Groundwater vulnerability Mapping of Jordanian phosphate mining area based on Phosphate concentration and GIS: Al-Abiad mine as a case study

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Abstract:

Groundwater constitutes the main water supply in Jordan. Therefore, various steps are taken to monitor groundwater quality and vulnerability for a sustainable groundwater development. The present study uses DRASTIC model on a national rate and assess the groundwater contamination through phosphate release from the mining activities in south of Jordan (Al-Abiad area) using GIS environment. The DRASTIC index was used with seven parameters to describe physical characteristics of the aquifers. It is found that about 58.6% of the area was considered to be of moderate vulnerability, while high and low vulnerability were found to be at 0.6% and 42.8% respectively of the total area. On the other hand, investigation of infiltration process of selected pollutants (Soluble phosphate and chloride ions) through the surface layer of study area has confirmed the vulnerability of the groundwater quality toward such as pollutants.. Chemical Analysis of the effluent washing water from the phosphate beneficiation process showed high concentration of P_2O_5(TCP) , Cl^- and SiO2 comparing with influent washing water. Currently, the effluent water from Al-Abiad and other Jordanian phosphate mining industry is discharged into the desert without treatment or any attempt for reuse. Therefore, urgent pollution prevention measures

should be considered for such mining activities within the whole Jordanian phosphate mining area .

Keywords: Vulnerability, Waste water, Groundwater, DRASTIC, Phosphate, GIS

1. Introduction

Jordan is considered one of the most-fourth poorest country in terms of water resources. (Ibrahim and Koch, 2015; Seckler*et al.*, 1999). Over the past few decades, there was a profound increase in water demands and water misuse as a result of economic and industrial growth, expansion of agriculture and irrigation projects, and improving living standards and population growth. These practices increased the deterioration of water quality (Gougazeh and Sharadgah, 2009; MWI, 2009). In addition, Jordan is among the main countries that has hosted unexpected huge number of refugees due to political crisis in the region. This situation has imposed further demands on the available Jordanian water resources.

On the other hand, Jordan is considered as the word fifth in the production of phosphate. It is estimated that Jordan has at least 798 million tons of proven reserves. About 744 million tons of this reserve is located East of Maan (Elshydia area). Currently, phosphate ore is mined from Al-Hessa (9.3%), Al-Abiad (26%), and from Eshidyia mines (about 65%). Phosphate in Jordan is found in three layers (A_1, A_2 and A_3) with two inner waste layers which are selectively removed during mining operations. A_1 phosphate layer requires the crushing, scrubbing, screening, and desliming to produce 70% tri-calcium phosphate (TCP). A_2 layer requires only dry screening to produce 73-75% TCP. However, A_3 layer contains high silica and the beneficiation processes employed for this layer consists of flotation process to remove silica and produce 75-78% TCP concentrate (JPMC, 2016).

During the production of phosphate from its mines considerable amount of wastewater is produced as a result of phosphate washing (A_1 and A_3 layers) and alsofrom flotation of A_3 layer. The present practice employed currently at Al-Abiad, Eshidyia and other phosphate mines is to send wastewater, to desert without any attempt to recycle this water. Additionally, this water contains considerable amount of fine P_2O_5 and other solid materials.

Groundwater is one of the major water resources in Jordan and the major source of drinking water of vast majority of Jordan population. Additionally this fresh groundwater is used extensively in industrial activities of phosphate production in the Al-Abiad and Al-Hisa and Eshidya mines(Jiries *et al.*, 2004). The wastewater generated from these mine activities runs off through adjacent valleys which may affect the quality of groundwater; this water is of high salinity and contains heavy metals leaching during the process operations of phosphate mines(Jiries *et al*., 2004; JPMC, 1998).The Jordanian Ministry of Water and Irrigation is responsible of developing techniques to protect water resources in the country, especially monitoring and protecting groundwater resources (Ibrahim and Koch, 2015). For this reason the vulnerability mapping approach has been chosen to achieve the aim of this work; the vulnerability map helps in assessing the effect of industrial activities and contributes in evaluating the potential regions to contamination of surface and groundwater resources and evaluating the areas which could be under effect of the pollution. Geographic information systems has a techniques which allow the management, analysis and display spatial data related with pollution vulnerability assessment and numerical score system such as such as DRASTIC, GOD, SINTACS, COP, EPIK and

PI (Aller, *et al.*, 1987; Foster, S. 1987; Civita, M. 1994; Vias, Doerfliger, N *et al.*, 1999; Goldscheider, N *et al.*, 2000; J. M *et al. 2006*; Ibrahim and Koch, 2015)DRASTIC model (Aller, *et al.*, 1987)is widely used to evaluate the contamination of surface and groundwater of potential region. It is considered a flexible in its application when all available datasets are almost reliable. The DRASTIC index is based on the score of seven parameters which represent the conditions of the study area, depending on aquifer properties and lithological environments, topography and the hydrology. The purpose of this study is to use DRASTIC model on a national rate and assess the groundwater contamination by phosphate concentration, released from the mining activities in south of Jordan (Al-Abiad area).

2.Material, Data collection and methodology

2.1. Industrial phosphate waste water characterization

Samples of effluent water were collected from Al-Abiad beneficiation plant. The slurry was collected from the point prior to pumping to the desert. These were characterized for their solid content, pH, and chemical composition. Table 1 below shows the approximate chemical composition of both slime water and its contained solids .

The slurry from the washing plant is normally pumped to abandoned mines and left for solar drying. Figure 1 below shows one abandoned mine after being filled with phosphate washing water. Three locations were selected (A, B and C) for characterization of the solid residues left after solar drying over a depth of 1m. TCP content was determined by Gravimetric Quimociac Technique(Shaver, 2008), while chloride content was determined by Mercuric Nitrate Method. Silica was determined by an acid digestion procedure involving the use of HF, while moisture content was determined by heating the collected sample at 105^0 C for 3hrs.

Figure 1: Abandoned mine filled with phosphate wash water after solar drying (marks A, B and C are the positions of samples)

To highlight the degree of the pollution of initial feed water used in washing process, a specifications for 2 different sources of water (wells) located at studied area were also obtained.

2.2.Study Area

Geological data are collected for the studied area and analyzed by GIS. To evaluate the effect of phosphate and other water pollutants on the groundwater quality. Samples of soil from several locations of the dumping area were collected at depths from 0 to 100 cm and subjected for analysis of Chloride, TCP(P_2O_5), SiO_2contents and humidity.

2.3.GIS analysis & Dastic index

The data obtained were then reconverted into GIS environment (Geographic information system) for subsequent analyses. The GIS environment is a good tool to manage and analyze the model parameters and allow to display aquifer vulnerability mapping using GIS geo-database (geographical, hydro geological, geological surface and chemically analyzed data).DRASTIC index was used in this study to evaluate groundwater quality as a strong indicator for the contamination leaching and effect the industrial activities to the aquifer system.

3.Results and Discussion

3.1.Study area

The study area (Al-Abiad mine) is located in south of Jordan near Al-Karak city and is about 130 km south of capital Amman (Figure 2 and Figure 3). It has a semi-arid climate of the Mediterranean region with a limited amount of rainfall where the mean annual rainfall is about 100 - 300 mm and the maximum temperature about 34 ˚C from May to September. It is wet in the winter season with a mean temperature about 14 ˚C from October to April. The lithology of the study area is characterized by a thick succession of sedimentary rock (2000 – 3000 m) from Cambrian-Recent, and the major aquifer used to supply water for the phosphate production in the study area is Amman/WadiEs-Sir formation , which is massive limestone and highly fractured (Mufeed and El-Hasan, 2009; Bender, 1974). The main source of recharge is the precipitation that falls on the western highland of investigated area.

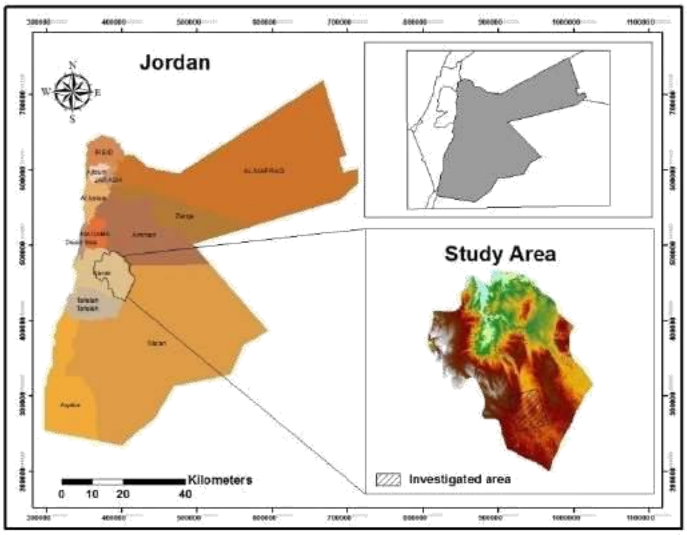

Figure 2: study area location

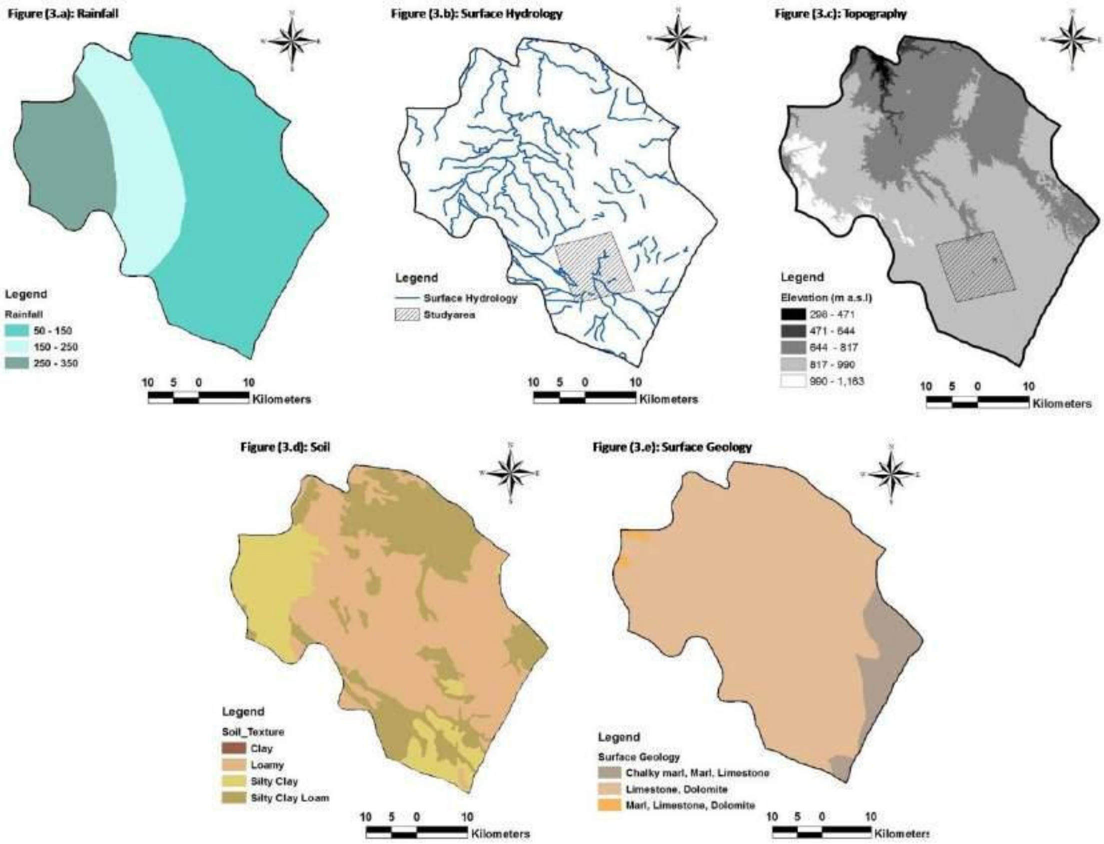

Figure 3: Study Area Location and features

3.2. Infiltration process of water pollutants on surface soil layer in dumping area

Specifications of washing wastewater presented in table (1) show high degree of pollution of this water with P_2O_5 (TCP), Cl^- and silica SiO_2 comparing with feed water quality presented in table (2) as a result of beneficiation process .These pollutants are expected to be penetrated through infiltration process from the surface of dumping area down to adjacent layers. Figure (4) illustrates the increase of some of selected pollutants basically P_2O_5 (TCP), Cl-, silica SiO_2 and humidity with depth. Continuous dumping of this type of water will result in accumulation of these pollutants in the surface soil and other layers of the area and can be expected as a main source of underground water pollution in the study area. The TCP content of the solid residue is about 38-39% while the silica is about 35% irrespective of the depth. However, the chloride content increased steadily with depth; the % increase within the first meter is about 50%. It is expected in near future that both soluble phosphate and chloride in phosphate washing water will find its way to the ground water in the area .

Table 1. General characteristics of used water in phosphate pontification process.

	Content	P_2O_5 (TCP), %	Cl^-, ppm	A.I. R	SiO_2,	pH	Pulp density of slime, kg/m^3
Liquid	87%	1.65	700	-	17.9 ppm	7.3	1085
Solid	13%	18.65 (40.75)	1240	25.36	- (25.36%)	-	

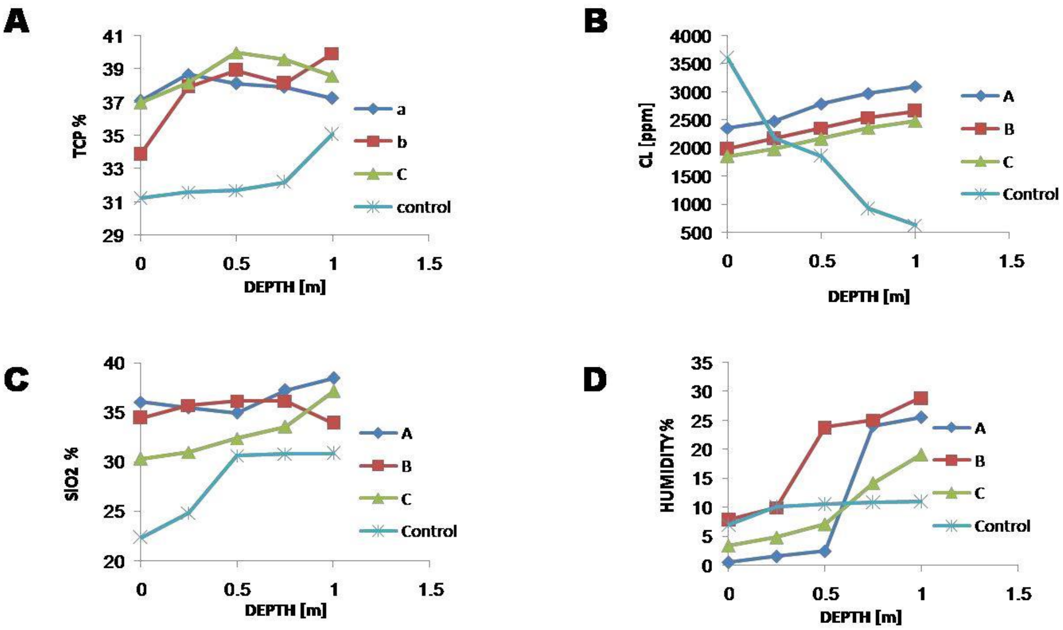

Figure 4: Infiltration of selected pollutants through the surface layer of study area (A- TCP(%), B-Cl^-(PPM), C-SiO_2(%), D-Humidity(%)). Legends A, B and C indicate the locations of collected samples.

Table 2: Specifications of water used in Beneficiation plant for phosphate

	Well(1)	Well(2)
E.C.µs/cm	718	719
pH value	7.53	7.50
Ca^{2+} mg/L	60.4	60.9
Na^{1+} mg/L	50.1	50.9
K^{1+} mg/L	1.5	1.5
Cl^{-} mg/L	105.1	105.9
HCO_4^{2-} mg/L	122.9	123
SO_4^{2-} mg/L	55	55.5
NO_3 mg/L	1.7	1.7
CO_3^{2-} mg/L	0	0
SiO2	NT	NT
T.D.S mg/L	430	433
PO_4^{2-} mg/L	0.052	0.053
Total hardness mg/L $CaCO_3$	294	297

4. DRASTIC index calculation

Based on the climate conditions and physical properties of study area in phosphate area and according to vulnerability models, DRASTIC index can be help to evaluate groundwater quality as a strong indicator for the contamination leaching and used to investigate of the effect the industrial activities to the aquifer system. The DRASTIC index given in the equation 1belowcan be considered as an indicator for the pollution potential (Merchant, 1994). The rating of these variables depends on their importance for water pollution (Table 3). The DRASTIC index given in the equation below is considered to be an indicator for the pollution potential (Merchant, 1994). and was used in this research without the hydraulic conductivity parameter because it lacks suitable data.

The DRASTIC index parameters weights and ratings are supposed to be suitable for different aquifer rock types, particularly for arid and semi-arid areas where the aquifer commonly in study area is limestone aquifer. The general equation for the DRASTIC index was defined by 7 parameters (Aller, *et al*., 1987; Knox*et al*, 1993. Fortin et al, 1997. Fritch, *et al.* 2000), as follows :

$$\text{DRASTIC index} = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + Cr \times Cw$$

The r and w terms are rate and weight respectively , and the main parameters of the index are the following:

Depth to groundwater (D): the depth to groundwater is less than 400 m (WAJ, 2004). The depth index was obtained from the depth rank and the depth weight; $Dr \times Dw = 5$ (Table 4). This value was estimated based on the weighting system.

Net recharge (R): the precipitation amount is considered one of the major sources to the recharge to the groundwater, This depends on rainfall data, soil permeability and the topographic setting (Equation (2)) and according Table 1. Digital Elevation Model (DEM) was used also to calculate recharge value; it was sub- divided into two classes

$$\textit{Recharge Value} = \textit{Slope\%} + \textit{Rainfall} + \textit{Soil Permeability}$$

Table.3. Building of recharge factor(Piscopo, 2001; MOA,1993; USDA, 1994)

Slope		Rainfall		Permeability		Net Recharge	
Slope (%)	Factor	Rain	Factor	Type of soil	Factor	Range	Rating
2>	4	<600	4	Sandy loam	4	3 - 6	1
2-10	3	600-700	3	Siltyclayloam	2	6 - 7	3
10-32	2	700-860	2	-	-	7 - 9	5
33<	1	> 860	1	-	-	-	-

Aquifer media (A): This factor describes the ability of contaminants to move within the aquifer (Aller, et al., 1987). Based on the geological description of the study area, the aquifer media includes two class limestone and Basalt, thus the net aquifer media was sub-divided into two classes as shown in Table 4.

Soil media (S): The ability of pollutants to move within the soil down to the groundwater is evident by soil media according to the size distribution of the soil cover. The soil map was classified into three classes based on the ratings for the soil texture based on Table 4.

Topographic slope (T): This refers to the ability of pollutants to infiltrate into the vadose zone and to reach the aquifer (Alleret al., 1987). DEM was used to derive slope based on Table 2, the topographic slope map was sub-divided into five classes.

Impact vadose zone (I): interpreting geological maps helps to derives impact on the vadose zone. The aquifer media was classified as fractured basalt and limestone.

Table.4. The rate and weight for the parameters of DRASTIC Index (Aller, L., et al. 1987; Knox et al., 1993; Piscopo, 2001).

Parameters		Rate (r)	Weight (w)	(r) x (w)
D: Depth to groundwater	Less than 200 m	1	5	5
R: Recharge(Range)	5 – 7	3	2	6
	7 – 9	5		10
A: Aquifer media (Material)	Limestone	6	3	18
	Basalt	9		27
S: Soil media (Type)	Clay	3	2	6
	Silty Clay	4		8
	Loam	5		10
T: Topography - Slope (%)	0–2	10	3	30
	2–6	9		27
	6–12	5		15
	12–18	3		9
	> 18	1		3
I: Impact of Vadose zone (Materia)	Limestone	6	5	30
	Basalt	9		45

4. Mapping the DRASTIC Index

In order to map DRASTIC Index we had to save all output maps in format. The output maps (vulnerability factors)were processed with GIS environment view by multiplying the raster values of each of the corresponding vulnerability weighting coefficients and all these processes to retrieve the final vulnerability map. The final vulnerability map for the study area showed categories (Low, Moderate, and High) as illustrated in Figure 5. The vulnerability classes were divided according to the standard deviation (SD). Table 5 shows the final groundwater vulnerability classes (DRASTIC index).

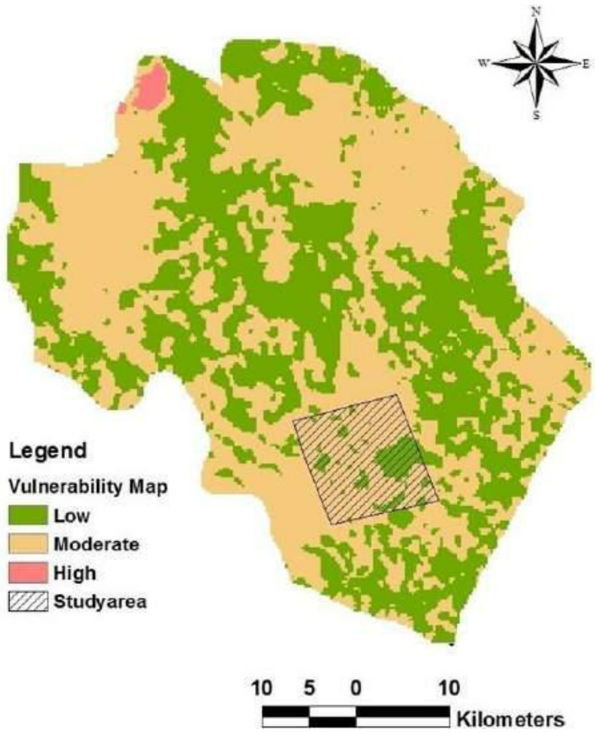

Figure 5.Vulnerability map (DRASTIC index map).

Table.5. final groundwater vulnerability classes (DRASTIC index).

Class	Area km^2	% of the total area
Low	881.2	42.8
Moderate	1165.9	58.6
High	11.4	0.6
Total	2058.5	100.0

Conclusion

Industrial phosphate waste water dumping in a desert area nearby mining & process area is practiced in phosphate mining industry in Jordan. This water was found to be highly polluted with P_2O_5, SiO_2,Cl^- and other contaminants. Continuous discharging of this water without treatment is responsible for the pollution in the area. The northern part of the study area has been characterized by high vulnerability degree. However, 56.6 and 42.8 % of the total area has been characterized by moderate and low vulnerability degrees respectively. Thus, the area that has possessed high levels of pollution is the northern part of the study area.

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