The Use of GIS and Leachability Tests to Investigate Groundwater Vulnerability to Pollution from Oil Shale Utilization at Lajjoun Area/Southern Jordan

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ABSTRACT

Jordan is a country that faces "absolute water scarcity" and may not be able to meet its water needs by the year 2025. Groundwater is the major water resource for many areas of the country and the only source of water in some areas. Most of the groundwater basins in Jordan are already exploited beyond their estimated safe yield. Groundwater is the second largest contributor to the irrigation sector and is the largest source for domestic consumption. Jordan also has a huge amount of oil shale that exists in the Southern and Eastern parts of the country. It is estimated that Jordan has a reserve of 50 billion tons of oil shale. The oil shale deposits in these locations are shallow and near the surface and can be utilized by the open cut mining method. The ash is considered one of the most important factors in selecting the suitable and more economical utilization technology for Jordanian oil shale. Oil shale ash is considered one of the main environmental challenges and a barrier which stands on the way of developing oil shale industry in Jordan. The main concern in this case is that ash might reach nearby surface water and/ or leach to groundwater recourses in the area. This study aimed to evaluate the risk of pollution of groundwater resources in Lajjoun area/ Southern Jordan as a result of oil shale development. It assessed groundwater vulnerability to pollution using GIS and DRASTIC index in combination with chemical analysis and leachability tests conducted on oil shale ash that might result from two possible utilizations of oil shale; producing electricity through direct burning of oil shale and extracting oil from oil shale. It was found that Lajjoun area has a moderate groundwater vulnerability to pollution. Yet, the leachabilty tests showed that there will be huge amounts of Fe, Cr, Cd, Pb, Al and Pb as possible leachates to groundwater for both types of oil shale utilizations; oil extraction and electricity generation.

KEYWORDS: Jordan, Groundwater, Oil shale, Vulnerability, GIS, DRASTIC.

INTRODUCTION

Jordan is a country that faces "absolute water scarcity" and may not be able to meet its water needs by the year 2025 (Seckler *et al*., 1999). Groundwater is the major water resource for many areas of the country and the only source of water in some areas (Al-Adamat, 2002). Most of the groundwater basins in Jordan are already exploited beyond their estimated safe yield. Total safe yield for all basins was estimated to be *ca.* 418.5×10^{6} m^3 yr^{-1}, yet the consumed water from these basins was 479×10^{6} m^3 yr^{-1}. Groundwater is the second

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largest contributor to the irrigation sector at 258.4×10^6 m^3 yr^{-1} and it is the largest source for domestic consumption at 182.8×10^6 m^3 yr^{-1} (Al-Adamat, 2002).

A variety of human activities stemming from agricultural, industrial, community and residential sources, as well as the misuse of groundwater resources, contributed to the deterioration of groundwater quality in Jordan. There are three types of pollution that affect groundwater (i) use and overuse of biocides and fertilizers and irrigation return flows, (ii) cesspools in towns, villages and refugee camps and (iii) use of vehicles with oil spills, lead and corroded particles (Salameh, 2001).

Jordan has a huge amount of oil shale that exists in the Southern and Eastern parts of the country. It is estimated that Jordan has a reserve of 50 billion tons of oil shale. This large reserve is located in several locations; Lajjoun, Sultani, Jurf Eddarawish, Wadi Mghar and Khan Ez-Zabib. The oil shale deposits in these locations are shallow and near the surface and can be utilized by the open cut mining method (NRA, 2006). The oil yield for the Jordanian oil shale ranges between 10% and 13% depending on the particle sizes (Jaber *et al*., 1999; Bsieso, 1997). This oil shale could substitute the demand of oil by either direct burning for production of electricity or extracting the oil for automobile usage. In both cases, processing of oil shale is accompanied with pollution in the area near the processing facility. In addition, ash will be a major by-product of oil shale processing, which is considered a second major problem for environment. The ash is considered one of the most important factors in selecting the suitable and more economical utilization technology for Jordanian oil shale. Utilization of oil shale ash is considered one of the main environmental challenges and a barrier which stands on the way of developing oil shale industry in Jordan. The main concern in this case is that ash might reach nearby surface water and/ or leach to groundwater recourses in the area. The main goal of this study is to evaluate the risk of pollution of our limited groundwater resources as a result of oil shale development. This research aims to assess groundwater vulnerability to pollution in combination with chemical analysis and leachability tests conducted on oil shale ash that might result from two possible utilizations of oil shale; producing electricity through direct burning of oil shale and extracting oil from oil shale.

MATERIALS AND METHODS

Groundwater Vulnerability Assessment

The worldwide concern about groundwater contamination problems has resulted in the development of the concept of groundwater vulnerability. This concept depends on the assessment and representation of various attributes such as vadose zone characteristics, aquifer depth and the amount of recharge (Murray and Rogers, 1999).

Groundwater vulnerability assessment is a way to convert complex hydrogeologic information into a form that is easily useable by planners, decision and policy makers, geoscientists and the public (Ligget and Talwar, 2009).

Several methods have been globally developed for the assessment of groundwater vulnerability (NRC, 1993). Process-based mathematical models, overlay and indexing methods as well as statistical methods are among these methods (NRC, 1993, p. 45).

Process-based mathematical models require analytical or numerical solutions to mathematical equations that represent coupled processes governing contaminant transport (NRC, 1993). Process-based mathematical models include the following examples:

- PRZM (Morgan, 1999; Loague *et a*l., 1998; Evans and Maidment, 1995),
- GLEAMS (Marchetti *et a*l., 1997; De Paz and Ramos, 2002),
- LEACHM (Ali *et a*l., 2000).

Mathematical models require significant amounts of a variety of data for several years (Knox *et a*l., 1993). A lack of essential groundwater data often means that such models cannot be practically used in groundwater contamination research.

Statistical methods are often used in evaluating, determining and quantifying the association between measures of vulnerability and various types of information that could be related to vulnerability (NRC, 1993). Statistical methods use the frequency of contaminant occurrence, contaminant concentration or contamination probability as a response variable. Multivariate statistical analyses are useful for ranking variables critical to estimating water quality responses of interest (Burkart *et al*., 1999). The difficulty of interpreting statistical analysis varies from one technique to another. It depends on the method used, the researcher's experience and the amount and quality of the available data (NRC, 1993). The major limitations of statistical methods are the requirements for high quality data and cost and time constrains (Evans and Maidment, 1995).

Overlay and index groundwater vulnerability assessment methods are based on combining maps of parameters considered to be influential in contaminant transport (e.g. geology, soil, depth to groundwater table) of a region, where each attribute is assigned a numerical score based on its perceived importance (NRC, 1993; Evans and Maidment, 1995). Indexing methods are very popular because they are (Ligget and Talwar, 2009):

- Easy to implement,
- Inexpensive to produce,
- Use readily available data and often
- Produce categorical results.

Also, index methods assess vulnerability spatially over large regions which show the vulnerability of the water table or uppermost aquifers in a region (Ligget and Talwar, 2009). Subjective numerical values or ratings are assigned to each parameter map. The rated maps are combined to produce a relative indication of the vulnerability spatially over an area (Ligget and Talwar, 2009).

By the use of Geographical Information System (GIS), digital maps of each parameter are easily rated and combined to produce the final vulnerability map. Index-based methods are best suited to produce regional-scale screening tools for use in decision making and for prioritizing focus areas and level of site assessments (Ligget and Talwar, 2009). Index methods include the following examples:

- DRASTIC (Aller *et al*., 1987; Evans and Mayers, 1990; Page, 1993; Engel *et al*., 1996; Stark *et al.,* 1999; Fritch *et al*., 2000; Piscopo, 2001; Al-Adamat *et al*., 2003).
- GOD (Foster, 1987; Gogu *et al*., 2003; Neukum and Hotzl, 2007).
- EPIK (Doerfliger *et al*., 1999; Vias *et al*., 2005; Neukum and Hotzl, 2007).
- Aquifer Vulnerability Index (AVI) (Van Stempvoort *et al*., 1993; Wei,1998).

DRASTIC is an overlay and indexing method which is widely used to assess groundwater vulnerability to a wide range of potential contaminants. Merchant (1994) argued that DRASTIC has been used throughout the world with exceptional frequency. In this model, spatial datasets on depth to groundwater, recharge by rainfall, aquifer type, soil properties, topography, impact of the vadose zone and the hydraulic conductivity of the aquifer are combined (Engel *et al*., 1996). The DRASTIC methodology was developed around a set of basic assumptions concerning a generic contaminant. These assumptions are (Al Farajat *et al*., 2005):

1) Material introduced at the land surface as a soluble solid or liquid travels to the aquifer with recharge waters derived from precipitation;
2) The mobility of the contaminant is assumed to be equal to that of the groundwater;
3) Attenuation processes are assumed to go on in the soil, vadose zone and aquifer.

The governing equation of the DRASTIC index was defined by (Knox *et al*., 1993; Fortin *et al*., 1997; Fritch *et al*., 2000):

$$DI = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where (1) D: Depth to groundwater, (2) R: Recharge rate (net), (3) A: Aquifer media, (4) S: Soil media, (5) T: Topography (Slope), (6) I: Impact of the vadose zone, (7) C: Conductivity (hydraulic) of the aquifer (8) r: rating for the area being evaluated and (9) w: importance weight for the parameter.

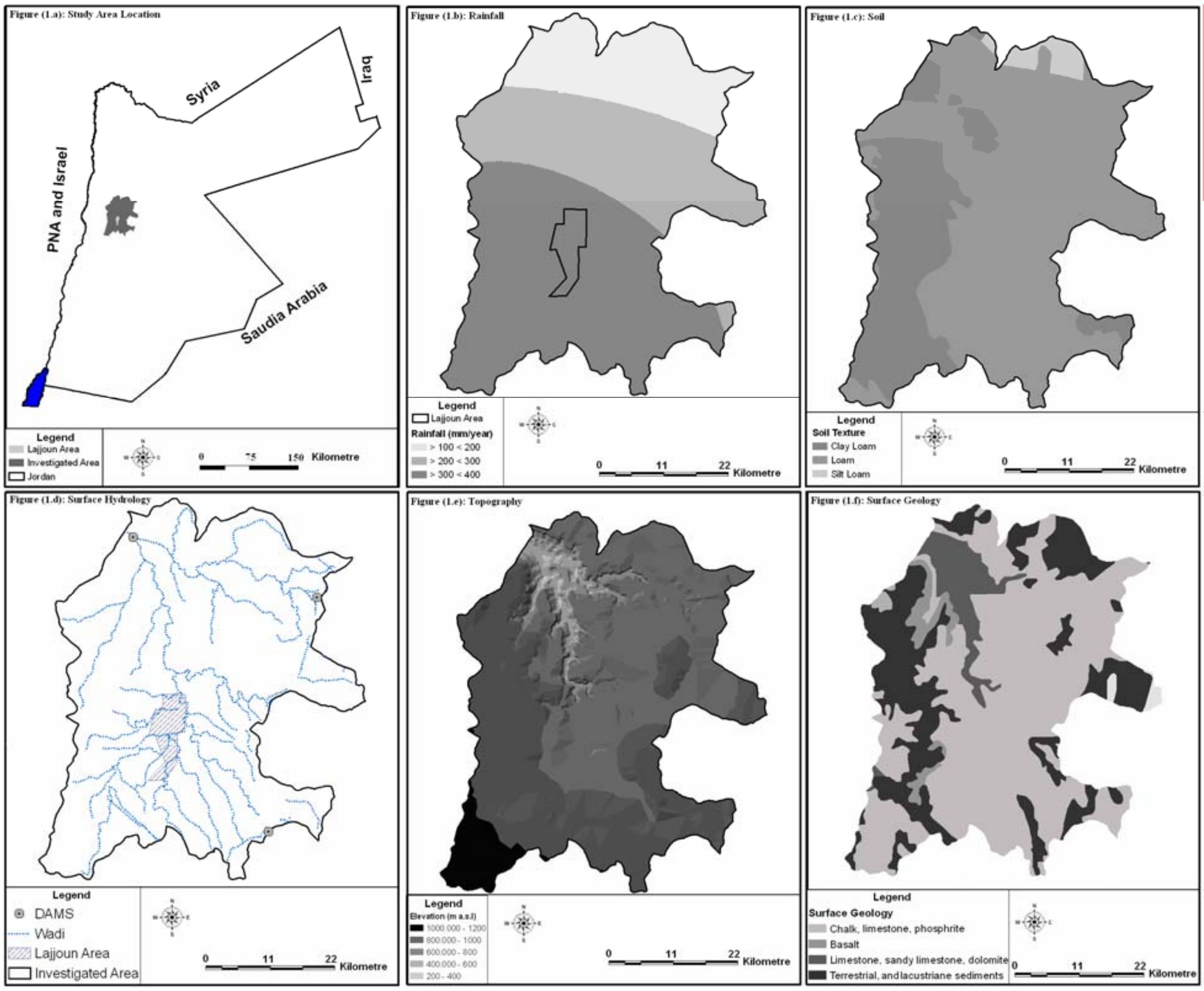

Figure 1: Study Area Location and Characteristics

In this paper, DRASTIC was adopted as a way for investigating the groundwater vulnerability in the study area because the available data for this paper were not enough to use any mathematical or statistical models recommended in the literature. Such methods require a large amount of data collected over a long period of time. Also, the use of GIS: DRASTIC is known through the published literature cited in this paper to be easily implemented entirely in a GIS environment due to the existence of the overlay procedure and the arithmetic operation functions in various GIS software, which facilitates the implementation of such model.

Oil Shale Sampling and Testing

Standard samples of Lajjoun deposit have been brought from Jordanian Natural Resources Authority (NRA). Samples were crushed, sieved, fractionated by size and stored in special containers for the following experiments. Ash was prepared for a fraction <250 μm in accordance with the Australian standards for ashing hard coal (Australian Standards *AS 1038.3*, 2000). The spent ash simulating the residue of the retorting process was obtained as a result of fisher assay test, a method of estimating the oil content. The oil content of the samples was determined according to fisher assay method (Standard 150647) at a temperature of 550°C. X-ray fluorescence spectrometry involves the identification of concentration of elements in the solid in the form of metal oxides. For this study, samples were analyzed in pressed powdered form using Philips (Magix) model. Sequential determination of the concentrations of most heavy and trace metals is present in the periodic table. For this study, samples were analyzed using ICP (Optima 2000) from Perking Elmer, USA.

Leachability Testing Methods

In order to study the leachability of ash produced by an electricity power station, ash was prepared for a fraction <250 μm in accordance to Australian standards for ashing hard coal (Australian Standards, 2000). Samples were heated in air to 500°C for 30 minutes, then to 850°C for 60 minutes and kept at 850°C for 3 hours to ensure the stability of weight. The residual ash obtained as a result of fisher assay tests has been used to test the leachability of ash produced from the oil extraction process. 10 grams of both samples of ash (at 850 and 550°C) were separately added to 200 ml of distilled water subject to 48 hours of shaking. Samples were then filtered, and the leachates have been tested using ICP to measure the concentrations of heavy metals.

Study Area

The study area is located in the central part of Jordan as shown in Figure (1.a). The study area is *ca.* 1384.2 km^2. Lajjoun oil shale area is located within the study area, with an estimated area of 33.6 km^2. The study area is classified as arid to semi-arid with an annual rainfall between 100 mm in the northern part to around 400 mm in the southern part. Lajjoun area is within the area that receives more than 300 mm of annual rainfall (Figure 1.b). Rainfall duration is usually between few hours to 48 hours per storm. Soil types (Figure 1.c) are classified into three classes; clay loam, loam and silt loam. Surface hydrology in the area consists of several wadis that have a flow direction toward the north and north-west (Figure 1.d). Figure (1.d) shows three dams existing in the study area. The largest dam within the study area is Al-Mujib dam which was constructed in 2003 with an estimated capacity of 35 MCM. The topography of the area is characterized by a high altitude (up to 1200 m a.s.l.) in the southern part to around 200 m a.s.l. at Al-Mujib dam (Figure 1.e). This large variation in altitude indicates that the area has a very high slope towards the north. The surface geology in the area is dominated with chalk, limestone, basalt, sandy limestone and terrestrial and lacustriane sediments as shown in Figure (1.f).

Data Collection

Table (1) shows the secondary data sets that have been obtained from different national and international agencies and previous research to achieve the main objectives of this research.

Table 1: The secondary data sets used in this research and their sources

Map type	Date	Format	Scale	Source
Contours (25 m)	1995	ArcGIS	1:250,000	Royal Jordanian Geographic Center
Surface Geology	1978	ArcGIS	1:750,000	Natural Resources
Soil	2007	ArcGIS	1:500,00	Bajits *et al*. (2003)
Wadis	1995	ArcGIS	1:250,000	Royal Jordanian Geographic Center
Rainfall	2007	ArcGIS	1:250,000	Al-Adamat *et al*. (2007)
Groundwater data	2007	Excel	-	Jordan Water Authority

Data Analysis and Results

The Drastic Index Calculation

The recharge ratings were based on Equation 2 (Piscopo, 2001) instead of using the total recharge, because there is no sufficient data to estimate the net recharge for the study area.

Recharge value = Slope % + Rainfall + Soil permeability ……………… (2)

By applying Equation 2 to the study area, the ratings for recharge were calculated based on Table (2).

The ratings and weights for the remaining DRASTIC parameters (Table 3) for the study area were estimated from (Knox *et al*., 1993; Piscopo, 2001; Aller *et al*., 1987; Al-Adamat *et al*., 2003). This Table shows also the vulnerability classes for the study area. Figure (2) illustrates the methods used within GIS environment to calculate the DRASTIC index for the study area.

Table 2: The recharge ratings and weightings for the study area (a: Slope, b: Rainfall, c: Soil permeability and d: Recharge value) (Modified from Piscopo, 2001); (* Soil permeability based on USDA, 1994)

Recharge Parameter	Factor	
Slope (%)	<2	4
	2 – 10	3
	10 – 33	2

+

Recharge Parameter	Factor	
Rainfall (mm)	< 500	1

+

Recharge Parameter	Factor	
Soil permeability	Moderate - High	6
	Moderate	4
	Low	2

↓

	Range	Ratings
Recharge Ratings	9 - 11	8
	7 – 9	5
	5 - 7	3

The DRASTIC Index for the Study Area

The GIS coverage resulting from producing the DARSTIC parameters was in raster format and values for each overlay were summed in ArcGIS according to the pixel value of each area that resulted from multiplying each of the ratings by its DRASTIC weight. A fixed number of 5 was added to the final raster grid coverage which represents Dr x Dw.

Table 3:The DRASTIC weights and ratings for the study area after (Knox *et al*., 1993; Piscopo, 2001; Aller et al., 1987) and the vulnerability classes

DRASTIC Parameter	Ratings		Weight
D: Depth to Groundwater (meter)	More than 30	1	**5**
R: Recharge (Value based on Table 2)	9 -11	8	**2**
	7 - 9	5	
	5 - 7	3	
A: Aquifer Media (Materials)	Basalt	9	**3**
	Sediments	8	
	Limestone	6	
S: Soil (Type)	Loam	5	**2**
	Silty Loam	4	
	Clay Loam	3	
T: Topography (Slope %)	0-2	10	**3**
	2-6	9	
	6-12	5	
	12-18	3	
	> 18	1	
I: Impact of Vadose Zone (Materials)	Basalt	9	**5**
	Sediments	8	
	Limestone	6	
C: Hydraulic Conductivity	Not used in this research (Based on Al-Adamat *et al*., 2003)		

Vulnerability Classes	No	Low	Moderate	High	Very High
Range	25 - 56	56 - 87	87-118	118-149	149-180

The minimum value in a DRASTIC index after ruling out the hydraulic conductivity and modifying the recharge values according to Table (2) is 25, while the maximum value is 180. In this research, this range of values was divided into five classes; no vulnerability, low vulnerability, moderate vulnerability, high vulnerability and very high vulnerability as shown in Table (4).

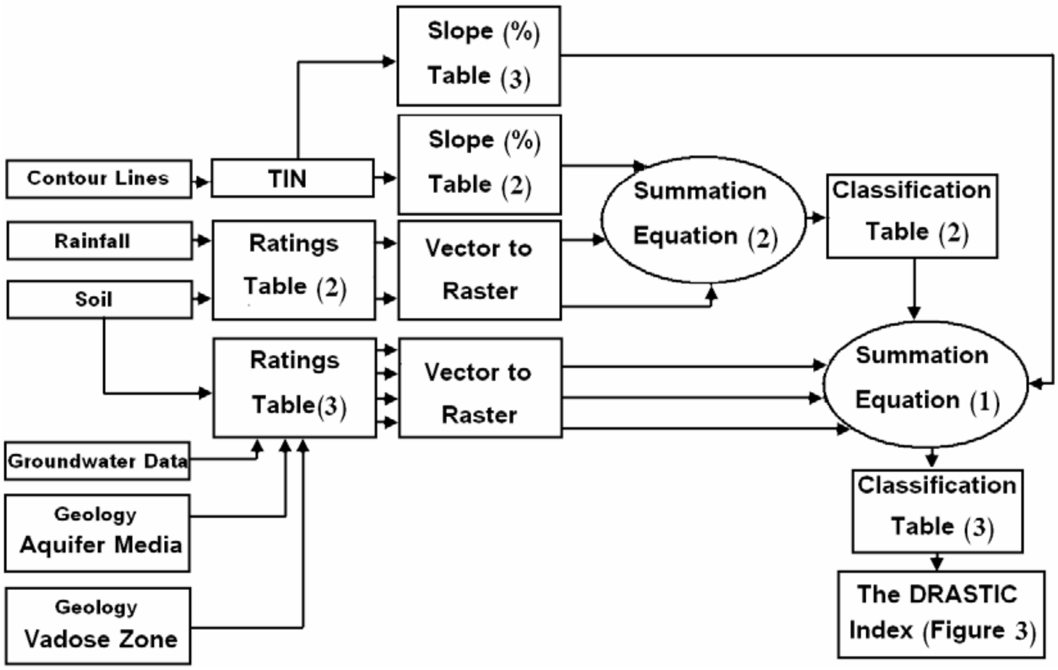

Figure 2: The Methods Used within GIS Environment to Calculate the DRASTIC Index for the Study Area

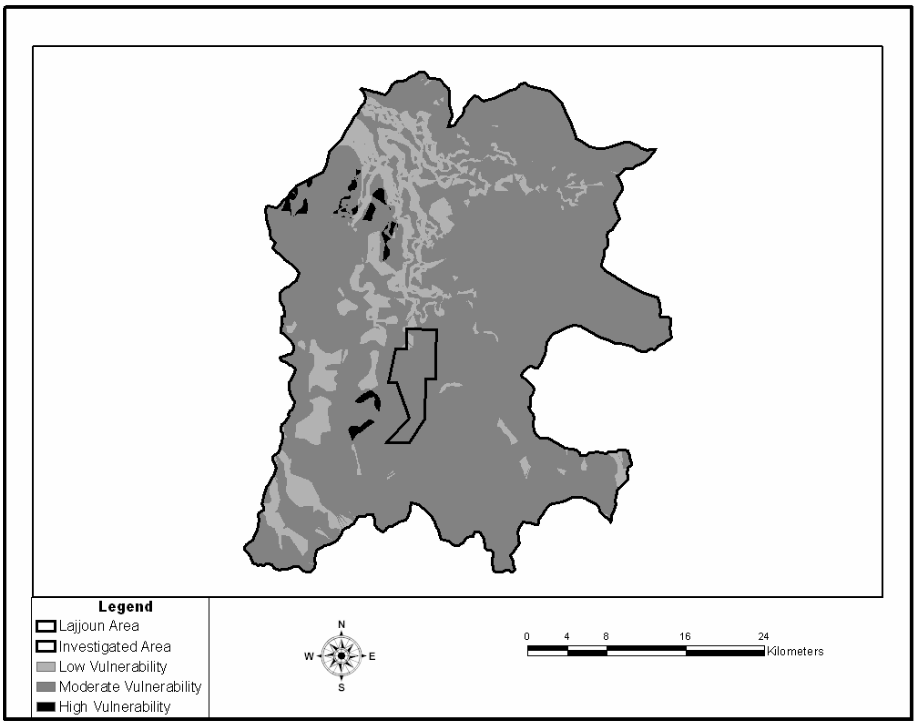

Figure 3: The DRASTIC Index for the Study Area

In this research, the resulting DRASTIC calculation values ranged between 67 and 123. This range was classified based on Table (3), the resulting map is shown in Figure (3).

Oil Shale Sample Characterization

The XRF analysis shows the presence of major metal oxides and the trace elements as shown in Table (4).

Table 4: XRF analysis for oil shale samples

Metal Oxides	(%)	Metal Oxides	(%)
Na_2O	0.071	NiO	0.013
MgO	0.292	CuO	0.016
Al_2O_3	4.887	ZnO	0.043
SiO_2	17.068	Rb_2O	0.005
P_2O_5	0.843	SrO	0.149
SO_3	2.085	Y_2O_3	0.005
K_2O	0.473	ZrO_2	0.026
CaO	35.935	MoO_3	0.031
TiO_2	0.258	BaO	0.026
Cr_2O_3	0.034	F	0.264
Fe_2O_3	0.951		

The oil content estimated based on fisher assay methods was found to be (14.38 wt.%). The residue of spent ash was determined to be (79.84 wt%). In order to produce 37,000 barrels/ day (based on an offer presented to the Jordanian government from an international oil company), it is required to use 5679.5 tons of oil shale/ day. The residual spent ash associated with the utilization of this amount of oil shale will be 4534.5 tons/ day.

Based on the industrial analyses of gasification of Lajjoun oil shale conducted by the Natural Resources Authority (NRA report, 2006), it was estimated that if oil shale will be utilized for generating electricity by direct burning of oil shale to produce 300 Mega Watt Hour (an offer presented to the Jordanian Government from an Estonian company), it is required to burn 880 tons/hour. Based on this estimation, the annual needed amount of oil shale is 4,074,470.4 tons, where 53% of this amount will be ash.

Leachabilty Data

The ICP analysis results indicated that the estimated ash lechate from producing electricity has traces (mg/l) of Al (0.268), Cr (7.86), Cd (0.018) and Pb (0.069), while for extracting oil form oil shale, there are traces (mg/l) of Fe (0.197), Cr (9.06), Cd (0.003) and Pb (0.024). Both types of ash lechates have no traces of Zn, Ni and Cu.

Risk Assessment and Evaluation

Based on the groundwater vulnerability map (Figure 3), it was found that Lajjoun area is within a moderate vulnerability zone. After converting the data in traces found in both types of oil shale treatment into percentages, it was found that oil extraction from oil shale will produce huge amounts (tons/ year) of Fe (6.5) and Cr (298.4) and small amounts of Cd (0.1) and Pb (0.8) that are available for leaching to groundwater. The direct burning of oil shale to generate electricity will produce huge amounts (tons/ year) of Al (21.8), Cr (640.5) and Pb (5.6) and a small amount of Cd (1.5) as leachates to groundwater. This indicates that the processing of oil shale for a production of oil and/ or generating electricity is associated with huge amounts of ash that will be leached by water and bring substantial amounts of heavy metals which pose a high risk to the limited groundwater resources in the area.

SUMMARY AND RECOMMENDATIONS

Groundwater is the major water resource for many areas of the country and the only source of water in some areas. Groundwater is the second largest contributor to the irrigation sector and is the largest source for domestic consumption. Jordan also has a huge amount of oil shale that exists in the southern and eastern parts of the country. It is estimated that Jordan has a reserve of 50 billion tons of oil shale. Ash is considered one of the most important factors in selecting the suitable and more economical utilization technology for Jordanian oil shale. Oil shale ash is considered one of the main environmental challenges and a barrier which stands on the way of developing oil shale industry in Jordan. GIS was used in combination with DRASTIC index in this research to investigate the groundwater vulnerability to contamination. It was found that Lajjoun area is within a moderate vulnerability zone. Leachability tests were conducted on two types of ash. It was found that the ash that might result from the utilization of oil shale to extract oil will have huge amounts of Fe, Cr, Cd and Pb that are available for leaching to groundwater. Also, the ash that might result from the direct burning of oil shale to generate electricity will have huge amounts of Al, Cr, Cd and Pb as leachates to groundwater.

Although, the DRASTIC index has several limitations and assumptions, the main findings of this research could be used as a preliminary impact assessment of oil shale utilization on groundwater. In conclusion, heavy metals that might result from the utilization of oil shale could be considered major threats to the limited available groundwater resources in the area. Based on the findings of this research, we highly recommend that:

1. The results of this research should be accounted for when utilizing oil shale in the area.
2. The industrial usages of ash must be investigated to reduce the available amounts of ash.
3. Ash must be considered as a hazardous waste, so, a dumpsite must be designed within the following requirements:
   a. A synthetic (plastic) liner,
   b. Daily covering of the disposed waste materials,
   c. A control system for subsurface landfill gas,
   d. A leachate collection system should be in place, with a possible on-site treatment system,
   e. Control of site access and disposal,
   f. Leveling and compaction of disposed waste materials,

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