cadmium and U had the highest enrichment factors of 16 and 4, respectively in Aqaba phosphogypsum and 18 and 1 in Eshidiya phosphogypsum. Geo-contamination index exhibits that all the analyzed elements are unpolluted to moderately polluted, Aqaba, Eshidiya with the Element with World phosphogypsum as well as immobility to low mobility.

Acknowledgement

The author's wishes to express their gratitude to the Fulbright Foundation, through Post-Doctoral research award to M. Al-Hwaiti, and by the Environmental Science and Engineering Division, the Department of Chemistry and Geochemistry the Geology and Geological Engineering Department, Colorado School of Mines. Brian Jackson, Savannah River Ecology Laboratory, Aikan, SC for ICP-MS analysis.

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